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Digital Road Operator Information and Data Strategy (DROIDS)

Final Report

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Digital Road Operator Information and Data Strategy (DROIDS)

D1.5 Final Report

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Executive summary

The Objective of the DROIDS project was 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 Digital Transformation Framework (DTF) methodology was applied by the DROIDS project. **Methods** applied during the project included introduced literature reviews, workshops, interviews, questionnaires, stakeholder collaboration and conferences as well as events.

Validation of results were done in collaboration with the European road operators in CEDR Project Executive Board (PEB), CEDR Call 2022 Data projects of PRESORT on third-party data and TIARA on trustworthy and secure data infrastructure, DROIDS on digital road infrastructure project experts as well as public and private stakeholders DROIDS Advisory group.

The DROIDS project's key results were the Digital Road Operator Data strategy and a roadmap to its implementation. These results summarise the outcomes of the DROIDS project work packages of NRA roles in digital twins, digital twin application evolution, trusted service provision and data strategy for NRAs.

The data strategy roadmap includes 11 action categories for the digital road operators. The following paragraphs summarise the action categories and actions included for road operators, CEDR, and specific actions concerning the European Data Spaces.

The following **seven high-priority action categories for road operators** were proposed in the roadmap:

1. **Provide education and enhance skills.** Tailored training programs and practical competency development using pilots, proof of concept and real-life use cases. Also, collaboration with educational institutions.
2. **Implement interoperability and utilise standards.** Actively participate in the implementation of International and EU standards to achieve interoperability.
3. **Carry out stakeholder collaboration and prioritise use cases.** Develop a stakeholder strategy with a use-case-driven stakeholder engagement plan.
4. **Develop and purchase data and services in accordance with established standards, guidelines, and design principles.** Treat data as a raw material with well-defined attributes and procurement processes. Use human-centric design principles and co-creation.
5. **Develop a data governance and risk management framework.** Agree on a data governance framework that safeguards, among other things, data quality, compliance, privacy, security, data diversity, stakeholder-led audits and ethics.
6. **Implement a change management process.** Implement a process that supports new processes, organisational changes, or the adoption of technologies to ensure a smooth transition and acceptance.
7. **Implement a trust framework.** Monitor PKI infrastructure to detect technical and security issues. Use the EU C-ITS PKI to allow for effective C-ITS data exchange across borders.

The following **high-priority action category for the Conference of European Directors of Roads (CEDR)** was proposed in the roadmap:

8. **Establish appropriate CEDR actions to support road operators**, such as establishment of needed skills for road operators and contractors, identification of the most important digital representation use cases and their types, ensure road operators embed in addition to legal also contractual and ethical responsibilities for data accuracy, use of open standards, definition of road operators role in the European mobility data space, and development of digitalisation strategy.

The following **three high-priority action categories for specific actions for the Common European Mobility Data Space (EMDS)** were proposed in the roadmap:

9. **Implement an EMDS-compliant data space supporting digital road operations.** Follow the step-by-step approach outlined in the Co-Creation Method, as provided by the DSSC and the Data Spaces Design Principles.
10. **Formalise the standards to be applied for digital road operations** as a data space "vocabulary service" that acts as a central repository for standardised data models and their documentation, enabling semantic interoperability.
11. **Implement a data governance framework and a data governance body.** Utilise recommendations proposed for the Common European Mobility Data Space, agree on a rulebook (governance model) for the data space, and establish a data governance body for digital road operations.

The priority of actions should be analysed based on the goals and business objectives of the road operator organisation and the current digital road operation maturity level. A holistic approach to trust should be applied in the actions.

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1 Introduction

1.1 Background

The background of the CEDR funded DROIDS project research was the ongoing transformation of the National Road Authorities (NRAs), road operators and road managers to digital road operators responsible for operating both the physical and digital road infrastructure.

This Final Report summarises the DROIDS (Digital Road Operator Information and Data Strategy) project main results and outcomes. DROIDS was CEDR (Conference of European Directors of Roads) Transnational Road Research Programme Call 2022 Data project. The DROIDS project was conducted from September 2023 until September 2025.

The CEDR Call 2022 Data research programme examined the following three subtopics of which the DROIDS project was the first (a):

- a) Maintaining and sharing the digital road infrastructure (DROIDS project)
- b) Improving the use of third-party data by NRAs (PRESORT project)
- c) Integrity, Authenticity and Non-Repudiation (e.g. proof of the origin, authenticity and integrity of data) integrated in Trust Models for C-ITS applications (TIARA project)

The DROIDS project Data strategy deliverable which results are also summarised in this final report, used the results and recommendations of the above mentioned CEDR Call 2022 Data PRESORT and TIARA projects.

1.2 Research Objectives and Questions

The Objective of the DROIDS project was 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.

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

Secondly, the project studied 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 was assessed.

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 highlighted the issues related to ensuring trust and security in the maintenance, sharing, and use of the digital road infrastructure.

Finally, the work of DROIDS concluded 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).

The DROIDS main research objectives and research questions are presented in the table below.

Table 1 DROIDS project research objectives and questions.

DROIDS Research Questions	DROIDS report	Chapter in this report
(RQ1) What role the NRAs should take in the larger ecosystem of digital twins for road infrastructures, and how they should fulfil this role?	D2.1/D3.1 (background), D2.2	Chapter 3.2
(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?	D2.1/D3.1 (background), D2.2	Chapter 3.2
(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?	D2.1/D3.1 (background), D2.2	Chapters 3.2 & 4
(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?	D2.1/D3.1 (background), D2.2	Chapters 3.2 & 4
(RQ5) What services and data is expected to be shared from NRAs?	D2.1/D3.1 (background), D2.2	Chapter 3.2
(RQ6) How do these different standards and specifications serve the future digital operator role of NRAs?	D2.1/D3.1 (background), D2.2	Chapter 3.2
(RQ 7) What kind of information models and services need to be standardized for the information that should be maintained and provided by NRAs?	D3.2	Chapters 3.3.2 & 4
(RQ 8) What are the most critical information items and services?	D5.1	Chapter 4
(RQ 9) How, and to what degree, can BIM information be reused for other purposes in the later stages (AIM and ITS) to reduce the need for new data capture for NRAs and Map Providers?	D3.3	Chapters 3.3.3 & 4
(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?	D2.1/D3.1 (background), D2.2, D3.3	Chapters 3.2, 3.3.3 & 4
(RQ11) Could the NRAs' OTLs (Object Type Libraries) be extended to cover information for the full life cycle?	D3.3	Chapters 3.3.3 & 4
(RQ12) How can traffic rules and regulations be transformed into a digital and machine-	D3.4	Chapter 3.3.4

readable representation that enables automated vehicles to understand and follow them on a European level?		
(RQ13) To what degree will physical traffic signs, signals and markings be needed in a future of automated driving, where rules and regulations are digital and machine-readable?	D3.4	Chapter 3.3.4
(RQ14) How can dynamic [regulation] information be described and shared with road users, in combination with the more static regulations?	D3.4	Chapters 3.3.4 & 4
(RQ15) How can the distribution of this information (maintained and provided by NRAs) be made resilient and trustworthy enough to ensure that vehicles and drivers have the information required to ensure that roads can be used safely?	D4.1	Chapters 3.4 & 4
(RQ17) What kind of information will be particularly critical to have verified, and how should trust in the authoritative information be ensured?	D4.1	Chapters 3.4 & 4
(RQ18) What information falls into the different security categories?	D4.1	Chapters 3.4 & 4
(RQ19) How can NRAs ensure that data is efficiently distributed to those who need to see it, and how can NRAs ensure that consumers of the information can trust its authenticity/veracity?	D4.1	Chapters 3.4 & 4

1.3 Final Report Reading Guide

The following reading instructions are suggested for the reader of this report based on his/her interest, knowledge of the research topic and from least time to read the results to most time to gain depth of the results.

For those interested reading **quickly the main research outcomes and results**, please read chapter Executive summary and chapter 6 Conclusions.

For those interested in reading **more deeply about the main results of the project**, please read **chapter 4** Digital Road Operator Data Strategy and Roadmap which includes the main results of the project. This chapter includes the actions and roadmap suggested for the road operators.

For those interested in **specific project research objectives results as well as references to find more information**, please read chapter 3 Results by Work Package where the following main research objective areas results are found: NRA roles in digital twins, Digital twin application evolution, Trusted service provision and Data strategy for NRAs.

For those who are interested on the **DROIDS project methodology including used methods and summary of deliverables**, please read chapter 2 Methodology.

Finally, **background of the research and discussion** are given in chapters 1 Introduction and 5 Discussion.

2 Methodology

The DROIDS project utilised the Digital Transformation Framework (DTF) presented in the Figure 1 to address the research objectives and research questions. The DTF approach followed a process where first it was first determined requirements, goals, and standards, secondly the gap between the current and future state and thirdly, implementation guidance for NRAs to overcome this gap.

The DTF process was followed in the DROIDS work packages where information needs and current practices (Phase A) were studied in the WP2 NRA roles in digital twins, design and perform gap analysis (Phase B) in WP3 Digital twin application evolution and WP4 Trusted service provision and finally, derived actions and recommendations (Phase C) in WP5 Data strategy for NRAs. The DROIDS work packages are presented more in detail in the following subchapter.

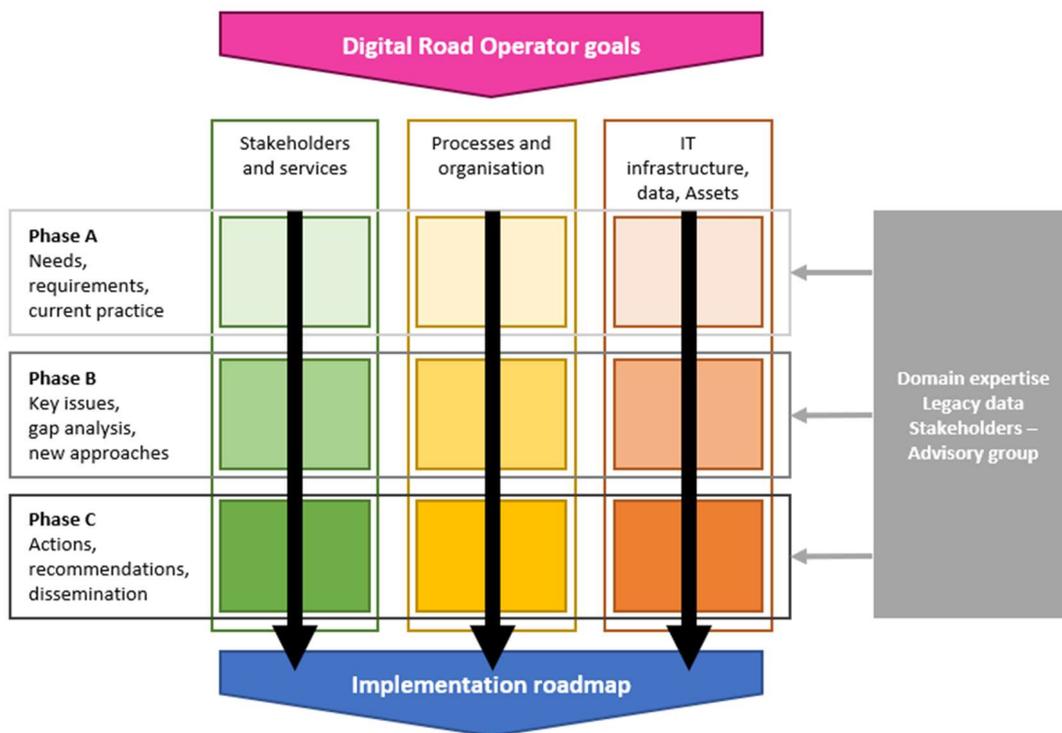


Figure 1 DROIDS Framework (Digital Transformation Framework, DTF)

2.1 Partners, Stakeholders and Governance

The below Table 2 describes the six **DROIDS project partners** and their roles as well as responsibilities. The responsibilities include deliverables of which each project partner was responsible and/or co-authored.

Table 2 DROIDS project partners and their roles as well as responsibilities.

DROIDS Partner	Role	Responsibilities
Traficon (Finland) 	Project Coordinator	Project management and coordination tasks. Main responsibility in deliverables 1.1 Inception report, 1.3 Interim report and 1.5 Final report. Co-author in DROIDS deliverables D2.1 State-of-the-Art of digital twins, D2.2 NRA Roles and D3.4 Digital twin use cases, D5.1 Recommendations and Guidelines on Conceptual Data Strategy for Road Operators, D5.2 A Roadmap for implementing the data strategy.
Forum of European National Highway Research Laboratories (FEHRL) (Belgium) 	Lead of Project communication and dissemination	Project communication and dissemination tasks. Main responsibility in deliverables 1.2 Dissemination plan and 1.4 Dissemination activities and reports. Co-author in DROIDS deliverable D1.5 Final Report.
Institute for energy technology (IFE) (Norway) 	Lead of Work Package 5 Data strategy for NRAs	Main responsibility in deliverables 5.0, 5.1 and 5.2. Co-author in DROIDS deliverable D1.5 Final Report.
MAPtm (Netherlands) 	Lead of Work Package 2 NRA roles in digital twins	Main responsibility in deliverables 2.1 and 2.2. Co-author in DROIDS deliverable D1.5 Final Report.
Haskoning (Netherlands) 	Lead of Work Package 3 Digital twin application and evolution	Main responsibility in deliverables 3.1–3.4 Co-author in DROIDS deliverables D2.1 State-of-the-Art of digital twins and D1.5 Final Report.
WMG department, University of Warwick (United Kingdom) 	Lead of Work Package 4 Trusted service provision	Main responsibility in deliverable 4.1 Co-author in DROIDS deliverable D1.5 Final Report.

The DROIDS governance structure and collaboration with stakeholders included the

following which are also presented and summarised in Figure 2.

- The DROIDS project work was supervised by the CEDR Call 2022 Data Programme Executive Board (PEB).
- The DROIDS Advisory Group included over twenty members from industry, academia, city and road operator stakeholders from more than 10 European countries. The Advisory Group had an important role on providing feedback and validating the results of DROIDS. The DROIDS Advisory Group chair was from the DROIDS project, Dr. Risto Kulmala, Traficon.
- CEDR Connected and Automated Driving (CAD) Working Group (WG) participated on DROIDS workshop and provided feedback on the NRA roles and responsibilities on digital twins.
- CEDR Call 2022 Data projects PRESORT (third-party data) and TIARA (trust in C-ITS) participated in the DROIDS workshops, provided feedback on the data strategy results and their results were used as a part of the digital road operator data strategy and roadmap.
- Other CEDR Member State Road operators also provided their feedback on the project results.

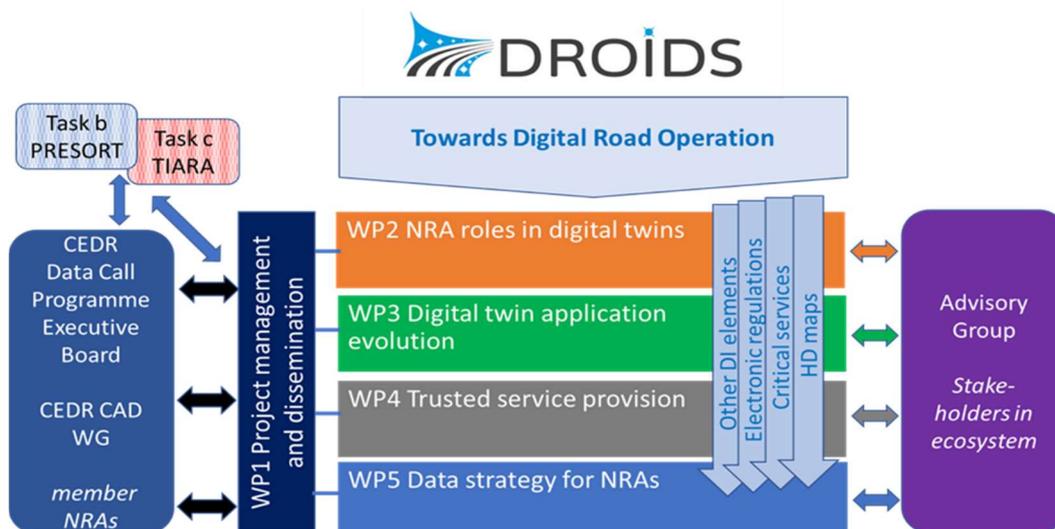


Figure 2 The DROIDS approach of governance and stakeholders.

2.2 Work Package Structure and Content

The DROIDS Work Packages (WPs) structure and methodology behind it was presented in the previous chapter as a part of the Digital Transformation Framework (DTF). The DROIDS approach and governance in the previous chapter Figure 2 introduced the DROIDS work packages. This chapter presents a short description of each of the work packages content.

Work Package 1 (WP1) Project management and dissemination was responsible for the project delivery and overall coordination and management as well as dissemination of the project. Content included cooperation between consortium partners, work packages, CEDR PEB, Advisory Group. CEDR PRESORT and TIARA projects as well as external stakeholders. Traditional and hybrid project management methodologies were used in addition of agile methodologies when solving key study topics iteratively.

Work Package 2 (WP2) NRA roles in digital twins studied understanding the role of NRAs

as digital road operators (DRO): The WP2 considers the roles of the NRAs as DROs and especially in the digital twin ecosystem taking into account the changes due to digitalisation and road transport automation. HD maps, electronic regulation, and other key infrastructure elements were under focus along with the critical services from the point of view of the DRO.

Work Package 3 (WP3) Digital twin application evolution studied understanding the digital twin application evolutions: The digital twins of the physical, operational and also digital infrastructure in response to traffic, environment, land use etc. The use potential of these applications for digital road operation was evaluated. The BIM- and AIM-related applications were specifically addressed, utilising the earlier CEDR and consortium project results, and the automation-related ones.

Work Package 4 (WP4) Trusted service provision studied the trust related to NRA-originated data and its veracity, availability and security. DROIDS assessed and classified the services on their needs concerning trust while monitoring the progress of CEDR TIARA project (Task C).

Work Package 5 (WP5) Data strategy for NRAs proposed a data strategy for Digital Road Operators (DROs). The WP5 was a concluding step that utilised the results of the aforementioned DROIDS WPs and targeted research of its own to develop the overarching data strategy on both strategic and functional levels. The work utilised for example the approaches and results of data, digital roads, automated driving facilitation, and asset management strategies from European countries.

2.3 Deliverables and Milestones

The following **DROIDS deliverables** presented in the below Table 3 were successfully published by the DROIDS project between 2023–2025. The Table shows also whether the publication was for internal project reporting purposes or CEDR online publication. The deliverables that were published online were uploaded to the CEDR Call 2022 Data website (2025) and DROIDS project website (2025).

The Deliverable 5.0 was added to the project deliverables when it was found beneficial to include the data strategy background research results into a one comprehensive study and this way to better summarise the data strategy results in deliverables 5.1 and 5.2.

Table 3 DROIDS project deliverables and their publication either internally for reporting purposes or online publication.

No	DROIDS Deliverables	Publication
1	D1.1 Inception report	Internal
2	D1.2 Dissemination plan	Internal
3	D3.1 Digital twin state of the art – Technical aspects (embedded in D2.1) (Soni et al. 2025)	Public Online
4	D2.1 State of the Art of digital twins for road infrastructure (Soni et al. 2025)	Public Online
5	D3.2 Information maintenance and availability (Soni 2024)	Public Online
6	D3.3 BIM representation for full life-	Public Online

	cycle of road infrastructure (Soni 2024)	
7	D1.3 Interim report	Internal
8	D3.4 Digital twin use cases – digital transport regulations, opening new roads, automated lane level navigation (Soni et al. 2025)	Public Online
9	D2.2 NRA roles in digital twins (Kulmala et al 2025)	Public Online
10	D4.1 Handling of trust and security in digital road infrastructure (Khastgir & Dodoiu 2025)	Public Online
11	D5.1 A data strategy for the digital road operators (Bokolo et al. 2025)	Public Online
12	D1.4 Dissemination activities and reports	Internal
13	D5.2 A roadmap for implementing the data strategy (Kvalvik et al. 2025)	Public Online
14	D1.5 Final report	Public Online
15	D5.0 Data strategy background research	Internal

The Table 4 below summarises completed **DROIDS milestones** between 2023–2025 and which deliverables the milestones results were reported. The milestones can be divided into four different categories: 1) DROIDS website, 2) DROIDS workshops, 3) DROIDS Advisory Groups and 4) DROIDS Taxonomy, digital road operator data strategy and roadmap background studies.

Table 4 Summary of the DROIDS project completed milestones between 2023–2025.

No	DROIDS Milestones	Milestone reported
1	DROIDS website was successfully published in the following address: https://droids.project.cedr.eu/	D1.2 and D1.4
2, 6, 9, 11, 16	DROIDS workshops 1–5 were successfully completed between 2023–2025. The workshops were mostly held as a part of the CEDR PEB meetings. The workshop topics included the following: <ol style="list-style-type: none"> 1. Data sources, requirements and standardisation 2. NRA responsibilities and governance 3. Data availability, trust and sovereignty 4. Roles, standardisation and in-life maintenance 5. Proposal for digital road operator data strategy 	D2.1, D2.2, D3.1, D3.2, D3.3, D4.1, D5.1, D5.2
3, 5, 8, 12, 15	DROIDS Advisory Group meetings 1–5 were successfully completed between 2023–2025. The Advisory Groups meeting topics and main aim included the following:	D2.1, D2.2, D3.1, D3.2, D3.3, D4.1, D5.1, D5.2

	<ol style="list-style-type: none"> 1. Terms of reference of the Advisory Group (AG) 2. First results on NRA roles and digital twins 3. Data governance and electronic transport regulations 4. First draft of the data strategy for digital road operators 5. Final draft of the data strategy for digital road operators 	
4, 7, 10, 13, 14	<p>Project milestones that related to the earlier mentioned research deliverables, either by supporting the background study or being a first version for comments and approval, included the following:</p> <ul style="list-style-type: none"> • Mapping of relevant data sources completed • Agreed data governance model supporting data sharing • Plan for integration with common European Mobility Data Space • Recommendation for a reference architecture for trusted data sharing • Conceptual data strategy 	D5.0, D5.1 and D5.2

2.4 Methods

The following methods introduced below in this chapter were used during the DROIDS project. These methods contributed to the **project quality assurance and validation**, which were supported by the earlier introduction of the DROIDS governance model where CEDR PEB and Advisory Group participated in the evaluation of the results.

Literature reviews

All DROIDS project deliverables and milestones used literature review and research. Literature reviews used academic journal articles, conference papers, research papers and websites.

Workshops

The first one was hosted by the CEDR CAD WG in Vienna, Austria on 12 June 2024 also including CEDR Traffic management WG members. The second one was hosted by the CEDR Data Call PEB in Ghent, Belgium on 18 June 2024. 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.

A workshop on digital road operator data strategy was conducted on June 17, 2025, as part of the CEDR Call 2022 Project Executive Board (PEB). The participants (n = 33) in the PEB meeting included road operators, as well as experts from the DROIDS, PRESORT, and TIARA projects—the workshop aimed to gather input from road operators regarding the data strategy and roadmap implementation. The workshop was conducted in a TEAMS virtual meeting. The participants shared a collaborative and interactive board, where they could comment on the data strategy and roadmap recommendations and actions.

A workshop in the CEDR Call 2022: Data Final Conference included a questionnaire on the priorities of the proposed data strategy and roadmap action categories and open discussion

on the questionnaire results.

Interviews

Several interviews were conducted during the project and reported in the deliverables. Interview contacts were established mainly through the CEDR PEB, DROIDS workshops and DROIDS Advisory Group.

Questionnaires

Questionnaires were used to gain further road operators experiences on digital twin implementations and best practices. Questionnaires were sent via email to road operators. Questionnaires were answered for example European Member State Road operators of Finland, Italy, Ireland, Iceland, Slovenia, Sweden and Switzerland.

Questionnaire was also used during the Final Conference workshop to question road operator and private industry members on their priorities to implement the proposed data strategy and roadmap action categories.

Stakeholder collaboration and DROIDS Advisory Group

Stakeholder feedback was mainly received from the DROIDS Advisory Group which provided valuable external feedback to the project. Stakeholder feedback was also received in the TRA2025 conference where the DROIDS together with the PRESORT and TIARA projects as well as CEDR took part to present the first results of the projects.

3 Results by Work Package

This chapter presents a summary of the following DROIDS five work package results. The main results include the main conclusions of each of the work package deliverables.

1. WP1 – Project Management and dissemination
2. WP2 – NRA roles in digital twins
3. WP3 – Digital twin application evolution
4. WP4 – Trusted service provision
5. WP5 – Data Strategy for NRAs

3.1 WP1 – Project Management and dissemination

DROIDS project work package 1 (WP1) Project Management and dissemination included activities such as coordination, internal project biweekly meetings with task tracking and meeting minutes, monthly progress reporting to the CEDR PEB, quality assurance, risk management, supporting work package leaders, stakeholder management including DROIDS Advisory Group. The WP1 also contributed and co-authored several deliverables as presented in the chapter 2.1 Partners, Stakeholders and Governance. WP1 was responsible for the quality assurance of the deliverables and milestones as well as final submission to the CEDR PEB for approval and publication.

Dissemination was one of the main responsibilities of the WP1. DROIDS took part in several events to present the results and gain feedback, TRA2025 being the main event. Main source for dissemination was the DROIDS website (2025) and LinkedIn platform.

The WP1 forementioned results were reported successfully in the following internal DROIDS project deliverables which include this final report of the DROIDS project:

- D1.1 Inception report
- D1.2 Dissemination plan
- D1.3 Interim report
- D1.4 Dissemination activities and reports
- D1.5 Final report

3.2 WP2 – NRA roles in digital twins

3.2.1 State of the art of road operation related digital twins (D2.1/D3.1)

The deliverables 2.1 and 3.1 (combined to one deliverable) described the **state of the art of road operation related digital twins** from terminology, technical, operational and organisational points of view. The study provided background information and knowledge that was utilised further in the other DROIDS project work package deliverables related to digital twin road operator roles, application evolution and trusted service provision. (Soni et al. 2025)

3.2.2 NRA roles in digital twins (D2.2)

The role of NRAs in the larger ecosystem of digital twins for road infrastructures, and how they should fulfil this role was described in the DROIDS **deliverable 2.2 “NRA roles in digital twins”** (Kulmala et al., 2025). The summary of the results is presented in 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 and role descriptions 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. The results are presented in the table below.

Table 5 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 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			
	Development	Operation	Maintenance	Use
Use Case				
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

The 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 are in their core business of road maintenance and asset management as well as in use of the digital models in road planning and building. In 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. The results are summarised in the table 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. 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

Table 6 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

(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 a standardised approach, the information stored in digital representations would be interoperable with variety of other applications.

A questionnaire provided insights on the assessment management use case's digital model throughout the 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?

Many of the road operators core businesses 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 important building blocks in 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 needs to be ensured that the data that is shared does not cause harm or damage. The damage can be for example related to security or privacy issues. The 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 (KPI) for the service, for example number of crashes (safety), throughput (efficiency), costs (productivity), accessibility (mobility), emissions (energy and environment). KPIs can also relate more closely to the system, such as its scalability (e.g. system performance vs. data volume) and cost-related metrics of development and maintenance.

The following five recommendations 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

3.3 WP3 – Digital twin application evolution

3.3.1 State of the art of road operation related digital twins (D2.1/D3.1)

The **deliverables 2.1 and 3.1** (combined to one deliverable) described the **state of the art of road operation related digital twins** from terminology, technical, operational and organisational points of view. The study provided background information and knowledge that was utilised further in the other DROIDS project work package deliverables related to digital twin road operator roles, application evolution and trusted service provision. (Soni et al. 2025)

3.3.2 Information maintenance and availability (D3.2)

The deliverable 3.2 Information maintenance and availability presented standardisation of models and processes to ensure that the digital representations can be shared and equally used by different stakeholders (e.g., NRAs, service providers, etc.). It provided an answer to the following main research question (Soni 2024):

(RQ 7) What kind of information models and services need to be standardized for the information that should be maintained and provided by NRAs?

Why standardisation is necessary?

Standardization is essential for road operators in the context of digital twins, ensuring seamless data exchange, interoperability, and efficient management of complex infrastructure. The absence of standardized data formats, protocols, and interfaces poses technical challenges that hinder the full potential of digital twin systems. By establishing common standards for data management, integration protocols, and terminology, road operators can overcome these challenges and unlock the benefits of improved data quality, compatibility, and cost reduction. Standardization also fosters collaboration among stakeholders, simplifies the integration of digital twins into existing systems, and paves the way for a data-centric network of interconnected digital twins that generates mutual value. Overall, standardization is crucial for the successful deployment and utilization of digital twins in the road sector, enabling road operators to optimize operations, enhance safety, and make informed decisions based on accurate and reliable data.

Existing standardisation landscape

In the context of digital twins for road transport, there is a mix of existing standards and ongoing standardization efforts. Standards cover physical entities (sensors, actuators), virtual entities (digital representations of physical objects), data exchange, communication protocols, and services.

While not specifically designed for road transport, many standards from other domains are applicable, such as IFC for description of the built asset and CityGML for representing 3D urban objects. Efforts like DATEX II for road-related traffic information exchange and NGSI-LD for context information are relevant to road transport digital twins. Communication standards like SensorThings API and NTCIP also play a role. On the other hand, BIM standards lay the foundation of standardisation for digital twin applications.

However, challenges remain in the standardization of road transport digital twins. Road operators often rely on legacy systems with diverse data formats and standards, hindering interoperability. While national standardization organizations exist, their standards can differ, creating further complications for harmonization across EU. Although EU-wide initiatives like DATEX II are underway, they lack the necessary depth for immediate implementation.

Models and process requiring standardisation

Road operators have a pressing need for standardization in the field of digital twins. A clear and **unified definition of digital twins** across different domains (BIM/AIM, traffic management) would be a crucial starting point. This would ensure everyone is on the same page, fostering better collaboration and understanding.

Additionally, road operators seek standardization in **data formats and communication** protocols. This ensures smooth data exchange and compatibility between different digital twin systems. A **common language for data and communication** would significantly streamline the integration of various technologies and applications, enabling a more efficient and cohesive road operation ecosystem. Road operators can align with their national

standards to standardise their existing information and data. Road operators currently maintain data related to their network and assets, which could be a first opportunity for standardisation.

Furthermore, road operators require **standardized interfaces** between digital twins of varying functionalities. For instance, the digital twin of a road planning system needs to seamlessly interact with that of a traffic management system. This **interoperability** is vital for effective coordination and data exchange, ultimately leading to better decision-making and improved traffic flow.

Finally, standardization is needed in the modelling of **automated traffic** and its management. This encompasses defining how automated vehicle flows and mixed traffic (human-driven and automated) are represented in digital twin environments. Additionally, there is a requirement of standardisation regarding **electronic traffic regulations** which is a work in progress within ISO/AWI TS 24315-1. Establishing such standards would facilitate the development of effective traffic management strategies for a future dominated by automated vehicles.

3.3.3 BIM representation for full life-cycle of road infrastructure (D3.3)

The deliverable presented results of research carried out during the Task 3.3: Potential of using BIM representations within Work Package 3 of DROIDS. It provided answers to the following DROIDS project Research Questions (RQ) (Soni 2024):

RQ9: How, and to what degree, can BIM representations be reused for other purposes in the later stages (AIM and ITS) to reduce the need for new data capture for NRAs and Map Providers?

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

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

Proposed process of BIM information reuse

To effectively recycle BIM representations throughout the full lifecycle of digital twins for road infrastructure, road operators can implement the process as outlined below:

- a. *Define Objectives and Scope*: Clearly define the goals and scope of BIM reuse, considering data availability, requirements, and stakeholders.
- b. *Establish Standards and Guidelines*: Develop and adopt BIM standards, ISO 19650, and OTLs to ensure consistency and interoperability.
- c. *Establish Collaboration and Communication*: Foster collaboration between BIM and AIM teams, engage stakeholders, and simplify processes.
- d. *Identify Information Requirements*: Define and prioritize information requirements aligned with OTL.

- e. *Facilitate Data Exchange*: Implement data governance, utilize CDEs, and establish data transfer protocols.
- f. *Integrate BIM into Design Processes*: Collect and standardize BIM data, incorporate BIM from early stages, and link BIM models to OTL.
- g. *Ensure Data Quality*: Implement quality control procedures, validate data against OTL, and conduct data audits.
- h. *Integrate BIM with Asset Management Systems*: Develop data migration strategies and integrate BIM data to enrich asset management systems.
- i. *Data Management and Maintenance*: Ensure continuous data updates, quality assurance, and effective change management.
- j. *Monitoring and Evaluation*: Conduct regular assessments, establish a feedback loop, and plan for scaling.

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

The BIM representation contains lot of valuable information that can be repurposed for asset management or creation of digital twin of road infrastructure. DROIDS deliverable D3.3 proposes the process of maintaining and reusing BIM information that can be adopted by road operators to enable standardised flow of information and efficient use of BIM information. Various steps that can be taken by the road operators include defining objectives and scope, establishing standards and guidelines, enabling collaboration and communication, identifying information requirements, facilitating data exchange, integrating BIM into design processes, ensuring data quality, integrating BIM with AMS, data management and maintenance, and monitoring and evaluation. These steps may vary between various road operators based on their BIM maturity and pre-established organisational processes.

The degree of reusing BIM information also depends on the maturity of the road operators. Since many road operators are at an earlier stage of BIM implementation, there is a lack of useful digital representations, from which information can be reused. For example, in Belgium, BIM process is followed merely in 20-25% projects. This number is even lower in other countries where BIM process is considered for only large-scale projects. Furthermore, even when the projects follow a BIM process, lack of implementation of standardised and comprehensive object type libraries makes it difficult to easily transition data due to different formats being used by different departments and their systems with road operators.

Thus, to improve the BIM information reuse, road operators should implement BIM standards within their organisation for information management and try implementing an OTL to provide structure to asset information. European policies for standardised OTL such as EuroOTL as described in previous CEDR INTERLINK project, would be helpful in ensuring that different organisations can work together with each other and use common resources.

RQ10: How should the [BIM] information be maintained throughout the life cycle of the road infrastructure, given the many different stakeholders involved in the maintenance of the physical infrastructure?

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

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

In order to maintain the BIM information throughout the lifecycle of road infrastructure, road operators have been recommended following considerations:

- **Implement ISO 19650:** Implement ISO 19650 as the framework for information management and exchange throughout the project lifecycle.
- **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).
- **Develop and implement 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.
- **Establish collaboration and communication:** Active collaboration between internal stakeholder such as BIM and AIM departments ensures mutual understanding of requirements and capabilities. On the other hand, collaboration with external stakeholders such as contractors, design and engineering firms, consultants, technology providers etc helps in identifying information requirements and ensuring the needs of every stakeholder.

RQ11: Could the NRAs' OTLs (Object Type Libraries) be extended to cover information for the full life cycle?

The implementation and development of OTL vary significantly across road operators in different countries. Ireland is in the early stages of developing data dictionaries and OTLs to standardize asset data, with policy implementation still pending. Belgium has a comprehensive and integrated OTL system that is continuously improved based on feedback and practical needs. Finland uses a machine-readable data dictionary to standardize and transfer information across project phases, with a well-defined OTL for railway projects. Denmark, however, is still exploring options for object-oriented BIM and the development of OTL, facing challenges due to the lack of standardized practices. Rijkswaterstaat in the Netherlands has a clear, well defined and comprehensive OTL.

State of Object Type Libraries (OTLs) utilisation within road operators

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

The focus of OTL extension also differs among road operators. *Belgium* is actively expanding its OTL to include more asset types and integrate dynamic information like sensor data.

Finland, on the other hand, is currently prioritizing information standardization but has plans to explore OTL extension for digital twin creation in the future. This highlights the need for road operators to consider their specific needs and priorities when developing and extending their OTLs.

As discussed with BIM and OTL experts within the interviewed road operators, it was found that their OTLs could be extended to cover information for the full lifecycle of assets. In fact, some road operators (Belgium and Finland) already have plans to extend their OTL with more asset types and dynamic information for future digital twins and asset maintenance. However, many road operators are in an early stage of BIM implementation and does not have an OTL implemented yet. In order to reap the benefits of standardisation emerging from OTL implementation and possible extension, road operators could consider the following key components:

- *Data Dictionary Foundation*: Build upon existing data dictionaries to establish standard definitions and meanings.
- *Leverage Open Sources*: Utilize open-source libraries like bSDD and Uniclass to establish a solid foundation and ensure continuous updates.
- *Extend with New Attributes*: Incorporate new attributes to accommodate dynamic information and future needs.
- *Collaborative Development*: Involve multiple stakeholders to ensure the OTL meets diverse needs and facilitates data exchange.
- *Continuous Adaptation*: Regularly review and update the OTL to adapt to evolving requirements and technologies.
- *Standardization and Interoperability*: Ensure the OTL is standardized and interoperable with other systems and platforms.
- *ISO Standards Implementation*: Adopt ISO 19650 to provide a framework for information management and exchange.

By following these principles, road operators can create a powerful OTL that supports efficient BIM information management and enhances asset lifecycle management.

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

The deliverable presented the results of research carried out during the Task 3.4: Digital Twin Use cases. It aims to provide answers to the following DROIDS project Research Questions (RQ) (Soni et al. 2025):

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

DROIDS deliverable D3.4 provided a comprehensive understanding of ongoing standardisation for Management of Electronic Traffic Regulations (METR). The ongoing METR standardisation initiative promises a structured way to digitise various traffic rules and regulations. Various traffic rules and regulations with their digitisation potential were identified. It was found that the operational traffic rules (related to the operation of vehicles dictate how vehicles should be driven, including speed limits, lane discipline, overtaking, and right-of-way at intersections) exhibit high digitisation potential. In addition, road signals, sign and marking also showcases high potential for digitisation. Temporary and conditional traffic regulations such as road works, closures, incidents etc also showcased high digitisation potential. Rules related ton specific road user groups such as HGVs, VRUs etc and

vehicle/driver compliance rules showcased medium to low digitisation potential.

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

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

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

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

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

During the workshop and also during the AG meetings, we discussed the roles of various stakeholders in the ecosystem of traffic rule digitisation. Road operators play a multifaceted and crucial role in the lifecycle of digital traffic rules and regulations. They are actively involved in issuing traffic regulation orders, adapting national and regional standards, and provisioning up-to-date, high-quality data for end users during the operational phase. They

also contribute to the maintenance of traffic rules and regulations and provide input to ensure standards accommodate local interests. Their activities span from the initial stages of standardisation and digitisation to the ongoing operation and maintenance of the digital traffic ecosystem.

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

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

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

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

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

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

DROIDS deliverable 3.4 explored various traffic rule digitisation initiatives. **Management of Electronic Transport Regulations (METR)** emerged as one of the most relevant standardisation efforts currently being made to digitise traffic rules and regulations. METR enables provision of traffic rules and regulations that machines can understand and trust.

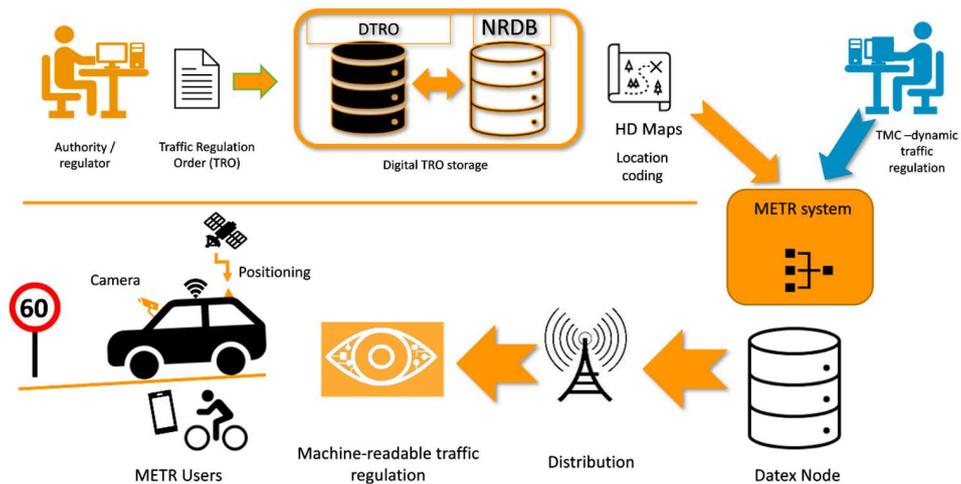


Figure 3 METR process

Figure 3 illustrates the METR system's process for digitizing traffic rules and regulations, as presented in a Norwegian Public Roads Administration (NPRA) webinar. It encompasses two primary workflows. First, the digitization of Traffic Regulation Orders (TROs), where issued TROs are converted into a digital format and stored in a database linked to national road data and HD maps. These represent static regulations. Second, provisioning of dynamic traffic regulations is issued by traffic management centres. The integration of these static and dynamic regulations constitutes the complete METR system which can be securely distributed to METR users in accordance with cybersecurity regulations.

Priority of rules for digitisation

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



Figure 4 Priorities of various traffic rules and regulations for digitisation as indicated by stakeholders. The rules which were indicated as high priority by more than 3 stakeholders are bold and underlined.

Figure 4 provides an overview of various traffic rules and regulations and their priorities for digitisation. The rules which were indicated as high priority by more than 3 stakeholders are bold and underlined.

The above prioritisation was made in focus to achieve the strategic goals on traffic safety and traffic flow. Road operators also mentioned that their focus currently is currently on implementing the delegated regulations on Safety-Related Traffic Information (SRTI) & Real-

Time Traffic Information (RTTI), and SSTP Delegated Regulation as per ITS directive. These rules are relevant for ADS as it can help them determine the legally allowed behaviour inside their Operational Design Domain (ODD).

Roles of stakeholders in traffic rule digitisation

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

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

DROIDS deliverable discussed various traffic rules and regulations that are dynamic in nature. The rules can be dynamic in temporal or spatial context or both. METR also enables provisioning of dynamic traffic regulations which can be issued on by traffic management centre. Gustin (2024) has proposed a mechanism for sharing the dynamic regulations via METR as shown in Figure 5.

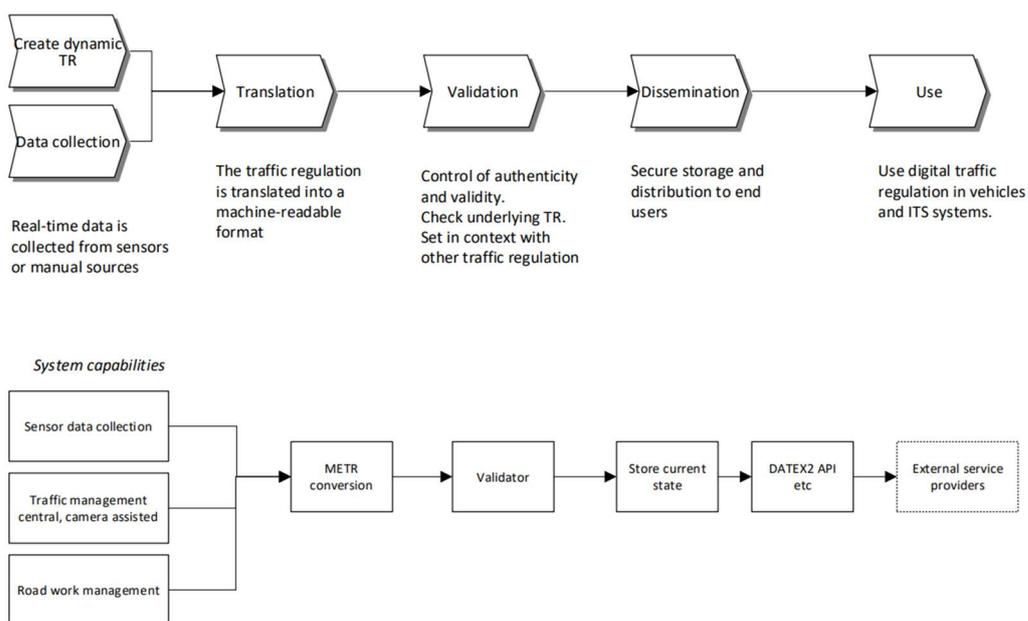


Figure 5: Provision of dynamic regulation (Gustin, 2024)

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

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

High-Definition (HD) maps are machine-readable and centimetre level precise digital representation of the physical infrastructure that can be used by the cooperative, connected, and automated mobility (CCAM). These maps are not intended for general navigation by

human drivers but are specifically designed for machines, serving as a detailed and precise representation of the physical world.

DROIDS deliverable 3.4 dived deeper into various technical details about the HD maps. First growth and adoption of HD maps was studied. Furthermore, HD maps were described with the help of various layered architectures. The creation process of HD maps was highlighted and a commentary on maintenance of HD maps was made.

Furthermore, a framework for BIM information reuse in HD maps was adapted and proposed (Figure 6). In this framework, Road operators provide validated BIM/AIM information (standardised via OTL) to HD map providers, either directly or via a National Access Point (NAP). HD map providers enrich their maps with this BIM/AIM data, reducing the need for extensive on-road data collection. A feedback loop from vehicle-generated data allows for the correction of discrepancies between digital information and physical infrastructure, demonstrated by projects like ROMO, where vehicle sensor data is used to enhance asset management and road condition monitoring. This integration aims to improve the accuracy and efficiency of HD maps for ADS.

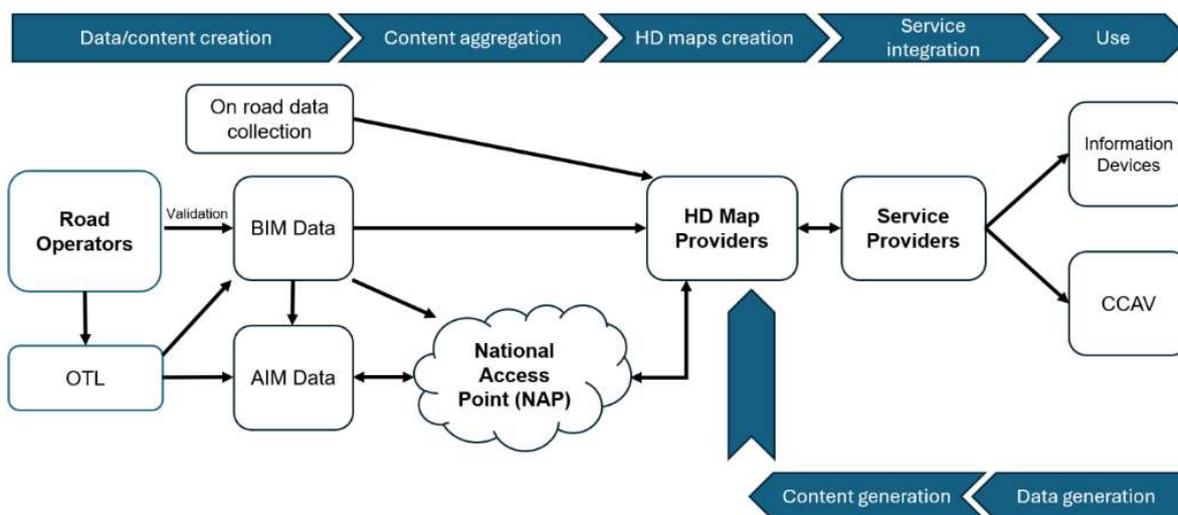


Figure 6 HD map process flow diagram adapted from Radics et al. (2020) for BIM information reuse

This use case explored the feasibility of utilising BIM and AIM data to improve the creation and maintenance of HD maps, aiming to reduce the reliance on costly, dedicated data capture. Through a literature review and collaborative brainstorming, we adapted the HD map process flow diagram proposed by Radics et al. (2020) to incorporate BIM/AIM data, mapping relevant BIM/AIM elements to the base, geometric, and semantic layers of HD map architecture. The findings indicated significant potential for BIM/AIM to enhance HD map accuracy and facilitate efficient updates, particularly when AIM is integrated to ensure continuous synchronization.

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

However, concerning the HD maps, there aren't any standards or regulations in place, and the HD map providers have different systems and algorithm which also makes it difficult for the road operators to be able to integrate their information into HD maps or have a good overview of quality of information available via HD maps. Thus, there is a requirement for HD map standardisation on an international level and dedicated regulation to ensure that HD maps are accessible, usable, understandable, transparent and accurate.

Use case 2: Authoritative information for ALKS

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

ODD of ALKS

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

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

Regulatory landscape for ALKS

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

Digital Information requirements for Lane-Level Navigation

This use case investigated the authoritative information needed for automated lane level navigation by ALKS. Lane-level navigation for automated vehicles, particularly ALKS, requires authoritative digital information from trusted sources like road authorities. This information, encompassing road types, geographic areas, speed ranges, rules, environmental conditions, and object/event detection, is crucial for safe operation. While sensor-based systems can perceive some data, comprehensive ODD attributes, as defined

by BSI PAS 1883 and ITS directives, require robust digital HD maps and real-time traffic updates. These maps, despite advancements, face challenges in coverage, accuracy, and maintenance. National Access Points (NAPs) facilitate data accessibility, emphasizing security, privacy, and data quality. METR would also play a major role in legal lane level navigation for ALKS. Road operators play active roles in developing, operating, and ensuring the quality of this information, adhering to European standards and regulations, to support reliable and interoperable automated driving systems.

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

- **Early engagement in standardization:** Road operators should engage in the METR standardization process as early as possible. This includes actively following the ongoing development and gaining a deep understanding of the relevant standards, particularly the foundational elements outlined in the initial parts of the ISO standards for METR. Participating in standardization efforts at both national and European levels will enhance the operators' maturity and knowledge, facilitating smoother METR implementation.
- **Local perspective and requirement sharing:** Road operators should thoroughly assess their local requirements and specific use cases for METR. Sharing these specific requirements with standardization bodies will ensure that METR is adaptable to a wide range of situations. Collaboration and knowledge exchange among road operators will promote alignment of interests and ensure interoperability across different regions.
- **Phased digitalization of traffic rules:** Begin with the digitalization of simple and easily achievable regulations, such as speed limits, which are mandated for the Trans-European Transport Network (TEN-T) by December 2025 and the entire public road network by December 2028. Gradually expand digitalization to include other traffic rules and information signs, following a prioritized approach.
- **Development of a clear digitalization strategy:** Road operators must develop a comprehensive digitalization strategy that outlines specific objectives, priorities, and timelines for the transformation. Ensure alignment with both national and European Union level initiatives.
- **Uniform Traffic Regulation Order (TRO) processes:** Standardize and digitize the processes for creating Traffic Regulation Orders (TROs).
- **BIM standardisation:** Road operators should develop or implement OTL within their BIM/AIM process to improve quality, standardisation and understandability of the data. This would enable opportunities to integrate BIM/AIM data within the HD maps.
- **Ensuring high-quality infrastructure for Automated Driving Systems (ADS):** Conduct regular assessments of road infrastructure to ensure the effective functioning of ADAS like Intelligent Speed Assistance (ISA). Identify and address issues with both digital information and physical infrastructure elements, such as the visibility and durability of road signs.

3.4 WP4 – Trusted service provision (D4.1)

Trusted service provisioning was described in the DROIDS deliverable 4.1 “Handling of trust and security in digital road infrastructure” (Khastgir & Dodoiu 2025). The summary conclusions of the results are presented in below.

Trust is a vast and nuanced topic. The trust model proposed in the deliverable and presented in the below figure can help provide a better understanding of it, through the most important elements that form trust in and trust with a system or data. Each component forming trust contributes to the whole in different ways.

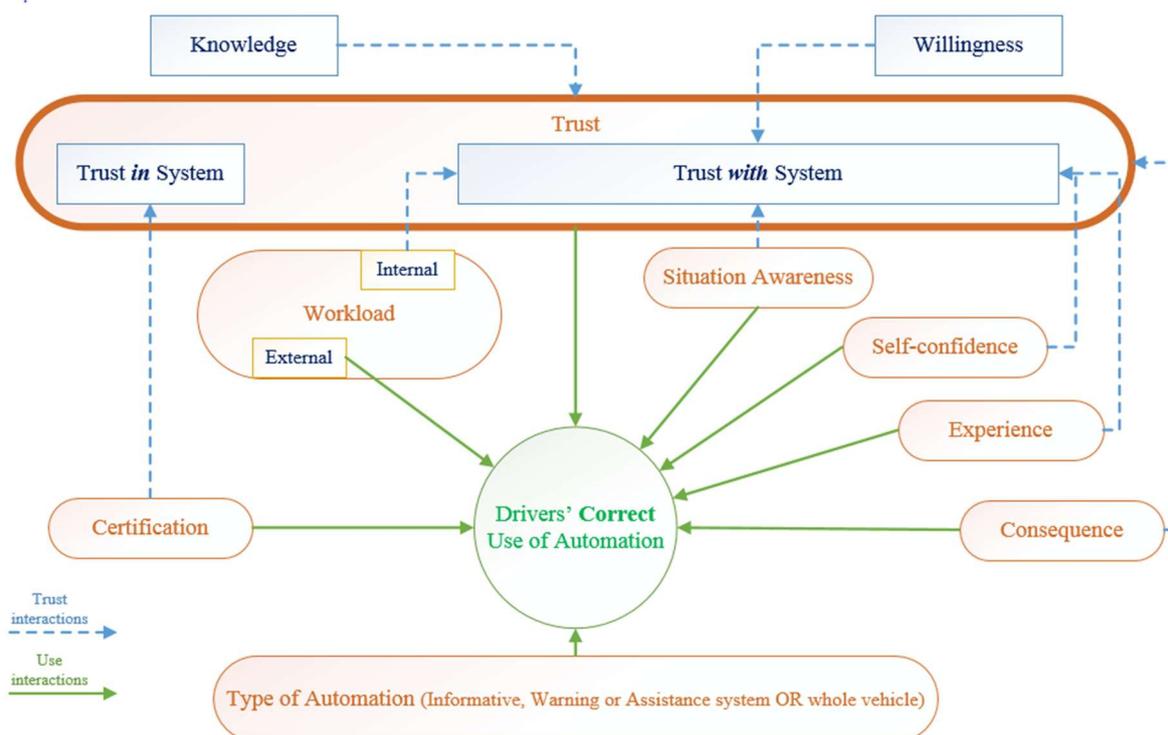


Figure 7 Framework for driver-automation interaction in automated systems in vehicles

For an organisation to be able to reap the true benefits of digitalisation, it needs to develop an appropriate level of trust to ensure correct use. We propose that instead of treating trust as a monolithic construct to instead consider two forms of trust:

- Trust in the system
- Trust with the system

By system in this context, we refer to informational systems, as well as their components. “Trust in the system” means an organisation’s trust in the capabilities of the system or in the system’s ability to do what it is supposed to do. When applied to data this refers to trust that the data is accurate and correct for its intended purpose. “Trust with the system” means the user’s awareness or attitude towards the limitations of the system and their ability to adapt their usage of the system to accommodate the limitations of the system to deliver the expected benefit. This extends to ensuring that members of the organisation are aware of these limitations and are able to adapt to them. In the context of data, trust with it is the user’s awareness of its limitations and degree of correctness, as well as the ability to ensure

that the data can be used for its intended purpose. This paradigm of trust was adapted from a paradigm of trust for the trust in the safety of autonomous driving systems (Khastgir 2019), as shown in Figure 1. To ensure that vehicles and drivers have the information required to ensure that roads can be used safely in this context can be equivalent to ensuring that these users can trust in the system and that they can be trusted with the system.

The workshop completed during the study provided valuable insight into what issues NRAs are concerned with, along with potential solutions. The workshop participants were given background information on the trust model, with positive feedback given on its usefulness. The results of the workshop were used to validate the initial recommendations to ensure relevance and potential impact.

“Trust in” recommendations:

- Reputation-based trust
- Identify potential conflicts of interest with OEMs
- Independent or Third-Party Certification
- Ensure adherence to standards and participation in standardisation activities.
- Use of Standardised Data Formats
- System Auditing
- Data Authentication
- Maintain Access Control and Audit Trails
- Data Redundancy and Cross-Verification

“Trust with” recommendations:

- Transparency of Data Collection and Processing
- Develop clear requirements for data provisioning
- Assess risks associated with data
- Document Assumptions and Use Constraints
- Validate Data Against Ground Truth
- Encourage Use of Complementary Data Sources
- Define Baseline for Data Quality
- Periodic Data Quality Assessments
- Cross-NRA cooperation
- Training and Capacity Building for NRAs

The recommendations given are a collection of actions or policies formed through an analysis of the trust model in coordination with the workshop. The list of recommendations has been given in no particular order as the priority and importance of each will not only depend on the implementing organisation, but also on the application. While individual consideration is important, there are two types of recommendations that should take priority over others. The first type is recommendations that deal with compliance with legal requirements and standards. These have the potential to cause the most detrimental or beneficial effects and therefore should be given a high priority. The other type of recommendations that should be given priority are those that deal with information security and cybersecurity, as they can heavily influence public trust.

3.5 WP5 – Data Strategy for NRAs (D5.1 and D5.2)

The WP5 Data strategy and roadmap were the main results of the DROIDS project that also included use of the other CEDR Call 2022 Data funded results of projects on third-party data

(PRESORT) and a trustworthy, secure data infrastructure (TIARA).

Due to the importance of the data strategy results, being the main results of the project, this work package results are presented more in detail at the next chapter 4 Digital Road Operator Data Strategy and Roadmap which summarises the following work package results.

- D5.1 A data strategy for the digital road operators (Bokolo et al. 2025)
- D5.2 A roadmap for implementing the data strategy (Kvalvik et al. 2025)

4 Digital Road Operator Data Strategy and Roadmap

4.1 Results of the Digital Road Operator Data Strategy and Roadmap

The CEDR DROIDS project main result was a digital road operator data strategy and roadmap which was described in the DROIDS deliverable 5.2 “A roadmap for implementing the data strategy” (Kvalvik et al. 2025). The summary conclusions of the results are presented below. The data strategy results are divided in two interrelated DROIDS deliverables with the following content.

1. Recommendations and Guidelines on Conceptual Data Strategy for Road Operators (DROIDS Deliverable 5.1, Bokolo et al. 2025): The deliverable summarises the CEDR Call 2022 Data projects of DROIDS, PRESORT and TIARA results and recommendations for the digital road operators.

2. A roadmap for implementing the data strategy, DROIDS Deliverable 5.2 (DROIDS Deliverable 5.2, Kvalvik et al. 2025): The data strategy roadmap study compiled findings from the previous D5.1, i.e. all the previous DROIDS work packages (WPs) related to road operator roles, digital twin evolution, trusted service provision, and data strategy. Additionally, the results from other CEDR Call 2022 Data projects, which responded to third-party data (PRESORT) and a trustworthy, secure data infrastructure (TIARA), were also included. In the CEDR and aforementioned projects' collaboration, a conceptual data strategy and roadmap were developed, acknowledging the different road operators at varying maturity levels.

The data strategy roadmap results included 11 action categories, which further comprise 15 actions for the digital road operators. The following paragraphs present the action categories and actions included for road operators, CEDR, and specific actions concerning the European Data Spaces.

The following **seven high-priority action categories for road operators** were proposed in the roadmap:

1. Provide education and enhance skills (Table 7)
2. Implement interoperability and utilise standards (Table 8)
3. Carry out stakeholder collaboration and prioritise use cases (Table 9)
4. Develop and purchase data and services based on standards, guidelines and design principles (Table 10)
5. Develop data governance and risk management framework (Table 11)
6. Implement a change management process (Table 12)
7. Implement a trust framework (Table 13)

Table 7 Action 1: Provide education and enhance skills

Action ID	1. Provide education and enhance skills
A1	<p>A training programme tailored to different road operators and contractors for a particular country based on their digital readiness levels and high priority use cases should be developed. Besides traditional competence development, the programme should include more practical approaches, such as participating in pilots, smaller proof-of-concept activities, or use-case-driven training. The educational institutions should be involved in the training program. For example, the following curriculum could be established:</p> <p>(1) Procurement of digital tools, services and third-party data, including competitive dialogue and innovation partnerships. (Laine et al., 2025), (2) IoT, (3) Digital Twins, (4) HD Maps, (5) Digital trust (PKI) and security (6) C-ITS services, use cases and their limitations (7) BIM, (8) AIM, (9) Interoperability and standards, (10) Cyber security, (11) Data governance, (12) Data science, (13) WEB3 and (14) Data space technology</p>

Table 8 Action 2: Implement interoperability and utilise standards

Action ID	2. Implement interoperability and utilise standards
A2	<p>Utilisation of international and EU standards shall be prioritised, but where they do not exist, national standards should be used. Appointed ambassadors from the road operation domain should take part in different standardisation committees and forums. Standards and their implementation profiles need to be validated and implemented, e.g. C-ITS in C-Roads Platform. High-priority standards within the following areas should be prioritised:</p> <ul style="list-style-type: none"> • Cooperative Intelligent Transport Systems (C-ITS PKI, C-Roads) • Real-time Traffic Information (RTTI delegated regulation, Datex II) • Road Infrastructure Data (OTL) • Privacy (GDPR, ePrivacy, ITS) • Road Infrastructure Asset Management (BIM, AIM, GIS).

Table 9 Actions 3 and 4: Carry out stakeholder collaboration and prioritise use cases

Action ID	3. Carry out stakeholder collaboration and prioritise use cases
A3	<p>By engaging stakeholders, road operators can ensure that data initiatives are closely aligned with the digital needs of road operations. This includes:</p> <ul style="list-style-type: none"> • Deploy the most important and useful digital representation use cases about road operators' core business in a cost-effective manner <p>The national road operators should outline real-world challenges and opportunities in prioritised use cases that promote the acquisition of new data sources. This can be achieved through early engagement with end-users by demonstrating selected use cases, pilots, and proof-of-concept activities.</p>
A4	<p>The road operators should develop a stakeholder strategy to engage with key data providers (e.g., road authorities, third-party data providers, citizens) to establish a shared vision on utilising data as an asset, ensuring comprehensive data coverage and fostering innovation (the CEDR PRESORT project, e.g. Laine et al. 2025). The national road operators should encourage collaboration between public administrations and private companies to share costs and expertise.</p>

Table 10 Actions 5, 6 and 7: Develop and purchase data and services based on standards, guidelines and design principles

Action ID	4. Develop and purchase data and services based on standards, guidelines and design principles
A5	<p>Data has become a new raw material for service provisioning and innovation in digital road operations (e.g., Digital Twins, AI tools, HD Maps). New, digital services and products should be developed, supporting data as an asset, by carefully considering the following:</p> <ul style="list-style-type: none"> • Development of new digital services and products based on data, adhering to a set of recommendations for interoperability and standards (such as data formats and quality attributes), ownership and usage rights, laws, and regulations (GDPR, Data Act, Data Governance Act). • Focus on developing mature, well-functioning products that have undergone MVP verification, provide clear commercialisation opportunities • Leverage open data sources while safeguarding sustainability, quality and accuracy.
A6	<p>A revised set of guidelines for purchasing data products and services must be incorporated into public procurement procedures (and supported by digital contract negotiations in data spaces). (e.g. Laine et al. 2025)</p>
A7	<p>Development and innovation of new services and products should integrate human-centric design principles and co-creation with relevant stakeholders.</p>

Table 11 Action 8: Develop a data governance and risk management framework

Action ID	5. Develop data governance and risk management framework
A8	<p>The national road operators should agree on a data governance framework that:</p> <ul style="list-style-type: none"> • Define the data attributes that are align with the requirements early (e.g. accuracy, coverage) • Ensures the efficient and effective utilisation of information, including backwards compatibility and diversity • Covering areas such as data privacy, data security, data quality, data catalogues and metadata management, data in cloud and hybrid environments, data ethics, data governance tools, and data governance maturity. • Supports quality metrics with well-established and accepted measurement methods • Road operators should be mindful of potential data quality issues in less populated regions, where third-party data providers often operate. • The road operator should embed legal, contractual and ethical responsibilities for data accuracy in their operation • Aims to integrate data from various sources and systems to meet objectives (accuracy, consistency, coverage, other requirements), facilitating interoperability and ensuring that data across the stakeholders is compatible and usable. • Effectively managing compliance and mitigating risks in data handling (e.g., sensitivity, potential impact, and C-ITS services) requires a strategic approach, and data governance plays a pivotal role. • Work across sectors to align legal frameworks, technical standards, and operational practices. • Conduct regular security audits • Define clear consent models, especially for pseudonymised vs. personal data that communicates well with the consentor. • Integrate privacy-by-design into procurement rules and certification processes • Work with legal, procurement and audit to elevate data as a deliverable and communicate all data policies internally and externally • Introduce adaptive governance, allowing stakeholder-led audits

Table 12 Action 9: Implement a change management process

Action ID	6. Implement a change management process
A9	<p>Implement a change management process that supports new processes, organisational changes or adoption of technologies to ensure smooth transition and acceptance.</p>

Table 13 Action 10: Implement a trust framework

Action ID	7. Implement a trust framework
A10	Apply adequate monitoring of PKI infrastructure to detect technical and security issues. Using the EU C-ITS PKI will allow for effective data exchange across borders

The key priority action for CEDR is **to establish appropriate CEDR activities that support the evolution of road operators towards digital road operation**. Such an activity can be a temporary working group, a workshop or series of them, or a research call, for instance. The actual format of the activity needs to consider the work topic, the needs of the road operators, and the urgency of the need for the activity. Following action category with a list of possible action topics is presented in the Table 14 below.

Table 14 Action 11: Establish appropriate CEDR actions to support digital road operation

Action ID	8. Establish appropriate CEDR actions to support digital road operation
A11	<p>Establish appropriate CEDR activities that support the evolution of road operators towards digital road operation. According to the road operators participating in the DROIDS workshops, the current list of possible topics for such a CEDR activity is:</p> <ul style="list-style-type: none"> • Establishment of skills needed by road operators and their contractors in digital representations (models, shadows, twins) and related processes including cybersecurity. • Identification of the most important digital representation use cases and their types based on European, national and CEDR priorities as well as a socio-economic assessment of the different use cases in various deployment scenarios • Aim to ensure that road operators embed legal, contractual and ethical responsibilities for data accuracy or in general high data quality in their operation so that the society and key stakeholders can trust and thereby fully utilise the data from the road operators. • Use of open standards to reduce dependency on proprietary technologies and patents, ensure cross-member state harmonisation, improve data quality and transparency as well as preserve privacy. • Define the role and actions of the road operators in joining the European mobility data space promoted by the European Commission including the need of a European data governance body. • Development of a clear digitalisation strategy for road operators taking on board related European strategies, national priorities and the varying digital maturity of the road operators.

The following **three high-priority action categories for specific actions for the European Data Spaces** were proposed in the roadmap:

9. Implement an EMDS-compliant data space supporting digital road operations (Table 15)
10. Formalise the standards to be applied for digital road operations (Table 16)
11. Implement a data governance framework and a data governance body (Table 17)

Table 15 Action 12: Implement an EMDS-compliant data space supporting digital road operations

Action ID	9. Implement an EMDS-compliant data space supporting digital road operations
A12	Road operator should create a data space that is compliant with the common European Mobility data space (European Commission, 2023). Deployment of data spaces supporting road operations should comply with the data spaces design principles, the step-by-step approach in the Co-Creation Method and the Deployment stages provided by DSSC to engage stakeholders in the following key areas: (1) Developing use cases and identifying functional requirements, (2) Defining the governance structure (Technical and organisational), (3) Developing data products and services, and (4) Defining the architecture and the technical infrastructure.

Table 16 Action 13: Formalise the standards to be applied for digital road operations

Action ID	10. Formalise the standards to be applied for digital road operations
A13	The standards agreed on for digital road operations should be implemented as a data space "vocabulary service" (see chapter 1.3 Terminology) that acts as a central repository for standardised data models and their documentation, enabling semantic interoperability.

Table 17 Actions 14 and 15: Implement data governance framework and data governance body

Action ID	11. Implement data governance framework and data governance body
A14	The data governance framework agreed by the road operators should be implemented according to the recommendations proposed for the Common European Mobility Data Space (Scholliers et al., 2025). Road operators should agree on a rulebook (governance model) for the data space.
A15	CEDR should agree up on the form for the data governance body (e.g. EU wide, Member state, Expert group) for digital road operations by reviewing the analysis performed by Directorate-General for Mobility and Transport (Scholliers et al., 2025)

The roadmap action implementation schedule differs between road operators, as it is dependent on two factors: first, the road operator's *maturity* level (or technical/organisational/competence readiness level) in road operation digitalisation, and secondly, the *priority* of the action for the local road operator. Also, implementation of actions

depends on combination of the local road operator ambitions and budget constraints.

Most of the actions were directed to the road operators. The actions directed to CEDR were fewer but still important, as several key actions and decisions by road operators require support from CEDR-initiated activities, including the sharing of best practices, identification of key digital representation use cases, and guidance to ensure trust in road operator data, among others.

A more detailed description of the roadmap actions can be read from the previously mentioned deliverable “A roadmap for implementing the data strategy” (DROIDS Deliverable 5.2, Kvalvik et al. 2025).

4.2 Outcomes of the Data Strategy and Roadmap Workshop

This chapter presents results of a workshop on the digital road operator data strategy and roadmap results presented in the previous chapter (Kvalvik et al. 2025). Aim of the workshop was to discuss priorities of the proposed data strategy roadmap actions and validate the results. The workshop was participated by road operator and private industry members. The workshop outcomes presented below provide qualitative and quantitative results and analysis for two use cases: asset management and electronic traffic regulation – speed limits.

Introduction to the workshop

The workshop on the digital road operator data strategy and roadmap results was organised during the CEDR Call 2022: Data Final Programme Conference in 14–15 October 2025 at Birmingham UK, parallel to the Highways UK 2025 conference. The workshop was participated by the CEDR Project Executive Board members, i.e. European road operators, and CEDR Call 2022 Data projects members from PRESORT on third-party data and TIARA on trustworthy and secure data infrastructure as well as DROIDS on digital road infrastructure.

The workshop started with a short recap of the DROIDS project results on digital road infrastructure and data strategy as well as roadmap. An introduction was given to the workshop tasks with a background explanation on differences of digital model, shadow and twin (automatic data flow: none in a model, from physical to digital object in shadow and bi-directional in twin. See more about State of the Art in Digital Twins in Soni et al. 2025).

Workshop methodology and tasks

Two tasks with two different use cases were given to the participants. The use cases were selected as being the two top priorities proposed in the NRA Roles in digital twins report (Soni et al. 2025) and in the data strategy (Bokolo J 2025) for road operator digitalisation for the next years. The tasks with background and questions can be found from the APPENDIX 1 of this report. The use cases were as follows:

1. Asset management (digital model/shadow)
2. Electronic traffic regulations – speed limits (digital shadow)

For each two use cases the participants were asked the following:

What would be your top 3 action priorities when implementing the use case?

The participants were instructed to consider them as being a road operator with low to medium maturity level digital road operation capability.

First, the participants answered individually and anonymously to an online questionnaire

where they could evaluate their top 3 priorities. Only three answers were instructed to be selected among the actions which could be then prioritised from 1 to 3 in priority order. The participants answered in two groups depending on their stakeholder group: either as a road operator or as a private industry member.

Secondly, the results of the questionnaire answers were discussed between all participants. Example questions were given to start the discussion, but the discussion was open and unstructured, i.e. participants could freely appoint their opinion on the results.

Results

The questionnaire of task 1 on asset management (digital model/shadow) use case was answered by nine road operators (n=9) and eight private sector members (n=8), i.e. total of 17 participants (n=17).

The questionnaire of task 2 on electronic traffic regulations speed limit (digital shadow) use case was answered by eight road operators (n=8) and eight private sector members (n=8), i.e. total of 16 participants (n=16).

Ranking of the actions was calculated using weighted sum score where first choice answers got 3 points, second choice answer got 2 points, and third choice answers got 1 point.

The below Table 18 present the task 1 questionnaire results on road operators top 3 ranking of action priorities when implementing the asset management (digital model/shadow) use case.

Table 18 TASK 1 questionnaire results on ROAD OPERATORS (n=9) top 3 ranking of action priorities when implementing the ASSET MANAGEMENT (digital model/shadow) use case.

Rank Num	Action Category	Total votes sum	Votes 1 st choice sum	<u>Weight score</u>
1	Carry out stakeholder collaboration and prioritise use cases	8	5	<u>18</u>
2	Provide education and enhance skills	7	1	<u>13</u>
3	Formalise the standards to applied for digital road operations	4	0	<u>7</u>
4	Implement interoperability and utilise standards	4	0	<u>6</u>
5	Develop and purchase data and services in accordance with established standards, guideline design principles	3	2	<u>5</u>
6	Establish appropriate CEDR actions to support road operators	2	0	<u>3</u>
7	Develop a data governance and risk management framework	2	1	<u>1</u>
8	Implement an EMDS-compliant data space supporting digital road operations	2	0	<u>1</u>
9	Implement a change management process	2	0	<u>0</u>
10	Implement a trust framework	1	0	<u>0</u>

The below Table 19 present the task 1 questionnaire results on private sector top 3 ranking of action priorities when implementing the asset management (digital model/shadow) use case.

Table 19 TASK 1 questionnaire results on PRIVATE SECTOR (n=8) top 3 ranking of action priorities when implementing the ASSET MANAGEMENT (digital model/shadow) use case.

Rank Num	Action Category	Total votes sum	Votes 1 st choice sum	<u>Weight score</u>
1	Provide education and enhance skills	4	4	<u>12</u>
2	Carry out stakeholder collaboration and prioritise use cases	3	2	<u>8</u>
3	Implement a trust framework	3	2	<u>8</u>
4	Implement interoperability and utilise standards	5	1	<u>7</u>
5	Formalise the standards to applied for digital road operations	3	0	<u>5</u>
6	Develop a data governance and risk management framework	3	0	<u>4</u>
7	Develop and purchase data and services in accordance with established standards, guideline design principles	2	0	<u>4</u>
8	Implement a change management process	2	0	<u>3</u>
9	Establish appropriate CEDR actions to support road operators	0	0	<u>0</u>
10	Implement an EMDS-compliant data space supporting digital road operations	0	0	<u>0</u>

The below Table 20 present the task 2 questionnaire results on road operators top 3 ranking of action priorities when implementing the electronic traffic regulation – speed limits (digital shadow) use case.

Table 20 TASK 2 questionnaire results on top 3 ranking of ROAD OPERATOR (n=8) action priorities when implementing the ELECTRONIC TRAFFIC REGULATION – SPEED LIMITS (digital shadow) use case.

Rank Num	Action Category	Total votes sum	Votes 1 st choice sum	<u>Weight score</u>
1	Formalise the standards to applied for digital road operations	5	3	<u>11</u>
2	Develop a data governance and risk management framework	4	1	<u>7</u>
3	Carry out stakeholder collaboration and prioritise use cases	2	2	<u>6</u>
4	Implement a trust framework	4	0	<u>5</u>
5	Implement a change management process	4	0	<u>5</u>
6	Establish appropriate CEDR actions to support road operators	3	1	<u>5</u>
7	Implement interoperability and utilise standards	2	1	<u>4</u>
8	Provide education and enhance skills	2	0	<u>1</u>
9	Implement an EMDS-compliant data space supporting digital road operations	1	0	<u>1</u>
10	Develop and purchase data and services in accordance with established standards, guideline design principles	1	0	<u>0</u>

The below Table 21 present the task 2 questionnaire results on private sector top 3 ranking of action priorities when implementing the electronic traffic regulation – speed limits (digital shadow) use case.

Table 21 TASK 2 questionnaire results on top 3 ranking of PRIVATE SECTOR (n=8) action priorities when implementing the ELECTRONIC TRAFFIC REGULATION – SPEED LIMITS (digital shadow) use case.

Rank Num	Action Category	Total votes sum	Votes 1 st choice sum	<u>Weight score</u>
1	Develop a data governance and risk management framework	8	3	<u>15</u>
2	Implement interoperability and utilise standards	5	1	<u>11</u>
3	Formalise the standards to applied for digital road operations	3	1	<u>6</u>
4	Carry out stakeholder collaboration and prioritise use cases	2	1	<u>4</u>
5	Develop and purchase data and services in accordance with established standards, guideline design principles	2	1	<u>4</u>
6	Establish appropriate CEDR actions to support road operators	1	1	<u>3</u>
7	Implement a trust framework	2	0	<u>2</u>
8	Provide education and enhance skills	1	0	<u>2</u>
9	Implement a change management process	1	0	<u>1</u>
10	Implement an EMDS-compliant data space supporting digital road operations	1	0	<u>1</u>

The following Tables 22 and 23 include both the road operators and private sectors answers top 3 priorities total weight score sums for the two use cases of asset management and electronic traffic regulation speed limits.

Table 22 The Task 1 questionnaire on top 3 ranking of road operators and private sectors (n=17) answers total weight scores sum when implementing the ASSET MANAGEMENT (digital model/shadow) use case.

Rank Num	Action Category	<u>Road operators and private sector total weight score sums</u>
1	Carry out stakeholder collaboration and prioritise use cases	<u>26</u>
2	Provide education and enhance skills	<u>25</u>
3	Implement interoperability and utilise standards	<u>13</u>
4	Formalise the standards to applied for digital road operations	<u>12</u>
5	Develop and purchase data and services in accordance with established standards, guideline design principles	<u>9</u>
6	Implement a trust framework	<u>8</u>
7	Develop a data governance and risk management framework	<u>5</u>
8	Establish appropriate CEDR actions to support road operators	<u>3</u>
9	Implement a change management process	<u>3</u>
10	Implement an EMDS-compliant data space supporting digital road operations	<u>1</u>

Table 23 The Task 2 questionnaire on top 3 ranking of road operators and private sectors answers (n=16) total weight scores sum when implementing the ELECTRONIC TRAFFIC REGULATION – SPEED LIMITS (digital shadow) use case.

Rank Num	Action Category	<u>Road operators and private sector total weight score sums</u>
1	Develop a data governance and risk management framework	<u>22</u>
2	Formalise the standards to applied for digital road operations	<u>17</u>
3	Implement interoperability and utilise standards	<u>15</u>
4	Carry out stakeholder collaboration and prioritise use cases	<u>10</u>
5	Establish appropriate CEDR actions to support road operators	<u>8</u>
6	Implement a trust framework	<u>7</u>
7	Implement a change management process	<u>6</u>
8	Develop and purchase data and services in accordance with established standards, guideline design principles	<u>4</u>
9	Provide education and enhance skills	<u>3</u>
10	Implement an EMDS-compliant data space supporting digital road operations	<u>2</u>

Validity of the results was impacted by one questionnaire error and one data analysis modification. First, the data strategy action category 11. titled as “Implement data governance framework and data governance body” was missing from the questionnaire due to technical error and difficulties with the used questionnaire software. Secondly, the software used for the questionnaire did not support limiting the number of actions selected to three (as top 3 priorities) and used “Borda count” points system where first choice gets value of max. choices, i.e. here 10, and then descending to calculate the ranking value. Therefore, the answers calculated here differ slightly from the discussed ranking order in the workshop. Only two action categories in the middle rankings were recognised of switching places in order with the presented weight score but still being closely the same in points.

Discussion about the questionnaire results during the workshop

After each participant had answered individually and anonymously to the questionnaire, the results were presented on a screen to all participants and discussed. Floor was open for discussion with example questions presented for possible discussion (see APPENDIX 1).

Complexity of each use cases (or tasks) was mentioned being high and including other possible required actions that were not included in the results. It was perceived difficult to answer due to the missing details that each of the actions categories; it would have required

more time reading each of the individual actions content.

Varying status of the implementation of the use cases by European road operators was commented having an impact on the answers. Whereas asset management (digital model/shadow) is in early stages of development and not harmonised in Europe, the electronic traffic regulation speed limits has been under work in Europe (e.g. METR) and is based on existing traffic rules and regulations, therefore formalising standards, and developing interoperability, standards and data governance would be the natural next steps.

Asset management digital models and shadows being early in the implementation in the member states, it was seen as a good idea that the priority of collaboration between the stakeholders was ranked as number one. Also, for new use cases or early in development, education and skills are naturally needed.

Status of the use case implementation by each road operator also was suggested on impacting the answers as the range of road operator maturity level from low to medium may have an impact on how the priorities were perceived.

Standards were seen important in both presented use cases as they ensure interoperability between the different implementations and where public and private sectors are both involved in.

Conclusions

Questionnaire on top 3 digital road operator data strategy action priorities when implementing two use cases of asset management and electronic traffic regulation speed limits was requested from road operators and private sector members as well as the results discussed.

The Asset management use case top 3 priorities for action categories to implement for both road operator and private sector members (n=17) were the following:

1. Carry out stakeholder collaboration and prioritise use cases
2. Provide education and enhance skills
3. Implement interoperability and utilise standards

The electronic traffic regulation speed limits use case top 3 priorities for action categories to implement for both road operator and private sector members (n=16) were the following:

1. Develop a data governance and risk management framework
2. Formalise the standards to applied for digital road operations
3. Implement interoperability and utilise standards

Most of the questionnaire answers by road operators and private industry members on top 3 priority actions to implement aligned which each other. Although the order of the answers in top 3 could slightly differ, the actions included in the top 3 were mainly the same.

When evaluating general trends and similarities in the answers, CEDR action was in both use cases considered as a mid-level priority, which itself reflects its nature as a supportive action. Road operator actions ranked high in both use cases, i.e. including stakeholder collaboration, provide education and develop a data governance and risk management framework. From Data space actions, the action number 10. Formalise the standards to be applied for digital road operation was high in both of the use cases (rank 4. in asset management and rank 3. in speed limits). Also, in both use cases the European Mobility Data Space (EMDS) related action was ranked low. This seems suitable as the use case

implementation, standards, etc. need to be established before taking action in the data space.

When comparing between the road operator and private industry members questionnaire results answers in the asset management use case, one major difference can be found. The action category “Implement a trust framework” was ranked by the road operators for last in the priority (with 0 points) while the private sector ranked it as rank 3 (with 8 points).

When comparing between the road operator and private industry members questionnaire results answers in the electronic traffic regulations speed limit use case, one major difference can be found. The action category “Implement interoperability and utilise standards” was ranked by the road operators for seventh in the priority (with 4 points) while the private sector ranked it as rank 2 (with 11 points).

Discussion in the workshop based on the questionnaire results underlined the difficulties to compare the detailed actions with each other due to complex use case implementation environments where road operators’ maturity levels can differ.

Validity of the results was impacted by one technical error with one action category missing from the questionnaire and the limitations of the questionnaire software to limit answers to only top 3 which required modifications in the final weight calculations.

5 Evaluation of expected results

This chapter evaluates the DROIDS project expected results, or expected outcomes, that the project initially aimed to provide in its research plan. Each Expected Result (ER) and its relation to a work package is presented in the table below. The numbered ERs are then evaluated in this chapter.

Table 24 Expected results of the DROIDS project Work Packages (WPs).

Expected end result	WP2	WP3	WP4	WP5
ER1 An analysis of and guidelines for, the role of NRAs in an ecosystem of digital twins for road infrastructure, including:	(X)	(X)	(X)	
ER1.1 The state of the art	X	X		
ER1.2 What information should NRAs maintain and share for future use	X			
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	X		
ER1.4 Considerations regarding standards and standardization processes and the expected level of complexity for the data		X		
ER1.5 Requirements for digital representation of traffic rules and regulations, including the need for a physical representation of restrictions in the future and the potential for improved utilization through more dynamic regulations		X		
ER1.6 Measures and approaches for handling trust and security concerning the maintenance, sharing and use of the digital road infrastructure			X	
ER2 An overarching European data strategy for the role of physical and digital road operator				X
ER3 A master plan for implementation of the strategy from 2025 and beyond				X
ER4 Report describing proof of concepts: A possible flow of information from BIM to HD Maps for new road sections to prepare the digital infrastructure for automated transport in parallel with the opening of the physical infrastructure		X		
ER5 Report describing proof of concepts: Provision of authoritative information needed for automated lane-level navigation to ensure automated vehicles navigate legally through complex traffic environments		X	X	

ER1 An analysis of and guidelines for, the role of NRAs in an ecosystem of digital twins for road infrastructure, including: ER1.1 The state of the art and ER1.2 What information should NRAs maintain and share for future use

The Expected Result 1 was successfully completed in the DROIDS Work Package 2 NRA roles in digital twins results of deliverable study (D2.2) on NRA roles in digital twins. These results were presented in chapter 3.2.2 of this report.

The ER1.1 was successfully completed in the DROIDS Work Package 2 and Work Package 3 results which included a deliverable study (D2.1/D3.1) on state-of-the-art of road operation

related digital twins. These results were presented in chapter 3.2.1 of this report.

The ER1.2 was successfully completed in the DROIDS Work Package 2 results of deliverable study (D2.2) which included digital representations (what kind of digital twins) that should be maintained by road operators. These results were presented in chapter 3.2.2 of this report.

ER1.3 How the information should be maintained and made available for maintenance contractors, map producers and road users throughout the lifecycle of the road infrastructure

The ER1.3 was successfully completed in the DROIDS Work Package 3 Digital twin evolution results of deliverable studies D3.3 BIM representation for full life-cycle of road infrastructure (chapter 3.3.3) and D3.2 information maintenance and availability (chapter 3.3.2 of this report).

ER1.4 Considerations regarding standards and standardization processes and the expected level of complexity for the data

The ER1.4 was successfully completed in the DROIDS Work Package 3 Digital twin evolution results of deliverable study (D3.2) Information maintenance and availability which included standards and standardisation process. These results were presented in chapter 3.2.2 of this report. Also, standardisation was included in the D3.3 BIM representation for full life-cycle of road infrastructure, which was presented in the chapter 3.3.3 of this report.

ER1.5 Requirements for digital representation of traffic rules and regulations, including the need for a physical representation of restrictions in the future and the potential for improved utilization through more dynamic regulations

The ER1.5 was successfully completed in the DROIDS Work Package 3 Digital twin evolution results of deliverable study (D3.4) which results included requirements for digital traffic rules and regulations as well as physical presentation. These results were presented in chapter 3.3.4 of this report.

ER1.6 Measures and approaches for handling trust and security concerning the maintenance, sharing and use of the digital road infrastructure

The ER1.6 was successfully completed in the DROIDS Work Package 4 Trusted service provision results of deliverable study (D4.1) which included results on handling of trust and security in digital road infrastructure. These results were presented in chapter 3.4 of this report.

ER2 An overarching European data strategy for the role of physical and digital road operator

The ER2 was successfully completed in the DROIDS Work Package 5 Data strategy for NRAs results of deliverable study (D5.1) which results included a data strategy for the digital road operators. These results were presented in chapter 4 of this report.

ER3 A master plan for implementation of the strategy from 2025 and beyond

The ER3 was successfully completed in the DROIDS Work Package 5 Data strategy for NRAs results of deliverable study (D5.2) which results included a roadmap for implementing the data strategy. These results were presented in chapter 4 of this report.

ER4 Report describing proof of concepts: A possible flow of information from BIM to HD Maps for new road sections to prepare the digital infrastructure for automated transport in parallel with the opening of the physical infrastructure

The ER5 was successfully completed in the DROIDS Work Package 3 Digital twin evolution results of deliverable study (D3.4) which results included proof of concept results on Reusing BIM/AIM information in HD-maps. These results were presented in chapter 3.3.4 of this report.

ER5 Report describing proof of concepts: Provision of authoritative information needed for automated lane-level navigation to ensure automated vehicles navigate legally through complex traffic environments

The ER5 was successfully completed in the DROIDS Work Package 3 Digital twin evolution results of deliverable study (D3.4) which results included proof of concept results on authoritative information for Automated Lane Keeping Systems (ALKS). These results were presented in chapter 3.3.4 of this report.

6 Conclusions

The Objective of the DROIDS project was 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 DROIDS project main results included NRA roles in digital twins, digital twin application evolution, trusted service provision and the Digital Road Operator Data strategy and a roadmap to its implementation. The conclusions are presented in the following paragraphs.

The role of the road operator for digital representations (model – shadow – twin) depends on the use case. It is important to bear in mind that the European NRAs have also other roles than the road operator depending on the national road transport system governance models. Thereby, many road operators have also the role of traffic managers, while some also have the role of traffic information service provider or road transport authority.

Typically, the road operator assumes an active role in development, operation and maintenance of the use cases directly connected to the primary tasks of the road operator. In addition, road operators tend to be the users of the digital presentations available for all use cases as this likely increases the efficiency of the road operators' own processes.

The restrictions of public sector budgets in road infrastructure and its operations mean that the NRAs have to move towards digital road operation as all evidence supports the view that digitalisation makes also NRA operations more efficient with high benefit-cost estimates. At the same time the restricted budgets mean that digital representations cannot be realised for every use case at once. The conclusion thereby is that the NRAs need to focus on some use cases. The data strategy proposes the following overall priority order for digitalisation for the next years:

- asset management (digital model/shadow)
- electronic traffic regulations – speed limits (digital shadow)
- road works (digital model/shadow)
- incident detection (digital shadow)
- access control/ UVAR incl. road tolls (digital shadow)
- electronic traffic regulations – general regulations (digital model)
- CCAM – distributed ODD awareness (digital shadow)

Digital twin application evolution concluded on the standardization of digital twin technology in the road transport sector is essential for its successful implementation and widespread adoption. While existing standards provide a foundation, there remains a pressing need for unified definitions, data formats, communication protocols, and interfaces specifically tailored to the unique requirements of road operators. Addressing these standardization needs will not only streamline operations and enhance data interoperability but also unlock the full potential of digital twins in optimizing road infrastructure, improving safety, and facilitating informed decision-making. The collaboration among stakeholders, including road operators, technology providers, and standardization organizations, is crucial in driving this standardization effort forward. By working together, the road transport sector can establish a robust framework for digital twin standardization, paving the way for a more efficient, connected, and intelligent road network in the future.

BIM representation for full life-cycle of road infrastructure research explored the practices and challenges surrounding BIM information management within road operators for road infrastructure. The findings highlight the potential of BIM for improved asset management, decision-making, and overall lifecycle optimization. However, challenges such as a lack of standardization, data quality issues, and limited interoperability hinder effective BIM information reuse.

To address these challenges, the research recommends a stepwise approach for road operators. This approach emphasizes the standardization of data through the use of ISO 19650 and OTLs. It also highlights the importance of collaboration, training, and the adoption of flexible software solutions. By implementing these recommendations, road operators can unlock the full potential of BIM information reuse, leading to a more efficient and effective approach to road infrastructure management.

Furthermore, the research identified key considerations for extending road operator's OTLs to cover the entire lifecycle of assets. This includes incorporating feedback from stakeholders, expanding the OTL to encompass a wider range of assets and data types, and ensuring standardization and interoperability through the adoption of open standards. Finally, the research proposes a process for effectively recycling BIM representations throughout the full lifecycle of digital twins for road infrastructure. This process emphasizes collaboration, data quality control, and integration with asset management systems. By following these recommendations, road operators can create a more sustainable future for their road networks through the effective use of BIM and digital twins.

Digital twin use cases of digital transport regulations, opening new roads and automated lane level navigation concluded that to effectively navigate the evolving landscape of digitalisation of traffic rules and regulations, HP mapping, and information provision for lane level navigation, road operators are advised to adopt a proactive and strategic approach. Based on the insights from previous sections, following recommendations can be made:

1. Early engagement in standardization
2. Local perspective and requirement sharing
3. Phased digitalization of traffic rules
4. Development of a clear digitalization strategy
5. Uniform Traffic Regulation Order (TRO) processes
6. BIM standardisation
7. Ensuring high-quality infrastructure for Automated Driving Systems (ADS)

DROIDS workshops and stakeholder consultations highlighted the importance of trust. To ensure **Trusted service provision** requires both trust with as well as trust in the digital representations of the NRAs and their processes utilising these representations. The long list of trust-related recommendations listed by DROIDS focus on the priority steps to be taken to ensure stakeholder trust with and in NRAs as digital road operators. It is essential to understand the need to maintain trust also in the future for the digital representations and processes in their whole life cycle. It is difficult to win back stakeholder trust when it has once been lost.

It will be a comprehensive process to implement a **data strategy** for the NRAs in their evolution towards becoming digital road operators. The European Commission has also recognised the strategic importance of mobility related data for European economy and welfare including the road transport system and road users. While the data strategy and the **roadmap** for its implementation acknowledge the need to exchange data with other

stakeholders within the European mobility and other data spaces, they focus on the actions for the NRAs and CEDR related to NRA core business processes.

The NRA actions are really the priority ones. The DROIDS deliverables, workshops and other stakeholder consultations produced in all almost a hundred (100) individual actions for the NRAs and/or CEDR. DROIDS with support from CEDR PEB and a specific workshop identified the actions included in the final list of action categories. That final list should be considered by the NRAs, and in reality, many of the most digitally mature NRAs have already started to implement most of these. This in itself proves the value of the final list.

The role of CEDR is a crucial one in supporting and accelerating the evolution via its own tools, which have proven its strength and worth in competence building and sharing in other domains of NRA core business.

A workshop was organised to evaluate top 3 digital road operator data strategy and roadmap action priorities when implementing two use cases of asset management and electronic traffic regulation speed limits. The workshop included first an individual and anonymous questionnaire for road operators and private sector members and then an open discussion on the questionnaire results.

The Asset management use case top 3 priorities for action categories to implement for both road operator and private sector members (n=17) were the following:

1. Carry out stakeholder collaboration and prioritise use cases
2. Provide education and enhance skills
3. Implement interoperability and utilise standards

The electronic traffic regulation speed limits use case top 3 priorities for action categories to implement for both road operator and private sector members (n=16) were the following:

1. Develop a data governance and risk management framework
2. Formalise the standards to applied for digital road operations
3. Implement interoperability and utilise standards

Most of the questionnaire answers by road operators and private industry members on top 3 priority actions to implement aligned which each other. Although the order of the answers in top 3 could slightly differ, the actions included in the top 3 were mainly the same. Road operator related actions were ranked high as well as Data spaces action to formalise the standards to be applied for digital road operation. CEDR action was mid-level priority, being a supportive action.

In the asset management use case, the “Implement a trust framework” was ranked by the road operators for last in the priority while the private sector ranked it as rank 3. When comparing between the road operator and private industry members questionnaire results answers in the electronic traffic regulations speed limit use case, the action category “Implement interoperability and utilise standards” was ranked by the road operators for seventh in the priority while the private sector ranked it as rank 2.

The actual validity of our results is influenced by the extent of road operators’ feedback throughout the DROIDS project lifecycle. As reported in this and other DROIDS project

deliverables, feedback from road operators was received through questionnaires and interviews, albeit to a minor extent, as well as through deliverable reviews.

A limited number of road operators participated in the final workshop to review the data strategy, and where the roadmap actions were discussed. The digital road operation level of maturity among the participating road operators was estimated to be medium to high, which could have had an impact and potentially caused bias in the results. This is because road operators with different maturity levels could review the proposed roadmap actions from different perspectives.

Other limitations of the study include the continuous evolution of the data space landscape, the restricted data space competence knowledge among the road operator participants in the work, and limitations on documenting data sources. There were also many technical and business development areas related to digital road operation that the three CEDR projects of DROIDS, PRESORT and TIARA did not cover. Such areas included, for example, specific service-dependent digital infrastructure developments, Service Level Agreements (SLAs), and data analysis capabilities.

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APPENDIX 1 CEDR Call 2022: Data – Final Programme Conference: DROIDS Workshop Presentation Material

Task 1: Asset management (digital model/shadow) top 3 priorities

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.

Task background

You are a road operator with low to medium maturity level digital road operation capabilities.

Answer Questionnaire

What would be your top 3 action priorities when implementing the asset management (digital model/shadow) use case?

Task 1: Asset management (digital model/shadow) top 3 priorities

Questions and discussion about the questionnaire results

- Thoughts on the questionnaire result of top 3 use case action priorities?
- What implementation obstacles there are for the actions?
- What success factors there could be for the actions?
- Are the required costs to implement the actions low, medium or high?
- Any national or European priorities for the actions?
- Any known actions already done in the Common European Mobility Data Space (EMDS)?

Task 2: Electronic traffic regulations – speed limits (digital shadow) top 3 priorities

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.

Task background

You are a road operator with low to medium maturity level digital road operation capabilities.

Answer Questionnaire

What would be your top 3 action priorities when implementing the electronic traffic regulations – speed limits (digital shadow) use case?

Task 2: Electronic traffic regulations – speed limits (digital shadow) top 3 priorities

Questions and discussion about the questionnaire results

- Thoughts on the questionnaire result of top 3 use case action priorities?
- What implementation obstacles there are for the actions?
- What success factors there could be for the actions?
- Are the required costs to implement the actions low, medium or high?
- Any national or European priorities for the actions
- Any known actions already done in the Common European Mobility Data Space (EMDS)?