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DROIDS

Digital Road Operator Information and Data Strategy (DROIDS)

Information maintenance and availability

Deliverable D3.2 Version 1.0

14th of June 2024

DRAFT deliverable

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

Digital Road Operator Information and Data Strategy (DROIDS)

D3.2 Information maintenance and availability

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Executive summary

The application of digital twin technology within transportation infrastructure is evolving swiftly. Many road operators and organizations are beginning to explore the use of digital twins (or digital representations like digital shadow) to optimize the performance and maintenance of their assets. However, the technology is still in the early stages of development, and many challenges need to be addressed before it can be fully adopted.

One of the main challenges facing the development of digital twins in transportation is the lack of standardisation. The absence of universally recognized standards for developing and utilizing digital twins poses a significant barrier for organizations wanting to leverage its benefits. There are currently no widely accepted standards for the creation and use of digital twins, which makes it difficult for organizations to compare and share data.

Scope

This deliverable presents the results of research carried out during the Task 3.2: Standardisation of models and processes within Work Package 3 of DROIDS. In this task the focus lies on the 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 provides an answer to the following main research question:

What kind of information models and services need to be standardised for the information that should be maintained and provided by NRAs?

Methodology

A literature review and a questionnaire were conducted to gather information about standardization needs for Digital Twins. The literature review was conducted using information from previous projects and snowballing from identified resources. A questionnaire was circulated to various organizations to capture their existing efforts, challenges, and specific needs in standardization. The questionnaire received 6 responses from organizations in Finland, Denmark, Belgium, and the United Kingdom. Additionally, some responses were received via email.

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 lays 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.

Conclusion

In conclusion, 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.

DROIDS project description

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

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

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

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

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

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

Expected achievements and benefits to road operators:

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

Glossary

AEC	Architecture, Engineering, and Construction
AG	Advisory Group
ADS	Automated Driving Systems
AIA	Aerospace Industries Association
AIM	Asset Information Modelling
API	Application programming interface
AIXM	Aeronautical Information Exchange Model
BIM	Building Information Modelling
C-ITS	Cooperative Intelligent Transport Systems
C-Roads	C-Roads Platform
C2C-CC	Car 2 Car Communication Consortium
CAD	Computer-aided design
CAM	Cooperative Awareness Messages
CEDR	Conference of European Directors of Roads
CEN/CENELEC	European Committee for Standardisation / European Committee for Electrotechnical Standardisation
COBie	Construction-Operations Building Information Exchange
CoDEC	Connected Data for Effective Collaboration project funded by CEDR
DfRS	Data for Road Safety
DROIDS	Digital Road Operator Information and Data Strategy project funded by CEDR
DT	Digital Twin
DTC	Digital Twin Consortium
DTDL	Digital twin definition language
EC	European Commission
ETSI	European Telecommunications Standards Institute
EU	European Union
EV	Electric vehicles
GML	Geography Markup Language
GPS	Global Positioning System
IATA	International Air Transport Association
ICT	Information and Communications Technology

IDTA	Industrial Digital Twin Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	Industry Foundation Classes
INTERLINK	INformation managemenT for European Roads using LINKed data project funded by CEDR
ISO	International Organization for Standardisation
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
IoT	Internet of Things
KPI	Key performance indicator
n.d.	No date mentioned in the reference
NAPCORE	National Access Point Coordination Organisation for Europe
NBIMS-US	National BIM Standard-United States
NRA	National Road Authority. NRA is often used in Europe. This study uses a term “road operator” that also includes NRAs.
NTCIP	National Transportation Communications for ITS Protocol
OASIS	Organization for the Advancement of Structured Information Standards
OGC	Open Geospatial Consortium
OMG	Object Management Group
OPC UA	Open Platform Communications Unified Architecture
PAS	Publicly Available Specification
PRESORT	ImPRoving thE uSe Of third-paRTy data by NRAs project funded by CEDR.
REST API	Representational State Transfer Application Programming Interface
RTTI	Real-Time Traffic Information
SAE	Society of Automotive Engineers
SGAM	Smart Grid Architecture Model
SRTI	Safety-Related Traffic Information
SPaT	Signal Phase and Timing
SPEC	Standard Performance Evaluation Corporation
SWIM	System Wide Information Management
V2V	Vehicle to vehicle
W3C	World Wide Web Consortium

Content

Tables

Figures

1 Introduction

The application of digital twin technology within transportation infrastructure is evolving swiftly. Many road operators and organizations are beginning to explore the use of digital twins (or digital representations like digital shadow) to optimize the performance and maintenance of their assets. However, the technology is still in the early stages of development, and many challenges need to be addressed before it can be fully adopted.

Road infrastructure assets typically involve a variety of systems and components, each with unique interfaces and protocols from different manufacturers. Internet of things (IoT) is one of the key enabling technology behind the proper functioning of digital twins as it enables gathering information from various infrastructure elements. The integration of these disparate elements into a unified digital twin presents a significant challenge, underscoring the need for standardisation.

One of the main challenges facing the development of digital twins in transportation is the lack of standardisation. The absence of universally recognized standards for developing and utilizing digital twins poses a significant barrier for organizations wanting to leverage its benefits. There are currently no widely accepted standards for the creation and use of digital twins, which makes it difficult for organizations to compare and share data. (Botín-Sanabria et al., 2022; Wang et al., 2024). This lack of standardisation hampers the ability to exchange and compare data effectively, which in turn obstructs collaborative efforts and the sharing of best practices, ultimately slowing the technological progress and adoption of digital twins.

Although the potential of digital twin technology in revolutionizing transportation infrastructure is undeniable, its widespread adoption is hindered by critical challenges, particularly the lack of standardisation. The absence of unified protocols and guidelines for developing and utilizing digital twins creates obstacles in data integration, interoperability, and collaboration. Thus it is critical to understand the current state of standardisation and identify what models, data and processes need to be standardised to reap the optimal benefits of digital twin. It is also important to dive deeper into interoperability standards which would allow effective communication between various IoT devices used for making digital twin of the road infrastructure.

Chapter 2 explains the purpose and scope of this deliverable. Chapter 3 introduces methodology of the study and project as well as the research methods used. Chapter 4 aims to shed light into the necessity and importance of standardisation as well as its benefits. Chapter 5 discusses the existing standardisation landscape and current standardisation practices. Chapter 6 highlights the models and process that can benefit from standardisation. Chapter 7 finally concludes the study findings.

2 Purpose and scope

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

This deliverable presents the results of research carried out during the Task 3.2: Standardisation of models and processes within Work Package 3 of DROIDS. In this task the focus lies on the 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 provides an answer to the research questions as in Table 1 below. The main research question is also broken down in sub-research questions.

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

DROIDS Task 3.2 research question	Sub-Research Questions answered in this Deliverable	Deliverable Chapter
(RQ7) What kind of information models and services need to be standardised for the information that should be maintained and provided by NRAs?	Why standardisation is necessary?	4
	What standardisation is necessary on country level? EU level?	4
	What kind of standardisation already exists?	5
	What are the challenges being faced with existing (or absence of) standardisation?	5
	What standardisation processes are there in other engineering disciplines?	5
	Which models and processes ask for immediate standardisation?	6

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

Table 2: DROIDS project Work Package3‘s expected end results and the scope of this deliverable.

DROIDS WP3 expected end result	Deliverables
ER1.1 - Building on results of WP2, The state of the art. (technical and functional aspects)	D2.1 & D3.1 (combined report)
ER1.3 - How the information should be maintained and made available for maintenance contractors, map producers and road users throughout the lifecycle of the road infrastructure. (technical and functional aspects)	This deliverable (D3.2)
ER1.4 - Considerations regarding standards and standardisation processes and the expected level of complexity for the data.	D3.3

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.	D3.4
ER4 - Report describing proof of concepts: A possible flow of information from BIM to HD Maps for new road sections to prepare the digital infrastructure for automated transport in parallel with the opening of the physical infrastructure	D3.4
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	D3.4

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

Key terminology

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

2. While the concept of Digital Twin has numerous definitions, the **DROIDS definition of Digital Twin** was formulated which is as follows:

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

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

3 Methodology

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

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

Project Methodology

The DROIDS project utilises the Digital Transformation Framework (DTF) structured approach that supports the design, development, planning and management of necessary organisational transitions. The DTF adopted for the DROIDS project is illustrated in Figure 1. Within the DTF, it is important to ensure vertical and horizontal alignment between the different columns and layers.

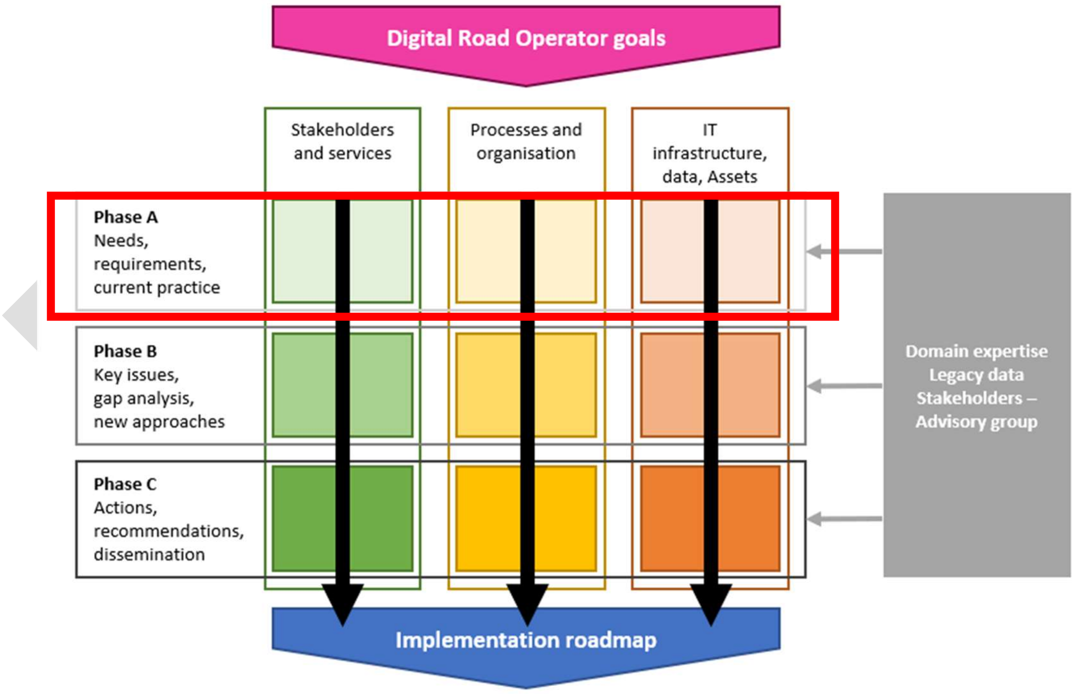

Figure 1 DROIDS project's Framework

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

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

This deliverable is a part of the first horizontal DTF Phase A that determines needs, requirements, and current practices as highlighted by a red box in the Figure 1.

Research Methodology

In order to gather the required information to achieve the objectives, a literature review was carried out. The results from existing and prior work conducted in CEDR projects were considered in desktop research as a starting point to enable the work carried out now and in the future work of the DROIDS Work Packages. The close liaison with CEDR projects PRESORT and TIARA was very useful in ensuring the state-of-the-art information acquired in those. Furthermore, a questionnaire was circulated to capture the current state of standardisation and standardisation needs of the organisation in context of digital twins. In addition, a few experts from Royal HaskoningDHV were consulted who work in the domain of digital twin with road operators in the Netherlands.

Literature review methodology

The information gathered during the previous phase of the project as well as previous CEDR projects: INTERLINK and CoDEC was used as a starting point to conduct the literature review. The research was then conducted around the main and sub research questions to gather relevant information. Furthermore, from the identified resources, snowballing was carried out to identify more relevant literature. In addition, any information shared by the stakeholders via questionnaire or during interaction such as AG meetings, consortium meetings, collaboration meetings etc. was also used.

Questionnaire methodology

To gather information about the standardisation needs for Digital Twins (in alignment with Phase A of the DTF), a questionnaire capturing the standardisation needs of the organisations was circulated. The questionnaire focussed on capturing the existing efforts of organisations in standardisation, challenges faced by them due to lack of standardisation and specific needs of various organisations. The questions asked in the questionnaire can be found in Appendix A.

The questionnaire received 6 responses in total. Table 4 provides an overview of various organisations who provided their inputs via the questionnaire.

Table 3: An overview of organisations who responded to the questionnaire

Organisation	Country
Fintraffic	Finland
Fintraffic	Finland
Fintraffic	Finland
Danish Road Directorate	Denmark
F2S2, consultant to AWV	Belgium
Syselek (UK) Ltd	United Kingdom

In addition to the above responses, a few responses were received via email with some key points to take into perspective.

4 Standardisation: Why is it necessary?

In the expanding field of digital twins, standardisation emerges as a critical factor that influences a spectrum of challenges, from data management to interoperability. The absence of standardised data formats, protocols, and interfaces is a notable technical challenge that indirectly affects other areas within digital twin systems (Lei et al., 2023; Wang et al., 2024).

Digital twins are powered by the combined efforts of data collection, processing, and communication elements. The necessity for data sharing across mechanical, digital, and human interfaces, especially when expanding beyond organizational or geographical boundaries, highlights the importance of standardization (Muir, 2022).

Due to their diverse applications and uses across industries, standardizing digital twins has proven difficult. The lack of a common definition among standards organizations underscores that the field of digital twins is still evolving, with implementation in its early stages (Wang et al., 2022).

Given the complex coordination required among different solution providers and service vendors, standardisation is not just beneficial but necessary for the successful deployment of digital twin technologies (Wang et al., 2022).

Standards are the fruits of the standardisation process and they cater to diverse aspects of the digital twin system, such as product design, process management, data structures, and organizational workflows. The depth and breadth of these standards vary based on the digital twin applications, highlighting the presence of standard gaps in the system (Olga Radchuk, 2020).

Despite the absence of universally adopted standards, the expanding scholarly interest and literature on digital twins indicate a promising trajectory. This attention is vital for organizations such as the International Organization for Standardization (ISO) to incorporate digital twins into their standardisation endeavours. Market forecasts for digital twins are optimistic, predicting substantial growth in value as the technology becomes more prevalent across different industries (Botín-Sanabria et al., 2022).

As technologies evolve within digital twin systems, standardisation addresses several issues (Wang et al., 2022):

- It reduces system incompatibilities by establishing standardised data management, integration protocols, and utilizing technologies like data lakes and APIs.
- It addresses inconsistencies arising from different architectures and domain-specific languages by providing universally accepted protocols and interfaces, thus facilitating integration and communication.
- It simplifies the management of heterogeneous cross-domain data and promotes interconnection among various enterprises and fields by standardising digital twin terminology, architecture, and models.

4.1 What is a standard?

Standards typically originate from national, European (CEN, CENELEC, ETSI), and international (ISO, IEC) organizations, which collaborate to harmonize terms, definitions, and frameworks for digital twins. Standards are created with the aim of helping organisations to establish levels of homogeneity in relation to the management, provision of services and product development in the industry (Consultoría, 2020).

A standard, as defined by ISO/IEC Guide 2:2004[1], is a document crafted through consensus and sanctioned by a reputable entity. It prescribes rules, guidelines, or characteristics for consistent use, aiming to establish an optimal level of order within a specific context.

A data standard is a documented set of agreements on representation, format, definition, structuring, tagging, transmission, manipulation, use and management of data. Development and formal approval of such a standard follows an agreed process. A data standard has a scope of application, based on the organisations that publish it. This scope can be international, European, national, company- or even project-specific. Data standards have different levels of maturity and different levels of acceptance in the industry. In some cases, the use of standards is prescribed in regulations or by the principal (CEDR INTERLINK, 2017).

Open standards
According to International Telecommunication Union (ITU) (2005), open Standards are standards made available to the general public and are developed (or approved) and maintained via a collaborative and consensus driven process. Open Standards facilitate interoperability and data exchange among different products or services and are intended for widespread adoption.

4.2 Benefits of standardisation

The benefits of standardisation in digital twin systems are manifold (Hendrik Haße et al., 2020, Wang et al., 2022)

- It guarantees both intra-operability and inter-operability of products and services.
- It enhances data quality control by eradicating errors, inconsistencies, and anomalies.
- It secures and sanctifies data exchange among stakeholders, strengthening confidence in the digital twin's insights.
- It simplifies the creation of transparent, enduring data systems, offering substantial benefits to stakeholders.
- It supports multilateral data exchange and sharing.
- It enables network structures that span companies, industries, and regions.
- It provides a unified framework for developing, deploying, and managing digital twins.
- It ensures compatibility and seamless integration across various digital twin systems.
- It diminishes complexity and costs by streamlining data and information exchange.
- It facilitates the integration of digital twins into existing infrastructure management systems.
- It establishes a common technical language and reference for all stakeholders.

[1] ISO/IEC Guide 2:2004 - Standardization and related activities — General vocabulary

- It assures data quality and accuracy, aiding in data conversion, processing, consistency, sharing, and integration.
- Over time, it aids in system scalability and reconstruction, reducing maintenance and update durations.
- On a societal level, it fosters social and economic growth by ensuring the safety, quality, and competitiveness of products, services, and processes, thereby enabling businesses to access global markets.
- It serves as a pivotal tool for the digital twin ecosystem, a novel concept involving a data-centric network of interconnected digital twins and stakeholders, generating mutual value through emerging technologies.

5 Existing standardisation landscape

This section aims to present the current of standardisation for digital twin technologies in context of road transport.

5.1 Standardisation bodies

The standardisation landscape is a collaborative effort, pooling resources from the databases of CEN, IEC, ISO, IEEE, and consortium partners. This collective approach integrates both formal and informal standards, paving the way for a more standardised future in digital twin technologies (Wang et al., 2022; Olga Radchuk, 2020).

Interoperability is one of the key requirements for the functioning of digital twin systems. The most important foundation for this interoperability and coexistence of the different systems and stakeholders is formed in the fundamentals by consensual standardisation by way of national (DIN, DKE, CROW etc.), European (CEN, CENELEC, ETSI, etc.) and international bodies (ISO, IEC, etc.), acting as so-called standard setters (HARTING technology group, n.d.). Figure 2 showcases the interrelationships of consensual international standardisation on the digital twin and the Internet of Things. These organizations interact and cooperate closely with each other: Terms, reference definitions, structural concepts, meta-models of digital twins are standardised and thereby enable the cross-company applicability of the same – which is highly beneficial for all the stakeholders along the entire value chain.

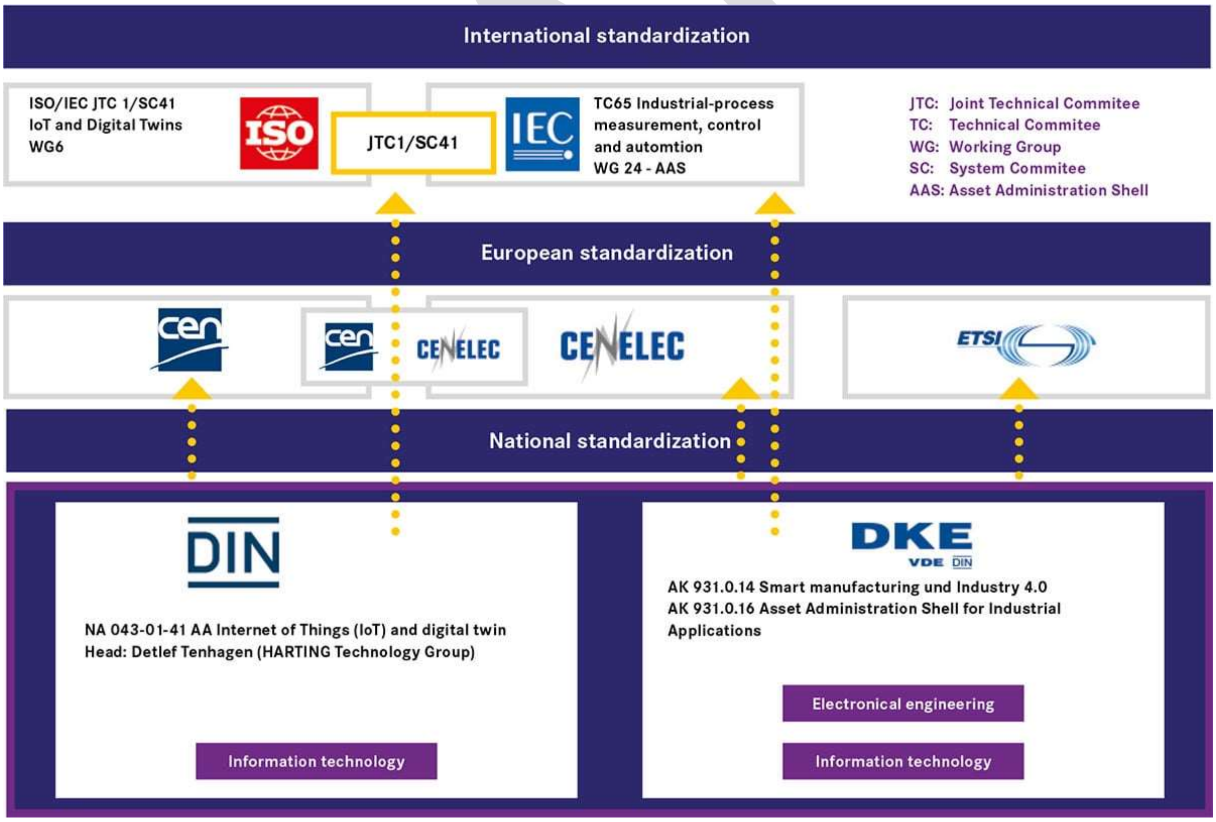

Figure 2: Interrelationships of the consensual international standardisation on the digital twin and the Internet of Things (The Meaning and Purpose of Standardising Digital Twins | HARTING Technology Group).

There are many standardisation organisations, however, some standardisation bodies or organizations with relevance to road transport digital twins are as follows (Flamigni, F. et al. (2021)):

International Organization for Standardisation (ISO)[2] is an independent, non-governmental international organization consisting of 165 national standards bodies. It unites experts for the sake of sharing knowledge and to develop voluntary, consensus-based, market relevant standards to support innovation and provide solutions to global challenges, like using digital twins. ISO is developing standards in all domains that are not covered by IEC. ISO and IEC harmonize their activities closely, currently especially related to sensor network, IoT and interoperability.

International Electrotechnical Commission (IEC)[3] is similarly structured and also a well-attended international standardisation organization as ISO. IEC publishes international standards for all electrical, electronic and related technologies. IEC standards include edge computing, electronics, IoT, sensor networks, interoperability, telecommunication and data exchange, as well as associated general disciplines such as data formats, concepts, terminology etc.

European Committee for Standardisation (CEN) and European Committee for Electrotechnical Standardisation (CENELEC)[4] are private international non-profit standardisation organizations controlled by 34 national members. They consider themselves as "business catalysts in Europe, removing trade barriers for European industry and consumers. Their mission is to foster the European economy in global trading, the welfare of European citizens and the environment. Through their services they provide platforms for the development of European Standards and other technical specs." CEN and CENELEC cooperate with their international "sister" organizations ISO and IEC for global standards to facilitate international trade. In distinction from ISO and IEC, CEN and CENELEC work closely with the European Commission to develop standards that correspond with relevant EU legislation ("Harmonised Standards").

European Telecommunications Standards Institute (ETSI)[5] is the third European Standards Organization that is officially recognized by the EU and may, thus, provide "Harmonised Standards". ETSI supports else the development and testing of global information and communications technology (ICT) standards across all sectors of industry and society. ETSI is an independent, not-for-profit, membership-based standardisation organization.

World Wide Web Consortium (W3C)[6] is an international membership organization of individuals and organizations that "develops open standards to ensure the long-term growth of the Web". Examples of W3C standards include HTML, XML, URI, RDF, OWL, SOAP and SPARQL. Several W3C standards are also published as ISO standards. W3C standards play an important role in digital twin solutions.

Object Management Group (OMG)[7] is a not-for-profit standards consortium founded in 1989. Vendors, end-users, academic institutions and government agencies develop internationally enterprise integration standards for a wide range of technologies and industries. For digital twins highly relevant consortia currently include the Industrial Internet Consortium (IIC), with over 250 members and formed to accelerate development, adoption and widespread use of

[2] https://www.iso.org
[3] https://www.iec.ch/
[4] https://www.cencenelec.eu/
[5] https://www.etsi.org/
[6] https://www.w3.org/
[7] https://www.omg.org/

interconnected machines and devices and intelligent analytics. More recently, a sister consortium of the IIC, called the **Digital Twin Consortium (DTC)**[8], joins industry, government and academia to drive towards consistent vocabulary, architecture, security, and interoperability of digital twin technology. Key industries of theirs include manufacturing, and aerospace & defence.

Organization for the Advancement of Structured Information Standards (OASIS)[9] is a global not-for-profit membership-based consortium that works on the development, convergence and adoption of open standards for cybersecurity, blockchain, Internet of Things (IoT), emergency management, cloud computing, legal data exchange, energy, content technologies, and other areas. Although the topics sound relevant for the context at hand, this survey could not identify a specific interest in OASIS deliverables.

Institute of Electrical and Electronics Engineers (IEEE)[10] is a professional association dedicated to advancing technology for the benefit of humanity. With nearly 1300 standards and projects under development, IEEE develops industry standards in a broad range of technologies that drive functionality, capabilities, and interoperability of products and services, transforming industries, like smart industry, and are critical to advanced digitization trends like the digital twin.

Standard Performance Evaluation Corporation (SPEC)[11]**:** SPEC is a non-profit corporation that aims to establish, maintain and endorse standardised benchmarks and tools that evaluate performance and energy efficiency for the newest generation of computing systems. This is essential, especially for the storage, processing and transportation of data using systems like cloud computing, edge computing, and High Performance Computing (HPC) used by digital twin solutions.

International Telecommunication Union (ITU)[12]**:** ITU is the United Nations specialized agency for information and communications technologies (ICT) with almost 200 Member States and over 1000 companies and other organisations. ITU develops technical standards for networks and technologies connectivity and for examples allocates global radio spectrum and satellite orbits.

Open Geospatial Consortium (OGC)[13]**:** OGC develops international standards for geospatial data and services, which are essential for digital twins of road transport infrastructure.

CROW[14] – CROW, based in the Netherlands, is the knowledge platform for infrastructure, public space, traffic and (public) transport, tendering and contracting. CROW organizes, mediates, records and shares knowledge and results with all parties in the market. CROW publishes some standards and technical documents, focused on APIs, data profiles and metadata standards.

In addition to these standardisation bodies, there are various national standardisation organisations. A list of various national standardisation bodies from each country is provided in Appendix C.

[8] https://www.digitaltwinconsortium.org
[9] https://www.oasis-open.org/
[10] https://www.ieee.org/
[11] https://www.spec.org/
[12] https://www.itu.int/
[13] https://www.ogc.org/
[14] https://www.crow.nl/

5.2 *Framework of digital twin standards*

According to Wang et al. (2022), digital twin related standards are categorized into five distinct sections (Figure 3), with each section encompassing a set of relevant standards. Those are Physical entities, Virtual entities, Data, Connection, and Services. Various key points are defined as follows:

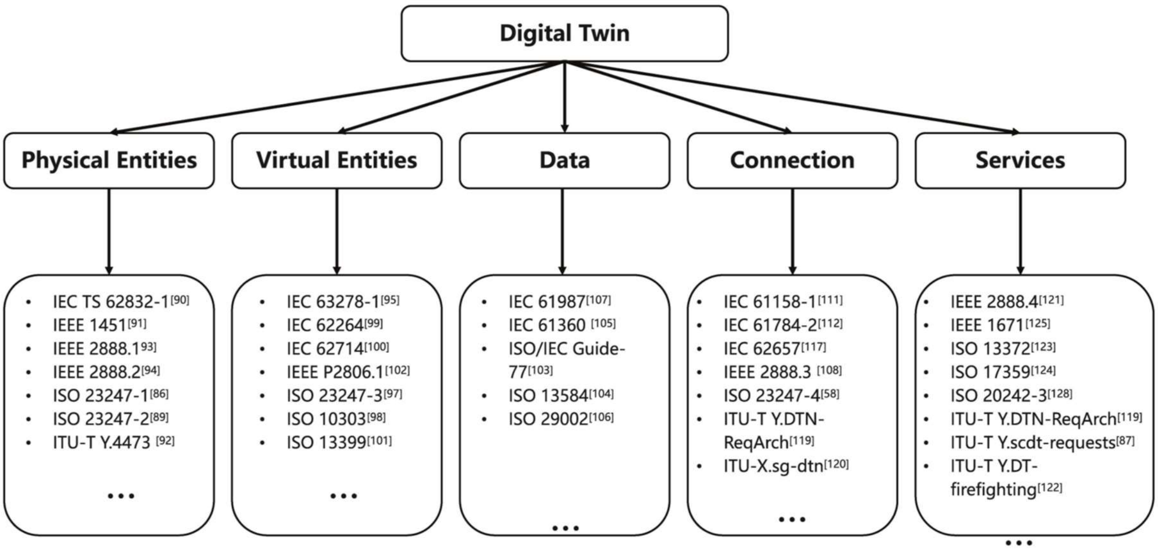

Figure 3: Framework of digital twin standards for smart manufacturing (Wang et al., 2022).

Various components of Digital Twin standard framework, including specifications (i.e. requirements) and profiles (of a standard), are described as follows:

Physical entities

Physical Entities refers to devices intended for two major functions: data collection (sensors) and device control (actuators). These devices serve as a data source or actuating mechanism for virtual entity. There are many standards in place regarding sensors and actuators, however not directly associated with the use within DTs.

Standard such as IEEE 1451[15] propose a solution for sensor interface. It provides a common interface by creating a self-descriptive electric datasheet and a network-independent smart transducer object model, which allows sensor manufacturers to support multiple networks and protocols, thus facilitating the plug and play of sensors to networks.

ITU-T Y.4473[16] specifies the application programming interface (API) which provides a framework to interconnect Internet of things (IoT) devices, data, and applications over the Web, thus managing and retrieving observations and metadata from heterogeneous IoT sensor systems.

IEEE also proposed standard series IEEE 2888, this standard series comprehensively defines interface between cyber (digital twin) and physical world, IEEE P2888.1[17] and IEEE P2888.2[18] defines the vocabulary, requirements, metrics, data formats, and APIs for acquiring information from sensors and commanding actuators, providing the definition of interfaces between the

[15] IEEE1451, 1997–2010: IEEE Standard for a Smart Transducer Interface for Sensors and Actuators.
[16] ITU-T Y.4473, 2020: Sensor Things API - Sensing.
[17] IEEE 2888.1: Specification of Sensor Interface for Cyber and Physical World.
[18] IEEE 2888.2: Standard for Actuator Interface for Cyber and Physical World.

cyber world and physical world, but the standards are still in progress.

SAREF4CITY[19]: This standard, developed by ETSI, provides a common vocabulary and ontology for describing the different elements of a digital twin, including sensors, actuators, and road infrastructure elements.

While no single standard defines the physical aspects of a digital twin, many existing standards can be leveraged. These include fieldbus profiles, companion specifications, and others that define device and component properties. These should be adapted into standardized dictionaries. Additionally, characteristics of conceptual assets, such as planning documents, should also be included in these dictionaries.

Virtual entities

Virtual entities refer to the digital representations of the physical entities. Virtual entities mainly comprise of modelling and describe physical entities on a multi-temporal and multi-spatial scale. There are several standards related to digital representations of physical entities in relation to the road transport.

GML (Geography Markup Language)[20]: This XML-based format is a widely used standard for encoding geographic information, including road networks. It provides a flexible framework for representing road features such as centrelines, lanes, intersections, and associated attributes.

CityGML[21]*:* This open data model focuses on representing 3D urban objects and is increasingly used for smart city applications. It includes classes for representing road networks, bridges, tunnels, and other transportation infrastructure elements.

ASAM OpenDRIVE[22]*:* This open-source file format is designed specifically for representing road networks for use in driving simulation and autonomous vehicle development. It defines a standardized way of describing road layouts, lane markings, traffic signs, and other essential road features.

IFC (Industry Foundation Classes)[23]: Developed by buildingSMART International, IFC is a standardized data model for representing building and infrastructure information across the entire lifecycle. While its focus is primarily on buildings, the IFC schema includes entities relevant to road infrastructure, such as alignments, road markings, and traffic signs.

LandXML[24]: This open standard is widely used for exchanging data between civil engineering and surveying software applications. It includes schemas for representing terrain models, alignments, cross-sections, and other features relevant to road design and construction.

Data

Data is one of the key components of any digital twin system. In a digital twin system, models and information representations are not independent, rather there is often an exchange of data and information within the model. Thus, it is essential to standardise the data structures, formats, properties like default value, type etc.

DATEX II[25]: This European standard is used for exchanging road-related traffic and travel information in real-time. It includes data definitions for road networks, traffic conditions,

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[19] https://saref.etsi.org/index.html
[20] https://www.ogc.org/standard/gml/
[21] https://www.ogc.org/standard/citygml/
[22] https://www.asam.net/standards/detail/opendrive
[23] ISO 16739-1:2024: Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. https://www.iso.org/standard/84123.html
[24] http://landxml.org/
[25] https://datex2.eu/

incidents, and other information that is crucial for intelligent transportation systems.

NGSI-LD[26]: This ETSI standard provides a flexible and scalable framework for representing and exchanging context information, including data related to road transport systems.

MAP[27] - The MapData (MAP) message is used to convey many types of geographic road information. At the current time its primary use is to convey one or more intersection lane geometry maps within a single message. The map message content includes such items as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications) (Based on following standards: SAE J2735, ISO TS19091, ETSI 103 301 and ETSI TS102 894-2).

SPaT[28] - Signal Phase and Timing (SPAT) message is used to convey the current status of one or more signalized intersections. Along with the MapData message (which describes a full geometric layout of an intersection) the receiver of this message can determine the state of the signal phasing and when the next expected phase will occur (Based on following standards: SAE J2735, ISO TS19091, ETSI 103 301 and ETSI TS102 894-2).

V-log[29] – V-log (in Dutch: Verkeerskundige Log, translated: Traffic engineer's Log) is a standardized protocol designed to record traffic data from intelligent traffic control systems. It was created to meet the needs of traffic engineers in performing and monitoring Dynamic Traffic Management. V-Log captures all relevant traffic data, including timestamps, message types, and associated data, allowing for real-time or scheduled retrieval of information.

Connection

Mainly refers to communication and interoperability, which enables seamless data exchange between physical and virtual entities. There are many standards related to communication which are not directly related to the digital twin for road infrastructure but are used quite often in transport applications.

IEEE P2888.3[30] defines the standards for digital synchronization between Cyber and Physical World.

SensorThings API[31]: This OGC (Open Geospatial Consortium) standard defines a web-based API for accessing and managing real-time sensor data, enabling integration of various data sources into a digital twin.

National Transportation Communications for ITS Protocol (NTCIP)[32]: This family of standards developed in the United States defines communication protocols and data dictionaries for intelligent transportation systems, including data exchange for traffic signal systems, dynamic message signs, and other roadside infrastructure.

Cooperative Awareness Messages (CAM) - CAMs are messages exchanged in the ITS network between ITS stations (ITS-S) to create and maintain awareness of each other and to

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[26] https://www.etsi.org/deliver/etsi_gs/CIM/001_099/009/01.05.01_60/gs_cim009v010501p.pdf
[27] https://www.crow.nl/downloads/pdf/verkeer-en-vervoer/verkeersmanagement/landelijke-ivri-standaarden/d3046-1_map-profile.aspx
[28] https://www.crow.nl/downloads/pdf/verkeer-en-vervoer/verkeersmanagement/landelijke-ivri-standaarden/d3046-2_spat-profile.aspx
[29] https://www.crow.nl/downloads/pdf/verkeer-en-vervoer/verkeersmanagement/v-log-protocol-en-definities-v3-0-1-wg-techniek-ch.aspx
[30] Standard on Orchestration of Digital Synchronization between Cyber and Physical World. Document IEEE P2888.3
[31] https://www.ogc.org/standard/sensorthings/
[32] https://www.ntcip.org/

support cooperative performance of vehicles using the road network. A CAM contains status and attribute information of the originating ITS-S. The content varies depending on the type of the ITS-S. For vehicle ITS-Ss the status information includes time, position, motion state, activated systems, etc. and the attribute information includes data about the dimensions, vehicle type and role in the road traffic, etc. On reception of a CAM the receiving ITS-S becomes aware of the presence, type, and status of the originating ITS-S. The received information can be used by the receiving ITS-S to support several ITS applications. (CAM data, CROW (2018))

Talking Traffic[33] *specifications* – Talking Traffic initiative lays out an architecture for smart traffic lights, which ensures software can directly communicate with all forms of hardware. This also involves communication using JSON- RPC 2.0[34] messages.

ITS-G5[35] is a wireless communication standard specifically designed for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. It operates in the 5.9 GHz frequency band and is based on the IEEE 802.11p standard. The primary goal of ITS-G5 is to improve road safety and traffic efficiency by enabling vehicles to exchange information about their position, speed, and other relevant data in real time.

Services

Digital twins are designed with a use case to provide specific services. These services can be for example making predictions, running simulations, traffic management, incident response, traffic flow optimization, asset management and maintenance, winter maintenance etc.

The standards related to services are dependent on use cases. The traffic light optimisation services such as Flowtack[36] uses C++20 standards for its services. In addition, TLS v1.2 with server-side certificate verification is used for safe and secure communication with Traffic light controllers (TLC).

REST API (*Fielding R. T., 2000)*, short for Representational State Transfer Application Programming Interface, is an architectural style for designing networked applications. It is a set of guidelines and constraints that, when followed, allow different software systems to communicate over a network, most commonly the internet. It is also used commonly within traffic applications.

It is interesting to note that the framework of Digital Twin standards also follows the similar structure as digital twin architecture (as described in DROIDS Deliverable D2.1 & D3.1 State of the art), whose key components are physical layer, digital layer, communication layer, service/application layer and data security layer. This indicates that the standards relevant for a Digital Twin is also dependent on its architecture, technical design, and use case. For each key component of digital twin architecture, relevant standards play a role.

The standards mentioned above are some examples that are relevant to various components of DT standard framework. It is to be noted that the there are many other standards related to digital twin but not specifically created for digital twin. For example, standards related to data format, internet protocols, interface standards, physical entity definitions, communication technologies, etc. A list of various standards that are relevant to the digital twin is given in Appendix B.

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[33] https://www.talking-traffic.com/en/
[34] https://www.jsonrpc.org/specification
[35] ETSI EN 302 663 - Intelligent Transport Systems (ITS); ITS-G5 Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band
[36] https://www.royalhaskoningdhv.com/en/services/flowtack

5.3 Overview of current standards related to digital twin technology

Transportation systems feature a wide array of data sources, both old and new, each with unique formats and standards. Integrating this varied data into a digital twin model necessitates meticulous attention to compatibility, transformation, and standardisation (Tripathi et al., 2024).

Digital Twins relies heavily on standardised practices to function effectively. These standards act as a common language, ensuring hardware, software, and data from various sources can seamlessly interact. Flamigni et al. (2024) provided a comprehensive list of various standards that are relevant to the concept of Digital Twin, however most standards are relevant to the digital twin of manufacturing. Although there aren't many standards specific to road DT, various standards related to interoperability, data management, secure communication, asset management, Internet of things, ITS and 3D modelling align well with the core functionalities of a Road DT system.

In addition to standards, various projects, initiatives, and organizations are focused on improving the standardisation in road transport. Table 4 provides an overview of various projects, organisations and initiatives which put an efforts towards the standardisation for digital twin of road transport.

Table 4: List of projects, legislation, specifications, organisations, and initiatives beneficial for improving standardisation for DT of road transport

Name	Description	Website/Link
Talking Traffic	Facilitating the exchange of data between road users and intelligent infrastructure within a public-private data chain	https://www.talking-traffic.com
Kennisplatform CROW	Based in the Netherlands, CROW is the knowledge platform for infrastructure, public space, traffic and (public) transport, tendering and contracting. CROW organizes, mediates, records and shares knowledge and results with all parties in the market. CROW publishes some standards and technical documents, focused on APIs, data profiles and metadata standards.	https://www.crow.nl/ https://docs.crow.nl/
SAREF4CITY	SAREF is a reference ontology for the Internet of Things that has been published as an ETSI Technical Specification and includes dedicated extensions to specific domains.	https://saref.etsi.org/saref4city
ITS Directive framework: Safety-Related Traffic Information (SRTI) & Real-Time Traffic Information (RTTI)	Legislation and EU specifications to ensure compatibility, interoperability and continuity for the deployment and operational use of Intelligent Transport Systems (ITS) for the provision of EU-wide safety related traffic information (SRTI) and real-time traffic information (RTTI) services.	https://transport.ec.europa.eu/transport-themes/intelligent-transport-systems/road/its-directive-and-action-plan/safety-related-traffic-information-srti-real-time-traffic-information-rtti_en

Technical Specification on data exchange on changes in road attributes (TN-ITS)	CEN/TS 17268:2018 defines the content specification for the exchange of road-related spatial data, and especially updates. Based on the content specification, this document defines also a physical exchange format (structure and encoding) for the actual data exchange.	https://tn-its.eu/
National Access Point Coordination Organisation for Europe (NAPCORE)	NAPCORE improves the interoperability of mobility data in Europe with mobility data standard harmonisation and alignment. Also, NAPCORE increases access and expands availability to mobility related data by coordinated data access and better harmonisation of the European National Access Points (NAPs). Within NAPCORE, a formal data specification will be elaborated, including maintenance and governance structures and a common approach will be developed as an input for a conceptualisation for a cross-border metadata registry. In addition, NAPCORE also aims to define the data types for interoperability among various NAPs.	https://napcore.eu/
European ITS Platform (EU EIP)	The European ITS Platform (EU EIP) serves as Technical ITS Knowledge Management Centre to National Road Authorities and Road Operators partnering in the EU EIP community, to the European Commission in their roles as funding and regulatory institution as well as to stakeholders and multi-stakeholder collaborations engaged in preparing Facilitating automated driving deployment.	https://www.its-platform.eu/
Car 2 Car communication consortium	The Car 2 Car Communication Consortium (C2C-CC) is a non-profit organization founded in 2002 by European vehicle manufacturers with the goal of developing and standardizing wireless communication between vehicles and their environment. This technology, also known as V2X (Vehicle-to-Everything), aims to improve road safety and efficiency by enabling vehicles to exchange information with each other and with infrastructure.	https://www.car-2-car.org/
C-roads	The C-Roads Platform is a joint initiative of European Member States and road operators for testing and implementing C-ITS services in light of cross-border harmonisation and interoperability. C-Roads platform published harmonised C-ITS specifications for Europe.	https://www.c-roads.eu/
5G Automotive Association (5GAA)	The 5G Automotive Association (5GAA) is a global, cross-industry organisation of companies from the automotive, technology, and telecommunications	https://5gaa.org/

	industries (ICT), working together to develop end-to-end solutions for future mobility and transportation services. 5GAA publishes technical reports in relevance to the digital twin of road infrastructure such as Vehicle-to-Network-to-Everything (V2N2X) Communications: Architecture, Solution Blueprint, and Use Case Implementation Examples (Link)	

A list of various standards that might be relevant for the DT of road transport systems are provided in Appendix B. However, not all standards are relevant or practical for implementation by road operators, as their specific responsibilities and operational contexts may vary.

5.4 Familiarity of road operators with Digital Twin and standardisation within their organisation

Many of the organisations who responded to the questionnaire are in the early stages of understanding and implementing digital twins. They have been involved in several projects that involve digital models (or shadows) but are still learning the full capabilities of digital twins.

They are involved in:

- Traffic management (Finland): Developing a digital twin for traffic management and participating in the development of a digital twin for the transport system.
- Investment project planning and design (Denmark): Using digital models for the planning, design, and design of investment projects.
- C-ITS services (Belgium): Exploring the use of digital models for various C-ITS services, including traffic monitoring, traffic handling, and sustainability.
- EV charging equipment design and management (UK): Developing digital models for the design and management of EV charging equipment.
- Automated driving behaviour assessment (UK): Utilizing digital models for assessing the behaviour of automated driving systems.

While they acknowledge that their work may not fully align with the strict definition of a digital twin, they are actively using digital models and data to inform decision-making and improve various aspects of their operations.

The organizations shared various standardization practices they follow for BIM. Finland primarily focusing on BIM and DWG formats for digital information management. On the other hand, in Denmark they adhere to BIM standardization through CEN/TC 442 and have implemented CAD layer structures, ICT agreements, and model specifications within their systems.

In Belgium, they align with EU C-ITS use cases and C-ROADS standards for data collection and dissemination. That have proven beneficial in convincing data owners to maintain data collection and sharing. In the context of EV charging infrastructure, they replicate the real cyber-physical system's digital communication as defined by ISO 15118 (UK).

In terms of familiarity, the responses indicate that participants were familiar with many standardisation organisations such as ISO (6 responses), CEN (4 responses) and ETSI (4 responses) whereas IEC (1 response) was the least familiar standardisation body. 4 out of 6 participants also indicated that they are not aware of any standardisation efforts in related fields which could serve as a model for road transport digital twin. One participant indicated that BIM standardisation could be a useful model for digital twin standardisation.

In terms of open data standards, 4 out of 6 participants indicated that they are familiar with the concept of open data standards, however none of their organisations are using open data standards as indicated by them (Figure 4).

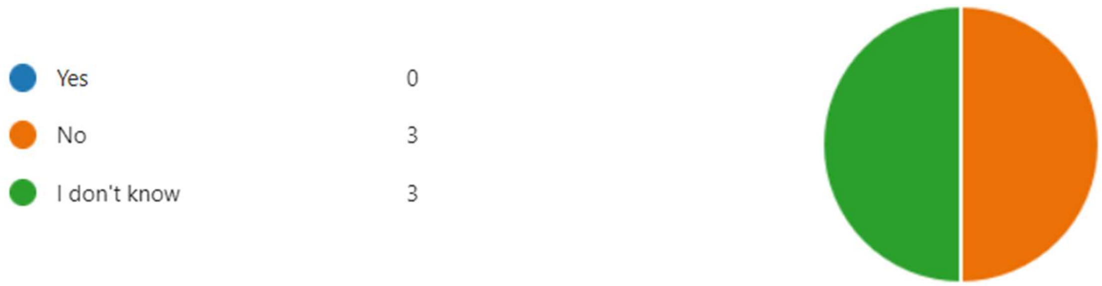

Figure 4: Response to question "Is your organisation currently using any open data standards for Digital Twins?"

In conclusion, the road operators that answered the questionnaire were in the early stages of digital twin adoption, primarily leveraging digital models for various applications like traffic management and infrastructure planning. While not strictly adhering to the formal definition of a digital twin, these organisations recognise the potential value and are actively exploring its capabilities. Standardisation practices vary across countries, with a focus on BIM and adherence to relevant industry standards. Familiarity with standardisation bodies like ISO and CEN is evident, yet awareness of standardisation efforts in related fields remains limited. The concept of open data standards is known, but their practical implementation within organisations is yet to be seen.

5.5 Standardisation within road operators

Within the standardisation ecosystem for digital twin, there are a number of standards that are relevant for its successful implementation. These standards are made by various international, European and national organisations.

Road operators often have their standards implemented in their legacy systems. They generally have a separate database and front-end system for their assets, whose functionality is based on the needs of their technical teams such as asset management team. Often, the databases are not linked, and the data may be duplicated or inconsistent. Even where NRAs have implemented large-scale single-software asset management systems at significant expense, NRAs report that those systems and the background data structures have not been based on open standards, and do not easily facilitate the linking of data and processes between different asset types. Secondly, information added to databases is often structured to suit the data requirements of the software which is being used to interrogate and edit the information (CEDR INTERLINK, 2017).

Furthermore, road operators tend to comply mainly with the standards from their national standardisation organisations. A list of various national standardisation organisations is provided in Appendix C. The standards published by national standardisation organisations may differ between countries as they try to accommodate various regional factors such as safety timings of a signal group might be dependent on driving behaviour in that country (e.g., maximum allowed response latency is 0.1 sec in NL, 0.3 sec in BE and 0.5 sec in DE). For example, traffic light system in the Netherlands follows NEN-EN 50556 standard, whereas in Germany DIN EN 50556 : 2011 is followed. Furthermore, there might be a difference in technical design for example in Germany, traffic signal turns yellow before turning to green from red whereas in the Netherlands traffic light changes from red to green directly. These differences lead to challenges in interoperability and lack of opportunities to unify and standardize the systems.

While the road operators are aware of various EU wide initiatives (like DATEX II) to harmonize standards for road transport, these initiatives currently lack sufficient depth or details for implementation. There is still work in progress for harmonization of standards on EU level. Harmonisation of standards would help to ensure that digital twins are interoperable and can be used effectively by road authorities across Europe.

5.6 Standardisation in connected topics

As it was seen in DROIDS Deliverables D2.1 and D3.1 report (2024), there is a relationship between Building information model (BIM) and Asset information model (AIM) with the digital twin and their information could be potentially harnessed within the digital twin of road infrastructure. Thus, the standardisation of information within BIM and AIM model also have an impact on the standardisation for digital twins.

5.6.1 Building Information Modelling (BIM)

A Building Information Model (BIM) is a digital representation of a building or infrastructure that contains data about its design, construction, and operation. BIM is used in the architecture, engineering, and construction (AEC) industries to improve the planning, design, construction, and management of buildings and infrastructure (Wang et al., 2024). To harness the full potential of BIM, it is essential to have standardized processes and guidelines in place. BIM standards provide a common framework that ensures interoperability, consistency, and quality across different projects and organizations. These standards are instrumental in achieving the following objectives (Unveiling the Impact of Different BIM Standards: Empower BIM Journey, 2023; A Guide to Understanding BIM Standards: BIM Levels and Global BIM Standards., 2024):

- **Interoperability**: BIM standards ensure that different software applications can exchange information seamlessly. This is crucial because various stakeholders often use different software tools for specific tasks within a project.
- **Consistency**: Standardized naming conventions and data structures enable consistency in how information is organized and presented in BIM models. This consistency aids in effective communication and understanding among team members.
- **Quality Assurance**: BIM standards promote best practices in modelling and data management, enhancing the overall quality of the project. Errors and inconsistencies can be minimized through adherence to these standards.
- **Global Collaboration**: BIM standards allow for global collaboration, as teams from different regions can work together using a common set of guidelines. This is particularly important for large-scale, multinational projects.
- **Less errors**: Following the standards, allows for the efficient exchange of data throughout the entire project lifecycle, promoting better coordination and reducing errors.
- **Easier integration**: compliance with global BIM standards ensures that projects are future-proof and can easily integrate with emerging technologies and software solutions.

Several BIM standards have gained prominence. Each of these standards serves a specific purpose and is adopted in various regions across the world. Some of the most notable BIM standards include (A Guide to Understanding BIM Standards: BIM Levels and Global BIM

Standards., 2024)

- **ISO 19650**[37]: ISO 19650 is an international standard for managing information throughout the life cycle of a built asset using BIM. It provides guidelines for information management, including naming conventions, data exchange, and collaboration processes. ISO 19650 is widely recognized and used in many countries.

- **BS 1192 (British Standard)**: BS 1192 is a British standard that outlines procedures for managing construction information, including BIM. It covers topics such as document naming, file formats, and information exchange. While primarily used in the UK, its principles have influenced BIM practices globally.

- **AIA CAD Layer Guidelines**: The American Institute of Architects (AIA) has developed CAD Layer Guidelines that are widely used in the United States. These guidelines provide standards for organizing and naming layers in BIM software to ensure consistency and clarity in drawings and models.

- **IFC (Industry Foundation Classes)**: IFC is an open standard for exchanging BIM data between different software applications. It is vendor-neutral and allows interoperability between various BIM software tools, making it a crucial standard for collaboration.

- **BIMForum LOD Specifications**: Developed by the BIMForum, an organization within the Associated General Contractors of America (AGC), these specifications define the levels of development (LOD) for BIM elements at different stages of a project. This framework provides guidance on how much detail and information should be included in a BIM model.

- **UK BIM Framework**: The United Kingdom has been a pioneer in BIM implementation. The UK BIM Framework includes documents such as PAS 1192 series, which provides guidance on BIM workflows and information management processes.

- **Singapore BIM Guide**: Singapore has a well-defined BIM e-submission guide that outlines requirements for BIM submissions for construction projects. It includes guidelines for LOD, BIM deliverables, and data exchange.

- **NBIMS-US (National BIM Standard-United States)**: This standard, developed by the National Institute of Building Sciences (NIBS), provides guidelines for information exchange, interoperability, and BIM best practices in the United States.

Within INTERLINK project (CEDR 2017), it was found that most road operators receiving and approving BIM models and associated drawings did not report that they have a standardised system for tagging the models with metadata recording the NRA's approval. Such approval is typically recorded in separate certificates. Also, NRAs generally have a separate database and front-end system for each asset type, with the functionality based on the needs of each asset management team, e.g. pavement, bridges and signage. Often, the databases are not linked, and the data may be duplicated or inconsistent. Even where NRAs have implemented large-scale single-software asset management systems at significant expense, NRAs report that those systems and the background data structures have not been based on open standards, and do not easily facilitate the linking of data and processes between different asset

[37] ISO 19650-1:2018 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling

types. Information added to databases is often structured to suit the data requirements of the software which is being used to interrogate and edit the information (CEDR, 2017). This showcases the lack of implementation of BIM standards within the road operators.

5.6.2 Asset Information Modelling (AIM)

The Asset Information Model or AIM is a term used to describe the collated set of information gathered from all sources that supports the ongoing management of an asset. The AIM serves as a single source of validated and approved information that relates to a built asset and is used during the operational phase of a building. It is a term that may relate to a single asset, a system of combined assets, or an organization's entire portfolio of assets (Richard McPartland, 2017)

In the literature, there are various standards for AIM, but in most cases, they are related to the BIM standards. Some of the standards are as follows:

- **ISO 19650 Series**: This international standard series provides a framework for managing information throughout the whole lifecycle of a built asset, including the operational phase. It defines the concepts and principles of information management using Building Information Modelling (BIM) and specifies the activities to be undertaken to support it.

- **PAS 1192-3:2014:** This Publicly Available Specification focuses on information management for the operational phase of assets using BIM. It provides guidance on how to define and manage asset information requirements (AIR) to support the operation and maintenance of assets.

- **IFC (Industry Foundation Classes):** IFC is a standardized, digital description of the built asset industry. It is an open, international standard (ISO 16739-1:2018) and promotes vendor-neutral, or agnostic, and usable capabilities across a wide range of hardware devices, software platforms, and interfaces for many different use cases. (*Industry Foundation Classes (IFC) - buildingSMART International*, 2019)

- **COBie (Construction-Operations Building Information Exchange)**: COBie is a standard of the data format for delivering asset information. It is designed to facilitate the handover of asset information from the construction phase to the operational phase. COBie is a subset of IFC.

- **ISO 55000**[38] **-** This series of standards provides an overview of asset management, including principles, terminology, and a framework for implementing an asset management system. While not specifically focused on AIM, it provides a valuable context for understanding the role of asset information in the broader asset management process.

[38] ISO 55000:2014 - Asset management — Overview, principles and terminology

5.7 Examples of digital twin implementations and their standardisation approaches

Flowtack[39]

Flowtack is a cloud-based traffic management software that leverages real-time data from various sources, including roadside sensors, GPS-enabled devices, and mobile apps, to dynamically assess traffic conditions and optimize signal timings across the entire road network. By continuously analyzing supply and demand patterns in accordance with transportation authority policies, Flowtack predicts and proactively adapts to changing traffic flows, ensuring smoother, more efficient journeys for all road users.

For road operators, the Flowtack service offers two monitoring dashboards. The first dashboard is Operational in which the current status of all Flowtack schemes is monitored. Through this dashboard, the current status of the intelligent traffic lights is visually displayed in real-time, such as priority requests, predictions, CAM vehicles, red/green requests, etc. This is visualized per intersection (see Figure 1) or schematized for the entire network.

Figure 5: Real time traffic monitoring in Flowtack's operational dashboard

The second dashboard is the key performance indicator (KPI) and Analysis dashboard. This online dashboard is automatically updated on a daily basis with the latest known data. With the KPI and Analysis dashboard, the road authority always has insight into the performance of the ITS application by comparing the measured values of KPIs with the set policy or target values. It is possible to compare these values per intersection or network. F gives an indication of the possible overviews available in the KPI and Analysis dashboard.

Figure 6: KPI and analysis dashboard showcasing more strategic KPIs

[39] https://www.royalhaskoningdhv.com/en/services/flowtack

Within flowtack, two way communication with the iVRIs (intelligent traffic light controllers) take place, which allows realtime monitoring, analysis, prediction and control. Flowtack is currently operational in many signalised intersections in Netherlands, Belgium and Germany. Its architecture components relies on various national standards of respective countries.

In the Netherlands, it follows various CROW standards related to iVRI (intelligent traffic light controllers) as mentioned in CROW's Landelijke iVRI standaarden page. These standards are combinations of various ISO, ETSI and SAE standards adapted for Dutch systems.

In addition, flowtack uses other follwing standards:

- JSON-RPC 2.0 messages over TCP - for communication with the traffic lights. The full standard is part of Talking Traffic specifications.
- TLS v1.2 with server-side certificate verification for secturity.
- REST-like API for internal object-setting management.
- C++20 standards for services.
- VLOG for traffic logging - logging of the sensors and the signalgroups.

Connected highway (Proof of concept)

Bentley Systems and Microsoft partnered to showcase the concept of digital twins for critical infrastructure at the Microsoft Build 2020 developer conference. They demonstrated how integrating Bentley's iTwin Platform and Microsoft's Azure Digital Twins could create a "connected highway." This digital twin combined real-time data from air quality and traffic monitoring devices with engineering models, maps, and terrain data. This allowed for real-time monitoring of safety hazards and traffic incidents.

The team developed a web application that provided 24/7 access to live highway conditions, including geometrically accurate and visually intuitive 3D visualization using Bentley's iTwin Viewer. The application also triggered alarms when specific thresholds were exceeded, showcasing the potential of digital twins for improving infrastructure management and response.

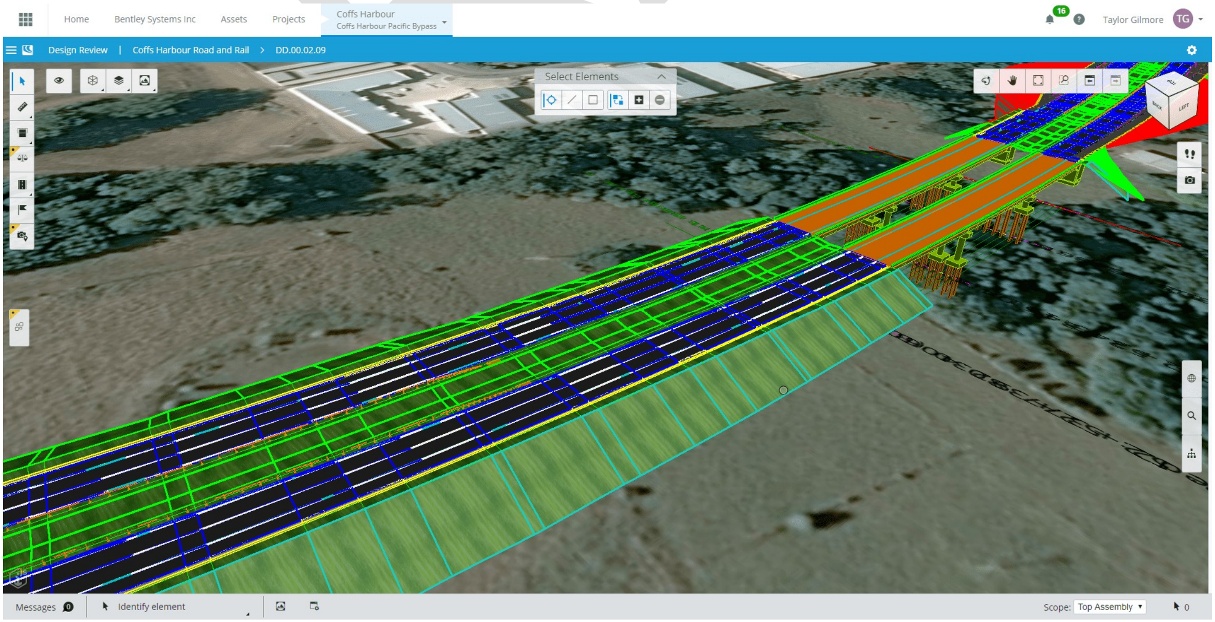

Figure 7: Digital twin built with bentley i-twin platform and azure environment (Dubey P., 2020)

Figure 8: Visualization of sensors in digital twin (Dubey P., 2020)

The project highlighted the benefits of integrating Bentley's expertise in complex engineering data aggregation and visualization with Azure's cloud services and IoT capabilities. The integration simplified the development process by automatically generating the digital twin definition language (DTDL) from the iTwin for creating the spatial intelligence graph in Azure Digital Twins.

5.7.1 Application of digital twins other engineering disciplines

Digital twin is an advancing technology which is applied in many fields. For instance, Wang, W., et al (2024), showcases various fields and use cases of digital twin in various industries.

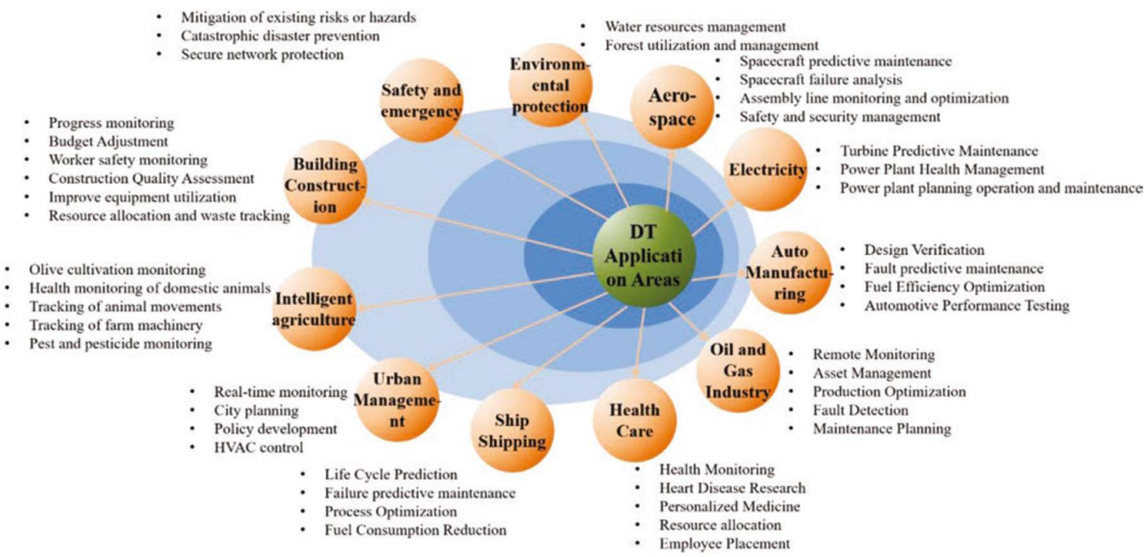

Figure 9: An overview of digital twin industrial applications (Wang, W., et al, 2024)

Digital Twins are being used across a wide range of industries to improve the performance and efficiency of assets. This section will explore some of the key applications of Digital Twins in different industries, including manufacturing, construction, aviation, and energy (Wang W., et al, 2024):

Aviation: Aviation is considered as one of the most standardised industry in relation to digital twin. In aviation, digital twins can represent aircraft, engines, air traffic, components, or even entire airports. However, the widespread adoption and full potential of digital twins hinge on the establishment of robust standards. Digital twins are used for aircraft design optimization, flight simulation, predictive maintenance, and performance monitoring.

Standardization plays a pivotal role in ensuring the interoperability, reliability, and scalability of digital twins within the aviation ecosystem. Organizations like the Aerospace Industries Association (AIA)[40] and the International Air Transport Association (IATA)[41] are developing standards and guidelines for digital twin implementation in the aerospace sector. Standards like the Aeronautical Information Exchange Model (AIXM)[42] and System Wide Information Management (SWIM)[43] provide a framework for data exchange between different aviation systems for air traffic management.

Industry and manufacturing: Digital Twins are being used in manufacturing to improve the performance of production lines and machinery. By creating Digital Twins of production lines and machinery, manufacturers can simulate their performance and identify potential issues before they occur. This allows them to make design changes and improve the efficiency of their production lines. Digital Twins can also be used to optimize the maintenance of machinery, reducing downtime and costs. Change2twin[44] is a European project focussing on the implementation of digital twin for manufacturing and also publishes reports about standardisation in manufacturing industry. Initiatives like the Industrial Digital Twin Association (IDTA)[45] and the Plattform Industrie 4.0[46] are working towards developing standardized architectures and interfaces for digital twins in manufacturing.

Design and construction: Digital Twins are also being used in the construction industry to improve the efficiency and safety of construction projects. By creating Digital Twins of construction projects, contractors can simulate the behaviour of the structure and identify potential issues before they occur. This allows them to make design changes and improve the efficiency of the project. Digital Twins can also be used to improve safety on construction sites by identifying potential hazards and taking preventative measures before they occur. For example, Skanska[47], a construction company, has used Digital Twin technology to improve the safety and efficiency of construction projects. BIM standards, such as ISO 19650, lays the groundwork for digital twin integration in the construction industry.

Energy: Digital Twins are being used in the energy industry to improve the performance of power plants, wind farms, and solar panels. By creating Digital Twins of power plants, wind farms, and solar panels, organizations can simulate their performance and identify potential issues before they occur. This allows them to make design changes and improve the efficiency of their energy production. Digital Twins can also be used to optimize the maintenance of power plants, wind farms, and solar panels, reducing downtime and costs. For example, Shell has used Digital Twin technology to optimize the maintenance of oil and gas production facilities, resulting in a 15% reduction in maintenance costs (Rassõlkin, A., et al., 2021). Initiatives like the Smart Grid Architecture Model (SGAM)[48] and the Open Platform

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[40] https://www.aia-aerospace.org/
[41] https://www.iata.org/
[42] https://aixm.aero/
[43] https://www.eurocontrol.int/concept/system-wide-information-management
[44] https://www.change2twin.eu/
[45] https://industrialdigitaltwin.org/en/
[46] https://www.plattform-i40.de/
[47] https://www.skanska.co.uk/expertise/sectors/education/our-approach/digitalisation/
[48] https://syc-se.iec.ch/deliveries/sgam-basics/

Communications Unified Architecture (OPC UA)[49] are contributing to the standardization of digital twin communication and interoperability in the energy sector.

Smart Cities: Digital Twin technology is being used in the development of smart cities, to improve the performance and efficiency of city infrastructure and services. By creating Digital Twins of city infrastructure and services, organizations can simulate the behaviour of the infrastructure and identify potential issues before they occur. This allows them to make design changes and improve the efficiency of the infrastructure. Digital Twins can also be used to improve the maintenance of city infrastructure, reducing downtime and costs. For example, Singapore has used Digital Twin technology to improve the performance and efficiency of its transportation infrastructure, resulting in a 15% reduction in maintenance costs (Huang, W. et. Al., 2022).

5.8 Challenges and gaps

A significant challenge in implementing digital twins for road transport is the lack of standardization across various processes. This includes disparate data modelling and exchange standards, leading to disconnections among specialized software (Hendrik Haße et al., 2020). Additionally, concerns have been raised about usability, coherence, selection, absence of suitable standards, complexity, and over-generalization in existing digital twin system standards (Olga Radchuk, 2020).

Interoperability also emerges as a critical issue due to this lack of standardization. The absence of universally accepted protocols and interfaces hinders seamless integration and communication between different digital twin systems (Wang W. et al., 2024). This results in data silos and prevents the technology from reaching its full potential. Establishing industry-wide standards and promoting interoperability frameworks is crucial to facilitate efficient collaboration, data exchange, and functionality across diverse digital twin deployments.

Addressing interoperability requires harmonizing technologies and standards within the digital twin ecosystem, especially when integrating various data sources and systems. While the literature offers limited solutions, frameworks like Open Platform Communications Unified Architecture (OPC UA) and ISO 23247 are recommended. These provide a standardized development framework, facilitating requirement analysis and common language use among ecosystem partners.

Currently, no widely accepted standards exist for creating and using digital twins, making it difficult for transportation departments and organizations to compare and share data. This lack of standardization hinders collaboration and the sharing of best practices, ultimately slowing down the adoption and advancement of the technology (Wang W. et al., 2024).

5.8.1 Challenges faced by Road operators

Road operators face various challenges due to lack of standardisation. All the participants indicated that they encounter difficulties (3 – very often, 3 - occasionally) integrating data from different sources into their digital representations (e.g. Digital Twin/ AIM/ BIM etc.) due to incompatible data formats or standards (Figure 10).

[49] https://opcfoundation.org/about/opc-technologies/opc-ua/

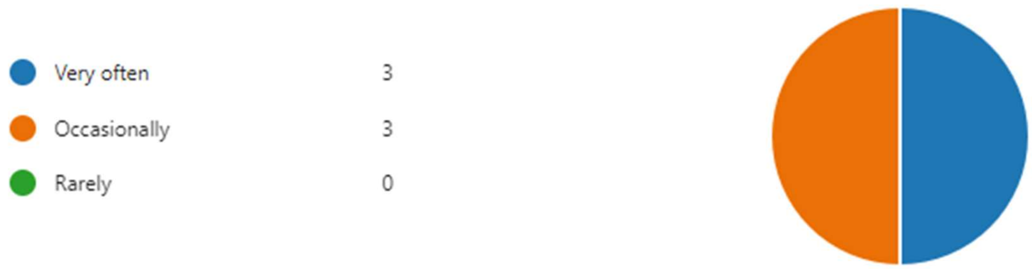

Figure 10: Frequency of difficulty in integrating data from different sources

Participants were also asked to rate how much challenge is the lack of standardised data formats for integrating data from different sources, on a scale of 1-5 where 1= Not a challenge, 5 = Major challenge. Three participants indicated 3 (average challenge) whereas other three indicated 4 (significant challenge). This indicated that lack of standardisation poses significant challenges to organisation with their digital implementations. Some of the challenges include:

As shared in questionnaire, the main challenge in integrating data from different sources is not the technology, but rather the lack of standardization and agreement among organizations on data formats, content, and representation (Finland). This is evident in various domains like traffic information and road safety, where there is no baseline or common understanding of what data should be included and how it should be represented (Finland). This lack of standardization makes it difficult to collect, compare, and analyse data from different sources, which can hinder efforts to create effective digital twins in use cases such as traffic light controllers (Belgium). Additionally, the lack of a common data format for vehicle telematics systems further complicates data integration efforts and limits the potential of this valuable data source (UK).

Participants via questionnaire also indicated that they face various challenges due to lack of standardisation. 3/6 participants indicated that they **very often face challenges** due to inconsistencies in terminology around digital representations which create confusion or hinder communication with other stakeholders. For example, inconsistency in (or lack of) understanding of terms like digital twin, digital shadow and digital model could lead to miscommunications (Finland, UK). There are also often inconsistencies in information management process (Belgium).

In terms of integrating digital representation made by other organisation, 1 organisation face challenges very often, 3 faced occasionally and 2 rarely faced challenges as seen in Figure 11.

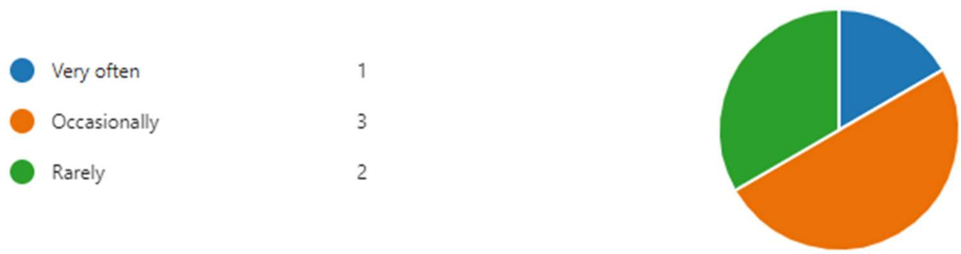

Figure 11: frequency of encounter difficulties in integrating different digital representations developed by different organisations due to a lack of standardisation

Figure 12 (Lei, B. et al., 2023) illustrates the five phases of a Digital Twin lifecycle. These phases represent the general steps involved in creating and maintaining a digital representation of a physical asset or process.

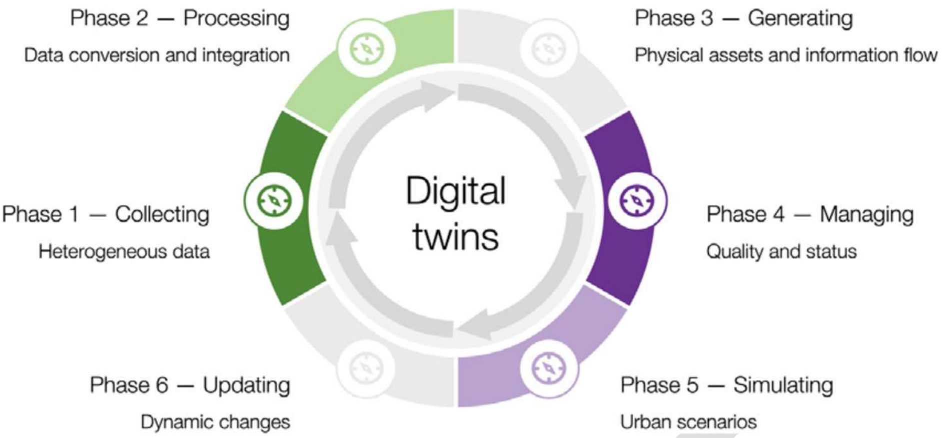

Figure 12: Five phases of Digital Twin lifecycle

Particpants indicated that they face most of the challenges in phase 4 (managing quality and status) followed by phase 2 (processing) and phase 1 (data collection) (*Figure 13*). The reason include different approaches and expectations between stakholders, technological complexity due to large datasets (like location and timeseries data), required preprocessing of data, and maintaining the validity of digital model/shadow.

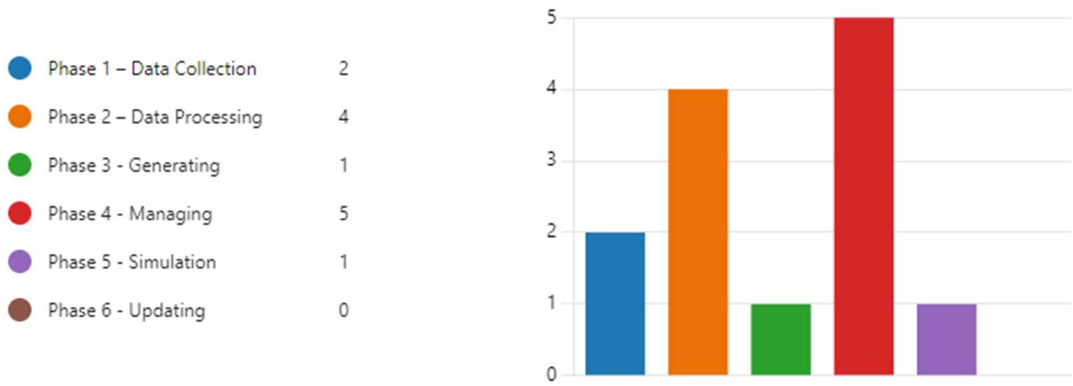

Figure 13: Phases indicated by participants where they experience the most challenges due to a lack of standardisation

In terms of non-technical challenges, the most complex aspects in digital representations for integration and collaboration are related to organizational coordination and alignment. Different organizations often have disparate working methods, leading to a lack of common rules and misaligned expectations. Furthermore, the challenge lies in aligning the purpose of the digital twin with the model architecture and input data, as well as ensuring that stakeholders can effectively utilize the results and visualizations provided by the digital twin. Resistance to change, adoption of new technologies and lack of common understanding are some key organisational challenges to overcome.

In addition, it was also mentioned that many standards related to digital twin are related to the digital twins of manufacturing. Thus there is a need for more standards focussed on road transport infrastructure.

6 Models and processes requiring standardisation

This section aims to highlight which information, models, and processes needs to be standardised which could benefit the road operators in maintaining their digital representations.

6.1 Requirements of standardisation process in digital twins

The standardisation process for digital twins should focus on the following requirements (Hendrik Haße et al., 2020; Living-in.EU, 2020; Metcalfe et al., 2023; Tripathi et al., 2024; Sisi Zlatanova et al., 2022; Muir, 2022):

- **Unified Definition**: Efforts must converge to establish a universally accepted definition, concepts and terminology of a digital twin. Varied interpretations across fields can lead to conflicts in compatibility and interoperability, hindering large-scale adoption.

- **Collaborative Development**: Defining common standards requires collaboration across all levels, including urban planning, mobility, environmental sectors, and the local innovation ecosystem, such as living labs and startups. The standardisation process demands the involvement of stakeholders, manufacturers, suppliers, standard-setting bodies, researchers, and policymakers, particularly in sectors like mobility. Standards should result from an inclusive process involving all stakeholders within the digital twin ecosystem, with a perspective that scales spatially, geographically, organizationally, and sectorally.

- **Diverse Standards**: Standards should reflect the specific technologies, physical boundaries, and application goals of each digital twin, acknowledging that one size does not fit all.

- **Mature Technology**: As digital twin technologies mature, a robust standard system is essential to enhance clarity, ensure quality, and promote service in the digital transformation of industries.

- **Open-source Standards**: Open-source standards improve interoperability and compatibility, reduce costs, and encourage adoption across industry, government, and academia due to the absence of royalties and licensing fees.

- **Scalability**: While specific standards may suffice for isolated digital twins, interconnected systems require inclusive and flexible standards to ensure interoperability on a larger scale.

- **Global Vision:** It's crucial to adopt and adapt existing standards where possible, guided by reference models that clarify scope and objectives, thus avoiding unnecessary duplication of efforts.

- **Data Interaction:** The standardisation process must facilitate interaction between diverse data formats and system architectures within digital twins.

- **General Design**: Standards should be general enough for communication with external systems and for later stages of simulation and management.

- **Consistency:** Standards must ensure consistency between international and domestic requirements.
- **Stakeholder Benefits:** Standards should be consolidated to maximize benefits for all stakeholders involved in a digital twin system.
- **Integration:** To save time and cost, standards should integrate existing standards from different domains.
- **Cross-domain Application**: Experiences from other areas, such as manufacturing, can inform the standardisation in mobility digital twins. For instance, ISO's framework for manufacturing digital twins includes general principles (ISO 23247-1), reference architecture (ISO 23247-2), essential information attributes (ISO 23247-3), and technical requirements for information exchange (ISO 23247-4).

6.2 Standardisation requirements from road operator's perspective

Within questionnaire, road operators have highlighted several key areas where standardization is required to fully leverage the potential of digital twins in the transportation sector. Figure 14 showcases the responses of road operators in questionnaire regarding which elements of digital twin would benefit them the most due to standardisation.

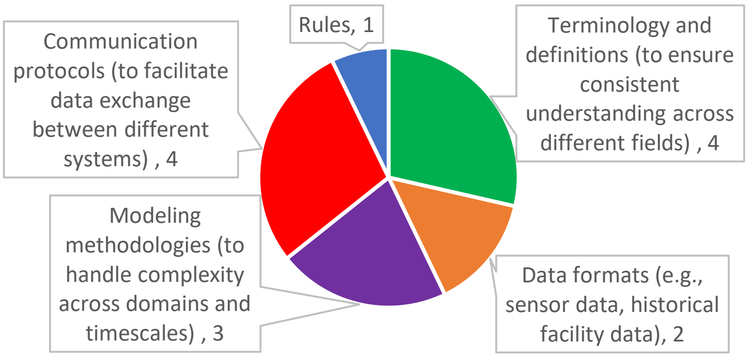

Figure 14: An overview of type of model, information, and process that would benefit from standardisation for digital twin of road infrastructure

It can be seen that communication protocols and terminology and definitions are most requested areas where standardisation is needed by the road operators. Clarity in understanding of key terminology related to digital twin would benefit road operators in communication with related stakeholders. Furthermore, communication protocols would enable smooth data exchange which is one key requirement for any digital twin architecture. Furthermore, standardisation of modelling methodologies would also enable road operators to handle more complex analysis and insights from data.

Other mentioned requirement for standardisation are elaborated as follows:

1. **Functional definitions and interoperability:**
   - There is a clear need for standardized functional definitions of digital twins tailored to specific purposes, similar to BIM/AIM for infrastructure and traffic management. These

definitions should account for the distinct requirements and operational contexts of different domains.
  - Interoperability between digital twins with varying functional scopes is crucial for seamless cooperation and data exchange. Standardized interfaces should be defined to facilitate the interaction between various digital twins, for example, road planning/maintenance digital twins and traffic management digital twins.

2. **Terminology and data usage:**
   - The development of a standardized terminology and data usage rulebook, similar to the DfRS multiparty agreement, is crucial for establishing a common understanding of digital twin concepts and ensuring consistent data practices across different stakeholders.

3. **Data formats and communication protocols:**
   - Standardized data formats and communication protocols are fundamental to ensuring interoperability and seamless data exchange between different digital twin systems and components. These standards should be aligned with existing ISO standards where applicable and focus on reducing complexity for ease of implementation.

4. **Modeling of automated traffic:**
   - The emergence of automated vehicles and traffic management systems necessitates the development of standardized models for automated traffic and its interaction with traditional traffic. These models should address the unique characteristics of automated vehicle flows and their integration within mixed traffic environments.

5. **Event modeling and management:**
   - A standardized approach to event modeling is essential for effectively managing and responding to real-time events within digital twin environments. This should include mechanisms for event detection, classification, prioritization, and response coordination.

6. **Fidelity and revision:**
   - Standards should address the fidelity and revision requirements of digital twins to ensure their trustworthiness and accuracy. This includes establishing guidelines for maintaining up-to-date and reliable representations of real-world systems within the digital twin environment.

7. **Regulatory alignment:**
   - Standardization efforts should align with existing directives and regulations, such as the ITS directive and RTTI/SRTI, to ensure legal compliance and facilitate the integration of digital twins into existing transportation frameworks.

8. **Understanding use case requirements:**
   - Thoroughly understanding the specific fidelity and validity requirements of various use cases is essential for aligning standards around these needs. This will ensure that standardized digital twins are fit for purpose and effectively address the challenges faced by road operators.

By addressing these standardization requirements, road operators can unlock the full potential of digital twins to optimize traffic management, enhance infrastructure planning and maintenance, and ultimately improve the efficiency, safety, and sustainability of transportation systems.

7 Conclusion and recommendations

Digital twin technology in transportation infrastructure is making rapid progress, but it's still in its early stages. Standardization is a key factor in the field of digital twins, addressing challenges like data management and interoperability. It's crucial for data sharing across different interfaces and necessary for successful deployment due to the diverse applications and lack of a common definition. Standards cater to various aspects of digital twin systems, but there are still gaps. Despite this, the growing interest and literature indicate a promising future, with ISO incorporating digital twins into its efforts. Standardization also solves issues like system incompatibilities, inconsistencies in architectures, and the management of heterogeneous data.

This deliverable explored the necessity and benefits of standardisation in context of digital twin for road infrastructure. Furthermore, the current landscape and state of standardisation was studied with the help of literature review and inputs from road operators. At the end, models and process requiring standardisation for road transport digital twins was explored.

Data standards are being developed with different target groups and scopes in mind and not sufficient without associated common business processes. Data standards should be harmonized across various stakeholders to ensure consistency and interoperability. These standards must be integrated into the daily business processes of all parties, including the software they use, rather than being treated as mere contractual obligations. Active participation from both road operators and industry players in the development and harmonization of these standards, particularly in the context of the European road infrastructure, is crucial for long-term success.

Road operators face challenges in implementing digital twin technology due to legacy systems, inconsistent data structures, and a lack of adherence to open standards. While national standardization organizations provide guidelines, differences in regional factors and technical designs hinder interoperability. Although EU-wide initiatives like DATEX II aim to harmonize standards, they lack sufficient detail (as of now) for practical implementation, highlighting the ongoing need for standardization efforts in the road transport sector.

Based on the information gathered from the research, the deliverable sub research questions mentioned in section 2 are reviewed as follows:

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.

What standardisation is necessary on country level? EU level?

To successfully implement digital twins in the road sector, standardization efforts are crucial at both national and EU levels.

At the country level, standardisation of data formats, structures, and attributes for road assets is essential. Aligning national standards with international or European standards is also important to ensure interoperability. Additionally, strategies should be developed to integrate legacy systems with new technologies, potentially involving data migration, API development, or middleware solutions. Collaboration among national standardization organizations, road operators, and technology providers is key to identifying and addressing any gaps or inconsistencies in national standards. Road operators can work towards incorporating various international or national standards in their current work flows.

At the EU level, harmonizing technical standards for road assets, covering data models, interfaces, communication protocols, and security requirements, is crucial. National standardization organizations from different countries should work together to establish common definitions and consistent data collection methods, addressing any regional variations. These standards should align with international standards to promote global interoperability. The EU should also establish frameworks to ensure interoperability between different digital twin platforms and provide incentives to support the development and adoption of these technologies in the road sector. Various standardisation initiatives such as the DATEX II should be expanded to provide more detailed guidance on data exchange formats, protocols, and standards specifically for road assets and digital twins.

What kind of standardisation already exists?

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 lays 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.

What are the challenges being faced with existing (or absence of) standardisation?

The lack of standardization in the road transport sector poses significant challenges for road operators. This includes difficulties integrating data from different sources due to incompatible formats, inconsistencies in terminology leading to miscommunication, and difficulties integrating digital representations from other organizations. Challenges are also faced in various phases of the digital twin lifecycle, including data collection, processing, and managing quality. The absence of standardized data formats and common understanding among organizations hinders collaboration and the effective use of digital twins. Additionally, organizational coordination, aligning purposes and expectations, and resistance to change further complicate the implementation and integration of digital twins in the road transport.

What standardisation processes are there in other engineering disciplines?

Standardization is critical in various engineering disciplines, especially in the development and implementation of digital twins. In aviation, organizations like AIA and IATA are developing standards to ensure interoperability and reliability. Standards like AIXM and SWIM provide a framework for data exchange between different aviation systems.

In the manufacturing and industrial sectors, initiatives like IDTA and Plattform Industrie 4.0 are working towards developing standardized architectures and interfaces for digital twins. BIM standards, such as ISO 19650, are essential in the construction industry for digital twin integration.

The energy sector also relies on standardization, with initiatives like SGAM and OPC UA contributing to digital twin communication and interoperability. In smart cities, digital twin technology is used to improve infrastructure and services. While standards are still evolving in this field, they are crucial for ensuring seamless integration and data exchange between various city systems.

Which models and processes ask for immediate standardisation?

Based on the information shared by the road operators, the most pressing need for standardization in digital twin implementations for road transport lies in the following areas:

- **Communication protocols and terminology/definitions**: Establishing standardized communication protocols and a clear, consistent terminology is essential for effective collaboration and data exchange between different stakeholders and digital twin systems. This includes defining common terms, data formats, and interfaces to ensure seamless integration and interoperability.
- **Modelling methodologies**: Standardizing modelling methodologies would enable road operators to create more consistent and reliable digital representations of road infrastructure, traffic flows, and other relevant aspects. This would facilitate better analysis, simulation, and decision-making based on the digital twin data.
- **Functional definitions and interoperability**: Clear functional definitions of digital twins tailored to specific purposes (e.g., infrastructure management, traffic optimization) are crucial for aligning expectations and ensuring that different digital twins can effectively cooperate and exchange information. Standardized interfaces would further enhance interoperability and data exchange between various digital twin systems.

Addressing these standardization needs would significantly benefit road operators by improving communication, facilitating data integration, and enabling the development of more robust and reliable digital twin applications for road transport.

Finally, the main research question is answered as follows:

> ***What kind of information models and services need to be standardised for the information that should be maintained and provided by NRAs?***
>
> 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.

In the field of digital twin for road transport, various challenges like standardization and data management need to be addressed. However, ongoing initiatives and projects are actively working to advance the development of digital twins in this field. As technology continues to advance and adoption becomes more widespread, digital twins are expected to play a crucial role in the future management and maintenance of transportation infrastructure.

Recommendations:

The following few recommendations can be made to road operators to improve standardisation for road transport digital twin:

- **Identify use cases and define the scope/purpose:** Having a well-defined scope helps align the project with the organization's objectives and ensures that resources are focused effectively.

- **Invest in skills and education:** With appropriate skills and knowledge, the organisations can assess their current state of standardisation, choose correct technologies for implementation, understand complex standards, perform validation and testing, and determine which data/information/process need to be standardised.

- **Adopt Open Data Standards:** Embrace open data standards for improved interoperability, flexibility, and cost-effectiveness. This will facilitate data exchange with other systems and stakeholders, enable easier integration with future technologies, and reduce reliance on proprietary software solutions.

- **Align with National Standards:** Ensure that information management practices comply with relevant national standards. This will promote consistency across different organizations, facilitate data sharing at a national level, and create a foundation for further collaboration and innovation. Road operators can start with

- **Prioritize Major Projects for Information Management Upgrades**: When implementing new information management standards or systems, focus on major projects first to gain experience, establish workflows, and realize benefits more quickly. Minor projects can be addressed later, leveraging the knowledge and infrastructure developed during the initial implementation.

- **Move Towards Integrated Asset Management Systems:** NRAs can prioritize transitioning away from siloed asset management systems (e.g., separate databases for pavements, bridges, signs) towards integrated solutions based on open standards. This will reduce data duplication, improve consistency, and enable seamless data sharing and analysis across different asset types. Consider partnering with other road operators to explore collaborative standardisation efforts.

- **Phased Implementation**: Recognize that transitioning to integrated systems and open standards may take time. A phased approach, starting with pilot projects and gradually expanding, can mitigate risks and ensure a smooth transition.

- **Change Management**: Implementing new information management systems often requires changes in processes and workflows. Invest in change management strategies to ensure successful adoption.

By adhering to these recommendations, road operators can lay a solid foundation for a future of road transport digital twins which can improve efficiency, safety, and sustainability in the transportation sector. Collaboration and knowledge-sharing among road operators will be crucial, ultimately leading to a more interconnected and intelligent road network.

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Appendix A: Questionnaire on standardisation needs for Digital Twins

Thank you for taking the time to participate in this survey. The goal of this survey is to understand different stakeholders' perspectives on standardisation needs for digital representations, particularly in the context of Digital twins for the DROIDS project.

*Digital representations are digital models or replicas that represent physical assets, processes, or systems. These systems can include, but are not limited to, **Digital Twins**, Asset Information Models (**AIM**), Building Information Models (**BIM**), and Geographic Information Systems (**GIS**) representations.*

*The **DROIDS project** (Digital Road Operator Information and Data Strategy: commissioned by CEDR.eu) aims to provide National Road Authorities (NRAs) with increased knowledge and support to benefit from digitalisation as they evolve into digital road operators. Understanding standardisation needs across various digital representations is crucial for effective data exchange and collaboration in this domain. You can read more about DROIDS project here https://www.droids-project.eu/*

This survey explores your organisation's experience with standardisation practices, existing efforts in related fields, the challenges faced due to a lack of standardisation, and your views on the benefits of standardisation for digital representations.

Your insights are valuable and will help us understand stakeholder perspectives on standardisation needs in this evolving field.

Please note: While the survey often refers to "digital representations", feel free to focus on the specific system most relevant to your work (e.g., Digital Twins, BIM, AIM etc.) when answering the questions.

We appreciate your participation!

This questionnaire will take around 20-25 minutes to complete.

What is your name?

What is the name of your organization?

Which country your organization is located?

What type of organization do you represent?

- Road operator or National Road Authority (NRA),
- Public Administration,
- Educational/Research Institution,
- Original equipment manufacturer (OEM),
- Service/data providers,
- Other (please specify))

What is your role/function in your organization?

Do you provide consent to use the shared information for use within DROIDS project?

Is your organization involved in any projects or initiatives related to digital twins? (Yes/No)

- If yes,
    - can you briefly describe your organization's experience with digital representation systems?
    - Which use cases is your organization working on related to digital twins (or digital representations)?

Importance of Standardisation and Existing Efforts

Standardisation plays a crucial role in ensuring digital representations, like Digital Twins, Asset Information Models (AIM), Building Information Models (BIM), and others, are interoperable and can share data effectively. This section explores your organisation's experience with standardisation practices and existing efforts in related fields.

Which use cases / models / data / information / processes are standardised in your organisation?

What kind of standardisation practices does your organization currently follow related to digital representations (e.g. Digital Twin/ AIM/ BIM etc.) development and implementation? (Open ended)

Can you provide some examples of how these standardisation practices have benefitted your organization in the past digital representation projects? (Open ended)

Which of the following standardisation bodies (related to digital representations) are you familiar with? (Select all that apply)

- ISO (International Organization for Standardisation)
- IEC (International Electrotechnical Commission)
- CEN (European Committee for Standardisation)
- ETSI (European Telecommunications Standards Institute)
- Other (please specify)

In your opinion how can these standardisation efforts be more effective in addressing the needs of the digital representation ecosystem in your organization? (Open ended)

Are you aware of any existing successful standardisation efforts in related fields (e.g., BIM, smart cities) that could serve as models for Digital Twins? (Yes, No)

- If yes, please describe the standardisation effort and how it could be adapted for road infrastructure Digital Twins (please feel free to include any references/ web links). (Open ended)

Challenges due to Lack of Standardisation

The lack of standardisation can create challenges in integrating data and collaborating across different digital representation systems. This section explores how the absence of standardisation impacts your organization when working with various systems, not just Digital Twins.

How often do you encounter difficulties integrating data from different sources into your digital representations (e.g. Digital Twin/ AIM/ BIM etc.) due to incompatible data formats or standards? (Very often, Occasionally, Rarely)

How much of a challenge is the lack of standardised data formats for integrating data from different sources into your digital representations? (Scale answer - 1 (not a challenge) to 5 (major challenge))

Can you provide specific examples of challenges you've faced due to incompatible data formats or standards when integrating data from different sources? Can you elaborate on the impact due to it? (Open Ended)

How often do inconsistencies in terminology around digital representations create confusion or hinder communication with other stakeholders involved in your projects? (Very often, Occasionally, Rarely)

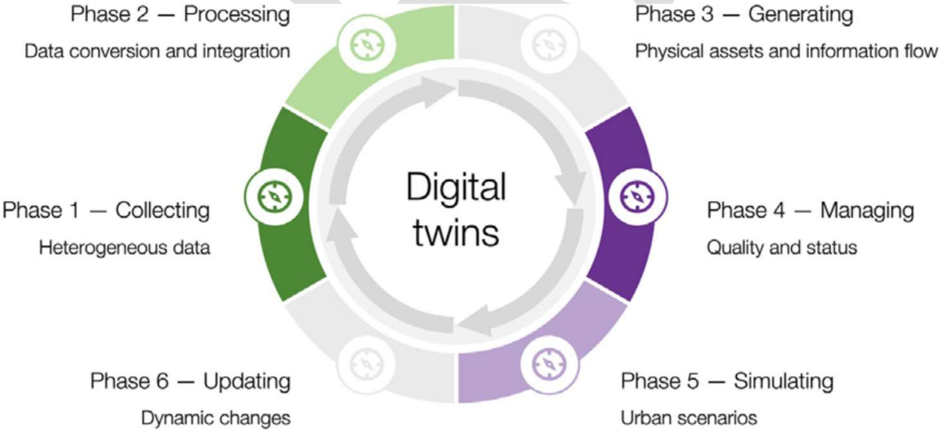
- Can you describe some specific examples of how inconsistencies in terminology around digital representations have created confusion or hindered communication with other stakeholders in your projects?

How often do you encounter difficulties in integrating different digital representations developed by different organisations due to a lack of standardisation? (Very often, Occasionally, Rarely)

- Can you describe a specific instance where you encountered difficulties integrating different digital representations due to a lack of standardisation?
- What specific aspects of the lack of standardisation caused these difficulties?

Digital Twin Lifecycle

Below picture (Lei, B. et al., 2023) illustrates the five phases of a Digital Twin lifecycle. These phases represent the general steps involved in creating and maintaining a digital representation of a physical asset or process.



Considering the different phases involved in creating and maintaining a digital representations, in which phases do you experience the most challenges due to a lack of standardisation? (Select all that apply)

- Phase 1 – Data Collection
- Phase 2 – Data Processing
- Phase 3 - Generating

- Phase 4 - Managing
- Phase 5 - Simulation

Can you elaborate on the specific challenges you encounter due to a lack of standardisation in the phases you selected? (Open ended)

In your experience, what specific aspects in digital representations create the most complexity for integration and collaboration? (open ended)

Which technologies or software do you use to access, exchange, and share data within your digital representations?

What non-technical challenges are keeping your organisation from implementing/developing various standards for digital representations? Non-technical challenges can be for example organisational, roles in the ecosystem, business models, etc.

Benefits of Standardisation and Specific Needs

Standardisation can offer numerous advantages for Digital Twin development and implementation. This section explores your views on the benefits of standardisation and the specific needs of your organization.

In your opinion, what are the different needs specific to your organization related to standardisation for Digital Twins? (This could include data formats, modelling techniques, terminology, or other aspects.) (Open ended)

Are you familiar with the concept of open data standards for Digital Twins? (Yes/No)

- If yes, is your organization currently using any open data standards for Digital Twins? (Yes/No)
    - If yes, which open data standards is your organization using? (Open ended)
- In your opinion, how can wider adoption of open data standards benefit the development and implementation of Digital Twins? (Open ended)

In your experience, which types of information models and processes would benefit most from standardisation in your area of work? (Select all that apply)

- Data formats (e.g., sensor data, historical facility data)
- Modelling methodologies (to handle complexity across domains and timescales)
- Communication protocols (to facilitate data exchange between different systems)
- Terminology and definitions (to ensure consistent understanding across different fields)
- Others (please specify)

Which information, models and processes would you want to be most immediately standardised?

In your opinion, what are the key considerations for developing successful standardisation initiatives for Digital Twins on a National level? (Open ended)

In your opinion, what are the key considerations for developing successful standardisation initiatives for Digital Twins on a European level? (Open ended)

Based on the challenges you've described, what specific recommendations do you have for overcoming these challenges through standardisation efforts? (Open ended)

Thank You!

Appendix B: A list of various standards in relevance to the Digital Twin of Road Transport

This section provide a list of various standards that might be relevant to the road transport digital twin.

Standard	Title/Use	Type	Status* (as of June 2024)
ISO/AWI TS 24315-1	Intelligent transport systems — Management of electronic traffic regulations (METR)	Definitions	Under development
ISO/TS 19091:2019	Intelligent transport systems — Cooperative ITS — Using V2I and I2V communications for applications related to signalized intersections	Communication	Published
ISO/IEC 30182:2017	Smart city concept model — Guidance for establishing a model for data interoperability	Conceptual model	Published
ISO/IEC 21778:2017 (JSON)	lightweight data-interchange	Communication protocol	Published
ISO/IEC 21823-1:2019 (IOT)	Peer to peer Interoperability among IoT systems	Internet of Things (IOT)	Published
ISO/IEC 21823-2:2020 (IOT)	Transport interoperability among IoT systems.	Internet of Things (IOT)	Published
ISO/IEC TR 30164:2020 (IOT)	UNIBO: Design principles, solutions and technologies applying to edge computing for IoT systems and applications.	Internet of Things (IOT)	Published
ISO/IEC TS 23167 (CLOUD)	UNIBO: Technologies and techniques applied to and used in conjunction with cloud computing.	Cloud computing	Published
ISO/PAS 17506:2012 (COLLADA)	Data exchange, sharing	Data model	Published
IEC 61131-3 (CONTROLLERS)	Remote control and command of machines	Textual modelling language	Published
ETSI MEC - MULTI-ACCESS EDGE COMPUTING	UNIBO: Multi-Access Edge Computing (MEC) reference architecture and integration with the telco domain.	Edge computing	Published
IEEE 802.1 AS	Real-time monitoring of machines/devices (Anomaly detection, Predictive	Deterministic	Published

	Maintenance, Asset performance management/Operations optimisation)	communication	
Data Distribution Service (DDS) standard	data-centric connectivity standard	Communication protocol	Published
FMU/FMI	Used for the exchange of models with internal and external partners using different modelling tools	Data exchange, sharing	Published
ETSI EN 302 663	Intelligent Transport Systems (ITS); ITS-G5 Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band	Communication	Published
JSON-RPC 2.0	JSON-RPC is a stateless, light-weight remote procedure call (RPC) protocol. Primarily this specification defines several data structures and the rules around their processing.	Data format	Published
C++20	C++20 is a version of the ISO/IEC 14882 standard for the C++ programming language.	Programming language	Published
ISO/IEC JTC 1/SC 41	Internet of Things and Digital Twin		Under development
ISO/IEC 20924:2024	Internet of Things (IoT) and digital twin	Vocabulary	Published
ISO/IEC 21823 series	Internet of Things (IoT) - Interoperability for IoT systems Part 1: Framework Part 2: Transport interoperability Part 3: Semantic interoperability Part 4: Syntactic interoperability	Interoperability	Published
ISO/IEC 29182 series	Information technology - Sensor networks: Sensor Network Reference Architecture (SNRA)	Sensor network	Published
ISO/IEC 30128:2014	Information technology -- Sensor networks -- Generic Sensor Network Application Interface	Sensor network	Published
ISO/IEC TR 22417:2017	Information technology - Internet of things (IoT) - IoT use cases	IoT - Use cases	Published
ISO/IEC 30161-1:2020	Internet of things (IoT) - Data exchange platform for IoT services - Part 1: General requirements and architecture	Data exchange	Published
ISO/IEC 30161-	Internet of Things (IoT) – Data exchange platform for IoT services – Part 2:	Data	Published

2:2023	Transport interoperability between nodal points	exchange	
ISO/IEC TR 30164:2020	Internet of Things (IoT) - Edge computing	Edge computing	Published
ISO/IEC 30165:2021	Internet of things (IoT) - Real-time IoT framework	IoT	Published
ISO/IEC 30173:2023	Digital twin - Concepts and terminology	DT	Published
ISO/IEC TR 30172:2023	Internet of things (IoT) - Digital twin - Use cases	IoT use cases	Published
ISO/IEC 30188 ED1	Digital Twin - Reference architecture	Architecture	Under developm ent
ISO/IEC 30186 ED1	Digital twin – Maturity model and guidance for a maturity assessment	maturity assessment	Under developm ent
ISO/IEC 30178 ED1	Internet of Things (IoT) - Data format, value and coding	Data	Under developm ent
OGC SensorThings API	SensorThings API provides an open, geospatial-enabled and unified way to interconnect the Internet of Things (IoT) devices, data, and applications over the Web.	Interoperabi lity	Published
ISO 16739-1:2024	Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries	Data sharing	Published
IEEE 1451	Smart transducer (sensors and actuators) interface standards for transducer electronic data sheets (TEDS)	Data	Published
V-Log Protocol (CROW)	Protocol designed to record traffic data from intelligent traffic control systems	Data	Published
ISO/AWI TS 24315-1	Intelligent transport systems — Management of electronic traffic regulations (METR)	Traffic rules	Under developm ent
DATEX II	DATEX II is a standard for the traffic and travel information sector to share data to deliver a comprehensive information service to the end user.	Data and communicat ion	Published
CityGML	The CityGML standard defines a conceptual model and exchange format for the representation, storage and exchange of virtual 3D city models.	Virtual model	Published
ASAM	The ASAM OpenDRIVE format provides a common base for describing road networks	Data format	Published

OpenDRIVE	with extensible markup language (XML) syntax, using the file extension xodr. The data that is stored in an ASAM OpenDRIVE file describes the geometry of roads, lanes and objects, such as roadmarks on the road, as well as features along the roads, like signals.		
ISO 16739-1:2018 (IFC)	IFC, or “Industry Foundation Classes”, is a standardized, digital description of the built environment, including buildings and civil infrastructure.	Digital model	Published
LandXML	LandXML is a specialized XML (eXtensible Mark-up Language) data file format containing civil engineering and survey measurement data commonly used in the Land Development and Transportation Industries.	Data format	Published
EU EIP SA46	Coordinated Metadata Catalogue – common concepts and definitions	Metadata manageme nt	Published
ISO 22741-1:2022	Intelligent transport systems — Roadside modules AP-DATEX data interface	Communica tion	Published
ISO 19650 Series	This international standard series provides a framework for managing information throughout the whole lifecycle of a built asset, including the operational phase. It defines the concepts and principles of information management using Building Information Modelling (BIM) and specifies the activities to be undertaken to support it.	BIM	Published
COBie (Construction Operations Building Information Exchange)	This is a data format for delivering asset information. It is designed to facilitate the handover of asset information from the construction phase to the operational phase.	AIM	Published
ISO 17427-1:2018	Intelligent transport systems — Cooperative ITS Part 1: Roles and responsibilities in the context of co-operative ITS architecture(s)	C-ITS roles	Published
ISO/DIS 22086-2	This standard specifies the functional requirements of a nomadic device for lane-level positioning and integrity monitoring with the Network based Precise Positioning Infrastructure for Land Transportation (NETPPI-LT), which is a lane-level positioning system based on Global Navigation Satellite Systems (GNSS) and	Positioning/ location	Under developm ent

	is described in ISO 22086-1.		
ISO 21219-1:2023	Intelligent transport systems — Traffic and travel information (TTI) via transport protocol experts group, generation 2 (TPEG2)	Data and information	Published
ISO/TS 19082:2020	Intelligent transport systems — Definition of data elements and data frames between roadside modules and signal controllers for cooperative signal control	Data	Published
ISO/TS 19321	Intelligent transport systems — Cooperative ITS — Dictionary of in-vehicle information (IVI) data structures	Data	Under publicatio n
ISO/TS 21176:2020	Cooperative intelligent transport systems (C-ITS) — Position, velocity and time functionality in the ITS station	Data	Published
ISO 20684 series	Intelligent transport systems — Roadside modules SNMP data interface Field devices include traffic signals, message signs, weather stations, traffic sensors, roadside equipment for connected ITS (C-ITS) environments, etc. ISO 20684 series aims to standardise information exchange from field devices.	Communica tion	Published
ISO/TS 19468:2022	Intelligent transport systems — Data interfaces between centres for transport information and control systems — Platform-independent model specifications for data exchange protocols for transport information and control systems. This document establishes specifications for data exchange between any two instances of the following actors: • Traffic information centres (TICs) • Traffic control centres/Traffic management centres (TCCs/TMCs) • Service providers (SPs).	Communica tion	Published
ISO/TS 19091:2019	Intelligent transport systems — Cooperative ITS — Using V2I and I2V communications for applications related to signalized intersections	Communica tion	Published
ETSI TS 103 301	Intelligent Transport Systems (ITS) - Facilities layer protocols and communication requirements for infrastructure services	Communica tion	Published
CAM Data	Cooperative Awareness Messages (CAMs) are messages exchanged in the	Data / communicat	Published

(CROW - NL)	ITS network between ITS-stations to create and maintain awareness and to support cooperative performance of vehicles using the road network.	ion	
DVM-Exchange 2.0 (NDW)	Open standard for the exchange of traffic management assignments and information between network management systems. The aim is to use this standard to implement Dynamic Traffic Management (DVM) coherently within and across the domains of road authorities.	Data / communication	Published
ETSI TS 103 191	Signal Phase and Timing (SPAT) and Map (MAP) data	Data/communication	Published
ISO TS19091	Intelligent transport systems – Cooperative ITS – Using V2I and I2V communications for applications related to signalized intersections	Communication	Published
SAE J2735	Dedicated Short Range Communications (DSRC) Message Set Dictionary	Data	Published
SPaT Data - Dutch Profile (CROW)	The Signal Phase and Timing (SPAT) message is used to convey the current status of one or more signalized intersections.	Communication	Published
SRM Data	The Signal Request Message (SRM) is a message sent by a Dedicated Short Range Communications (DSRC) equipped entity (such as a vehicle) to the RoadSide Unit (RSU) in a signalized intersection. It is used for either a priority signal request or a pre-emption signal request depending on the way each request is set. Each request defines a path through the intersection which is desired in terms of lanes and approaches to be used.	Communication	Published
MAP data - Dutch Profile (CROW)	The MapData (MAP) message is used to convey many types of geographic road information. At the current time its primary use is to convey one or more intersection lane geometry maps within a single message. The map message content includes such items as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications). A given single MapData message may convey descriptions of one or more geographic areas or intersections.	Communication	Published

ISO/IEC 30173:2023	Digital twin — Concepts and terminology	Definitions	Published
ISO/TS 19091:2019	Intelligent transport systems — Cooperative ITS — Using V2I and I2V communications for applications related to signalized intersections	Communication	Published
ISO/TS 22726-1:2023	Intelligent transport systems — Dynamic data and map database specification for connected and automated driving system applications — Part 1: Architecture and logical data model for harmonization of static map data	Map	Published
Digital Controller Interface Specification (DCIS) - Transport Technology Forum (TTF) - UK	The Digital Controller Interface Specification (DCIS) aims to provide a national unique numeric identifier for road authorities, a convention for uniquely numbering signalised junctions, a JSON schema for describing the features and allowed turning movements, and another schema describing the signal controller configuration in terms of its phasing, staging, timings and other engineering parameters traditionally held in the TOPAS 2500 specification.	Data	Published – In progress

Appendix C: National standardisation organisations

Country	National Standardization Organization
Austria	Austrian Standards International – Standardisation and Innovation (A.S.I.)
Belgium	Bureau voor Normalisatie/Bureau de Normalisation (NBN)
Bulgaria	Bulgarian Institute for Standardization (BDS)
Croatia	Croatian Standards Institute (HZN)
Cyprus	Cyprus Organization for Standardization (CYS)
Czech Republic	Czech Office for Standards, Metrology and Testing (ÚNMZ)
Denmark	Danish Standards Foundation (DS)
Estonia	Estonian Centre for Standardisation (EVS)
Finland	Finnish Standards Association (Suomen Standardisoimisliitto) SFS
France	French Association for Standardization (Association française de normalisation - AFNOR)
Germany	German Institute for Standardization (DIN)
Greece	Hellenic Organization for Standardization (ELOT)
Hungary	Hungarian Standards Institution (MSZT)
Ireland	National Standards Authority of Ireland (NSAI)
Italy	Italian National Unification Body (UNI)
Latvia	Latvian Standards (LVS)
Lithuania	Lithuanian Standards Board (LST)
Luxembourg	Luxembourg Institute for Standardization, Accreditation, Safety and Quality of Products and Services (ILNAS)
Malta	Malta Competition and Consumer Affairs Authority (MCCAA)
Netherlands	Royal Netherlands Standardization Institute (NEN)
Norway	Standards Norway (SN)
Poland	Polish Committee for Standardization (PKN)
Portugal	Portuguese Institute for Quality (IPQ)
Romania	Romanian Standards Association (ASRO)
Slovakia	Slovak Office of Standards, Metrology and Testing (ÚNMS SR)
Slovenia	Slovenian Institute for Standardization (SIST)
Spain	Spanish Standardization Association (UNE)
Sweden	Swedish Institute for Standards (SIS)
Switzerland	Swiss Association for Standardization (SNV)
United Kingdom	British Standards Institution (BSI)