MANUFACTURING AS A SERVICE FOR THE EU'S TWIN TRANSITION UNTIL 2040

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Executive Summary

Project **MASTT2040 – Manufacturing as a Service for the European Twin Transition until 2040** aims to help Europe reimagine its manufacturing landscape by 2040. Using strategic foresight methods, the project builds a shared vision for how **Manufacturing-as-a-Service (MaaS[1])** can boost resilience, sustainability and competitiveness and accelerate Europe's twin transition through distributed, data-driven manufacturing ecosystems.

The main purpose of this report, developed within the "Sense-making and Recommendations" phase of foresight study is to translate earlier projects results into a structured analysis of data standardisation needs for MaaS. It bridges foresight outcomes and standardisation aspects by showing where standardisation can accelerate MaaS adoption, providing strategic alignment with EU policy as well as understanding and compliance with EU standardisation workflows.

A framework is proposed that structures a definition of MaaS and a MaaS ecosystem into four layers: business, functional, data and standardisation (**2.1. Introduction to the framework**). This framework makes it possible to consistently map use cases, services and technologies with relevant legal acts and standards, and to classify barriers and opportunities in a systematic way. This is considered to be a first step towards definition of a MaaS Reference Architecture.

Building on this framework, the report develops a knowledge base, combining an exploratory mapping of relevant standards with insights from case studies, market reviews and stakeholder interviews.

Research results are presented in Chapter **4. An ISO Standardisation** analysis exercise highlights priority areas for action: **semantic interoperability**, **data governance and sovereignty**, **cybersecurity and trust**, as well as **circular economy enablers** such as **Digital Product Passports** and **human-centric MaaS**. These priorities are structured into short-, medium-, and long-term needs, providing guidance to Standards Development Organisations and policymakers in setting agendas.

This report also introduces a standardisation stakeholder engagement scheme, identifying the **organisations** and **communities**, from **Standards Development Organisations** and **policymakers**, regulators to **industry consortia and academia**, whose involvement is essential for validation and uptake of MaaS.

Finally, the work lays the standardisation groundwork for the formulation of recommendations to the European Commission, guiding investment, regulation and international collaboration in European industrial data spaces standardisation.

[1] **Manufacturing as a Service (MaaS)** is a distributed system of production in which resources (including data and software) are offered as services, allowing manufacturers to access distributed providers to implement their manufacturing processes [EC Definition [22]]

1. Introduction to MASTT2040

The MASTT2040 project applies **participatory strategic foresight** to anticipate changes, opportunities, and disruptions that will shape Manufacturing-as-a-Service up to 2040. By engaging a broad range of stakeholders, the approach builds a shared vision, roadmap and recommendations that guide decision-making and actions, aiming to advance Europe's industrial manufacturing resilience, digitalisation, circularity, decarbonisation, and sustainability.

This report presents the results of analytical work from the MASTT2040 project, focusing on the role of data and its standardisation in enabling MaaS models in Europe. Its purpose is **to provide the basis** for recommendations to the European Commission on industrial data standardisation.

MASTT2040 applied a six-stage strategic foresight process – framing, scanning, forecasting, visioning, planning, acting – adapted to project objectives (Hines & Bishop, 2006) [1]. Each stage clarified scope, engaged stakeholders, and broadened perspectives on challenges in European manufacturing to identify standardisation measures supporting the EU's strategic ambitions. Standardisation analysis was conducted in Work Package 4, "Sense-making and Recommendations," building on earlier results.

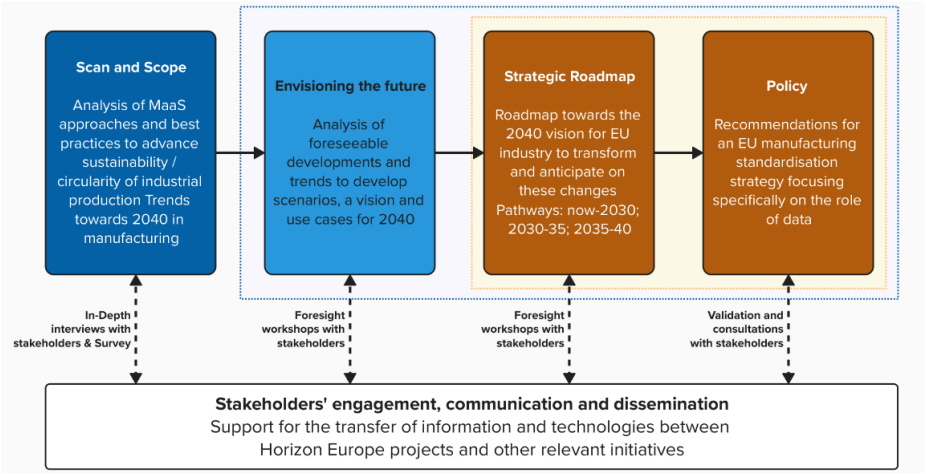

Figure 1. Overview of the MASTT2040 Phases

- **The first phase of the study (scan & scope)** defined the foresight framework by setting the scope, objectives, audience, and key stakeholders of MASTT2040. Using desk research and structured interviews, it mapped the current state of MaaS in European manufacturing, its links to the circular economy and resilience strategies, and its alignment with EU policy goals. This phase identified the defining features of MaaS, relevant use cases, and major forces shaping Europe's manufacturing. A central finding was that existing MaaS solutions are limited by proprietary systems, restricting openness, interoperability, and scalability. To unlock MaaS full potential, **open systems and shared standards are needed** to ensure cross-platform interoperability, support collaborative value networks, and build a resilient, future-proof manufacturing ecosystem;
- **The second stage (envisioning)** developed scenarios for EU manufacturing in 2040, exploring how distributed MaaS and centralised models interact under key trends such as digitisation, decarbonisation, circularity, and sustainability. These scenarios showed MaaS evolving into a

cross-border ecosystem that depends on interoperability, trust, and **alignment across data spaces and regulations**. This phase highlighted **standardisation as a critical enabler**[2] – ensuring platform compatibility, secure data exchange, and governance frameworks needed for scalable, reliable, and sustainable **MaaS networks across Europe**.

- **The third stage (strategic roadmap)** transformed the scenarios into actionable pathways for MaaS development to 2040, defining short-, medium-, and long-term strategies for resilience, sustainability, and human-centric production. Through collaborative roadmapping workshops, it produced an Industry Strategy and Action Plan aligned with EU goals for circularity, decarbonisation, and competitiveness. The roadmap emphasised that MaaS can scale only through open, interoperable systems underpinned by common standards – covering trusted data spaces, digital product passports, and cross-border interoperability frameworks. **Standardisation thus emerges as a core enabler** of the MaaS transformation, ensuring seamless, secure, and sustainable collaboration across industries in line with Europe's twin transition objectives.
- **The fourth stage (sense-making and recommendations)** assessed previous results against existing regulations to guide Standards Development Organisations (SDOs) in prioritising MaaS-related standardisation. It introduced a framework to identify **standardisation gaps**[3] in interoperability, cybersecurity, data spaces, and national data policies. Based on this, short-, medium-, and long-term actions are proposed to define the standards and data frameworks needed for MaaS ecosystems up to 2040. These recommendations, co-created with stakeholders, aim to steer strategic investments and remove barriers[4] to scalable, secure, and sustainable MaaS adoption across Europe.

The project actively involved a broad range of European manufacturing stakeholders. The results of the research are available at mastt2040.eu.

The deliverable given here has set of objectives and the developed *framework* addresses them:

1. To **explain the role of standards** in enabling distributed MaaS ecosystems (Chapter 4. An ISO Standardisation analysis exercise);
2. To **clarify the role of data** to support the development of future MaaS ecosystems in Europe;
3. To **analyse the current contributions** and most important ongoing data standardisation efforts and current policies including MaaS-specific issues such as trusted data spaces,

[2] Enabler (force pushing standardisation forward – regulation, policy, industry demand, digitalisation) or driver in MaaS standardisation: an external force or supportive mechanism (policy, regulation, market demand, industry initiative or technology trend) that pushes or accelerates the need for standardisation.

[3] A **standardisation gap** (what's missing – new standards required) in MaaS is a critical missing element in interoperability, governance or capability that prevents MaaS ecosystems from scaling, being trusted or contributing to the EU's TWIN transition. Gaps arise when existing standards do not sufficiently address data, processes or business models, making it hard for MaaS actors (suppliers, platforms, clients, regulators) to collaborate seamlessly. A standardisation gap in MaaS is an area where the lack of harmonised technical, data, or governance standards prevent MaaS ecosystems from ensuring interoperability, trust, scalability, sustainability and alignment with EU twin transition goals.

[4] **Barriers in MaaS standardisation** are practical obstacles that prevent or slow down the implementation, adoption or scaling of MaaS ecosystems, even when some standards already exist. Barriers often arise from fragmentation, lack of alignment, inconsistent adoption or conflicting regulations/market practices.

customer, product and lifecycle data, contractual and operational data, sustainability and circularity related data, semantic interoperability and data governance.

2. A framework for analysing MaaS standardisation lifecycle

The **common characteristics** observed by MASTT2040 for all MaaS approaches [5] [6] were identified as:

- Easy to use, instant cloud services with short lead-times;
- Digitized and highly automated processes which can be hyper-scaled in a cost-effective way while retaining the ability for micro-caring on the specific needs of a customer;
- The integration of manufacturing knowledge in the digitized services limiting the need for highly skilled workers;
- The cloud services highly rely on real-time data exchange and learning algorithms to improve over time;
- Their development requires new skills in manufacturing, to combine software development, data analytics and Artificial Intelligence with manufacturing expertise.

Challenges observed that need to be addressed by recommendations include:

- Interoperability gaps: **lack of data standards**, **especially semantic interoperability**, for seamless data exchange across networks;
- IP protection: mechanisms to ensure data sharing without compromising intellectual property;
- Speed of transactions: **standards enabling** fast, reliable quotations and order processing in competitive markets;
- Sustainability integration: limited circularity in current MaaS models and the **need to align MaaS with EU decarbonisation and circularity goals**;
- Digital product passports: **development of harmonised approaches** to enable life-cycle management, traceability, and R-cycle strategies (reuse, repair, refurbish, remanufacture);
- Collaboration frameworks: **standards to facilitate cross-company inventory and equipment sharing**, supporting regional supply chains.

Considering the definition of MaaS, it should be emphasised that MaaS is an umbrella term for a broad field of approaches, business models[7] and digitized services.

To enable the analysis of complex relationships between the results of previous studies and the challenges observed during the study of the MaaS use cases, it was necessary to develop a framework that would support analysis in standardisation. This deliverable now builds on these outcomes to provide a **structured analysis of standardisation lifecycle, availability and main ongoing initiatives**, preparing the ground for concrete **recommendations to the European Commission**.

[5] **MASTT2040 D1.1 Casebook**: Current state of MaaS approaches and best practices to advance the CE, https://www.mastt2040.eu/2024/09/09/d1-1-casebook-current-state-of-maas-approaches-and-best-practices-to-advance-the-ce/

[6] **MASTT2040 D3.2 MaaS Industry Strategy and Action Plan**, https://www.mastt2040.eu/2025/09/12/mastt2040-d3-2-industry-action-plan/

[7] A description of the way an organisation creates, delivers, and captures value. Such a description typically includes for whom value is created (customer) and what the value proposition is. Typically, a tool called business model canvas [14] is used to describe or design a business model, but alternatives that are more suitable for specific situations, such as data spaces, are available.

2.1. Introduction to the framework

The developed framework provides a structured way to analyse and design the future Manufacturing-as-a-Service (MaaS) ecosystem.

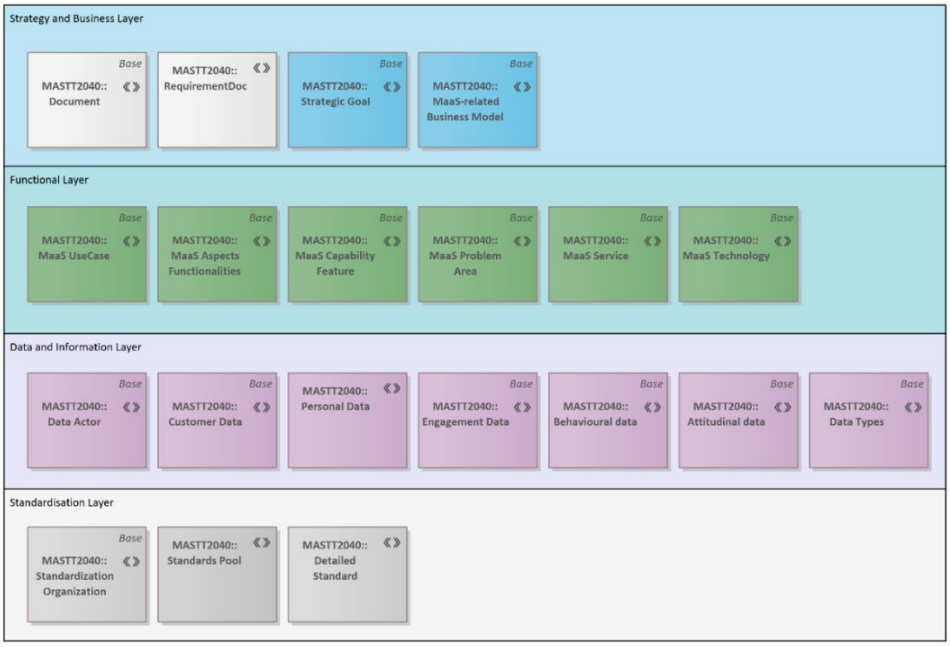

Figure 2. Overview of the MASTT2040 framework layers

The framework helps to trace research results from high-level foresight insights to actionable recommendations by capturing the complexity of MaaS across four interconnected layers:

1. **L01. Strategy / Business Layer (BL)**, defining MaaS in terms of its vision, strategic goals and requirements, business models, and value creation logic; it includes the following building blocks[8]: **Document**, **Requirement**, **Strategic Goal** definition, **MaaS-related Business Model**;
2. **L02. Functional Layer (FL)**, outlining the MaaS functional ecosystem and showing how use cases, services, and enabling technologies linked; it includes **MaaS UseCase**, **MaaS Aspects Functionalities**, **MaaS Problem Area**, **MaaS Service**, **MaaS Capability Feature**, **MaaS Technology**;
3. **L03. Data / Information Layer (DL)**[9], clarifying the central role of data, semantics, and interoperability in making MaaS networks work; it includes **Data Actor**, **Customer Data**, **Personal Data**, **Engagement Data**, **Behavioural Data**, **Attitudinal Data**, **Data Types**;
4. **L04. Standardisation Layer (SL)**, mapping the European standardisation ecosystem and identifying where new or harmonised standards are needed to unlock MaaS adoption; it includes **Standardisation Organizations**, **Standards Pools** (e.g. Technical Committees), **Standards**.

[8] A description of related functionalities and/or capabilities that can be realised and combined with other **building blocks** to achieve the overall functionality of the framework. In Manufacturing as a Service (MaaS), a "building block" is a fundamental, often modular component or capability that enables a service, which can be both technological and non-technological. The set of elements presented here is minimal in terms of the possibilities for analysing complex relationships between the results of previous studies and the standardisation analysis.
[9] https://maasstandards.askew.nl/

Based on four layers of the framework, the MASTT2040 foresight results can be transformed into a structured picture of MaaS, akin to a Reference Architecture building a coherent storyline from business rationale to standardisation enablers.

2.2. MaaS-related Business Models

To indicate the key features of MaaS that distinguish these models the identified approaches can be ascribed to one main theme, "distributed on-demand manufacturing of parts and components", and three supporting themes[10]:

- Custom design automation and access to digital product models,
- Provision and servitisation of production equipment,
- Enabling the Circular Economy.

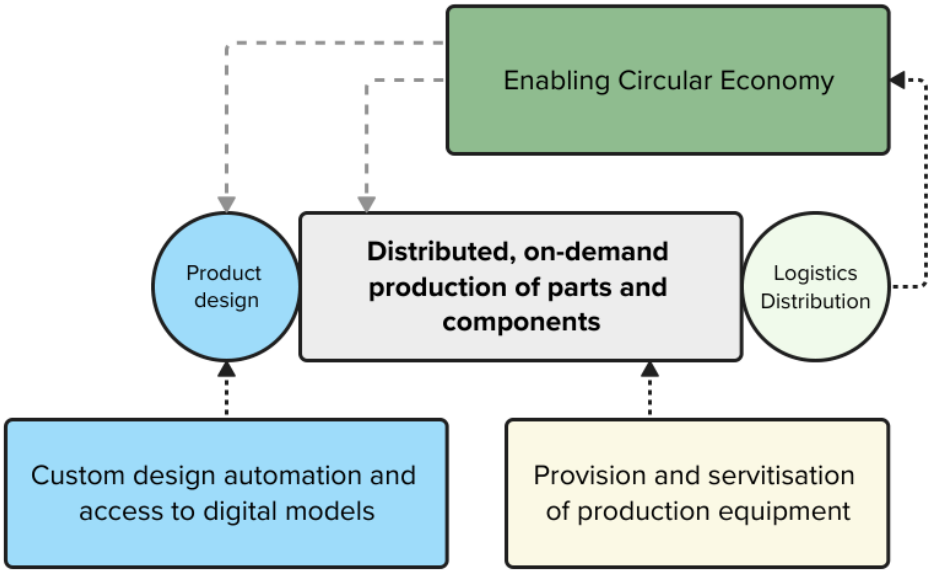

Figure 3. Overview of different MaaS themes

MaaS business model "Distributed on-demand manufacturing of parts and components" refers to the business models and digital services enabling seamless online access to distributed manufacturing capabilities characterized by high flexibility and short lead times, usually based on digital cooperative manufacturing platforms linking different parts of MaaS ecosystem.

Table 1. Business value for **Distributed on-demand manufacturing of parts and components**

Business value	**Description**
What it shares	Manufacturing capacity, data, logistics, **standards**
Payment model	Pay-per-use or per-order transaction-based
Supplier's responsibilities	Provide capacity, **quality**, data, **traceability**
What the client gets	Fast, scalable, transparent, cost-optimized, **sustainable** manufacturing services

[10] D1.1 Casebook: Current state of MaaS approaches and best practices to advance the CE, available on the project website https://www.mastt2040.eu/category/project-outcomes/

The "Custom design automation and access to digital product models" business model refers to the digitalization and automation of the design phase of production processes as well as to the increasing trend of products' digitalization (digital twins) enabling the distributed on-demand manufacturing of parts and components.

Table 2. Business value for **Custom design automation and access to digital product models**

Business value	**Description**
What it shares	**Digital product models**, automated design tools, **standards** and simulations
Payment model	Pay-per-design, subscription, licensing, sometimes bundled with production
Supplier's responsibilities	Provide models, automation, **IP protection**, **interoperability**
What the client gets	Faster, cheaper, customizable, validated designs linked to distributed MaaS production

The MaaS business model "Provision and servitisation of production equipment" refers to offering flexible access to equipment, infrastructure, or production facilities, along with cloud platforms and digitized services that remotely optimize their operation.

Table 3. Business value for **Provision and servitisation of production equipment**

Business value	**Description**
What it shares	Equipment, infrastructure, cloud services, **operational data**
Payment model	Pay-per-use, subscription or outcome-based
Supplier's responsibilities	Maintain and optimize equipment, **ensure interoperability**, provide lifecycle services
What the client gets	Flexible access, cost savings, performance optimization, scalability and sustainability

The "Enabling the Circular Economy" business model refers to the different solutions enabling enhancing sustainability and supporting the R-cycles in the product's circular life cycle as well as supporting implementation of sustainability measures across the production value chains.

Table 4. Business value for **Enabling the Circular Economy**

Business value	**Description**
What it shares	Recycled materials, R-cycle services, **sustainability** data, **DPPs**
Payment model	Pay-per-service, subscription, outcome-based, certification/licensing fees
Supplier's responsibilities	Ensure transparency, deliver circular services, comply with regulations, maintain certification
What the client gets	Sustainable products, cost/ resource efficiency, **compliance** and competitive advantage

For each key theme, **archetypal MaaS business models** were identified across different contexts and industrial sectors. They provide a framework for understanding commonalities and differences. In practice, companies might combine different business models in their service offering.

A detailed description of the identified themes and related MaaS business models with examples of implementations, is presented in the deliverable from the first phase of the project **D1.1 Casebook:**

The current state of MaaS approaches and best practices to advance the CE [2] is available on the project website https://www.mastt2040.eu/category/project-outcomes/

Generalizing the issue, one can observe that five main generic MaaS-related business models can be proposed. Mixing them creates the real business value for clients, with the need for some other parameters to be defined, as highlighted in Table 5.

Table 5. Business value for **generic MaaS-related business models**

MaaS-related Business Model	**What it shares**	**Payment model**	**Supplier's responsibilities**	**What the client gets**
Equipment-as-a-Service	Machinery/ Equipment	Subscription/ Pay for Usage	Equipment maintenance, service, repairs	Use of the equipment, without the need for investment
Product-as-a-Service	Product/ Service	Subscription/ Pay for Usage	Product Maintenance + Service	Access to the effect, not product ownership
Production-as-a-Service	The entire production process	Payment to produce the product ordered to be made	Production Line Maintenance	Finished components/production - the know-how of the designer of the production line and production process
Platform-as-a-Service	A development environment, an environment for parameterizing implemented functions, an administrative environment for managing users and permissions	Subscription/ Pay for Usage	Runtime, middleware, infrastructure	Focus on code and features, depending on the level of flexibility of the platform
Everything-as-a-Service	Any asset - digital/ physical	Subscription/ Pay for Usage	Comprehensive: resources, service, access	Flexible access to all the resources necessary to create value

Key features were extracted via analysis of common issues that apply to all the main themes. The resulting archetypes of MaaS business models were therefore chosen as a main aspect for the further research work regarding **data standardisation**. These are summarised below:

- seamless online access to distributed manufacturing capabilities and manufacturing platforms (relevant to Production-as-a-Service / Equipment-as-a-Service),
- digital/ digitized services (Product-as-a-Service),
- seamless online access to digital product data and across value chain,
- provision of development environments and infrastructure enabling parameterization, runtime services, and user management (Platform-as-a-Service),
- comprehensive access to any digital or physical resource through Everything-as-a-Service approaches.

3. Standardisation for Europe. Invisible infrastructure of MaaS

Without stable published standards, MaaS risks remaining fragmented and dependent on proprietary solutions. This would block cross-border collaboration, increase costs, and undermine Europe's ambitions for **strategic autonomy** and **sustainability**.

Standardisation in MaaS is particularly important in the context of ensuring **alignment with EU policy** – supporting implementation of the **Data Act**[11] **, Data Governance Act**[12]**, Cyber Resilience Act**[13]**, AI Act**[14]**, Digital Product Passports**[15], and other measures.

The European Union has recognised that **data, interoperability** (i.e. enabling different systems and companies to work together)**, and trust** (i.e. ensuring safe, reliable, and compliant data exchange) are central **to scaling** (i.e. allowing MaaS networks to expand across industries and borders) digital manufacturing. These measures make clear that standards are essential to translate EU policy into practice and to give companies legal certainty. Data standards are an essential enabler for MaaS. Standardisation is an arduous endeavour, during which experts from different interested parties/ bodies/ companies/ associations/ organizations provide their knowledge, write down requirements, recommendations, definitions, and within a defined standardisation process discuss in different meetings until they reach consensus. The standards development process is a time-consuming activity, which is depicted below[16]. The whole cycle can take typically up to 40 months or longer.

[11] Regulation (EU) **2023/2854** of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data and amending Regulation (EU) 2017/2394 and Directive (EU) 2020/1828 (**Data Act**); creates rules for data access and portability, requiring interoperability standards for connected products and industrial data; The Data Act gives individuals and businesses the right to access the data produced through their utilisation of smart objects, machines and devices;

[12] Regulation (EU) **2022/868** of the European Parliament and of the Council of 30 May 2022 on European data governance and amending Regulation (EU) 2018/1724 (**Data Governance Act**); introduces frameworks for trusted data sharing, including data intermediaries and altruism mechanisms; The Data Governance Act addresses privacy of data, e.g. customer data for personalised products or data being collected through interactions between humans in MaaS production facilities or supply chains;

[13] Regulation (EU) **2024/2847** of the European Parliament and of the Council of 23 October 2024 on horizontal cybersecurity requirements for products with digital elements and amending Regulations (EU) No 168/2013 and (EU) 2019/1020 and Directive (EU) 2020/1828 (**Cyber Resilience Act**); sets baseline cybersecurity requirements for digital products and services, to be supported by harmonised standards; The Cyber Resilience Act which is important due to the digital nature of products and increased data being recorded, e.g. Product Passports, and interconnectivity between actors in the supply chain;

[14] Regulation (EU) **2024/1689** of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence and amending Regulations (EC) No 300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 (**Artificial Intelligence Act**); defines risk-based requirements for AI systems, again depending on standards for implementation; The AI Act which classifies AI into risk categories Prohibited AI, High Risk AI, Limited Risk AI and Minimal Risk AI. Potentially due to the nature of manufacturing machinery and cobots interacting with humans it is likely that applications will fall under the High-Risk AI category. The Act also provides requirements for transparency and disclosure for generative AI;

[15] **Digital Product Passport (DPP)** – a core tool of the Circular Economy Action Plan, requiring product data standards to enable reuse, repair and recycling; Product Passports will be a key driver for circularity requiring collection of data throughout a products life. The general requirements for digital product passports include having a data carrier on the product, its packaging or on documentation, with a unique product identifier according to ISO/IEC 15459:2015. This needs to be in an interoperable machine-readable, structured, and searchable format with information on the product model, batch, or item.

[16] ISO deliverables. The different types of ISO publication. https://www.iso.org/deliverables-all.html

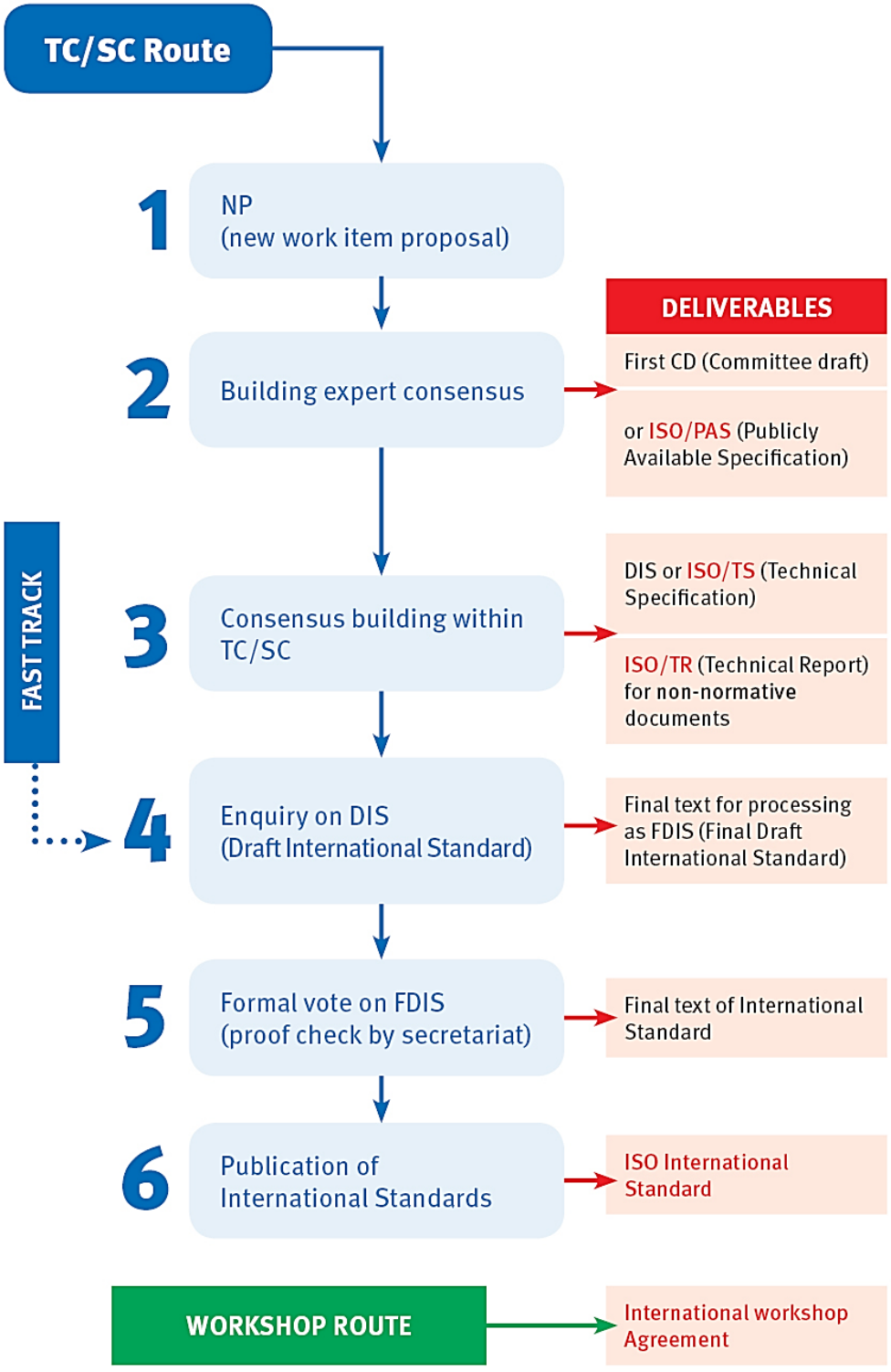

Figure 4. Developing ISO standards.

For MaaS, standards can be used to determine:

- **How data are exchanged** between companies, machines and platforms;
- **How trust is built** between partners who may never have worked together before;
- **How interoperability is ensured** so that a service designed in one country can be integrated into production in another;
- **How sustainability goals can be achieved** by supporting transparency, traceability and circular economy practices.

Europe does not start from scratch. Already there are four mature frameworks proposed that demonstrate how standards can structure complex manufacturing systems:

- **Reference Architecture Model Industry 4.0 (DIN SPEC 91345:2016-04)** – provides a reference architecture for Industrie 4.0, organising manufacturing into layers (business, functional, information, communication, integration, asset);
- **Reference architecture for Industrial Cloud Federation (DIN SPEC 92222:2021-12)** – denotes communication between endpoints of cloud services and endpoints of devices physically located in a production shop floor; framework is a subset of RAMI 4.0;
- **IDS-RAM (IDS Reference Architecture Model ver. 5.0)** – provides a framework for designing and implementing Industrial Data Space-compliant data spaces[17], that supports companies collaborating with scientists, technologists and policymakers;
- **Smart Manufacturing Reference Model (IEC TR 63319:2025)** – offers a metamodeling approach to harmonise different smart manufacturing models and ensure global alignment.

Two very important initiatives are also underway in Europe, summarising and analysing the current state of standardisation in the field of Smart Manufacturing:

- **German Standardisation Roadmap Industrie 4.0 (Version 5, 2023)[18]** – which identifies priority topics such as interoperability, autonomy, and sustainability, and links them to specific standardisation actions;
- **Rolling Plan for ICT Standardisation (2025)[19]** – bridges EU digital policy with standardisation activities, emphasising cross-cutting enablers such as data economy, cybersecurity and AI.

When analysing standardisation issues, the MASTT2040 project builds on these experiences and data sources, adapting them to the specific needs of the **MaaS ecosystem**, which combine **digital services, distributed manufacturing and cross-border data exchange**.

An important element of analysing the role of data and standardisation needs within MaaS is to **properly identify and describe the role of individual participants in the ecosystem** and the links between them. To this end, the MaaS standardisation ecosystem has been mapped in terms of key stakeholders.

[17] Interoperable framework, based on common governance principles, standards, practices and enabling services, that enables trusted data transactions between participants. Note 1 to entry: Data space enabling services are implemented by one or more infrastructures. Note 2 to entry: Data spaces enable one or more use cases [23]

[18] https://www.din.de/resource/blob/907744/61cf955a9830c84aefee02747b3d9fa0/nrm-industrie-4-0-version-5-2023-engl-web-data.pdf

[19] https://interoperable-europe.ec.europa.eu/sites/default/files/custom-page/attachment/2025-04/RollingPlan_ICT_2025.pdf

Standardisation ecosystem in Europe Institutional perspective				
European Commission bodies **[EC]**	European Standardisation Organizations **[ESOs]** [3]	National Standardisation Bodies **[NSBs]**	Standards Development Organizations **[SDOs]**	Other stakeholders (i.e. technical associations)

Figure 5. Standardisation ecosystem in Europe from the perspective of selected institutions [4]

It is important to understand and distinguish between different types of standards in use. From the perspective of the MaaS ecosystem, we would like to know, how standards can be made more accessible to SMEs, and whether there is a need for harmonised standards linked to compliance with specific legal acts. This will be further examined until the end of MASTT2040 project.

A harmonised standard [5] is a European standard developed by a recognized European Standards Organisations: CEN, CENELEC, or ETSI (**A1.2. European Standardisation Organizations (ESO)**). It is created following a request from the European Commission to one of these organisations. Manufacturers, other economic operators, or conformity assessment bodies can use harmonised standards to demonstrate that products, services, or processes comply with relevant EU legislation. The references of harmonised standards must be published in the Official Journal of the European Union (OJEU). The purpose of the OJEU portal is to provide access to the latest lists of references of harmonised standards and other European standards published in the OJEU.

Annex 1. Standardisation ecosystem in Europe provides an overview on the organisations analysed:

- **European Commission** Directorates Generale and Executive Agencies financing programmes solving MaaS problems, setting regulations and standardisation initiatives at the EU level (**A1.1. European Commission Bodies. Policy makers relevant to MaaS**);
- **International Standardisation Bodies** reviewed the roles of ISO, IEC and IEEE (**Chapter 4. An ISO Standardisation** analysis exercise) in shaping global frameworks relevant to MaaS;
- **European Standardisation Organisations** focuses on CEN, CENELEC, ETSI [3], and ETOA as well as their alignment with EU policy goals (**A1.2. European Standardisation Organizations (ESO)**);
- **Domain-Specific Initiatives** highlights sector-driven efforts such as GAIA-X, Catena-X, IDSA, and the OPC Foundation, which are crucial for data spaces, interoperability, and industrial platforms;
- **Emerging Topics and Policy-Linked Standards** examines areas such as digital product passports, cybersecurity, lifecycle management, where standardisation is evolving rapidly in response to the twin transition.

To work at scale, MaaS ecosystems depend on **shared technical and organisational standards** forming the hidden infrastructure that enables industries to function across countries, sectors and technologies. For these reasons, standardisation is not a parallel activity but a **core enabler of Europe's industrial transformation**. Without **shared standards**, MaaS risks **becoming fragmented, locked into proprietary systems and unable to scale** across Europe.

4. An ISO Standardisation analysis exercise

The following sections present an exercise on MaaS-related standardisation analysis as shown in Figure 6.

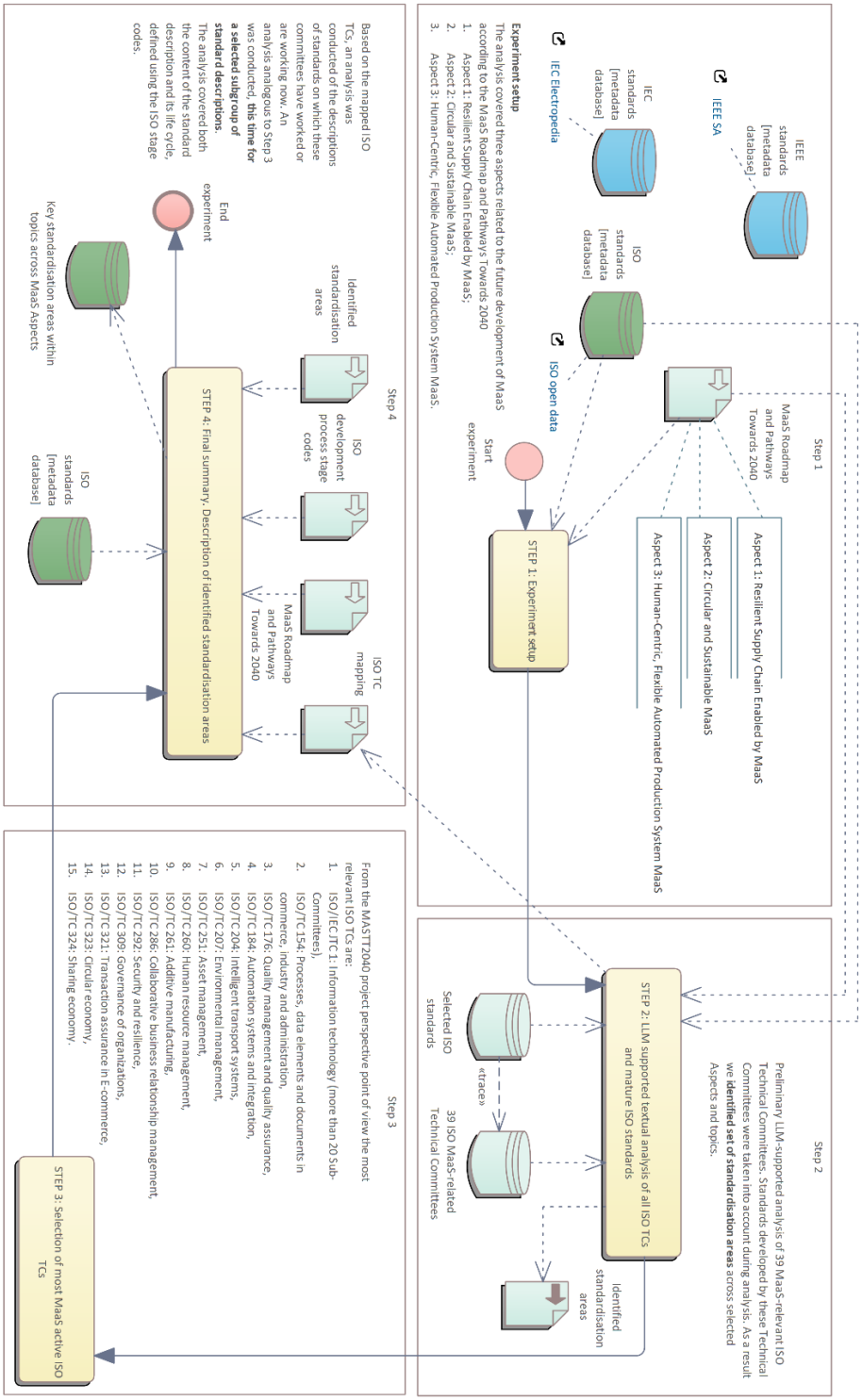

Figure 6. Workflow of an ISO standards analysis experiment

This exercise translates available scattered data (on the standardisation ecosystem, state of work on selected standards, and SDOs involved through participation in technical committees) into identified standardisation areas for synthesising a knowledge base for standardisation recommendations.

The analysis was performed on **ISO standards metadata** because this provides a comprehensive, openly accessible database of standard titles, abstracts and classification data that can be systematically mined and filtered. This allowed to identify a wide range of standards relevant to MaaS across domains such as manufacturing, data exchange and sustainability. IEEE Xplore, IEC and other data sources could also be used as a source of reference, however, while valuable, these bodies do not offer open metadata access for automated analysis and would have limited reproducibility. Although they offer websites with lots of data, only the ISO open data provides a one-stop shop approach for analysis like that presented here. A similar exercise could be performed, but considerably more work would be required to access, compile and format the data in an appropriate way for analysis.

Using ISO data ensures that the findings are transparent, repeatable and aligned with the standards most widely recognized and adopted by European industry and policy frameworks.

Step 1. **Experiment setup**. The analysis covered three aspects related to the future development of MaaS according to the MaaS Roadmap and Pathways Towards 2040[20]: Aspect 1: Resilient Supply Chain Enabled by MaaS; Aspect 2: Circular and Sustainable MaaS; Aspect 3: Human-Centric, Flexible Automated Production System MaaS.

Step 2. **Preliminary analysis**. Based on a **preliminary analysis** of **all ISO standard descriptions** and the **work programmes of ISO/IEC Technical Committees** (see **Annex 2. ISO Technical Committees related to MaaS**)[21], conducted using **embedding models** (specialized neural networks trained to convert text: words, sentences or documents; text mining was a complementary method for the use of the developed framework) [6], [7], [8] the following, presented in table 6 **standardisation topics have been proposed**. The proposal also takes into account information from "Rolling Plan for ICT standardization 2025"[22], "Standardization Roadmap Industrie 4.0"[23] and prepared in MASTT2040 project, presented on the website https://maasstandards.askew.nl/.

Table 6. Key MaaS Standardisation categories and areas. Focus on the role of data

Aspect	Standardisation category	Identified standardisation area
Aspect 1: Resilient Supply Chain Enabled by MaaS	Digital Supply Chain and Logistics	Data modeling and semantic interoperability Data exchange and Machine-to-Machine (M2M) communication Data management/governance, access and protection Data for real-time analysis, business intelligence and forecasting Data trust, compliance, and Smart Contracting
	Interoperability and Data Sharing	Modeling semantics in the data domain, ontologies Data exchange and API (Application Programming Interface) interoperability Data Spaces and data governance

[20] MASTT2040 D3.1 MaaS Roadmap and Pathways Towards 2040, https://www.mastt2040.eu/2025/09/12/mastt2040-d3-1-maas-roadmap-and-pathways-towards-2040/
[21] ISO Open Data, https://www.iso.org/open-data.html
[22] https://interoperable-europe.ec.europa.eu/collection/rolling-plan-ict-standardisation/rolling-plan-2025
[23] https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/standardization_roadmap_i40.html

Aspect	Standardisation category	Identified standardisation area
		Fair value of data and rights to share it/use it Data for monitoring, planning, scheduling and performance optimization
	Cloud Manufacturing and Marketplaces	Data exchange and API standardisation Data models for reputation assessment and certification Data governance and privacy management Data for trust, access, and identity management Data-driven contracts and compliance verification automation
	Cybersecurity and Trust in Supply Chains	Data governance and secure data spaces Data models for reputation assessment and certification Data for identity, access, and credential management Data-driven contracts and compliance Standards and monitoring of data related to cybersecurity
Aspect 2: Circular and Sustainable MaaS	Sustainable Manufacturing Practices	Interoperable product and process data Trusted sustainability data spaces Harmonised data models for the Circular Economy, including the use of resources Standardisation of data for environmental performance measurement Data-driven maturity and benchmarking models
	Circular Economy and Resource Recovery	Interoperable product and material data Trusted data spaces related to the Circular Economy Data governance, accessing it and fair value sharing Harmonised data models for the Circular Economy and Life Cycle Assessment (LCA) reporting Data Standards for Digital Material Passports and recovery processes
	Traceability and Transparency	Semantic data models, ontologies, reference architecture models Linked product and process data for lifecycle tracking Governed Data Spaces Data standards for trust, access, and compliance Integrated lifecycle and transparency framework
	Circular Supply Chain Models	Semantic data models and ontologies for the Circular Economy Linked Life Cycle and Product Data Framework Data spaces and governance for circular value chains Data on sustainability, maturity and readiness indicators Data infrastructure for policy coordination and alignment
Aspect 3: Human-Centric, Flexible Automated Production System MaaS	Flexible and Adaptive Manufacturing Systems	Semantic data models and ontologies describing manufacturing capabilities Data exchange and real-time system integration Data spaces and data governance procedures Data-driven monitoring, forecasting and adaptation Data standards for maturity, readiness and policy alignment
	Robotics, Automation and Human-Robot Collaboration	Semantic data models for machines and knowledge, skills and competencies Data sharing and interoperable automation frameworks Data for real-time analysis and digital twins Data standards for trust, access, and compliance Data-driven standards for knowledge, skills, competences, safety and ergonomics
	AI, Data and Decision Support in MaaS	Semantic data models and knowledge representation Trusted Data Spaces for AI Data for real-time analysis and digital twins Data governance, fair and equitable distribution of value and transparency Data-driven maturity, policy alignment and coordination standards
	Human-Centric and Safe Work Environments	Governed employee and workforce data spaces Data models for knowledge, skills, competencies and roles in the organization Data on safety, work ergonomics and human-machine interaction Trust, data access, and compliance mechanisms Data-driven maturity and governance framework

Step 3. Most MaaS-relevant ISO TCs. For each of the **aspects and topics** indicated in table 6 we selected ISO Technical Committees that are most relevant. We analysed descriptions of ISO TCs, given at ISO Open Data website: https://www.iso.org/open-data.html. When deciding on the data to be examined, we focused on ISO and IEC Technical Committees. These are sufficient for the analysis of the standardisation Technical Committees, as their scope covers the above-mentioned aspects of MaaS (see table 6). The joint ISO and IEC committees are currently doing the most work on standardisation in the areas of MaaS.

Therefore, for the purposes of our research, we decided to analyse standardisation work in the field of data from the perspective of ISO technical committees. Another reason for this is the very detailed and transparent definition of the method for determining the current status of work on standards (https://www.iso.org/stage-codes.html), which **will be extremely useful in defining the time-frame for standardisation recommendations** in further project work.

The **ISO Stage Codes** indicate the maturity level of a standard: from proposal and committee draft to publication, revision or withdrawal. These codes allow to filter standards not just by topic but also by their lifecycle stage, ensuring that the exercise focuses on active, published, and broadly applicable standards rather than obsolete or still-draft versions.

As a result of analysing the descriptions of the scope of TC activities, we have listed the committees presented in **Annex 2. ISO Technical Committees related to MaaS** (see table 11). The result of the research in **Step 3** was a mapping of ISO TCs to the issues as shown in the table 7.

Table 7. Proposed mapping of MaaS Aspects to ISO/IEC Technical Committees

Aspect	Topic	Relevant ISO / IEC Technical Committees
Aspect 1: Resilient Supply Chain Enabled by MaaS	Digital Supply Chain and Logistics	ISO/IEC JTC 1 (Information technology), ISO/TC 184 (Automation systems and integration), ISO/TC 204 (Intelligent transport systems), ISO/TC 315 (Cold chain logistics)
	Interoperability and Data Sharing	ISO/IEC JTC 1 (Information technology), ISO/TC 154 (Processes, data elements and documents in commerce, industry and administration), ISO/TC 307 (Blockchain);
	Cloud Manufacturing and Marketplaces	ISO/IEC JTC 1 (Information technology), ISO/TC 184 (Automation systems and integration), ISO/TC 324 (Sharing economy), ISO/TC 321 (Transaction assurance in E-commerce)
	Cybersecurity and Trust in Supply Chains	ISO/TC 292 (Security and resilience), ISO/TC 307 (Blockchain and distributed ledger technologies), ISO/TC 309 (Governance of organizations), ISO/IEC JTC 1 (Information technology)
Aspect 2: Circular and Sustainable MaaS	Sustainable Manufacturing Practices	ISO/TC 207 (Environmental management), ISO/TC 184 (Automation systems and integration), ISO/TC 323 (Circular economy), ISO/TC 261 (Additive manufacturing);
	Circular Economy and Resource Recovery	ISO/TC 323 (Circular economy), ISO/TC 207 (Environmental management), ISO/TC 322 (Sustainable finance)
	Traceability and Transparency	ISO/TC 307 (Blockchain and distributed ledger technologies), ISO/TC 176 (Quality management and quality assurance), ISO/TC 286 (Collaborative business relationship management)
	Circular Supply Chain Models	ISO/TC 323 (Circular economy), ISO/TC 342 (Management consultancy), ISO/TC 315 (Cold chain Logistics)
Aspect 3: Human-Centric, Flexible Automated Production System MaaS	Flexible and Adaptive Manufacturing Systems	ISO/TC 39 (Machine tools), ISO/TC 184 (Automation systems and integration), ISO/TC 261 (Additive manufacturing), ISO/TC 199 (Safety of machinery)
	Robotics, Automation and Human-Robot Collaboration	ISO/TC 299 (Robotics), ISO/TC 184 (Automation systems and integration), ISO/TC 199 (Safety of machinery)
	AI, Data and Decision Support in MaaS	ISO/IEC JTC 1 (Information technology), IEC/ISO JTC 3 (Quantum technologies), ISO/TC 262 (Risk management), ISO/TC 279 (Innovation management)
	Human-Centric and Safe Work Environments	ISO/TC 199 (Safety of machinery), ISO/TC 260 (Human resource management), ISO/TC 251 (Asset management);

From the MASTT2040 project perspective point of view the most relevant ISO TCs are:

1. ISO/IEC JTC 1: Information technology (more than 20 Sub-Committees),
2. ISO/TC 154: Processes, data elements and documents in commerce, industry and administration,
3. ISO/TC 176: Quality management and quality assurance,
4. ISO/TC 184: Automation systems and integration,
5. ISO/TC 204: Intelligent transport systems,
6. ISO/TC 207: Environmental management,
7. ISO/TC 251: Asset management,
8. ISO/TC 260: Human resource management,
9. ISO/TC 261: Additive manufacturing,
10. ISO/TC 286: Collaborative business relationship management,
11. ISO/TC 292: Security and resilience,
12. ISO/TC 309: Governance of organizations,
13. ISO/TC 321: Transaction assurance in E-commerce,
14. ISO/TC 323: Circular economy,
15. ISO/TC 324: Sharing economy.

Step 4. **Final summary**. Based on the mapped ISO TCs, an analysis was conducted of the descriptions of standards on which these committees have worked on or are working on now. An analysis analogous to **Step 3** was conducted, **this time for a selected subgroup of standard descriptions**.

The analysis covered both the content of the standard description and its life cycle, defined using the ISO lifecycle codes. The full results of research from **Step 4**, including time-frame aspects of ISO standardisation projects, are presented in **4.1. Analysis results**.

After conducting an extensive ISO Open Data website analysis, key themes and trends in data standardisation that are shaping the evolution of Manufacturing-as-a-Service (MaaS) have been identified and described.

These represent consolidated conclusions on how ISO, IEC, and related bodies are structuring the digital standardisation landscape across **interoperability, data governance, cybersecurity, sustainability, human-centric approach** and **maturity modelling** – all relevant for future MaaS ecosystems.

These Key standardisation areas encapsulate the **main conclusions of the ISO Open Data analysis on data standardisation**. They align ISO's evolving portfolio with the **strategic vision of MaaS by 2040 and beyond**.

4.1. Analysis results

Far-future (post-2035; **ISO Stage code: 10.99 – New project approved**) standardisation initiatives focus on **IoT, digital twins, AI governance** and **trusted data exchange**. They include projects on digital entity modelling, AI ethics and data quality, de-identification and lifecycle assessment for machine learning, next-generation electronic data interchange (EDIFACT, Buy-Ship-Pay) and standards for trustworthiness of digital platforms and knowledge management systems.

These emerging areas will be crucial for future Manufacturing-as-a-Service ecosystems, shaping interoperability, data governance, ethical AI and platform trust **over the coming decades**.

Future-oriented standardisation projects (up to 2035; **ISO Stage codes: 20.00, 20.20, 20.60, 20.99, 30.00, 30.20**) focus on **emerging technologies** and **trustworthy digital ecosystems**. Key areas include **AI, digital twins, quantum computing, cybersecurity, cloud and edge networking** and **data governance**. Work also advances on **ontology-based interoperability, IoT architectures, sustainability integration** and **human-machine collaboration**.

Complementary initiatives address trust frameworks, decentralized identity, digital product definitions and blockchain-based traceability, alongside competency and leadership models for innovation and shared manufacturing. Together, these projects will establish the foundations for secure, interoperable and sustainable Manufacturing-as-a-Service systems **leading up to 2035**.

Near-future standardisation activities (up to 2030; **ISO Stage codes: 30.60, 30.99**) concentrate on **trust, AI quality, interoperability** and **digital business frameworks**. They include standards for **trustworthiness, identity management, AI privacy and performance evaluation** and **reference architectures for enterprise and software systems**. Other initiatives focus on **smart contracts, digital transactions (UBL v2.4), industrial data models** and **3D engineering integration**, alongside **collaborative business relationships, sustainability in finance** and **provider verification in the sharing economy**.

Collectively, these efforts aim to strengthen reliability, transparency, and interoperability in digital and AI-driven manufacturing and service ecosystems **by 2030**.

Currently, ISO's standardisation work focuses on **digital transformation, AI governance, data interoperability** and **sustainability** across industries (**ISO Stage codes: 40.00, 40.99, 50.00, 50.20, 60.00, 60.60**). Key initiatives include developing **digital twin** and **digital thread frameworks**, **ontology-based interoperability** and **system-of-systems (SoS)** approaches for engineering and manufacturing. ISO also advances standards for **AI transparency, explainability and data quality**, as well as **cybersecurity labelling**, **privacy assurance** and **trustworthy supply chains**.

Other active areas cover **circular economy performance**, **sustainable business models**, **service excellence**, **additive manufacturing** and **resilience management**.

In parallel, work continues **blockchain and DLT architectures**, **cloud and IoT data platforms** and **human-robot safety and ergonomics**.

Overall, the **2025-2030 ISO agenda** aims to build a globally interoperable, secure and sustainable digital-industrial ecosystem, supporting AI-enabled, Cyber-Physical and **service-oriented manufacturing**.

4.2. Key MaaS Standardisation categories and areas

This chapter distils the MASTT2040 mapping into three aspects: Resilient Supply Chains, Circular & Sustainable MaaS, and Human-Centric, Flexible Automated Production – and translates them into concrete, data-centric standardisation areas summarised in the following tables.

Across all aspects, five cross-cutting needs consistently recur: (i) shared semantics/ontologies, (ii) interoperable APIs and M2M exchange, (iii) governed data spaces and access/consent, (iv) AI- and real-time-ready data for monitoring/forecasting, and (v) trust, credentials and machine-readable contracting. The tables below therefore provide a concise, aspect-by-aspect overview that will feed directly into the standardisation analysis.

Table 8. Key standardisation areas for **Aspect 1:** Resilient Supply Chain Enabled by MaaS

Aspect	Standardisation category	Identified standardisation area
Aspect 1 Resilient Supply Chain Enabled by MaaS	**A1-1** Digital Supply Chain and Logistics	**1. Data modeling and semantic interoperability** Providing a common language of description: machines, services and competencies in MaaS ecosystems. **Scope of standardisation:** shared ontologies (modeling languages, reference architecture models), production capability models, and data descriptors.
		2. Data exchange and Machine-to-Machine (M2M) communication Enable automated and reliable data sharing between manufacturing, logistics and service platforms. **Scope of standardisation:** standardized APIs; Service Level Agreement (SLA), standardised data exchange formats.
		3. Data management/governance, access and protection Ensure the secure, fair, and transparent use of data across all organizations connected in the MaaS ecosystem. **Scope of standardisation:** data access, anonymization of data and users, management of consents to the use of data (in accordance with the EU Data Governance Act).
		4. Data for real-time analysis, business intelligence and forecasting Support for predictive analytics, predictive maintenance, logistics coordination and adaptive, uncertainty-resistant decision-making. **Scope of standardisation:** data standards for the use of artificial intelligence, digital twins, and real-time monitoring.
		5. Data trust, compliance, and Smart Contracting Ensuring safe and verifiable supply chain operations. **Scope of standardisation:** contracts in data formats suitable for machine read automation, trust protocols, and credential management standards in a collaborative network.
	A1-2 Interoperability and Data Sharing	**1. Modeling semantics in the data domain, ontologies** Enabling a common understanding of each other's machines, services and skills across different systems and organisations. Understanding not only in terms of interfaces, but above all in terms of data interpretation. **Scope of standardisation:** development of common ontologies (data models), capabilities models and MaaS-specific data semantics to ensure interoperability (semantic).
		2. Data exchange and API (Application Programming Interface) interoperability Facilitating the automated flow (read and write) of data and the integration of processes between IT systems from different manufacturers. **Scope of standardisation:** standardize APIs, SLAs, and contract formats for automation and interoperability for machine-readable structured data.
		3. Data Spaces and data governance Supporting trusted, regulated data sharing within and across value chains. **Scope of standardisation:** alignment with the common European data spaces and the EU Data Governance Act, focusing on standards for data access, portability between systems and anonymisation.
		4. Fair value of data and rights to share it/use it Ensuring a fair distribution of value and protecting trade secrets in data-driven collaboration. **Scope of standardisation**: creating data sharing frameworks that define ownership, access rights, and compensation and compensation mechanisms in MaaS environments.
		5. Data for monitoring, planning, scheduling and performance optimization Use of all available real-time machine and service data for: planning, condition monitoring and adaptive system control (individual machines and IT systems within the system). **Scope of standardisation**: Standardized data descriptors; interoperability to the needs of MaaS-specific production monitoring.

Aspect	Standardisation category	Identified standardisation area
	A1-3 Cloud Manufacturing and Marketplaces	**1. Data exchange and API standardisation** Provide interoperable data flow and automate transactions between production services, based on cloud access. **Scope of standardisation:** development of standardized APIs, agreements (patterns and handling mechanisms) SLAs, data formats for automation and integration of services that are to be readable (accessed) by machines.
		2. Data models for reputation assessment and certification Use of structured, machine-readable data to assess the reliability, reliability, and compliance of suppliers. Development of data models describing the quality certification of processes taking place in the MaaS ecosystem. **Scope of standardisation:** create reputation models, certification schemes, and policy implementation standards that are consistent across different vendors' IT platforms.
		3. Data governance and privacy management Ensure trusted and secure data sharing while protecting sensitive information. **Scope of standardisation:** implementation of standards for anonymization, consent management and controlled access to data, in accordance with the EU Data Governance Act.
		4. Data for trust, access, and identity management Support secure authentication and access control on distributed production networks. **Scope of standardisation**: development of common trust, credential, and identity management protocols to ensure interoperability and compliance with information security management systems (cybersecurity).
		5. Data-driven contracts and compliance verification automation Facilitating and simplifying the conclusion of transparent, verifiable and formally and legally self-verifying contracts between service providers and customers. **Scope of standardisation:** adoption of machine-readable standards and smart contracts to implement automation: compliance, traceability, completeness, and legal correctness.
	A1-4 Cybersecurity and Trust in Supply Chains	**1. Data governance and secure data spaces** Establish a trusted framework (reference architecture) for secure data sharing between supply chain participants. **Scope of standardisation:** Alignment with the Common European Data Spaces and the EU Data Governance Act, setting standards for data access, anonymisation and consent management.
		2. Data models for reputation assessment and certification Use structured, machine-readable data to assess the reliability, reliability, and compliance of suppliers. Development of data models describing the quality certification of processes taking place in the MaaS ecosystem. **Scope of standardisation:** Create reputation models, certification schemes, and policy implementation standards that are useful for expressing policies to support automatic validation of partners.
		3. Data for identity, access, and credential management Enable secure identification and authorization of entities within distributed production networks. **Scope of standardisation:** Implementation of common data exchange protocols, metadata (data structures) for the implementation of validation, trust, access control, and credential management algorithms in IT platforms from different manufacturers.
		4. Data-driven contracts and compliance Ensure transparency and traceability of digital transactions with structured data (metadata). **Scope of standardisation:** Standardize machine-readable and intelligent contracts for automated compliance, auditing, and legal enforcement as part of MaaS operations.
		5. Standards and monitoring of data related to cybersecurity Leverage data-related reference architecture models to detect, report, and mitigate cybersecurity threats across connected supply chains. **Scope of standardisation:** standardisation of cybersecurity data models, ensuring that MaaS platforms comply with EU-wide security and reporting obligations. Standards related to interoperable, verifiable data exchange.

Table 9. Key standardisation areas for **Aspect 2:** Circular and Sustainable MaaS

Aspect	Standardisation category	Identified standardisation area
Aspect 2 Circular and Sustainable MaaS	**A2-1** Sustainable Manufacturing Practices	**1. Interoperable product and process data** Ensure uniquely traceable links between product, machine and process data, to support fully digital tracking and analysis of sustainability data, within the digital platforms of various vendors. **Scope of standardisation**: Develop data interoperability standards that combine production, operational, and product lifecycle data in MaaS value chains.
		2. Trusted sustainability data spaces Supporting secure, real-time management of environmental and performance data exchange between stakeholders in the MaaS ecosystem. **Scope of standardisation:** alignment with the Common European Data Spaces and the EU Data Governance Act; define a standard for data access, anonymisation and consent to share sustainability-related data.
		3. Harmonised data models for the Circular Economy, including the use of resources Ensure a consistent data structure for reporting and decision-making on material flows, as well as material reuse. The structure of data related to the consumption of utilities (electricity and heat) is also crucial. **Scope of standardisation:** Creation of harmonized data structures, definition of indicators for the Circular Economy, efficiency and optimization of resources in MaaS networks.
		4. **Standardisation of data for environmental performance measurement** Enabling measurable and comparable sustainability assessments across all operations and regions in MaaS chains. **Scope of standardisation:** Standardization of carbon footprint, energy efficiency and resource use indicators, ensuring the interoperability of measurement data, regardless of the European region.
		5. **Data-driven maturity and benchmarking models** Use aggregated sustainability data to assess and compare maturity in achieving sustainable production goals. **Scope of standardisation:** development of common indicators and data formats (metadata) for cross-regional maturity assessment and alignment with both ESG and Life Cycle Assessment reporting standards.
	A2-2 Circular Economy and Resource Recovery	**1. Interoperable product and material data** Enable the traceability of materials, components and products throughout their life cycle for possible reuse, recycling and regeneration. **Scope of standardisation:** development of standards that combine data on products, processes and machines on different platforms to support the flow of materials in the Circular Economy.
		2. Trusted data spaces related to the Circular Economy Supporting secure, regulated and managed data exchange between manufacturers and recycling service providers. **Scope of standardisation:** alignment with the Common European Data Spaces and the EU Data Governance Act, focusing on data access, consent and anonymisation in circular value chains.
		3. Data governance, accessing it and fair value sharing Ensuring equitable access, portability, and protection of data in circular ecosystems. **Scope of standardisation:** establishment of mechanisms and standards for the fair distribution of value, data ownership and protection of trade secrets between industrial entities.
		4. Harmonised data models for the Circular Economy and Life Cycle Assessment (LCA) reporting Provide a consistent set of data and metrics to track material consumption, recovery rates, and environmental impact. **Scope of standardisation:** Define harmonised data structures and ontologies for Circular Economy reporting and decision-making, including resource efficiency.
		5. Data Standards for Digital Material Passports and recovery processes Facilitate the interoperable exchange of data on material composition and reuse potential. **Scope of standardisation:** development of standardized data models (metadata) and exchange formats for material passports, recycling and remanufacturing processes, to ensure a transparent ecosystem of resource recovery.

Aspect	Standardisation category	Identified standardisation area
	A2-3 Traceability and Transparency	**1. Semantic data models, ontologies, reference architecture models** Provide a common language for data to describe machines, services and processes for a transparent and consistent exchange of information. **Scope of standardisation:** development of common models and ontologies of production capacities and processing of materials and waste for MaaS; The aim is to ensure semantic interoperability between data storage and exchange platforms and supply chain participants.
		2. Linked product and process data for lifecycle tracking Provide comprehensive visibility into product, asset and manufacturing process information; availability of information on origin, reusability in a circular manner. **Scope of standardisation:** Establish standards that combine data on products, processes and machines across different systems (manufacturing, ICT) to ensure traceable and interoperable data flows related to lifecycle management (including analysis).
		3. Governed Data Spaces Ensuring the secure and transparent exchange of all possible data between participants in the MaaS ecosystem. **Scope of standardisation:** alignment with the Common European Data Spaces and the EU Data Governance Act, including data access, portability and a fair way to switch ICT providers. Ensuring the protection of end-users against monopolization of the market by a single supplier.
		4. Data standards for trust, access, and compliance Build trusted data environments where every transaction or data exchange is verifiable and accountable. **Scope of standardisation:** Standardize trust, credential, and data access management protocols, and machine-readable digital contracts to provide automatic verification and validation of compliance.
		5. Integrated lifecycle and transparency framework Leverage connected data storage, sharing, and management systems to connect operational, life-cycle and environmental data. The goal is to ensure ongoing automated compliance for all participants in the MaaS ecosystem. **Scope of standardisation:** Development of interoperable lifecycle data models combining traceability, transparency and reuse of information within MaaS, in circular value chains.
	A2-4 Circular Supply Chain Models	**1. Semantic data models and ontologies for the Circular Economy** Provide a common semantic basis for describing products, processes and resources in circular value chains. **Scope of standardisation:** development of common models and ontologies of capabilities for services, machines and materials; adaptation to standardised APIs and data formats to ensure interoperability and automation.
		2. Linked Life Cycle and Product Data Framework Ensure full visibility and continuity of access to data at all stages of production, use, recycling and recovery. **Scope of standardisation:** Establish standards for combining product and machine data, creating data models for material passports, and integrating lifecycle information within MaaS platforms.
		3. Data spaces and governance for circular value chains Supporting secure, trustworthy and fair data sharing between actors in circular ecosystems. **Scope of standardisation:** alignment with the common European data spaces and the EU Data Governance Act, ensuring data access, anonymisation, compliance, transferability and fair sharing of value.
		4. Data on sustainability, maturity and readiness indicators Provide comparable, data-driven information on environmental and organizational performance. **Scope of standardisation:** define harmonised data structures and indicators on carbon footprint, energy efficiency, resource use and circularity maturity assessments linked in a transparent way to EU policy objectives.
		5. Data infrastructure for policy coordination and alignment Creating a shared data ecosystem to support the monitoring of standardization, policy integration and innovation. **Scope of standardisation:** creation of a central repository of MaaS-related standards, identification of standardisation gaps with the help of SDOs, and ensuring compliance with EU and global standardisation observatories through open ICT data platforms.

Table 10. Key standardisation areas for **Aspect 3:** Human-Centric, Flexible Automated Production System MaaS

Aspect	Standardisation category	Identified standardisation area
Aspect 3 Human-Centric, Flexible Automated Production System MaaS	**A3-1** Flexible and Adaptive Manufacturing Systems	**1. Semantic data models and ontologies describing manufacturing capabilities** Providing a shared data structure (metadata) for a coherent description of: machines, services, competencies, skills and available manufacturing capabilities in adaptive production systems. **Scope of standardisation**: development of common data models, ontologies and minimum descriptors to ensure semantic interoperability and simpler deployment of new providers (services) in MaaS networks.
		2. Data exchange and real-time system integration Ensure dynamic coordination of data exchange and automation in distributed production systems. **Scope of standardisation**: Standardization of APIs, widespread use of SLAs and machine-readable data formats for real-time data sharing, planning and integration of AI and digital twins for predictive control or predictive diagnostics.
		3. Data spaces and data governance procedures Ensure secure, managed data collaboration across flexible production networks. **Scope of standardisation:** alignment with the common European data spaces and the EU Data Governance Act, including data access, anonymisation, consent and trust management between platforms of different providers.
		4. Data-driven monitoring, forecasting and adaptation Use integrated machinery, logistics, and demand data to ensure adaptive planning and resource optimization. **Scope of standardisation:** Creation of standardized data structures and interoperability protocols that connect monitoring systems with real-time forecasting and scheduling tools.
		5. Data standards for maturity, readiness and policy alignment Supporting the assessment and benchmarking of organisational and technological adaptability. **Scope of standardisation:** development of common uniform data indicators and maturity assessment frameworks aligned with the EU's industrial, digital and green policy objectives, enabling the construction and implementation of data-driven development pathways.
	A3-2 Robotics, Automation and Human-Robot Collaboration	**1. Semantic data models for machines and knowledge, skills and competencies** Provide consistent, machine-readable representations of robot capabilities, services, and competencies. Scope of standardization: development of common ontologies, models of capabilities, knowledge, skills and competencies, enabling interoperability between human and robotic agents on MaaS platforms.
		2. Data sharing and interoperable automation frameworks Ensure seamless data exchange between machines and between humans and machines and robots to coordinate activities. **Scope of standardisation:** standardize APIs, SLAs, and service descriptors to provide real-time planning, alignment, and interoperability across platforms.
		3. Data for real-time analysis and digital twins Leverage data processed with AI and digital twins to forecast opportunities, availability, optimize workflow, and enhance collaboration security. **Scope of standardisation:** establish standardized data structures and models for AI-driven monitoring, predictive control, and decision-making in dynamic production environments.
		4. Data standards for trust, access, and compliance Ensuring secure data sharing and accountability between humans, robots and digital platforms. **Scope of standardisation:** develop machine-readable agreements, trust protocols, and credential management standards to guarantee traceability, authorization, and compliance with accepted policies.
		5. Data-driven standards for knowledge, skills, competences, safety and ergonomics Supporting human-centric system design and competency development with standardized data and data models. **Scope of standardisation:** defining data-driven frameworks and guidelines for digital skills, the use of artificial intelligence and sustainability, as well as ergonomics and safety standards for human-machine and human-robot interactions.

Aspect	Standardisation category	Identified standardisation area
	A3-3 AI, Data and Decision Support in MaaS	**1. Semantic data models and knowledge representation** Provide a common semantic basis for AI systems used to interpret and infer manufacturing capabilities, services, and skills. **Scope of standardisation**: development of common ontologies and capability models that combine data about products, processes and machines to support semantic interoperability and train AI models.
		2. Trusted Data Spaces for AI Provide secure and compliant access to distributed data for the development, validation and deployment of AI-powered algorithms. **Scope of standardisation:** alignment with the Common European Data Spaces, the EU Data Governance Act and the Artificial Intelligence Act, which set standards for data sharing, consent and anonymisation for the responsible use of AI.
		3. Data for real-time analysis and Digital Twins Leverage real-time data streams for AI-powered forecasting, decision support, and optimization tools. **Scope of standardisation:** establish standardised data descriptors and formats for the integration of AI algorithms, digital twins and monitoring systems within MaaS platforms.
		4. Data governance, fair and equitable distribution of value and transparency Ensuring fair, auditable and transparent use of data in AI-based production decisions. **Scope of standardisation:** creating mechanisms and standards for fair data sharing, portability, protection of trade secrets and explainability of AI results.
		5. Data-driven maturity, policy alignment and coordination standards Supporting the evaluation, coordination and integration of system-level policies in AI-driven manufacturing. **Scope of standardisation:** development of common indicators and maturity models aligned with EU industrial, digital and green policies, supported by a central repository and standardisation observatories to identify gaps and establish contacts between stakeholders.
	A3-4 Human-Centric and Safe Work Environments	**1. Governed employee and workforce data spaces** Enable secure, ethical management of employee and operational data while maintaining privacy and trust. **Scope of standardisation:** alignment with the Common European Data Spaces and the EU Data Governance Act, setting standards for anonymisation, consent management and access to data in systems that support people's work.
		2. Data models for knowledge, skills, competencies and roles in the organization Supporting continuous data-driven upskilling, task assignment, and human resource planning across MaaS networks. Real-time data analysis in competency models. **Scope of standardisation:** development of standardised models of competences and skills, with guidance on digital capabilities, artificial intelligence and sustainability.
		3. Data on safety, work ergonomics and human-machine interaction Use sensor data, operational and environmental data to ensure a safe, ergonomic and adaptive workplace. **Scope of standardisation:** define data standards and metrics to monitor security, ergonomics, and role distribution in collaborative environments.
		4. Trust, data access, and compliance mechanisms Creating a transparent, accountable framework for managing employee and operational data. **Scope of standardisation:** standardize trust, credential, and access management protocols, and machine-readable contracts to ensure compliance and secure data exchange.
		5. Data-driven maturity and governance framework Use aggregated data to compare the level of development of the organization and the greater use of human-centric innovation in the company's growth strategy. **Scope of standardisation:** develop common maturity indicators and data models for assessment and governance, aligned with the EU's industrial, digital and green policies.

Standardisation metadata sources availability – Comment on possibility to extend approach to other Standard Bodies

The approach to identifying areas of standardisation for MaaS proposed in the example is a general one, and its results may be better the more information is available on:

1. Descriptions of the areas of activity of technical committees and working groups: **ETSI**, **ISO**, **IEC**, **IEEE**;
2. Descriptions of areas and detailed data for other SDOs, including: **ITU**, **AIOTI**, **IDSA**, **VDE**, **VDMA**, **W3C**, **ZVEI**, **oneM2M**;
3. Descriptions of the relationships between standards, the technical teams involved in their development, their life cycle, and detailed descriptions;
4. Descriptions of the involvement of individual SDOs in the work of working groups and technical committees.

Currently, this data is available in the form of text extracts from information databases. The institutions publishing this data have different approaches to the information describing the standards, which makes it very difficult to analyse, especially when the information is dynamic and changing (as the status of work on each standard changes).

Issues related to standardization and available descriptions of standards can be found on the following websites:
ETSI: https://www.etsi.org/standards#Pre-defined%20Collections
ISO: https://www.iso.org/open-data.html
IEC: https://www.electropedia.org/
IEEE: https://ieeexplore.ieee.org/Xplorehelp/discovery-services/kbart-title-lists#ieee-standards
ITU-T: https://www.itu.int/en/ITU-T/publications/Pages/default.aspx
IOTI: https://aioti.eu/resources-standardisation/
VDE: https://www.vde.com/en/working-areas/standards
VDMA: https://www.vdma.eu/en/technical-rules-standards

The lists of members of technical committees and working groups are available on the websites:

1. ETSI Technical Groups: https://www.etsi.org/committees
2. ISO Technical Committees: https://www.iso.org/technical-committees.html
3. IEC Technical Committees and subcommittees: https://www.iec.ch/technical-committees-and-subcommittees#tclist

Based on more widely available data in the future, it will be possible to develop a concept for a tool that will link all the information necessary to analyse the state of standardization for MaaS in real time. An example of such a tool for the ICT area is the EU Observatory for ICT Standardization (https://www.standict.eu/euos), developed and maintained as part of the StandICT.eu project.

Currently, this information is scattered, inconsistent, and published using the platforms and tools of the organizations that publish it.

5. Concluding Remarks and Next Steps

Deliverables within the "Sense making and recommendations" stage of project was guided by the standardisation objective of MASTT2040: **"Develop recommendations for an EU manufacturing standardisation strategy with a specific focus on the role of data,"** which addresses the following:

Identification of *cross-cutting aspects* (**standardisation gaps**, **barriers**, **enablers**) which might **require standardisation** at the EU level.
Identification of main Standardisation Development Organisations that **supports implementation** of MaaS.

This deliverable discussed how **standardisation of data** can accelerate the development and adoption of **Manufacturing-as-a-Service (MaaS)** in Europe.

MaaS has input to many areas, supported by the EU regulations:

1. Artificial Intelligence (AI Act);
2. Cybersecurity (Cyber Resilience Act);
3. Trusted Data Spaces, cloud and edge computing, interoperability, blockchain and distributed ledger technology, trusted digital signatures, E-invoicing (Data / Data Governance Act).

There are still gaps both in EU regulations and proper domain-specific standardisation:

1. Digital skills, digital learning – DigComp 2.2 [9] is available, but on the other hand there is no competence model for MaaS;
2. Digitisation of European Industry, robotics and autonomous systems, Internet of Things – "IEC/TR 63319:2025 – A meta-modelling analysis approach to smart manufacturing reference models" [10] is the first standards that leads to creation of Smart manufacturing unified semantics description, probably creation of MaaS Reference Architecture could be a solution;
3. Circular Economy and sustainability, ICT environmental impact – there is a need for development of APIs for Materials Banks, creation of Open trade off tools for sustainability and cost, as well as provision of eco-design standards due to Zero Waste Certification.

Even though there are EU Acts (Data, Data Governance, AI and Cyber Resilience) that are highly relevant to MaaS, there is still significant work to do with development of proper standards, that enable scaling of MaaS. It is also unclear if ongoing standardisation efforts are addressing MaaS recommendations and whether specific new actions may be needed.

Results from analysis will assist Standards Development Organisations (SDOs) in identifying priority areas for work. Suggestions for closing standardisation gaps in the near-term (5 years), midterm (5-10 years) and long-term (10+ years) will be discussed with SDO representatives. Based on this, recommendations for an EU manufacturing standardisation strategy can be drafted.

The next deliverable will be devoted to **recommendations for an EU** manufacturing standardisation strategy focusing specifically on the role of data.

6. Tools and approaches used for research (summary)

Generative Artificial intelligence (AI) tools were used exclusively to support the development of selected Python code snippets for textual analysis and consistency analysis of XML files created during development of Standardisation Framework. Also, mermaid flowchart codes were improved by the AI tools built-in the mermaidchart.com application.

No genAI/LLM was employed in the drafting, structuring or preparation of the document content. The authors remain fully responsible for the implementation, validation and interpretation of all results. **LLMs have been utilized** to shorten descriptions in final version of the document, based on the authors results and reviewer's comments.

There were different transformations developed and used for verification of the consistency of the final document – none of them utilizes generative AI (i.e. Large Language Models).

For textual analysis **TF-IDF Vectorization with Cosine Similarity** have been applied (Chapter 4. An ISO Standardisation analysis exercise). Three different embedding models from **sentence-transformers** group: all-MiniLM-L6-v2 [7], paraphrase-mpnet-base-v2 [6] and all-mpnet-base-v2 [8] embedding models have been used for analysis of the content of technical committee descriptions and standard descriptions in ISO standards example.

The MASTT2040 **Framework** has been developed for purposes of "Sense making and recommendations" stage of the project (Chapter 2. A framework for analysing MaaS standardisation lifecycle).

"A conceptual framework explains, either graphically or in narrative form, the main things to be studied – the key factors, constructs, or variables – and the presumed relationships among them. It serves as a map for the research and guides data collection and analysis." [11] While data model for the project is wide, multi-dimensional and full of different relationships, the so-called concept of **Interactive Model** combined with metamodeling design technique has been applied [12], [13].

The Standardisation Framework has been developed as a maintenance-free plug-in technology, that can be imported and used with world-standard modelling software Enterprise Architect.

To ensure high quality of use in the research process, **the framework has met certain requirements**:

1. the framework **named all structures** that are key to the project and combined them within a metamodel,
2. the framework explicitly **named the relationships** between objects (not only through links, but also defines the direction of the relationship),
3. it **separated the layers of analysis** (key), which allowed them to be simplified and divided in the case of complex issues,
4. it **used definitions** to understand the framework,
5. it **enabled iterative expansion** of the framework and continuous validation of compliance with the specified criteria – for now, it is based on compliance with the Manufacturing-as-a-Service vocabulary.

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Annex 1. Standardisation ecosystem in Europe

In this annex, we have attempted to present the links between the institutions representing the European Commission (see Figure 5), identified by the Commission as key for Europe [3] (ESO), implementing standardisation procedures (NSB) and actively participating in them, both in terms of content and organisation (SDO, technical associations, SMEs).

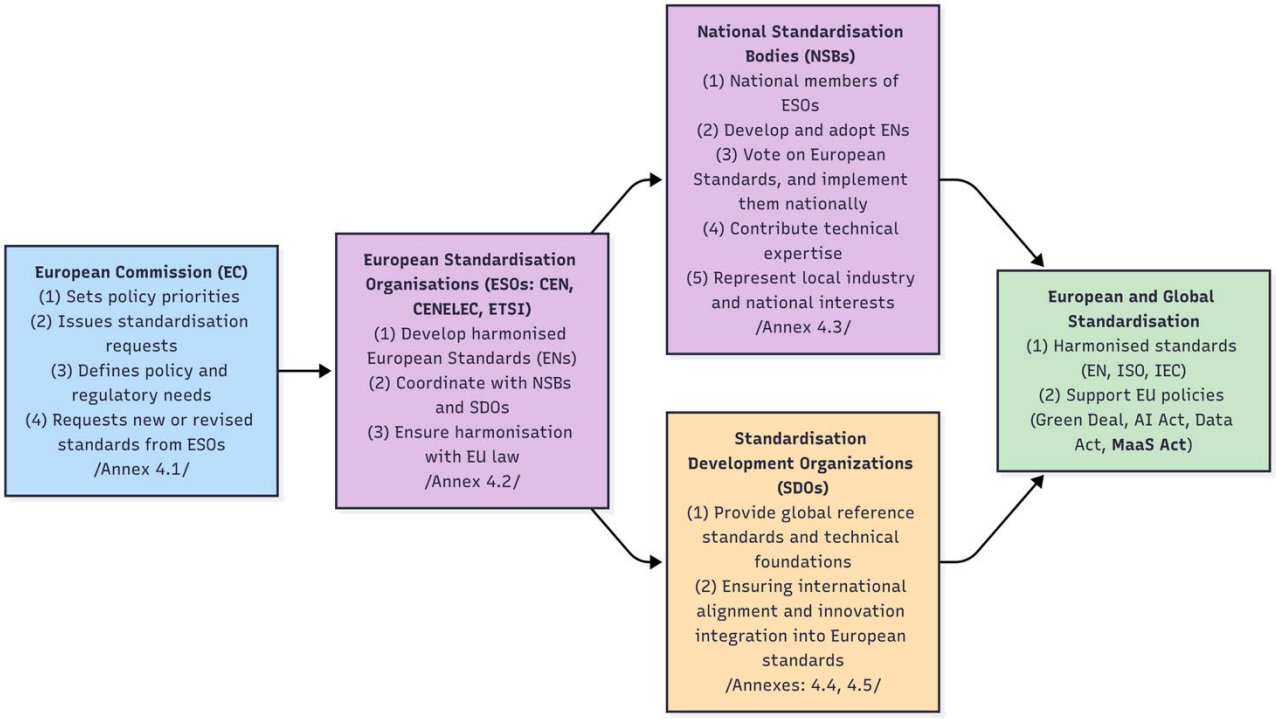

Figure 7. Standardisation workflow in Europe

In this appendix, we discuss only those whose activities directly or indirectly support the development of Manufacturing-as-a-Service.

A1.1. European Commission Bodies. Policy makers relevant to MaaS

Several Directorates-General (DGs), Executive Agencies and research bodies of the European Commission are directly involved in shaping policies, legislation and funding instruments that affect the development of Manufacturing-as-a-Service (MaaS). They cover climate neutrality, digital transformation, data protection, defence, environment, employment, innovation, industry competitiveness and research:

1. Digital and Data (**DG CONNECT**, DPO) – ICT, cybersecurity, platform regulation and data protection;
2. Industry and Competitiveness (**DG GROW**, DG DEFIS, EISMEA) – Single Market governance, SME support, defence/space applications;
3. Research and Innovation (**DG RTD**, REA, JRC) – funding, research infrastructure, foresight for MaaS innovation;

4. Climate and Environment (DG CLIMA, DG ENV, CINEA) – sustainability and decarbonisation framework for MaaS;
5. Employment and Society (DG EMPL) – social inclusion, reskilling, labour policies for MaaS workforce.

Together, these Commission bodies **set the legal, financial and policy framework** within which MaaS can scale, ensuring alignment with the **EU Green Deal** [14]**, Digital Strategy** [15]**, AI Act** [16]**, Data Act** [17] **and Industrial Strategy** [18]. The list of most important policymakers involved in development of legal acts, connected with Manufacturing-as-a-Service:

- Communications Networks, Content and Technology (DG Connect[24]),
- Internal Market, Industry, Entrepreneurship and SMEs (DG GROW[25]),
- Directorate-General for Research and Innovation (DG RTD[26]),
- Climate Action (DG Clima[27]).

Other relevant, supporting the overall policymaking processes for MaaS:

- Environment (DG ENV[28]),
- European Climate, Infrastructure and Environment Executive Agency (CINEA[29]),
- Data Protection Officer (DPO[30]),
- Defence Industry and Space (DEFIS[31]),
- European Innovation Council and Small and Medium-sized Enterprises Executive Agency (EISMEA[32]),
- Employment, Social Affairs and Inclusion (EMPL[33]),
- European Research Executive Agency (REA[34]),
- Joint Research Centre (JRC[35]).

Selected, most important from the MaaS point of view, policymakers are briefly described as follows.

A1.1.1. Communications Networks, Content and Technology (DG Connect)

The Directorate-General for Communications Networks, Content and Technology (DG Connect / DG CNECT) works on shaping Europe's digital present and future. Support, fund and regulate digital and frontier technologies to strengthen our democracy and to make Europe safe, more competitive and

[24] https://commission.europa.eu/about/departments-and-executive-agencies/communications-networks-content-and-technology_en
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[35] https://commission.europa.eu/about/departments-and-executive-agencies/joint-research-centre_en

technologically sovereign. DG Connect enforces the European rulebook for online platforms, digital markets and artificial intelligence (AI). Connect helps defend the EU against cyber and hybrid security threats and counter disinformation.

DG CONNECT underpins Manufacturing-as-a-Service by providing the **policy, infrastructure and regulatory framework** for Europe's digital manufacturing transformation. It advances **connectivity, interoperability and data governance** – all essential for distributed and data-driven manufacturing ecosystems. Through initiatives like the **European Data Strategy**, **AI Act**, and **Digital Europe Programme**, DG CONNECT enables secure data sharing, trustworthy AI and robust digital networks.

A1.1.2. Internal Market, Industry, Entrepreneurship and SMEs (DG GROW)

The Directorate General for Internal Market, Industry, Entrepreneurship and SMEs is working to uphold and manage the Single Market for goods and services and to strengthen its governance. Its work helps ensure an open, seamless and resilient internal market, which is one of the cornerstones of European integration. The DG GROW supports the competitiveness, growth and resilience of the EU economy. It focuses on strengthening the leadership of European industries across different industrial ecosystems, by leveraging the power of the Single Market and addressing strategic dependencies in our supply chains. In addition, it implements policies that sustain entrepreneurship and growth, in particular to the benefit of small and medium sized enterprises (SMEs), including facilitating access to funding and to global markets for EU companies.

The DG GROW leads efforts on digitisation and decarbonisation of European industry and SMEs. It contributes to the objective of turning the EU into a greener, more digital and more resilient economy.

DG GROW plays a central role in enabling **Manufacturing-as-a-Service (MaaS)** by shaping the industrial and policy environment that supports flexible, digital, and sustainable manufacturing models. Its focus on **industrial competitiveness, SME innovation and supply chain resilience** directly advances the adoption of MaaS across Europe. Through its leadership in the EU's **twin transition**, DG GROW fosters the integration of digital and green technologies that underpin the development of **resilient, data-driven, and service-oriented manufacturing ecosystems**.

A1.1.3. Research and Innovation (DG RTD)

The Directorate-General Research (DG RTD) and Innovation develops and carries out the Commission's policies on research and innovation. It oversees the current EU research and innovation funding programme Horizon Europe, as well as EU Missions.

The Directorate-General is leading the Commission's work to develop an EU start-up and scale-up strategy that will improve the framework conditions. Furthermore, the Directorate-General is planning to further expand the European Research Area, develop a long-term strategy to boost European Research Infrastructure and study the role of artificial intelligence in European research.

Finally, the Directorate-General coordinates numerous projects, helps disseminate and exploit their results and partners with industry and EU countries on common research topics and events.

A1.1.4. Climate Action (DG Clima)

The Directorate-General for Climate Action (DG CLIMA) is the European Commission department responsible for leading the EU's efforts to combat climate change and achieve climate neutrality. It develops and implements policies and legislation to meet the **EU's 2030 climate goals** and reach **net-zero greenhouse gas emissions by 2050**. DG CLIMA works to strengthen **climate resilience**, enhance preparedness for environmental risks, and protect citizens and the economy from climate-related impacts. It also represents the EU in international climate negotiations and fosters global cooperation on climate action.

A1.2. European Standardisation Organizations (ESO)

Among the others, **EC Regulation 1025/2012** points key European Standardisation Organisations and presents the following definitions:

standard - means a technical specification, adopted by a recognised standardisation body, for repeated or continuous application, with which compliance is not compulsory, and which is one of the following:

- **international standard** - means a standard adopted by an international standardisation body;
- **European standard** - means a standard adopted by a European standardisation organisation;
- **harmonised standard** - means a European standard adopted on the basis of a request made by the Commission for the application of Union harmonisation legislation;
- **national standard** - means a standard adopted by a national standardisation body.

Regulation [3] indicates CEN, CENELEC and ETSI as so-called European Standardisation Organizations. The list of European organisations involved in development of standards and harmonisation initiatives, connected with Manufacturing-as-a-Service, can be supplemented with ETOA and GS1. The European standardisation landscape supporting **Manufacturing-as-a-Service (MaaS)** is shaped by these organisations that develop, harmonise, and promote standards across ICT, industrial, electrotechnical and supply chain domains:

1. CEN[36] (European Committee for Standardisation/ Comité Européen de Normalisation) brings together 34 National Standardisation Bodies. CEN Develops standards across a broad range of sectors including ICT, transport, energy, healthcare, environment and smart living. CEN provides a platform for harmonised European Standards facilitating interoperability and safety;
   CEN plays an important role in **Manufacturing-as-a-Service (MaaS)** by developing harmonised standards that enable **interoperability, product quality, and regulatory compliance** across Europe. Its cross-sectoral work in **ICT, smart manufacturing, and sustainability** provides the technical foundation for connected, safe, and efficient MaaS ecosystems, facilitating Europe's transition toward **standard-driven, circular, and resilient industrial systems**;
2. CENELEC[37] (European Committee for Electrotechnical Standardisation/ Comité Européen de Normalisation Électrotechnique) coordinates 34 National Electrotechnical Committees. CENELEC

[36] https://www.cencenelec.eu/about-cen/
[37] https://www.cencenelec.eu/about-cenelec/

focuses on electrotechnical standards (i.e. EMC, batteries, transformers, smart grids, electric vehicles). CENELEC supports trade facilitation, compliance cost reduction and EU Single Market integration;

CENELEC is essential for **MaaS** as it ensures **technical safety, electrical interoperability, and energy efficiency** in connected manufacturing systems. Its standards underpin technologies such as **smart grids, electric mobility, and automation**, which are vital for MaaS platforms and industrial data exchange. By aligning electrotechnical standards with EU policy, CENELEC supports **secure, interoperable, and sustainable manufacturing networks**;

3. ETSI[38] (European Telecommunications Standards Institute) is an EU-recognised Standards Organisation with 900+ members from 60+ countries. ETSI specialises in ICT-enabled systems, telecom, applications and services. ETSI ensures global impact of European ICT standards and supports early adoption advantages;

   ETSI is central to **MaaS** as it establishes standards for **connectivity, communication, and data interoperability**, forming the backbone of networked manufacturing. By advancing **5G, IoT, and edge computing standards**, ETSI enables the secure, real-time data exchange that supports **autonomous production, supply chain transparency, and cross-factory collaboration** within MaaS ecosystems;

4. EOTA[39] (European Organisation for Technical Assessment) coordinates Technical Assessment Bodies for construction products under the Construction Products Regulation (CPR) [19]. ETSI provides European Technical Assessments (ETA) [20] to allow CE marking for innovative/non-standard products. EOTA ensures consistent product performance information across Europe.

   EOTA contributes to **MaaS** by providing a model for **modular, performance-based product validation** that can inspire similar approaches in manufacturing services. Its work ensures **trust, conformity, and quality assurance** – key principles for digital product and service certification in **distributed MaaS environments**;

5. GS1[40] is a global not-for-profit association with member organisations in more than 100 countries. GS1 develops global standards for supply chain visibility and efficiency (i.e. barcodes, RFID, digital product identifiers). GS1 plays a key role in traceability, logistics, and digital product data exchange;

   GS1 is vital for **MaaS** by providing **universal data identification and tracking standards** that support end-to-end visibility and trust in supply chains. Its global interoperability framework enables **real-time monitoring of materials, products, and services**, ensuring traceability and efficiency in **distributed and service-oriented manufacturing ecosystems**.

Together, these organisations form the core European ecosystem of standardisation ensures that MaaS can operate across manufacturing, ICT, logistics and sustainability value chains, while remaining aligned with EU harmonisation and standardisation initiatives, the Single Market and global interoperability goals.

[38] https://www.etsi.org/
[39] https://www.eota.eu
[40] https://www.gs1.org/

A1.3. National Standardisation Bodies (NSB)

National Standardisation Bodies (NSBs) act as the **national members and representatives** within the European Standardisation Organisations (CEN, CENELEC, and ETSI). Each NSB contributes national expertise, proposals and votes in the development of **European Standards**, ensuring that national interests are reflected while maintaining **harmonisation across the Single Market**.

Once a European Standard is approved by an ESO, all member NSBs are required to **adopt it as a national standard** and **withdraw any conflicting national standards**, creating a unified system across Europe.

In essence, **ESO coordinate standardisation at the European level**, while **NSB implement, maintain and disseminate these standards nationally**, ensuring coherence between **local industry needs and European policy objectives** – a structure that is fundamental for interoperable and scalable **Manufacturing-as-a-Service (MaaS)** development.

What we observed is that several National Standardisation Bodies (NSBs) play a central role in shaping and implementing standards that affect Manufacturing-as-a-Service (MaaS):

1. Germany (DKE[41], DIN[42]) – strong leadership in electrotechnical, ICT, and industrial standards, essential for MaaS platforms, interoperability and safety;
2. Poland (PKN[43]) – emerging central actor in aligning national and EU/global standardisation, fostering SME participation in MaaS ecosystems;
3. Sweden (SIS[44]) – active in global sustainability and digitalisation standards, with wide stakeholder engagement and industry-driven initiatives.

Together, these NSBs bridge national, European and international levels of standardisation. Their involvement is key to ensuring MaaS standards are globally interoperable, industry-driven and supportive of EU policies such as the Green Deal, Data Act and Digital Strategy.

A1.4. Standardisation Development Organizations (SDO)

Standardisation Development Organizations (SDOs) play a **crucial complementary role** to the European Standardisation Organisations (ESOs) by providing **technical expertise, innovation inputs, and global alignment** in the creation of European Standards.

NSBs and **Standardisation Development Organizations (SDOs)** work in **complementary partnership** with the European Standardisation Organisations (ESOs) to ensure a coherent, technologically advanced and internationally aligned standards ecosystem.

While ESOs (CEN, CENELEC and ETSI) are formally recognised under EU regulation to develop **harmonised European Standards**, NSBs provide the **national expertise, voting rights and implementation** mechanisms that make these standards operational across Europe. In parallel,

[41] https://www.dke.de/de/normen-standards/arbeitsergebnisse
[42] http://www.din.de/go/european-standardisation-regulation
[43] https://www.pkn.pl/
[44] https://www.sis.se/en/

SDOs – such as **ISO, IEC, IEEE, ITU, AIOTI, IDSA, VDE, VDMA, W3C, ZVEI, oneM2M** – supply **technical innovation, sector-specific specifications and global coordination**, often serving as the **pre-normative foundation** for future European standards.

Through this multi-level collaboration,
NSB acts as the bridge between national industry and EU policy,

while through collaboration, liaison agreements and technical committees,
SDO connects the European standardisation system to global developments,

ensuring that European standards remain:
technologically advanced, interoperable, future-oriented and internationally relevant.

A wide range of international, European, and industry-driven SDOs shape the standardisation landscape for Manufacturing-as-a-Service (MaaS). They cover ICT, data spaces, digital product passports, IoT/AI, blockchain, electrotechnical, mechanical and industrial domains. Together, they drive interoperability, data sovereignty, trust and innovation:

1. ICT, Data and AI – AIOTI[45], bitkom[46], CEN JTC 25[47], IDSA[48], ISO/IEC JTC 1[49], ITU-T[50], oneM2M[51], W3C[52];
2. Product Lifecycle and Traceability – CEN JTC 24 (DPP[53]), ISO TC 307 (Blockchain[54]);
3. Electrotechnical and Automation – IEC[55], IEEE SA[56], VDE[57], ZVEI[58];
4. Mechanical and Manufacturing – VDMA[59], DIN/DKE links, Plattform Industrie 4.0;
5. Cross-sectoral Global Standards – ISO[60], ITU-T, W3C.

[45] AIOTI – Alliance for AI, IoT and Edge Continuum Innovation, https://aioti.eu/
[46] bitkom – German Digital Association (formerly Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V.), https://www.bitkom.org/EN
[47] CEN JTC 25 – Data management, Dataspaces, Cloud and Edge, https://standards.iteh.ai/catalog/tc/cen/7afc45b9-a16d-45e0-bb7c-71859878ffdf/jtc-25?srsltid=AfmBOoqT8BFSlAC5igYz-SARJWfXVCO5dYZoecyMhmnVQKrjMIM6PT2T
[48] IDSA – International Data Spaces Association, https://internationaldataspaces.org/
[49] ISO/IEC JTC1 – Information Technology (Joint Technical Committee 1), https://jtc1info.org/
[50] ITU-T – International Telecommunication Union Telecommunication Standardization Sector, https://www.itu.int/en/ITU-T/about/Pages/default.aspx
[51] oneM2M The IoT Standard, https://www.onem2m.org/
[52] W3C – World Wide Web Consortium, https://www.w3.org/
[53] CEN JTC 24 – Digital Product Passport (DPP), https://standards.iteh.ai/catalog/tc/cen/b2e63c3a-8446-4d3f-b148-51c2b3928ecd/jtc-24?srsltid=AfmBOoqYAt0DbsO82l3UrQmxr0InMwXkUFFdVUsJn72V2NaFxnol0HRn
[54] ISO/TC 307 – Blockchain and distributed ledger technologies, https://www.iso.org/committee/6266604.html
[55] IEC – International Electrotechnical Commission, https://www.iec.ch/technical-committees-and-subcommittees#tclist
[56] IEEE Standards Society, https://standards.ieee.org/
[57] VDE Verband der Elektrotechnik Elektronik Informationstechnik e.V., https://www.vde.com/en
[58] ZVEI – German Electro and Digital Industry Association (Zentralverband Elektrotechnik und Elektroindustrie e.V.), https://www.zvei.org/en/
[59] VDMA – Verband Deutscher Maschinen- und Anlagenbau, https://www.vdma.eu/en-GB/
[60] ISO: the International Organization for Standardization, https://www.iso.org/standards-catalogue/browse-by-tc.html

A1.5. Standardisation MaaS-related networks in Europe (supporting associations)

Standardisation activities are supported by technical associations: Industrie 4.0, BDVA, BDI, ORGALIM and IMXC.

Plattform Industrie 4.0[61] provides a structured national and international framework through its reference architecture and active working groups. **The Big Data Value Association** (BDVA[62]) fosters innovation in data and AI, linking technological, legal and societal dimensions while maintaining close cooperation with formal SDOs.

In contrast, the **Federation of German Industries** (BDI[63]) and **Orgalim**[64] represent high-level industrial and technological interests, focusing on policy advocacy, coordination and engagement with the European standardisation system. **IMXC**[65] actively engages with national and international initiatives, harmonizing standards, use cases, and regulations to foster trust, resilience, and innovation in manufacturing ecosystems worldwide.

Collectively, these networks strengthen the development and adoption of standards by aligning **technical**, **industrial** and **policy-driven perspectives**, thereby advancing common holistic approach to MaaS standardisation across Europe.

[61] https://www.plattform-i40.de/IP/Navigation/EN/Home/home.html
[62] https://bdva.eu/
[63] https://www.bdi.eu/
[64] https://orgalim.eu/en/
[65] https://imxc.org/

Annex 2. ISO Technical Committees related to MaaS

Based on the results from previous findings 39 Technical Committees most relevant for MaaS aspects and supporting more generic topics, connected with general development of Industry 4.0 were selected. Having these ISO Technical Committees, we cover all MaaS-related standardisation areas. Technical Committees have plenty of Sub-Committees inside the structure tree [21]. MaaS most relevant TCs were selected with the methodology described in **Chapter 4. An ISO Standardisation** analysis exercise.

Table 11. Summary of ISO Technical Committees scope of interest [21]

ID	ISO Secretariat	Name	Scope of interest
IEC/ISO JTC 3	BSI, United Kingdom	Quantum technologies	IEC/ISO JTC 3 is being supported administratively by IEC. All information related to IEC/ISO JTC 3 is available on the IEC web site Standardization in the field of quantum technologies. The scope includes standardization in the field of quantum technologies, including quantum information technologies (quantum computing and quantum simulation), quantum metrology, quantum sources, quantum detectors, quantum communications, and fundamental quantum technologies. The JTC will coordinate the results of these efforts with relevant committees and subcommittees that have within their scopes the development of specific sector-based applications of quantum technologies. Excluded: Specific sector-based applications and standardisation in the fields of information technology (JTC 1 and its subcommittees).
ISO/IEC JTC 1	ANSI, United States; JISC, Japan; KATS, Korea, Republic of; BIS, India; BSI, United Kingdom; DIN, Germany; AFNOR, France; SA, Australia; SAC, China	Information technology	Standardization in the field of information technology: Coded character sets; Telecommunications and information exchange between systems; Software and systems engineering; Cards and security devices for personal identification; Programming languages, their environments and system software interfaces; Digitally recorded media for information interchange and storage; Computer graphics, image processing and environmental data representation; Interconnection of information technology equipment; Information security, cybersecurity and privacy protection; Office equipment; Coding of audio, picture, multimedia and hypermedia information; Automatic identification and data capture techniques; Data management and interchange; Document description and processing languages; User interfaces; Information technology for learning, education and training; Biometrics; Cloud computing and distributed platforms; Sustainability, IT and data centres; IT service management and IT governance; Internet of things and digital twin; Artificial intelligence; Brain-computer interfaces; Consumer protection in the field of privacy by design. Almost 25 Sub-Committees works on standards in the area.
ISO/TC 10	SIS, Sweden; BSI, United Kingdom; SAC, China; SN, Norway; DIN, Germany	Technical product documentation	Standardization and coordination of technical product documentation (TPD), including computer-generated 2D or 3D, and manually-created 2D or 3D, throughout the product life cycle from concept to end of life, to facilitate preparation, management, storage, retrieval, reproduction, exchange and use.
ISO/TC 37	SAC, China; SCC, Canada; DIN, Germany; KATS, Korea, Republic of	Language and terminology	Standardization of descriptions, resources, technologies and services related to terminology, translation, interpreting and other language-based activities in the multilingual information society; standardization of principles and methods related to terminology, terminology policies and knowledge organization; standardization of terminological methods and applications for languages and linguistic content; standardization of the specification, design and interoperability of terminology resources; standardization of the modelling, specification, design, documentation and encoding of digital language resources to enable integration, interchange and replicability; standardization in the field of translation, interpreting, as well as translation and interpreting related technology, technical writing, content management, localization, globalization, internationalization.
ISO/TC 39	SNV, Switzerland; ASI, Austria; UNI, Italy; DIN, Germany	Machine tools	Standardization of all machine tools for the working of metal, wood and plastics, operating by removal of material or by pressure.

ID	ISO Secretariat	Name	Scope of interest
ISO/TC 44	AFNOR, France; ANSI, United States; DIN, Germany; BSI, United Kingdom	Welding and allied processes	Standardization of welding, by all processes, as well as allied processes; these standards include terminology, definitions and the symbolic representation of welds on drawings, apparatus and equipment for welding, raw materials (gas, parent and filler metals) welding processes and rules, methods of test and control, calculations and design of welded assemblies, welders' qualifications, as well as safety and health. Excluded: electrical safety matters related to welding.
ISO/TC 46	AFNOR, France	Information and documentation	Standardization of practices relating to libraries, documentation and information centres, publishing, archives, records management, museum documentation, indexing and abstracting services, and information science.
ISO/TC 69	ANSI, United States; DIN, Germany; BSI, United Kingdom; JISC, Japan; SAC, China	Applications of statistical methods	Standardization in the application of statistical methods, including generation, collection (planning and design), analysis, presentation and interpretation of data. Note: ISO Council, by Council Resolution 12 / 1959 and Council Resolution 26 / 1961 has entrusted ISO / TC 69 with the function of advisor to all ISO technical committees in matters concerning the application of statistical methods in standardization.
ISO/TC 154	SAC, China	Processes, data elements and documents in commerce, industry and administration	International standardization and registration of business, and administration processes and supporting data used for information interchange between and within individual organizations and support for standardization activities in the field of industrial data. Development and maintenance of application specific meta standards for: process specification (in the absence of development by other technical committees); data specification with content; forms-layout (paper / electronic). Development and maintenance of standards for process identification (in the absence of development by other technical committees); data identification. Maintenance of the EDIFACT-Syntax.
ISO/TC 176	SCC, Canada; ANSI, United States; BSI, United Kingdom; SA, Australia	Quality management and quality assurance	Standardization in the field of quality management (generic quality management systems and supporting technologies), as well as quality management standardization in specific sectors at the request of the affected sector and the ISO Technical Management Board. Note: ISO/TC 176 is also entrusted with an advisory function to all ISO and IEC technical committees to ensure the integrity of the generic quality system standards and the effective implementation of the ISO/IEC sector policy on quality management systems deliverables.
ISO/TC 184	AFNOR, France; DIN, Germany; ANSI, United States	Automation systems and integration	Standardization in the field of automation systems and their integration for design, sourcing, manufacturing, production and delivery, support, maintenance and disposal of products and their associated services. Areas of standardization include information systems, automation and control systems and integration technologies. Note: There will be active collaboration with the relevant technical committees responsible for areas such as machines, manufacturing resources and facilities, robotics, electrical and electronic equipment, PLC for general application, quality management, industrial safety, information technologies, multi-media capabilities, and multi-modal communication networks.
ISO/TC 199	DIN, Germany	Safety of machinery	Standardization of basic concepts and general principles for safety of machinery incorporating terminology, methodology, guards and safety devices within the framework of ISO / IEC Guide 51 and in cooperation with other ISO and IEC technical committees. Excluded: product safety standards, as defined in ISO / IEC Guide 51, and which are explicitly covered by the work of other ISO or IEC technical committees.
ISO/TC 204	ANSI, United States	Intelligent transport systems	Standardization of information, communication and control systems in the field of urban and rural surface transportation, including intermodal and multimodal aspects thereof, traveller information, traffic management, public transport, commercial transport, emergency services and commercial services in the intelligent transport systems (ITS) field. Excluded: in-vehicle transport information and control systems (ISO / TC 22) Note: ISO / TC 204 is responsible for the overall system aspects and infrastructure aspects of intelligent transport systems (ITS), as well as the coordination of the overall ISO work programme in this field including the schedule for standards development, taking into account the work of existing international standardization bodies.
ISO/TC 207	SCC, Canada; BSI, United Kingdom; UNI, Italy; SA, Australia; ANSI, United States;	Environmental management	Standardization in the field of environmental management to address environmental and climate impacts, including related social and economic aspects, in support of sustainable development. Excluded: test methods of pollutants, setting limit values and levels of environmental performance, and standardization of products. Note 1: TC 207 is focused on environmental management systems, auditing, verification/validation and related investigations, environmental labelling, environmental performance evaluation, life cycle assessment, climate change and its mitigation and adaptation, ecodesign,

ID	ISO Secretariat	Name	Scope of interest
	AFNOR, France		material efficiency, environmental economics and environmental and climate finance. Note 2: Where appropriate, the ISO/TC 207 works in cooperation with existing committees on subjects that may support environmental management.
ISO/TC 251	BSI, United Kingdom	Asset management	Standardization in the field of asset management.
ISO/TC 258	ANSI, United States	Project, programme and portfolio management	Standardization in the field of project, programme and portfolio management.
ISO/TC 260	ANSI, United States	Human resource management	Standardization in the field of human resource management.
ISO/TC 261	DIN, Germany	Additive manufacturing	Standardization in the field of Additive Manufacturing (AM) concerning their processes, terms and definitions, process chains (Hard- and Software), test procedures, quality parameters, supply agreements and all kind of fundamentals.
ISO/TC 262	BSI, United Kingdom	Risk management	Standardization in the field of risk management.
ISO/TC 267	BSI, United Kingdom	Facility management	Standardization in the field of facility management.
ISO/TC 279	AFNOR, France	Innovation management	Standardization of terminology tools and methods and interactions between relevant parties to enable innovation.
ISO/TC 286	BSI, United Kingdom	Collaborative business relationship management	Standardization in the field of collaborative business relationship management, which enhances value realization between organizations by harnessing the benefits of collaborative working.
ISO/TC 292	SIS, Sweden; DIN, Germany	Security and resilience	Standardization in the field of security to enhance the safety and resilience of society; standardization in the field of emergency management. Emergency management is addressed as a managerial function for creating capability for communities to reduce vulnerability to hazards and cope with incidents or potential incidents of different scale. Excluded: Sector specific security projects developed in other relevant ISO committees and projects developed in ISO/TC 262 and ISO/PC 278
ISO/TC 299	SIS, Sweden	Robotics	Standardization in the field of robotics, excluding toys and military applications.
ISO/TC 301	ANSI, United States	Energy management and energy savings	Standardization in the field of energy management and energy savings.
ISO/PC 302	ANSI, United States	Guidelines for auditing management systems	Standardization in the field of guidelines for auditing management.
ISO/TC 307	SA, Australia	Blockchain and distributed ledger technologies	Standardisation of blockchain technologies and distributed ledger technologies.
ISO/TC 309	BSI, United Kingdom	Governance of organizations	Standardization in the field of governance relating to aspects of direction, control and accountability of organizations.
ISO/TC 312	DIN, Germany	Excellence in service	Standardization in the field of excellence in service.
ISO/TC 313	UNI, Italy	Packaging machinery	Standardization in the field of machines used for packaging goods, including the detailed safety requirements for a particular machine or group of machines. Such requirements are applicable to the design, construction and information for use of packaging machinery, addressing hazards, hazardous situations and hazardous events. Moreover, the scope covers other aspects related to machine classification, energy consumption, determination of efficiency and availability of packaging machines.

ID	ISO Secretariat	Name	Scope of interest
ISO/TC 315	JISC, Japan	Cold chain Logistics	Standardization in the field of cold chain logistics. The scope will include, but is not limited to; terms and conditions for carriage/storage service of refrigerated goods, physical handling of refrigerated goods (acceptance, loading, transshipment, storage, sorting, transportation and delivery), maintenance and control methods of temperature-controlled facilities, quality control methods throughout the cold chain (e.g. temperature monitoring and control, prevention of damage, loss and delay), hygiene management during carriage/storage service to prevent contamination of goods, facilitation of logistical efficiency manpower management, staff education and training, safety management for staff and workplaces, safety and reliability of carriage/storage services, information management and data processing such as customer management and cargo/parcel tracking (including labelling), as well as terminology.
ISO/TC 321	SAC, China	Transaction assurance in E-commerce	Standardization in the field of "transaction assurance in e- commerce related upstream/downstream processes", including the following: Assurance of transaction process in e-commerce (including easier access to e-platforms and estores); Protection of online consumer rights including both prevention of online disputes and resolution process; Interoperability and admissibility of inspection result data on commodity quality in cross-border e-commerce; Assurance of e-commerce delivery to the final consumer.
ISO/TC 322	BSI, United Kingdom	Sustainable finance	Standardization in the field of sustainable finance to integrate sustainability considerations including environmental, social and governance practices in the financing of economic activities. Note: the TC for sustainable finance will have close cooperation with TC 68 in the field of financial services, TC 207 in the field of environmental management, TC 251 in the field of asset management and TC 309 in the field of governance of organizations.
ISO/TC 323	AFNOR, France	Circular economy	Standardization in the field of Circular Economy to develop frameworks, guidance, supporting tools and requirements for the implementation of activities of all involved organizations, to maximize the contribution to Sustainable Development. Excluded: Aspects of Circular Economy already covered by existing committees. Note: In parallel, the ISO TC 323 works in cooperation with existing committees on subjects that may support Circular Economy.
ISO/TC 324	JISC, Japan	Sharing economy	Standardization in the field of sharing economy. Excluded: Technical aspects of information security or risk management guidelines already covered by ISO/IEC JTC 1/SC27 and ISO/TC 262, respectively.
ISO/TC 342	SAC, China	Management consultancy	Standardization in the field of management consultancy. Excluded: Technical aspects already covered by ISO/TC 225 (Market, opinion and social research) and ISO/TC 260 (Human resource management).
ISO/PC 343	DS, Denmark	Sustainable development goals management	Standardization to support the UN Sustainable Development Goals.
ISO/TC 350	SAC, China	Creative digital design	Standardization of protocols, including requirements and guidance, for processes, organization, operations and capacity building activities, related to human-based creative design of digital elements to be used, in the field of e-games, digital art, digital fashion design, cinema effects. By being technology-neutral, this doesn't include specifications related to IT-technology aspects. Excluded: ISO/IEC JTC 1 Information technology ISO/TC 68/SC 8 (Reference data for financial services) ISO/TC 83 (Sports and other recreational facilities and equipment) ISO/TC 145/SC3 (Graphical symbols for use on equipment) ISO/TC 171 (Document management applications) ISO/TC 307 (Blockchain and distributed ledger technologies) IEC/TC 100 (Audio, video and multimedia systems and equipment).
ISO/TC 352	SAC, China	Digital marketing	Standardization in the field of terminology, requirements, guidance, practices, tools and methods for organizations and professionals conducting digital marketing. Excluded: Digital marketing activities that will lead to E-commerce transactions and relevant work within the scopes of the following committees: ISO/IEC JTC 1 (Information technology) ISO/TC154 (Processes, data elements and documents in commerce, industry and administration) ISO/TC 207 (Environmental management) ISO/TC 225 (Market, opinion and social research) ISO/TC 307 (Blockchain and distributed ledger technologies) ISO/TC 321 (Transaction assurance in E-commerce) ISO/TC 324 (Sharing economy) Note: In parallel, the proposed TC works in cooperation with existing committees on subjects that may support digital marketing.