Technologies for Manufacturing as a Service Ecosystems

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Standardization activities report v1

WP6: Impact creation and sustainability

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Executive Summary

The Tec4MaaSEs project embraces key enabling technologies to support Manufacturing as a Service (MaaS) ecosystems. At its core, it develops a network of Digital Twins (DTs) that possess both trustworthiness and cognition, allowing them to work collaboratively within a distributed value network. Standardization in the areas of DTs, submodels of the Asset Administration Shell, description of capabilities as well as information modelling with ontologies is fundamental for the project goals. A MaaS is a complex System of Systems with multiple stakeholders in which interoperability based on standards is essential for economic and sustainable solutions. This report describes the standardization activities of Tec4MaaSEs in these areas. Tec4MaaSEs has made and continues to make significant contributions to several key standards activities at the core of MaaS technology: Digital Twins as AAS (Asset Administration Shell), data spaces and data space connectors as well as information modelling based on ontologies. This work is being done in the international standards bodies Plattform Industrie 4.0, Industrial Digital Twin Association (IDTA), International Data Spaces Association (IDSA) and Open Applications Group, Inc. (OAGi). The report gives an overview of the respective standardization status and roadmaps and includes a comprehensive list of references.

Table of Contents

EXECUTIVE SUMMARY **4**

1 INTRODUCTION **8**

1.1 Purpose and Scope 8
1.2 Methodology and landscape 8
1.3 Structure of the document 11

2 STANDARDIZATION ACTIVITIES **12**

2.1 DT Standardisation 12
2.2 Plattform Industrie 4.0 14
2.2.1 Asset Administration Shell specification (IEC 63278) *15*
2.2.2 Capabilities, Skills & Services (CSS) *16*
2.3 IDTA 17
2.3.1 IDTA AAS Specification work and WG "Quality Management" *17*
2.3.2 IDTA WG Relations *18*
2.3.3 IDTA WG Production Calendar *19*
2.3.4 IDTA WG "Capability Descriptions" *20*
2.3.5 IDTA WG Time Series *23*
2.4 Data Spaces and IDSA 24
2.5 Information Modelling Framework (IMF) 25
2.6 OAGi Industrial Ontologies Foundry (IOF) 26

3 OPEN-SOURCE SOFTWARE DEVELOPMENTS **28**

CONCLUSIONS **29**

REFERENCES **30**

List of Tables

Table 1: Positioning of standardization activity 11
Table 2: Life cycle stages of assets 12
Table 3: IEC TC 65 WG24 standards 15
Table 4: Plattform Industrie 4.0 WG “Semantics and Interaction of I4.0 Components” 16
Table 5: IDTA "Quality Management" 18
Table 6: IDTA WG "Relations" 18
Table 7: IDTA WG "Production Calendar" 19
Table 8: IDTA WG "Capability Descriptions" 20
Table 9: IDTA WG "Time Series" 23
Table 10: Information Modelling Framework 25
Table 11: Industrial Ontologies Foundry 27

List of Figures

Figure 1: Tec4MaaSEs architecture with layers 10

Acronyms and Abbreviations

Acronym	Description
AAS	Asset Administration Shell
ASTM	American Society for Testing and Materials
DT	Digital Twin
FA³ST	Fraunhofer Advanced Asset Administration Shell Tools for Digital Twins
IDTA	Industrial Digital Twin Association
IEC	International Electrotechnical Commission
IMF	Information Modelling Framework
IOF	Industrial Ontologies Foundry
ISO	International Organization for Standardization
KG	Knowledge Graph
KPI	Key Performance Indicators
LLM	Large Language Model
MaaS	Manufacturing as a Service
OAGi	The Open Applications Group, Inc.
SAC	Standardization Administration of the People's Republic of China
SMT	Submodel Template (for an AAS)

1 Introduction

1.1 Purpose and Scope

By its very nature, a MaaS involves many stakeholders, complex workflows and diverse interacting IT systems that need to be interoperable across organisation boundaries. A MaaS is also a living entity, having to easily on-board new participants, and expand to handle new products and services. Standards are therefore of fundamental importance to achieve a sustainable system that can operate economically for all participants. However, many MaaS aspects such as data models and service interfaces are not yet adequately addressed by existing standards and further work is required.

Accordingly, standardization is critical for three major objectives of Tec4MaaSEs:

- OBJ1: (To establish a guiding framework supporting MaaS. Provide overall framework for value networks, where processes, stakeholders and resources could be modelled as interconnected Digital Twins.
- OBJ2: To Develop a digital twin platform for MaaS, to enhance the collaboration along the value network)
- OBJ4: Provide governance services for trustworthy data spaces: real-time orchestration of DTs with a plug-and-work registration process of users, grounded on suitable standards (e.g., OPC UA, Asset Administration Shell) that makes assets and capabilities accessible without barriers dictated by proprietary software.
- Tec4MaaSEs aims to increase its impact through the standardization activities that are reported on in this document. The document is intended to be read by the industrial community and contributors to standardization bodies. It informs on the status of several on-going standards development activities and explains the contributions of Tec4MaaSEs as well as gaps to be filled by future work.

1.2 Methodology and landscape

The development of formal (or de jure) standards within CEN/CENELEC, ISO or IEC takes several years and is by nature much slower than the development of standard specifications in industry organizations such as Platform Industrie 4.0 or IDTA. The later are sometimes referred to as de-facto standards in contrast to the de-jure standards of the formal standards bodies at national, European or global level.

Specifications need to be trialled in practical applications to ensure that they meet user requirements. Multiple independent implementations of a specification are normally required to identify gaps and errors in the specification. These need to be addressed and removed in a consensus-oriented process. Moreover, new IT technologies impact standardization, since any standard must be implementable in an efficient and performant way. An industry organisation is in a better position to carry out this type of development and validation work. The standardization process in the IT field comprises several main phases:

1. Consensus building and agreement on the requirements and terminology in the field of concern.
2. Agreement on core concepts at a general functional level
3. Detailed specification of information models, component interfaces and interaction protocols.
4. Validation of the above specifications through implementations and trials, adaption of the specifications as needed to improve characteristics such as interoperability or performance.
5. Development of best practices for given use cases
6. Agreement on what should be standardized and how.

7. Development and approval of a formal specification for the parts to be standardized.

These phases together with the essential consensus building and agreements are done according to the rules of the respective organisation. These rules may or may not involve soliciting comments from external parties. Different organizations may also produce conflicting specifications, often due to market competition or a focus on different requirements. Furthermore, the desire to quickly provide products to meet market needs puts pressure on a strict standardisation process.

Standards at a conceptual level are useful to understand and reach a consensus on the main ideas and functional requirements. They form a basis for the subsequent development of implementation specifications suited for available technologies.

Developers of IT solutions look for ready-to-use and widely accepted software components (especially as open source) implementing the relevant specifications. In this case, the “standardized” software plays a more important role than the original base specification that may be difficult for a developer to fully understand and implement from scratch. This general approach to standardization with a parallel open-source development aligns with that described in (DIN / DKE, 2023) for Plattform Industrie 4.0 (cf. especially section 6.1 therein).

In critical application areas where it is vital to ensure that implementations conform to certain standards, the standardisation process may be accompanied by the development of conformance and interoperability test systems. This is quite frequently the case in process automation and telecommunications.

Figure 1 shows the layered Tec4MaaSEs architecture as defined in Tec4MaaSES Deliverable D2.5. Like MaaS architectures in general, Tec4MaaSEs’ architecture will be realized as a system of systems with software components from various sources. These components are typically loosely coupled with specified interactions to achieve the MaaS workflows specified in D2.5. Such a system of systems can only function successfully in a maintainable and reliable way if standards are followed as far as possible for the individual components as well as their interfaces and interactions.

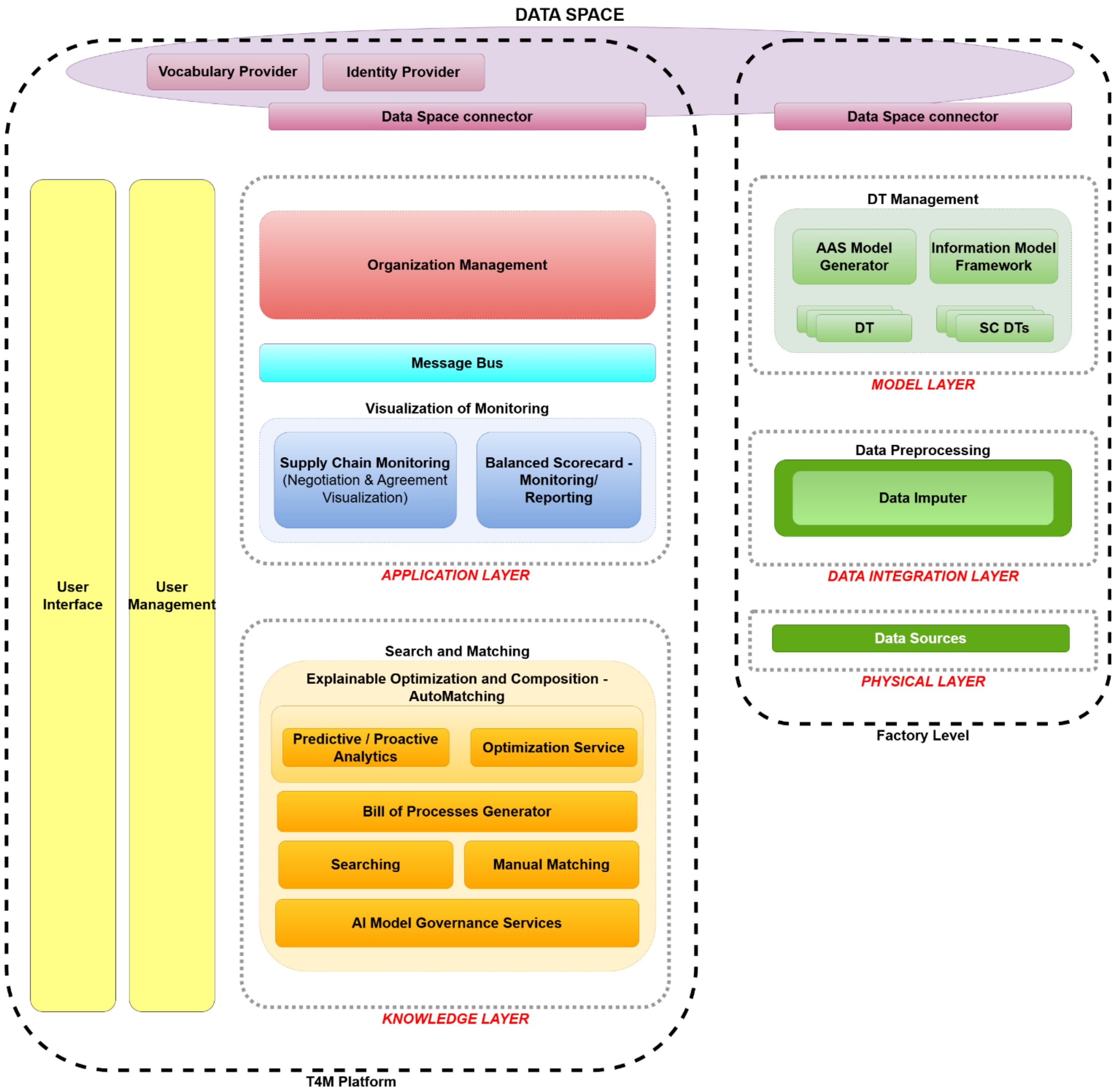

Figure 1: Tec4MaaSEs architecture with layers

The standardization activities described in this document address primarily the Model Layer, Knowledge Layer and Data Space connector in the Tec4MaaSEs architecture. The Model layer organizes the digital representation of physical assets using DTs. It incorporates the AAS Model Generator and the Semantic Framework, enabling Tec4MaaSEs to replicate the actual manufacturing system and incorporate relevant attributes. The Knowledge layer employs analytics and the Optimization Service to facilitate service composition and matching. The components of this layer, including AI Model Governance Services and proactive/predictive analytics, conduct data-driven analysis to enhance resource use and service composition. The data space connector is a technology to enable dataset sharing in accordance with defined usage policies. It is a single point of entry to data sources. It enables participants to access the data space and is responsible for handling the data according to the usage policies defined by the owner of the access and usage rights, thereby guaranteeing data sovereignty.

Table 1: Positioning of standardization activity

Standards Activity	Position in architecture
DT	Model layer
Plattform Industrie 4.0	Knowledge Layer: searching and matching
IDTA	Model layer: AAS submodels
Data Spaces and IDS	T4M platform and Data Space connector at platform and Factory Level
Information Modelling Framework	Model layer
Industrial Ontologies Foundry	Model layer

1.3 Structure of the document

The rest of the document is organised as follows:

- Section 2 is the principal body of the document and describes the contributions of Tec4MaaSEs to the standardization of Digital Twins (DT), the Asset Administration Shell of Plattform Industrie 4.0 and its submodels, information modelling frameworks and ontologies. These standardization activities are conducted in several organisations with international participation: Plattform Industrie 4.0, Industrial Digital Twin Association (IDTA), International Data Spaces Association (IDSA), and Industrial Ontologies Foundry.
- **Section 3** describes the supporting open-source software developments led by partners of Tec4MaaSEs.
- **Section 4** gives a summary of the standardization activities with main conclusions.

2 Standardization Activities

Each standardization topic below has a general background description supplemented by a table summarizing the related Tec4MaaSEs activities. The table is structured as follows

1. Name of standard and responsible organisation
2. Type of organisation
3. General level (conceptual or implementation)
4. Relevance for Tec4MaaSEs
5. Current status and scope
6. Gaps and challenges
7. Contribution by Tec4MaaSEs (actual and planned)
8. Roadmap

2.1 DT Standardisation

There are various somewhat different definitions of Digital Twin (DT). IDTA defines a DT to be a "data image of an asset containing all information defining the characteristics and behaviour of the asset"[1]. The report (Lin, S-W. et al 2023) gives a further-reaching definition emphasizing the relationship to the real-world asset: "A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity". The Digital Twin Consortium defines DT similarly[2]: "A digital twin is an integrated data-driven virtual representation of real-world entities and processes, with synchronized interaction at a specified frequency and fidelity". (ISO 23247-1, 2021) also has a similar definition of a DT for manufacturing as a "fit for purpose digital representation of an observable manufacturing element with synchronization between the element and its digital representation"; this definition puts focus on the purpose of the DT. Indeed, a DT will typically be designed for a limited set of purposes depending on the application and will not represent all characteristics of the real-world asset. In this report we will use the definition of (Lin, S-W. et al 2023). The degree and type of interaction between the DT and the asset can vary from none at all (the DT is simply a digital representation of the asset) to a high-fidelity replica of the asset with bi-directional interactions in real-time. There are many standards describing DT concepts and aspects; cf (Lin, S-W. et al 2023) for a summary. Here we focus on standards most relevant for the work in Tec4MaaSES and especially where Tec4MaaSEs partners have made or are making contributions. For a general survey of DT standardization in the manufacturing domain see (Shao, 2024).

DTs at factory level

The assets represented by a DT may be a product of the factory or a manufacturing machine in the factory. DTs are designed to cover as many life cycle stages of the asset as possible. For example:

Table 2: Life cycle stages of assets

Product as asset Life cycle stages as in (WBCSD, 2023)	**Machine as asset**
Material acquisition and pre-processing	Design and engineering

[1] https://industrialdigitaltwin.org/en/technology

[2] https://www.digitaltwinconsortium.org/initiatives/the-definition-of-a-digital-twin/

Production	Manufacture
Distribution and Storage	
Product use	Operation (including repair)
End-of-life (with disposal / recycling)	Decommissioning and recycle or disposal

The DTs will change across the life cycle stages as different data for different purposes is required. Ideally, DT data can be efficiently transferred from one stage to the next to preserve consistency and interoperability.

- IEC 63278-1:2023 (AAS)

The Asset Administration Shell (AAS) specifications are maintained and further developed by the Industrial Digital Twin association (IDTA). They are targeted to be standardized in the IEC 63278 series. The AAS is the digital twin for industry as proposed by Plattform Industrie 4.0 and IDTA. IDTA has published several parts[3]

Part 1: Metamodel (IDTA 2024a)
Part 2: Application Programming Interfaces (IDTA 2024b)
Part 3a: Data Specification – IEC 61360 (IDTA 2024c)
Part 5: Package File Format (AASX) (IDTA 2024d)

Part 4, the security metamodel, is under development.

- ISO 23247-1:2021 Digital twin framework for manufacturing with parts ISO 23247-1 to ISO 23247-4. These standards are at the conceptual level describing general principles, requirements, and framework views (functional view, information view and networking view). They are motivated by and directed towards use cases in the manufacturing domain, but do not define specific data formats or communication protocols.
- IEC 62832 Digital Factory framework (IEC 62832-1:2020) with parts
  - IEC 62832-1:2020 General principals
  - IEC 62832-2:2020: Model elements
  - IEC 62832-3:2020: Application of Digital Factory for life cycle management of production systems
- IEC 62832-1:2020 defines a digital factory as a digital representation of a production system. The standards in the IEC 62832 series describe the information model in a digital factory and hence are in principle relevant for digital twins of factories. The IEC 62832 definitions of concept version identifier and property values are referred to by the AAS specification (IDTA 2024a). However, the AAS specifications are independent of IEC 62832.ISO/IEC JTC1, SC41 Internet of things and digital twin[4]

This joint standards body has published the following standards on digital twins:

ISO/IEC 20924:2024 (2024-02). *Internet of Things (IoT) and digital twin — Vocabulary*
ISO/IEC 30194:2024 (2024-12). *Internet of things (IoT) and digital twin:* Best practices for use case projects.

[3] https://industrialdigitaltwin.org/en/content-hub/aasspecifications
[4] https://www.iso.org/committee/6483279.html

ISO/IEC TR 30172:2023 (2023-10). *Internet of things (loT) — Digital twin — Use cases*
ISO/IEC 30173:2023 (2023-11). *Digital twin — Concepts and terminology*

These standards are at a conceptual level and are not referenced by (IDTA 2024a-d). On the other hand, they are more general and address practically all application domains. The use cases include examples from the application domains of smart building, power grid, smart city, energy and transport. ISO/IEC 30173:2023 describes the life cycle stages in which digital twins can be applied: inception, design and development, verification and validation, deployment, operation and monitoring, re-evaluation and retirement.

DTs at platform level, for supply chains

Supply chain participants are the buyers and suppliers (i.e., consumers and providers in MaaS terms) of part-products in the chain as well as the logistic companies responsible for the transport of part-products from the suppliers to the buyers. The main usage scenario for a DT of a supply chain is to provide visibility and traceability to the supply chain participants, helping them to participate efficiently, identify possible disruptions and risks, and develop risk mitigation strategies. The supply chain DT will normally be specific to the view and matters of concern of the respective participants.

A related scenario is addressed by a DT of the transportation network underlying the supply chain. The goal here is to find the best distribution routes and intermediate storage locations for part-products.

Product DTs describe the product class and pertinent properties. Products may be structured in a hierarchy and refer to a Bill of Materials. (ISO 13584-42, 2010) defines general concepts for product class hierarchies and dictionaries of product properties with semantic identification. Product classes and properties in the ISO 34584 information model are mapped to the common ISO 34584 / IEC 61360 dictionary model. The IEC 61360 information model is also used by (IDTA, 2024c). Finding suitable supply chains for a given product requires standardized descriptions of the intermediate part-products in order to match suppliers and buyers for each step in the chain.

2.2 Plattform Industrie 4.0

(DIN / DKE 2023) gives a comprehensive overview of the German Standardization Roadmap Industrie 4.0 covering the design of digital ecosystems, recommendations for standardization actions and the role of many relevant standardization bodies and stakeholders at German, European and international level. The chapter on 'Requirements for the development of standards and specifications' addresses the following topics in the context of standardization:

- Open source
- Use cases
- Machine-readability
- Harmonization of terminology
- Usage of AI methods to identify semantic information and generate cross-domain references.

The most prominent and widely referenced specification results of Plattform Industrie 4.0 are the Reference Architecture Model Industrie 4.0 (RAMI 4.0) (Heidel, R., 2019) and the Asset Administration Shell (AAS) (IEC 63278-1:2023).

2.2.1 Asset Administration Shell specification (IEC 63278)

Results of the work in Plattform Industrie 4.0 are submitted to IEC for formal standardization. A central result is the Asset Administration Shell which has become the multipart standards project IEC 63278 in IEC TC65 WG24:

- IEC 63278-1:2023: Asset Administration Shell for Industrial Applications - Part 1: Asset Administration Shell structure
- IEC 63278-2 ED1: Asset Administration Shell for Industrial Applications - Part 2: Information meta model (Project IEC 63278-2 ED1)
- IEC 63278-3 ED1: Asset Administration Shell for Industrial Applications – Part 3: Security provisions for Asset Administration Shells (Project IEC 63278-3 ED1)
- IEC 63278-4 ED1: Asset administration shell for industrial applications - Part 4: Use cases and modelling examples (Project IEC 63278-4 ED1)
- IEC 63278-5 ED1: Asset Administration Shell for industrial applications – Part 5: Interfaces (Project IEC 63278-5 ED1)

Table 3: IEC TC 65 WG24 standards

Name	IEC TC65 WG24
Type of organisation	Standards body within IEC (International Electrotechnical Commission) TC65
General level	Formal specification
Relevance for Tec4MaaSEs	Tec4MaaSEs uses AAS as the basis for its work on Digital Twins.
Current status and scope	The standard IEC 63278-1:2023 has been published by IEC[5]. IEC 63278-2 is currently a CDM (Committee Draft to be discussed at meeting). The forecasted publication date is 2026-04. IEC 63278-3 is currently an ACD (Approved for Committee Draft). The forecasted publication date is 2026-04. IEC 63278-4 is currently a PCC (Preparation of compilation of comments on a committee draft). The forecasted publication date is 2026-02[6]. IEC 63278-5 is currently an ACD. The forecasted publication date is 2027-12[7].
Gaps and challenges	The formal standardization in IEC is considerably slower than work in IDTA. Companies will implement IDTA specifications first. At some time

[5] https://www.vde-verlag.de/iec-normen/252417/iec-63278-1-2023.html
[6] https://www.iec.ch/dyn/www/f?p=103:38:5268737084351::::FSP_ORG_ID,FSP_APEX_PAGE,FSP_PROJECT_ID:1250,23,116472
[7] https://www.iec.ch/dyn/www/f?p=103:38:5268737084351::::FSP_ORG_ID,FSP_APEX_PAGE,FSP_PROJECT_ID:1250,23,121674

	in the future IEC standards and IDTA specifications will have to be harmonized.
Contribution by Tec4MaaSEs	The Tec4MaaSEs partners are not involved directly in the IEC standards work (but in IDTA).
Roadmap	The various parts of IEC 63278 will be published on a timeline extending to 2027.

2.2.2 Capabilities, Skills & Services (CSS)

Plattform Industrie 4.0 has published the Whitepaper „Information Model for Capabilities, Skills & Services", Plattform Industrie 4.0. (2022).

The working group "Semantics and Interaction of I4.0 Components" of Plattform Industrie 4.0 has updated the Whitepaper as Discussion Paper "Capabilities, Skills and Services - CSS Model Extensions and Engineering Methodology". The discussion paper is undergoing final editing and is expected to be published in 2025.

According to Plattform Industrie 4.0. (2022, 2025):

"A capability provides an implementation-independent specification of a function in industrial production aimed at achieving an effect in the physical (normally in production) or virtual world (for software functions that only apply to a virtual representation).

Capabilities specifying a production function refer to terms of actual manufacturing methods (e.g. "drilling") and have properties (e.g. depth, diameter) as well as constraints (e.g. the material type)."

A focus of the paper is on the detailed description at conceptual level of the activity methods Determining Capabilities, Describing Capabilities, Assigning Capabilities und Deriving Capabilities. These methods are relevant wherever no standardized capabilities are available a-priori for a resource and the capabilities need to be derived or determined by considering relevant standards in the domain.

The discussion paper includes the model validation in 5 use cases in production and manufacturing.

Table 4: Plattform Industrie 4.0 WG "Semantics and Interaction of I4.0 Components"

Name	WG "Semantics and Interaction of I4.0 Components" of Plattform Industrie 4.0
Type of organisation	Network of companies, research organisations and industry associations led by the German federal Ministry for Economic Affairs and Climate Action and the Ministry of Education and Research.
General level	Conceptual
Relevance for Tec4MaaSEs	The activity methods for determining, describing, assigning and deriving capabilities are relevant for Tec4MaaSEs.
Current status and scope	A whitepaper has been produced that is being updated in a discussion paper.

Gaps and challenges	The concepts and methods need to be mapped to actual implementations and realized in practice with further validation steps.
Contribution by Tec4MaaSEs	IOSB has contributed use case descriptions and also participates in a reviewing role.
Roadmap	Expected to be published by Plattform Industrie 4.0 in 2025.

2.3 IDTA

The IDTA (Industrial Digital Twin Association)[8] was initiated by the industry organisations ZVEI (German Electro and Digital Industry Association), VDMA (Machinery and Equipment Manufacturers Association) and Bitkom together with 20 companies in the machinery and electrotechnical industry. The mission of IDTA is to transform the results of Plattform Industrie 4.0 into practical applications, i.e. make them operational. Accordingly, IDTA work is directed towards implementation specifications and technologies for the Asset Administration Shell (IDTA 2024a-d) and its submodels (IDTA 2025).

The submodel templates (SMT) of IDTA are currently in an unstructured list. There are plans to group the SMTs in a hierarchy or matrix with usage guidelines matching various use cases.

The following published SMTs are of relevance for Tec4MaaSEs:

- Contact Information
- Data Model for Asset Location
- Hierarchical structures enabling Bills of Material
- Digital Nameplate for industrial equipment
- Handover Documentation
- Information Model for P&I Diagrams based on DEXPI Standard
- Creation and classification of materials in an ERP, PDM/PLM and PIM system
- Time series
- Generic Frame for Technical Data for Industrial Equipment in Manufacturing (02003)

In addition, the SMT OPC UA Server Data Sheet is under development. Moreover, the InterOpera project[9] has submitted a SMT 'Purchase Order' which is under review within IDTA. Tec4MaaSEs is investigating its relevance for the project.

The following subsections describe Tec4MaaSEs contributions to further IDTA SMTs under development and AAS specification work.

2.3.1 IDTA AAS Specification work and WG "Quality Management"

IOSB has been an active participant in the AAS specification work, providing feedback and bug reporting. The IDTA WG "Quality Management" is developing AAS test software as a "test engine" to validate the compliance of AAS implementations against the AAS standard.

[8] https://industrialdigitaltwin.org/en/
[9] https://interopera.de/ funded by the German Federal Ministry for Economic Affairs and Energy

Table 5: IDTA "Quality Management"

Name	IDTA WG "Quality Management" [10]
Type of organisation	IDTA is an industry association responsible for further development of AAS
General level	Implementation
Relevance for Tec4MaaSEs	The AAS is a core technology in Tec4MaaSEs. Hence tools to validate AAS implementations are essential.
Current status and scope	The WG was established in June, 2024 and has to date released an initial version of the code of the test engine covering file-based (type 1) AASs and some basic API profiles limited to read operations.
Gaps and challenges	The test cases need to be aligned with the AAS specification. Additionally, for each published submodel, test cases that align with both the AAS specification and the submodel template must be defined.
Contribution by Tec4MaaSEs	IOSB has actively participated in this IDTA working group by running its AAS implementation generated by FA³ST (see below for details) against the test engine. This process has exposed bugs and issues in the test engine as well as FA³ST that were subsequently fixed. IOSB has also proposed how to better display the test results in both JSON and HTML. The FA³ST-Validator is based on the test engine.
Roadmap	The working group is currently updating the test engine to ensure compatibility with the upcoming version of the AAS.

2.3.2 IDTA WG Relations

Table 6: IDTA WG "Relations"

Name	IDTA WG "Relations"
Type of organisation	IDTA is an industry association responsible for further development of the AAS
General level	Implementation as an AAs submodel, domain-independent
Relevance for Tec4MaaSEs	Simplifying the management of knowledge graphs from VNs during AAS implementation while making the results of the semantic framework more flexible to use.
Current status and scope	A proposed white paper is under discussion within the WG. This AAS submodel off-loads the semantics of references to an external graph, which serves as ground truth for the references.

[10] https://github.com/admin-shell-io/aas-test-engines

Gaps and challenges	The evaluation case needs to be representable and meet the needs of the interest group. In addition, currently, there are several mapping approaches between external KGs and the AAS submodels. Which mapping approach corresponds to which application scenario is under investigation.
Contribution by Tec4MaaSEs	UiO has led the progress of this IDTA working group. The design of this AAS submodel could support semantic matching and reasoning in the Tec4Maas platform.
Roadmap	The working group aims to have a concrete white paper design before Q3 2025 and submit it to IDTA within 2025.

2.3.3 IDTA WG Production Calendar

Table 7: IDTA WG "Production Calendar"

Name	IDTA WG “Production Calendar”
Type of organisation	IDTA is an industry association responsible for further development of the AAS
General level	Implementation as an AAS submodel, domain-independent
Relevance for Tec4MaaSEs	Unified production calendars are required for the production scheduling and capacity allocation functionalities of MaaS platforms.
Current status and scope	A draft specification for the AAS submodel "Production Calendar" is currently under discussion in the IDTA Working Group. This submodel aims to standardize the representation of production calendars, encompassing operating hours for machines, production lines, and entire plants, as well as maintenance windows, breaks, and other relevant timeframes. Information regarding planned production activities is not included within the scope of the production calendar.
Gaps and challenges	Currently, industrial applications lack a single source of truth for production schedules, complicating synchronization across various systems. This is addressed by the AAS submodel “Production Calendar”. A major challenge in specifying this submodel is the lack of existing standards to build upon. Therefore, the iCalendar format defined in RFC 5545 has been extended with custom properties to represent production days, as well as break and maintenance timeframes. These extensions are initial suggestions based on the working group's experience and may be adapted to the needs of the industrial domain. Additionally, representing the production schedule at different levels, such as the machine or production line level, is also considered a major challenge. To address this issue, the submodel allows for inheritance

	between different production calendars. In combination with the sub-model "Hierarchical Structures Enabling Bills of Material," this sub-model facilitates the construction of hierarchical production calendars that represent the company structure, including its different locations, departments, production lines, and machines.
Contribution by Tec4MaaSEs	IOSB has actively participated in the IDTA working group by providing use cases and supporting the drafting of the specification. Additional contributions are being evaluated based on the timing of results from Tec4MaaSEs.
Roadmap	The working group aims to finalize the specification draft by Q2 2025. This document will be reviewed internally and submitted for final review through the IDTA no later than April 2025. This review is expected to take three months.

2.3.4 IDTA WG "Capability Descriptions"

IDTA follows the above capability definition of Plattform Industrie 4.0. (2022, 2025). A capability description for a machine covers at least the first of the following aspects:

- The manufacturing method and its properties
- The manufacturing tools that can be used in the machine
- For additive manufacturing, which materials can be used.
- The properties of the workpiece that can be produced or processed in the machine (esp. geometry, weight, material and surface condition; cf. also (ISO 14649-10:2004, 2004, December 15).
- The hierarchical relationship to other capabilities
- Constraints on the order in which the capability can be executed in relation to other capabilities.
- Constraints for specific properties.

The level of detail is variable depending not only on the available information about the machine, but also on the maturity of negotiations between a supplier and buyer of a manufacturing service.

Table 8: IDTA WG "Capability Descriptions"

Name	IDTA WG "Capability Descriptions"
Type of organisation	IDTA is an industry association responsible for the further development of the AAS
General level	Implementation as an AAS submodel, domain-independent
Relevance for Tec4MaaSEs	Capability descriptions are needed for the registration, searching and matching functionalities in a MaaS platform
Current status and scope	A draft specification of an AAS submodel "Capabilities for industrial appliances" is under discussion in the IDTA WG. It is being validated within the WG by assessing its suitability for a use case taken from continuous

	process control. The content of this subsection has been contributed by Fraunhofer IOSB to the IDTA specification.
Gaps and challenges	The description of capabilities at a (lower) domain level is in most instances not supported by standardized semantics. For applications in practice there is a need for governance procedures to avoid conflicting specifications as well as LLM-based analysis and mapping of descriptions. A challenge is the complexity of the capability description and the effort required for the modelling process. A key issue here is the handling of capabilities at different levels of detail with different sets of properties. Static capability hierarchies and property sets will not be flexible enough to deal with emerging technologies. Implementation examples at different levels of complexity depending on the use case are required as a guide. The concept of capacity is not covered (although relevant for Tec4MaaSEs). The IDTA WG "production calendar" may cover some aspects.
Contribution by Tec4MaaSEs	IOSB has contributed use case descriptions. References to domain standards for capability and property definitions have been provided by Tekniker (in the area of machine tools) and IOSB. IOSB also participates in the IDTA working group in a reviewing role. Further contributions are being considered depending on the timing of results in Tec4MaaSEs.
Roadmap	The IDTA WG "Capability Descriptions" plans to submit the submodel specification for internal review by June 2025. The review is expected to take 3 months. Target for the submodel publication is 12/2025.

The IDTA capability submodel can reference domain standards for capability and property descriptions specific to machine classes. In this regard, the standards of ISO/TC 39/SC2 and ISO/TC 39/SC10 are relevant for a wide range of machine tools used in Tec4MaaSEs (cf. D2.1, Annex C for details):

Manufacturing service	Manufacturing resource	Standards
Additive manufacturing	Manual machine control	ISO 13041-1:2020
	CNC control	ISO 13041-5:2015
CNC machining	Milling machine	ISO 16090-1:2022
	Machining centre	Standards as for the separate manufacturing resources in the machine centre
	Grinding machine	ISO 16089:2015

	Drilling machine	ISO 8636-1:2000
	Threading machine	ISO 3655:1986
	Turning machine	ISO 3655:1986, ISO 13041-1:2020, ISO 23125:2015
	Turning centre	ISO 13041-1:2020, ISO 16089:2015, ISO 23125:2015
	Electrical Discharge Machining	ISO 28881:2022, ISO 13041-1:2020
	Grinding machine	ISO 16089:2015
Plastic injection moulding	Plastic injection machine	ISO 28881:2022, ISO 13041-1:2020, ISO/ASTM 52900:2021

The above standards reference the multi-part standard ISO 230 "Test code for machine tools" which defines many basic terms for machine tools (cf. ISO 230-1:2012 on geometric accuracy).

ISO/TC 29 Small tools has published the ISO 13399 series of standards on cutting tool data representation and exchange. A cutting tool is defined to be "device or assembly of items for removing material from a workpiece through a shearing action at the defined cutting edge or edges of the device. A cutting tool can be the assembly of one or more adaptive items, a tool item, and several cutting items on a tool item." The tools covered include tools for turning, milling, drilling and threading. In particular:

- ISO 13399-1:2006: Part 1: Overview, fundamental principles and general information model
- ISO/TS 13399-2:2021 Reference dictionary for cutting items: describes the classes of cutting item features, cutting item types, and the reference systems defining the properties of these classes
- ISO/TS 13399-3:2021 Reference dictionary for tool items: describes the characteristics of cutting tools including their classes and properties

The standards of ISO/TC 261 and ASTM F42 are relevant in the field of additive manufacturing. (ISO/ASTM 52900:2021) defines the terminology, processing types and material classes. Detailed property definitions for processes and materials are specified in further standards (ISO/TC 261, 2025).

An important aspect of the machine capabilities is the description of properties of the workpiece that can be handled by the machine. ISO 14649-10:2004 defines a general data model for a workpiece. This includes the material, surface condition and geometric data. Materials are classified in further standards depending on the process, for example:

- ISO 513:2012 defines identification letters for material groups (steel, stainless steel, cast iron, non-ferrous metals, superalloys and titanium, hard materials) to be machined with hard cutting materials
- ISO 2107:2023 defines temper designations for aluminium and aluminium products

- ISO 4885:2018 defines material types resulting from heat treatments of ferrous materials
- ISO/ASTM 52942:2020 defines powder groups for laser metal powder bed fusion machines.

In addition, there are two quite general standards on capability classes, that are often cited in German documents: (TGL 25000-1, 1974) and (DIN 8580:2022-12).

2.3.5 IDTA WG Time Series

Table 9: IDTA WG "Time Series"

Name	IDTA WG “Time Series”
Type of organisation	IDTA is an industry association responsible for the further development of the AAS
General level	Implementation as an AAS submodel, domain-independent
Relevance for Tec4MaaSEs	Factory and machine data is usually stored in large Time series. To capture and describe this data in the AAS, the Time Series Submodel Template was created. Time series data are needed for the transfer of factory and machine status information to the MaaS platform. The specification of this SMT should be improved to be clearer in the application scenarios.
Current status and scope	Version 2.0 is in progress
Gaps and challenges	The challenge is to improve the specification regarding clear understandability and examples. In the Time Series SMT, links and references are described. The current version 1.0 has some gaps that Fraunhofer IOSB identified during implementation, especially regarding concise description and timestamps.
Contribution by Tec4MaaSEs	Fraunhofer IOSB has been working on a prototype implementation of the SMT Time Series Data in FA³ST Service. Therefore, the SMT is relevant for FA³ST as a basis for implementation while at the same time the prototype implementation of the SMT in FA³ST provides value valuable feedback to the specification. Fraunhofer IOSB has participated in the discussion for Version 2.0 to improve the specification. We discussed improvement regarding timestamps and records. We recommended to use common timestamp formats to prevent complex conversions. Fraunhofer IOSB is one of the co-authors of the released version of this SMT.
Roadmap	Version 2.0 of the SMT Time Series specification is likely to be completed and submitted for review in 2025. However, limited availability of key partners is currently delaying progress.

2.4 Data Spaces and IDSA

A data space is a "*distributed system* defined by a *governance framework* that enables secure and trustworthy *data transactions* between *participants* while supporting trust and *data sovereignty*"[11]. A comprehensive overview of data spaces is given in the Tec4MaaSEs deliverable D2.5. Figure 1 shows the central role played by data spaces in the Tec4MaaSEs architecture. The International Data Spaces Association (IDSA) has created the IDS Reference Architecture Model (IDS-RAM)[12] as a conceptual and technical framework for building a secure and trusted data space.

The core specifications by IDSA and Eclipse Foundation are the

- Dataspace Protocol[13]; from the abstract: "The Dataspace Protocol is a set of specifications designed to facilitate interoperable data sharing between entities governed by usage control and based on Web technologies. These specifications define the schemas and protocols required for entities to publish data, negotiate Agreements, and access data as part of a federation of technical systems termed a Dataspace."
- Eclipse Decentralized Claims Protocol[14]; from the abstract: "Dataspaces require the ability to communicate participant identities and credentials to secure data access. This specification defines a set of protocols for asserting participant identities, issuing verifiable credentials, and presenting verifiable credentials using a decentralized architecture for verification and trust."

The primary components of a data space are listed below with short definitions taken from the Data Spaces Support Centre (DSSC) Glossary[15]:

- Data space protocol: A set of specifications that allow interoperable data sharing among two or more participants within a data space or between two or more data spaces.
- Data space connector: A technical component that is run by (or on behalf of) a participant and that provides connectivity with similar components run by (or on behalf of) other participants. A connector can provide more functionality than is strictly related to connectivity. The connector can offer technical modules that implement data interoperability functions, authentication interfacing with trust services and authorisation, data product self-description, contract negotiation, etc.
- Trust framework: A composition of policies, rules, standards and procedures designed for trust decisions in data spaces based on verifiable credentials. Trust framework is part of the data space governance framework.
- Data space participant registry: A federated registry of validated participants from a data space, governed by the data space governance authority and optionally by one or multiple data space administrators that govern the participants from a specific subsegment (branches) of the data space.
- Identity Provider; from the glossary of IDSA[16]: Intermediary offering services to create, maintain, manage and validate identity information of and for Participants in the International Data Spaces.
- Usage policy; from the glossary of IDSA: Set of rules specified by the Data Owner restricting usage of its data

[11] Core Concepts - Glossary - Data Spaces Support Centre; https://dssc.eu/space/Glossary/176554052/2.+Core+Concepts
[12] https://docs.internationaldataspaces.org/knowledge-base/ids-ram-4.0
[13] https://eclipse-dataspace-protocol-base.github.io/DataspaceProtocol/HEAD/
[14] https://eclipse-dataspace-dcp.github.io/decentralized-claims-protocol/v1.0-RC1/
[15] https://dssc.eu/space/Glossary/176553985/DSSC+Glossary+%7C+Version+2.0+%7C+September+2023
[16] https://github.com/International-Data-Spaces-Association/IDS-G/tree/main/Glossary

Tekniker has implemented the Tekniker Dataspace Connector[17] used in Tec4MaaSEs following the IDSA Specifications.

The IDSA Working Group Architecture contributes its RAM, Rulebook and Dataspace Protocol to the Eclipse Dataspace Working Group, which in turn contributes to ISO/IEC JTC 1/SC38 'Cloud Computing and distributed platforms'. The Draft International Standard ISO/IEC DIS 20151 'Dataspace concepts and characteristics' is now in the review and voting process. The Dataspace Protocol is planned to be submitted to ISO as a PAS (Publicly Available Specification) in August 2025. IDSA also contributes to the CEN/CENELEC Workshop 'Trusted Data Transaction' and JTC 25 'Data management, Dataspaces, Cloud and Edge'[18]. The standardization roadmap for the European Trusted Data Framework[19] covers 7 work items with target completion dates between March 2026 and May 2027. Furthermore, IDSA is aiming to align its content and roadmap with the Chinese technical committee for data spaces SAC609.

2.5 Information Modelling Framework (IMF)

IMF is a modeling framework for capturing, integrating, and exchanging technical data about industrial assets. It strikes a balance between simplicity, expressiveness, and formal rigor so that subject-matter experts can both read its models and merge information across disciplines. Covering an asset's entire life cycle, IMF lets you compare data at different abstraction levels. Its language draws on systems-engineering principles, the "aspects" concept from ISO/IEC 81346-1:2022 (function, product, location), and formal ontologies and knowledge graphs—and even extends those aspects by analyzing their information domain, stakeholder interests, and modalities.

In Subsection 1.4.3.2, we have introduced the ongoing work of IDTA WG Relations. This Relations submodel is designed to connect AAS with external KGs as ground truth to support validation and check. Through this design, AASs can point directly to IMF models—covering design function, product specs, etc.—and even support multiple references when needed. The current solution does not address the mapping from AAS to IMF or reverse mapping directly, which will be the next step research after the Relation submodel in AAS.

Currently, in the energy industry, IMF has been included as a recommended practice in industrial asset information management (DNV-RP-0670). This recommended practice establishes a common digital vocabulary and machine-readable models for equipment, systems, processes, and technical data, thereby improving decision-making, enhancing maintenance planning, optimizing asset performance, and supporting comprehensive risk management. In parallel, a dedicated IMF interest group—comprising Aker BP, Aker Solutions, Aibel, Equinor, and UiO group—has been formed under the leadership of the POSC Caesar Association (PCA) to validate and implement these models in operational settings.

Moreover, the UiO side is also contributing to the development of including IMF as a new part of ISO 23726 to support ontology-based interoperability. All these efforts will support the data and information interoperability of the Tec4MaaSEs platform.

Table 10: Information Modelling Framework

Name	Information Modelling Framework (IMF)

[17] https://toolbox.dssc.eu/?tool=tekniker-dataspace-connector&tool-details=tekniker-dataspace-connector

[18] https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:3485479&cs=1EF27AE97B5DBDA9B990D3DAF8BD63366

[19] https://ec.europa.eu/docsroom/documents/62854

Type of organisation	University of Oslo
General level	Conceptual
Relevance for Tec4MaaSEs	This is the main component of the Tec4MaaSES Semantic Framework to enable interoperability of information on the Tec4MaaSEs platform. It will serve as the foundation for KG creation, which could support the development of analytics, optimisation, DTs and other decision support tools.
Current status and scope	Version 3 is available and included in the DNV-RP-0670 recommended practice for Asset information modelling framework
Gaps and challenges	The current challenge is to ensure the IMF method is not only usable by semantic experts but also by domain expert users. This method should be easy to understand, while comprehensive enough to cover domain users' needs.
Contribution by Tec4MaaSEs	UiO has contributed use case modelling in value network 3 of Tec4MaaSEs. In this use case Aibel described a realistic use case to test the IMF method. Further contributions will follow the development of the Tec4MaaSEs platform development.
Roadmap	A new version of the IMF method and tooling is under development. UiO aims to have an update within 2025.

2.6 OAGi Industrial Ontologies Foundry (IOF)

The Industrial Ontology Foundry (IOF)[20] provides an open ontology—built on the Basic Formal Ontology (BFO), standardized as ISO/IEC 21838-2:2021—to support interoperability of information and industrial data across digital manufacturing systems. For the Tec4MaaSEs project, which employs the Information Modelling Framework (IMF) as its semantic backbone, aligning IMF concepts with the IOF Core Ontology is critical. In this alignment, IMF is a supplementary information modeling method to the IOF Core Ontology.

The IOF core ontology like BFO, focuses on the concepts of what actually exists in the world—a realism view. This view is extensional, which is great for cataloguing real objects and their relationships. For example, IOF defines concepts such as PlanSpecification, ObjectiveSpecification, and RequirementSpecification in a clear way. However, IOF itself does not provide a method to allow users especially engineers to structure and model the information content within these specifications. In complex systems engineering, users often need to talk explicitly about those schemas—what properties, connections, and constraints define a "sensor" or a "data report"—before any real sensor or report has been built or recorded. IMF is the tool designed to achieve this goal. Using IMF as a supplementary information modeling method will ensure that all exchanged data adhere to industry-accepted standards for integration, retrieval, and lifecycle management of industrial assets, thereby delivering consistent, interoperable data management across the ecosystem.

[20] https://spec.industrialontologies.org/iof/

Table 11: Industrial Ontologies Foundry

Name	Industrial Ontologies Foundry (IOF)
Type of organisation	OAGi is a US-based non-profit standards organization for the purpose of addressing interoperability challenges among ERP systems through standards development.
General level	Conceptual
Relevance for Tec4MaaSEs	IOF provides an open ontology based on ISO/IEC 21838-2:2021—to support interoperability of information and industrial data across digital manufacturing systems. It is therefore, important for Tec4MaaSEs to align with existing industrial practice.
Current status and scope	The initial mapping between IMF and IOF is done. IOF itself does not provide a method to allow users especially engineers to structure and model the information content within these specifications, this is where the IMF method could be supplementary about.
Gaps and challenges	The initial mapping is robust but also rough. Some fine-grain concepts mapping remains in discussion to ensure the mapping is accurate and useful.
Contribution by Tec4MaaSEs	The use case from Value Network VN3 provides UiO team a realistic example to test and validate the result. Further contributions will follow the development of the Tec4MaaSEs platform development.
Roadmap	The initial mapping is done. The fine-grain concept mapping is depending on the needs of the development of Tec4MaaSEs platform to continue.

3 Open-Source software developments

Open-Source software implementing a given standard has become an important way to improve the specification quality and useability of the standard (see also the remarks in Section 1.2). (Jacoby et al 2023) gives an overview of open-source implementations of the AAS as of 2023.

FA³ST (Fraunhofer Advanced Asset Administration Shell Tools for Digital Twins)[21] is a set of tools for Digital Twins based on the AAS; it is used extensively in Tec4MaaSEs. The current process of creating AAS is often time-consuming and prone to errors, as users typically start from scratch or modify existing AAS using expert tools like the AAS Package Explorer[22]. To enhance this process, the FA³ST CreAItor aims to automate Natural Language Processing tasks in a semi-automated manner, with human oversight. This approach reduces the manual workload involved in data preparation, information extraction, structuring, and validation. The FA³ST CreAItor focuses on providing an intuitive, dialogue-like experience that guides users in developing precise, use-case-specific AAS. Currently, the CreAItor assists users in creating AAS Models that incorporate nameplate information by extracting relevant data from unstructured textual input, such as content from websites. Future developments will expand its capabilities to include modeling AAS that contain information about capabilities and capacities

[21] https://www.iosb.fraunhofer.de/en/projects-and-products/faaast-tools-digital-twins-asset-administration-shell-industrie40.html

[22] https://projects.eclipse.org/projects/dt.aaspe

Conclusions

Tec4MaaSEs has made and is making significant contributions to several standards activities at the core of MaaS technology: Digital Twins as AAS (Asset Administration Shell), data spaces and data space connectors as well as information modelling based on ontologies. This work is being done in the international standards bodies Plattform Industrie 4.0, Industrial Digital Twin Association (IDTA), International Data Spaces Association (IDSA) and Open Applications Group, Inc. (OAGi).

These standards are in most cases under development and will evolve to meet new requirements or to respond to experience gained from practice. Technology developers such Tec4MaaSEs must design their implementations to be as generic and flexible as possible.

An on-going challenge requiring further work is the gap between current standards at a general conceptual level and more detailed domain specific standards and manufacturer specifications for classes of assets and applications.

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