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D7.8 - Report on the standardization landscape and applicable standards

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Executive Summary

This document contains an initial analysis of the standardization landscape, starting from needs of other WPs about existing standards that can be related, as well as the related standardization committees and organizations involved. It includes both a classification to position various standards and an analysis of a selection of standards deemed most relevant. Finally, this document provides an overview of white spots for standardization for MAS4AI.

Document History			
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1 Introduction

The relevance of standards is widely acknowledged: standards among others ensure Interoperability between systems, facilitate integration of components, reduce complexity, create a basis for a common language, allow structure for engineering efforts, provide a common reference for knowledge, allow interchangeability of components. In Industry 4.0, the challenge is to connect the physical and digital worlds of smart manufacturing and let them interact. Standards provide consensus and ensure secure, efficient and reliable collaboration between components and systems of different vendors.

The MAS4AI project regards the application of standards as essential for developing and integrating the various components in its heterogeneous architecture, that consists of many cyber physical systems collaborating as agents. MAS4AI also aims to contribute to standardization efforts by targeting acceptance and utilisation by the market of the solutions developed within the project via contributions to standardization bodies and organisations.

The purpose of this document is threefold:

- It provides an overview of existing standards that are relevant to adoption and use within MAS4AI. This ensures compatibility with what already exists in the market and a starting point for use of standards in the MAS4AI project.
- It classifies relevant standards according to the RAMI 4.0 architecture framework. This ensures standards can be compared and positioned relative to each other.
- It provides an analysis of standards and points at white spots for MAS4AI standardization. This provides a starting point for MAS4AI in meaningfully contributing to future standardization on topics that are within scope of the project.

The outcome of the deliverable should therefore be an analysis of relevant standardization organizations, efforts and activities and identification of potential opportunities.

This deliverable is meant as a collection of references to relevant standardization efforts and organizations, it does not aim to provide a detailed description of all standards. The selection of standards is based on expertise of all project partners.

2 Approach

2.1 Research approach

This deliverable takes the following approach:

1. Choice of classification framework – we need to able to compare standards and relate them to each other. There are several reference frameworks in existence in industry, but we applied RAMI 4.0 as the framework for classification of standards.
2. Collect standards from relevant sources - we will collect standards from all relevant sources. Each partner will be tasked to provide input specifically on a standardization topic according to the classification framework (RAMI 4.0).
3. Classification of standards - The classification contains:
    a. Reference to the standard: the standardization body behind the standard.
    b. Focal area of the standard: provided via positioning it in the industry reference architecture RAMI 4.0 framework.
    c. Discussion of the standard: a brief description of the goal of the standard.
    d. Mentioning relations to other standards within the same focal area (e.g. collaboration, competitor, different angle, etc.).
4. Analysis of standards – in order to evaluate standards on their potential for standardization contributions by MAS4AI (white spot), we will include a brief analysis of the standards based on three relevant metrics.

In this approach, we will collect Input from:

- Relevant standardization bodies for the domain. A long list is provided in the Annex []
- Literature providing investigations of standards. A list of references is provided in the Annex [].
- The results of the requirements of the use cases, gathered in deliverables D1.1 and D1.2 in WP1.

We will initially collect input to this deliverable by creating a longlist of standards based on the partners expertise via a template (excel sheet) to make gathering input a collaborative, transparent effort.

2.2 Scope of investigation

In order to avoid a potentially long list of standards relevant to AI, industry 4.0 and modular production in general, we will define a scope of the investigation of relevant standards.

First of all, the project is focusing on the application of AI in the manufacturing industry for the purposes of smart production. Specifically, MAS4AI focuses on deployment of different AI agents for autonomous modular production and worker support.

Standardization requirements for MAS4AI should therefore align with the four technological objectives identified in the proposal:

- Multi-agent systems for distributing AI agents
- Knowledge-based representation using semantic web technologies
- AI agents for hierarchical planning
- Model-based machine learning

Whereby standards should be applicable in the context of manufacturing IT systems.

These objectives point towards the key topics of standardization in MAS4AI:

- AI: the encompassing set of technologies to enable functions for systems that perceive and act according to goals
- Agent technology: the technology required to enable coordination and collaboration between assets.
- Knowledge representation: the (semantic web) technologies required to create unambiguous representations of assets.
- The application in a manufacturing IT environment

We can discern various levels of abstraction in order to create interoperable AI agent technology. The standards we will investigate in this deliverable will thus address these topics at different layers of (hierarchical) abstraction.

In order to address the topic of human assistance in MAS4AI, we will also investigate standardization efforts on the topics of:

- Workers on the shopfloor: the interaction of the human with the systems in the production environment.
- Data privacy: privacy aspects of information exchange related to humans.

2.3 Standards classification framework

2.3.1 Reference Architecture – RAMI 4.0 / IEC PAS 63088

We propose to use the RAMI model to classify standards. RAMI 4.0 is the de facto reference architecture for Industry 4.0 with corresponding standards. Requirements from industries can be pictured in RAMI to define and develop standards and to identify at which point a standard is missing or incomplete, or otherwise if many standards are available for the same content. The identified and described standards in this deliverable will follow the axes of the framework:

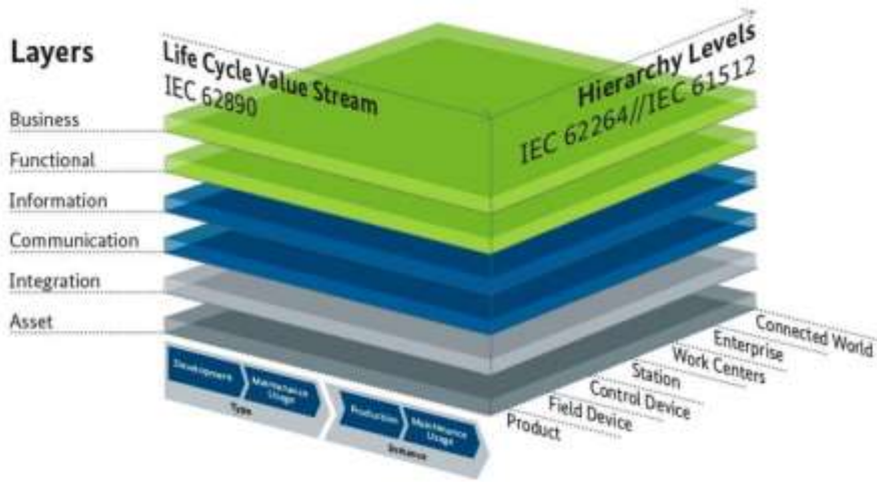

Figure 1 RAMI 4.0 reference architecture

1. Axis 1: Product life cycle
2. Axis 2: Hierarchy Levels
3. Axis 3: Layers

To use the RAMI model, a brief description about the indentation is given and the purpose of the three axes of the model will be introduced. The standards which can be referenced to RAMI will be shown up more in detail in the following sections of the deliverable.

Since the MAS4AI project does not aim to cover the entirety of the RAMI model in all three dimensions, we will indicate the parts of the three axes that are deemed relevant to MAS4AI.

Axis 1: Product life cycle

The life cycle of assets in RAMI is represented with an own axis “Life Cycle Value Stream”. The corresponding standard for the value-stream is IEC 62890. The IEC 62890 describes the basic principles for the life cycle management of systems which are used for control and automation and for industrial-process-measurement. A main distinction at this axis is made between "Type” and "Instance” of an asset, so a “Type” can become an “Instance”, if the development and the prototyping in the engineering related part of this model have been done and the product can be manufactured. In this case, an asset which is categorized in “Development” will then be set up to “Production”. This is also possible for the maintenance related part of an asset, which can also be divided into "Type” and “Instance”

IEC 62890 provides a set of generic reference models and terms. Key models are a Life-Cycle-Model, Structure Model and Compatibility Model. These models provide a basis of this topic to all participants of a supply chain.

Some standards which are related to the engineering part of RAMI are:

- IEC 62714 Automation Markup Language
- IEC 61987 Industrial-process measurement and control
- IEC 61360 / ISO 13584 Industrial automation systems and integration

MAS4AI scope: MAS4AI targets the product life cycle both on the type level as on the instance level. The type level is addressed by the development of the software components as agent prototypes, i.e. we focus on Type/Development. The instance level is addressed by the instantiation of the agents in the production of the use cases, i.e. we focus Instance/Production.

Axis 2: Hierarchy Levels

The “Hierarchy Levels” of RAMI are based on IEC 62242, describing the integration of the IT of companies and control systems. These levels represent the different functionalities in a factory or plant and are supplemented with the levels of product and connected world. With IEC 61512 the ANSI/ISA-88 standard for batch control has been adopted. Based on ISA-88, ISA-95 provides a standard for company and operational management level. The range of this standards can be found in RAMI considering all layer from device level to the enterprise level.

The ISA-95 standard provides terminology and information models for application functionality and how information is to be used and consists of 5 parts:

- Context
- Hierarchy Models
- Functional Data Flow Model
- Object Models
- Operations Activity Models

With the reference to “Connected World”, the meaning of IoT takes part in this model. This means that also a connected environment, for example for a "Work Center”, can be presented in the model but also each IoT-based object has the possibility to interact with a digitalized and connected factory.

The representation of “Product” has an important meaning due to the importance of batch-size one production and the possibilities to meet customer-individual requirements with smart manufacturing. The value of the product is also considered in related models, for example it is pointed out within the PPR-Model (Product-Process-Resource), describing the requirements from a products perspective to a manufacturing process and available resources.

MAS4AI scope: MAS4AI has the main focus on the station (module) and the work center, but also addresses the functionalities on the control device (optimization of control) and enterprise (production planning) hierarchy levels.

Axis 3: Layers

The layers on the vertical axis of RAMI describes the IT representation and the digital images of assets. The layers come from the information and communication technology. Related to the layers, several standards can be identified. Related standards to these layers are described in more detail in the following sections.

MAS4AI scope: MAS4AI addresses all layers of the vertical axes, from assets in the production lines to business functions.

The scope of MAS4AI in the RAMI model is highlighted in Figure 2.

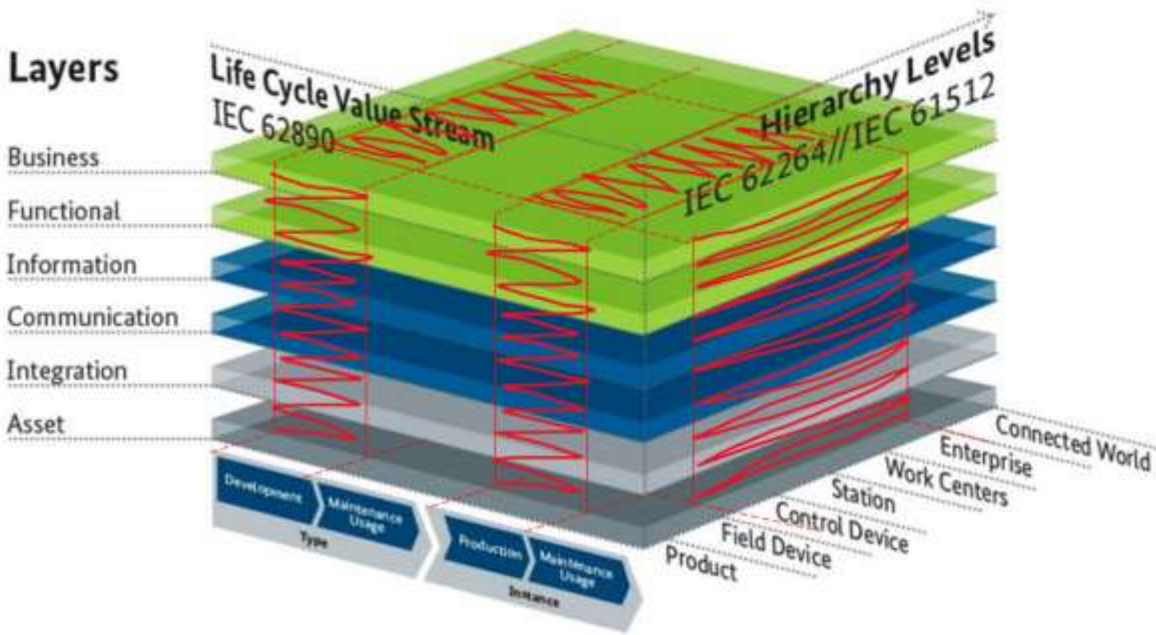

Figure 2 Scope of MAS4AI in the RAMI model

2.3.2 Other reference architectures

Several other reference architectures exist that can be considered in this context: they similarly structure the notions of systems in industry 4.0 and provide pointers for systems integration. We will identify some of these below and mention how they relate to RAMI 4.0. We find that most of these frameworks further detail or provide similar scope to layers/parts of the RAMI model.

- *IDSA-RAM*

  The International Data Spaces Association provides (IDSA) a Reference Architecture Model for several layers. The IDS is a virtual data space and considers standards and technologies to enable a secure and a standardized data exchange in trusted business ecosystems.
  - Business Layer
  - Functional Layer
  - Process Layer
  - Information Layer
  - System Layer

  Relevance: IDSA-RAM can be considered a reference model for data sharing and seems to target part of the RAMI model, most notably the integration/communication layers.

- *IIRA* - Meta Reference Architecture and Reference Architecture for System Integration. The Industrial Internet Reference Architecture (IIRA) is an architectural template and methodology which bases on standards systems design for Industrial Internet of Things (IIoT).
  Relevance: IIRA focuses more on generic architectural concepts and guidance for development of solution and application architectures and.
- *ISO/IEC JTC1 AG08*. This standard contains a guide for Reference Architecture for Systems Integration. It brings definitions, concepts, processes, models and templates for entities in the scope of the Meta Reference Architecture for Systems Integration.
- *ISO/IEC 30141 Reference Architecture for IoT (ISO/IEC JTC 1 SC41).* The ISO/IEC 30141:2018 provide a standardized IoT Reference Architecture. Therefore, a common vocabulary, design for the purpose of reuse and best practices are presented.
  Relevance: ISO/IEC 30141 focuses on providing a reference architecture for the integration layer of the RAMI model.
- *IEC 63339 ED1* - Unified reference model for smart manufacturing (ISO/TC 184 – IEC/TC 65/JWG 21). The unified reference architecture for smart manufacturing (IEC 63339) is a project of the technical committee 65, joint working group 21 of the IEC. It plans to release standards concerning smart manufacturing and is forecasted to publish in 06/2023.

2.4 Standards analysis

In order to assess the standards on their potential for extensions and contributions from the MAS4AI project, we will look at several metrics:

- Market adoption of the standard: is the standard well-established, accepted and used by industry? Preferably the project wants to contribute to standardization efforts that are acknowledged both by end-users and adopted by formal standardization bodies with a significant and relevant community involved.
- Openness and quality of the standardization organization: is the organization behind the standard open to contributions or are there impediments for membership? Is there a fee for obtaining/use of the standards? Is there a maintenance process to implement changes? Preferably, the MAS4AI project wants to contribute to standards that are accessible to both solution providers and users and are managed in an open development and maintenance process that promotes contributions to its decision making without

excluding stakeholders. In addition, the organization behind the standard preferably has a well-defined maintenance process in order to produce quality standards.

- Functional applicability to MAS4AI: does the standard address the core interest of MAS4AI? The focus of potential contributions should be to standards that address topics at the heart of MAS4AI: standards that support interoperability, multi-agent architectures and AI technology, including knowledge representation for intelligent systems.

These metrics will be considered from a qualitative perspective, i.e. these metrics will not be expressed in measurable or quantifiable terms in order to assess standards, but rather be taken as a guideline for assessment.

2.5 MAS4AI standards requirements

This section details the requirements of the MAS4AI project from the perspective of the use cases.

WP1 has collected functional and technical requirements of the use cases. In addition, we have requested a list of technical standards from the use case owners related to daily operations of the use case. In order to keep an open mind, the request was aimed at all technical standards in use, including those aimed at data/information communication, life cycle management of assets, human-machine interaction standards, safety related standards, etc.

The table below provides an overview of standards that have been submitted by the use cases and are within scope of the core topics of MAS4AI. It lists standards applicable and a brief description of how the standard is applied in daily operations of the use case.

Some of the standards that have been submitted are limited to the scope of the line-of-business of the use case, e.g. bicycle-specific standards for Baltic Vairas. These are included in the longlist of all technical standards that are required in the use cases (Appendix A).

Table 1 Standardization requirements from use cases for core MAS4AI topics

Use case 0: Smart Factory testbed demonstrator			
Standard id	**Standard name**	**Organisation**	**How this standard is applied in your daily operations?**
Use case 0: Smart Factory testbed demonstrator			
IEC62541:1-100	OPC Unified Architecture	TC 65/SC 65E - Devices and integration in enterprise systems	The OPC-UA standard describes the standardized interface protocol of the SF modular testbed demonstrator. It contains the standards which describes the concepts, security, address space, identification and registration of services, device interfaces, machine safety states, access history, discovery, access levels and pub sub interfaces.
Use case 1: Automotive industry demonstrator			
IEC62541:1-100	OPC Unified Architecture	TC 65/SC 65E - Devices and integration in enterprise systems	The OPC-UA standard describes the standardized interface protocol on machine level. VW is interested in integrating this standard in their systems landscape
Use case 2: Contract manufacturing demonstrator			
ISO 9001:2015	Quality management systems - requirements	ISO	All organizationally relevant processes are tested against this.
Use case 3: Bicycle industry demonstrator			
-	-	-	-
Use case 4: Bearings production demonstrator			
-	-	-	-
Use case 5: Woodworking industry demonstrator			
-	-	-	-

3 Classification of standards

3.1 Axis 3: The architecture layers of the RAMI model

We will analyse and classify standards according to the layers of the RAMI model. We will extend/use the framework on all three dimensions. Classification in next chapters is streamlined according to axis 3, the layers of RAMI.

Figure 3 RAMI 4.0 layers on axis 3

3.2 Business layer

The business layer maps the relevant business processes of the system. It does not contain concrete systems such as an ERP system, but rather ensures the integrity of the functions in the value stream and sets the legal and regulation conditions for the functioning of the system. The business layer is responsible for the orchestration of the different services in the function layer, links the business processes as well as receives events that may advance the processes. What's more, it models the rules under which the system should be functioning and maps the business models as well as the resulting overall process.

In the MAS4AI system multiple autonomous systems were released to provide cognitive improvement of production planning and control, warehouse management, and quality assessment in collaboration with the production's personal. Local scheduling agents were integrated in the business environment in order to calculate and provide the schedule to a limited number of resources in a dynamic or static way. As such, the agent provides the ability to adapt to stochastic changes in the production and react with a high-quality solution. Human-Machine Interface (HMI) systems where provided to visualize this information to the user as well as enable interaction with the backend environment. In this way the developed organization tools where able to adjust their weights to approach the human decision-making strategies as possible.

Quality assessment and control systems introduced to ensure the different limitations to the products and processes and tune the deviation from the ideal product. Product, resource, and material management were enabled in that context, in order to track and manipulate the parameters that lead into an error-free production system.

Autonomous systems were also introduced into logistics management, coordinating the operations in the warehouse in collaboration with other important orchestration systems, that were defined within the business layer of the RAMI architecture.

3.3 Function layer

The function layer in RAMI defines Architectural functions for assets and asset roles in MAS4AI. This layer is where services (including decision logic) are operated and described. Additionally, the run-time environment for developed applications is supported[1].

3.3.1 IEC/ISO 62264 - Enterprise Control System

IEC 62264 is associated with the management of manufacturing operations and activities. Integration is enabled between manufacturing operations, control domain and enterprise domain, increasing uniformity and consistency of interface terminology and reduce the risk, cost, and errors associated with implementing these interfaces. It also defines transactions in terms of information exchanges between applications performing business and manufacturing activities. The exchanges are intended to enable information collection, retrieval, transfer and storage in support of enterprise-control system integration.

[1] Sharpe, R., Van Lopik, K., Neal A., Goodall, P., Conway, P.P., & West, A.A. (2019). An industrial evaluation of an Industry 4.0 reference architecture demonstrating the need for the inclusion of security and human components. *Computers in Industry*, *108*, 37-44.

3.3.2 IEC 61499 – Function blocks

IEC 61499 standard provides a generic model for distributed systems including processes and communication networks for a resources, devices and application entities. Applications are thus built by a network of different function blocks, each providing an interface for handling events and data I/O's. Composite blocks may include other Composite Function Blocks or/ and Basic Function Blocks. Basic Function Blocks include event-driven Executive Control Charts (ECC) that can trigger the execution of algorithms included in the block by the corresponding event. It provides the main attributes of:

- Combination of distributed programming language and PLC programming with IEC 61131-3
- Generic modeling approach for distributed control applications
- Function Block concept
- Separation of data and event flow

3.4 Information layer

The information layer in RAMI4.0 is required for applying the context to events that are passed and uses rules to determine when to initiate the adjacent functional layer. It also completes data integrity checks for ensuring high-quality data[2].

We can discern two generic groups of standards in this layer:

- Semantic web standards: a technology stack of standards related to the semantic web (W3C), that allow automated encoding, querying and processing of information across application boundaries (sections 3.4.1 – 3.4.5).
- Product classification and product description standards, that provide terminologies, identification schemes and other means to describe and identify specific products and services (sections 3.4.6 – 3.4.10).

[2] Sharpe, R., Van Lopik, K., Neal A., Goodall, P., Conway, P.P., & West, A.A. (2019). An industrial evaluation of an Industry 4.0 reference architecture demonstrating the need for the inclusion of security and human components. *Computers in Industry*, *108*, 37-44.

3.4.1 RDF – Resource Description Framework (W3C[3])

The Resource Description Framework (RDF) is a framework for representing information in the Web. This abstract syntax is quite distinct from XML's tree-based infoset. It also includes discussion of design goals, key concepts, datatyping, character normalization and handling of URI references. RDF is designed to represent information in a minimally constraining, flexible way. It can be used in isolated applications, where individually designed formats might be more direct and easily understood, but RDF's generality offers greater value from sharing. The value of information thus increases as it becomes accessible to more applications across the entire Internet.

The design of RDF is intended to meet the following goals:

- having a simple data model
- having formal semantics and provable inference
- using an extensible URI-based vocabulary
- using an XML-based syntax
- supporting use of XML schema datatypes
- allowing anyone to make statements about any resource

3.4.2 OWL – Web Ontology Language (W3C)

This document describes the Web Ontology Language (OWL[4]). OWL is intended to be used when the information contained in documents needs to be processed by applications, as opposed to situations where the content only needs to be presented to humans. OWL can be used to explicitly represent the meaning of terms in vocabularies and the relationships between those terms. This representation of terms and their interrelationships is called an ontology. OWL has more facilities for expressing meaning and semantics than XML, RDF, and RDF-S, and thus OWL goes beyond these languages in its ability to represent machine interpretable content on the Web.

[3] https://www.w3.org/TR/2015/NOTE-rdfa-primer-20150317/

[4] https://www.w3.org/TR/owl-overview/

3.4.3 SPARQL – SPARQL Query Language for RDF (W3C[5])

The SPARQL query language for RDF is designed to meet the use cases and requirements identified by the RDF Data Access Working Group in RDF Data Access Use Cases and Requirements [UCNR].

The SPARQL query language is closely related to the following specifications:

- The SPARQL Protocol for RDF [SPROT] specification defines the remote protocol for issuing SPARQL queries and receiving the results.
- The SPARQL Query Results XML Format [RESULTS] specification defines an XML document format for representing the results of SPARQL SELECT and ASK queries.

3.4.4 XML – Extensible Markup Language

XML standards[6] are omnipresent in enterprise computing and are part of the foundation of the Web. The standards are highly interoperable and affordable and are used in a wide variety of applications Formal descriptions of vocabularies create flexibility in authoring environments and quality control chains. The XML ecosystem uses additional tools to create an environment for using and manipulating XML documents. A processing model defines what operations should be performed in what sequence on an XML document.

3.4.5 RFC8259 – The JavaScript Object Notation (JSON) Data Interchange Format

JavaScript Object Notation (JSON)[7] is a lightweight, text-based, language-independent data interchange format. It was derived from the ECMAScript Programming Language Standard. JSON defines a small set of formatting rules for the portable representation of structured data. JSON can represent four primitive types, (strings, numbers, booleans and null) and two structured types (objects and arrays).

3.4.6 ISO 13584-4/IEC 61360 – Classification and product description

This standard supports the necessary information transfer the use of common concepts based on information/classification models is inevitable. Concepts specified on a global basis support

[5] https://www.w3.org/TR/rdf-sparql-query/

[6] https://www.w3.org/standards/xml/

[7] https://www.rfc-editor.org/info/rfc8259

error-free information sharing. In addition, the dictionaries of concepts may be used as reference collections for setting up master data repositories for product data that serve as company internal information backbones. The exchange of product data is free from media discontinuities and requires a unified and a joint approach both for exchanging product data internally within a company or for exchanging product data with suppliers or customers. It provides the following:

- unambiguous identification of classes and properties, and their relations;
- commonly accepted terminology and definitions based on accepted sources such as IEC International Standards, other International Standards, industry standards, or public authorities;
- hierarchies of concepts enabling users to appropriately characterize their products and services;
- relevant conditions and constraints if necessary on possible values of characteristics;
- technical representation of concepts including units and data types and their identification.

In the context of the asset administration shell, we find properties and lists of properties. These serve the purposes of unique identification of hierarchies, classes and features and of their relationships; introduce a common distributed terminology; and merge different attributes into one technical feature of a representation. It can be viewed as basic components and words of a common language between the various different entities. The data types are thus distinguished into identifying attributes, semantic attributes, value attributes and relational attributes of data element types for the relationships between the entities.

The standard ISO 13584 is Industrial automation systems and integration – Parts library and specifies data models. It serves as the basis for the component data dictionary of IEC 61360 as used in the asset administration shell (the IEC 61360 Component data dictionary is using the same data model as specified in ISO 13584). Especially important for the asset administration shell is ISO13584-42, which specifies the principles to be used for defining characterization classes of parts and properties of parts which provide for characterizing a part independently of any supplier-defined identification.

3.4.7 IEC 61987 – Industrial-process measurement and control – Data structures and elements in process equipment catalogues

IEC 61987-1:2006[8] defines a generic structure in which product features of industrial-process measurement and control equipment with analogue or digital output should be arranged, thus facilitating the understanding of product descriptions when they are transferred from one party to another. The standard describes data structures and elements in process equipment. It was created by the technical committee TC65/SC 65E. The standards contain

- IEC 61987-1 which applies to the production of catalogues of process measuring equipment, supplied by the manufacturer of the product and helps the user to formulate his requirements.
- IEC 61987-10 which describes industrial-process device types and devices using structured lists of properties and makes the associated properties available in a component data dictionary.
- Further specifications for the list of properties are described in more detail in IEC 61987 parts 11, 12, 13, 14, 15, 16, 21, 22, 23, 24-1, 24-2, 24-3 and 92.

3.4.8 eCl@ss/eClass – Reference-data standard for the classification and unambiguous description of products and services

ECLASS supports the digital exchange of product descriptions and service descriptions, based on a data model defined according to IEC 61360. The standard is maintained by the industry consortium ECLASS e.V. association. It is used in engineering tools as base for transfer of planning data, in ERP systems as base for product master data, and as base for exchange of product data[9] . Tens of thousands of product classes and unique characteristics are recorded in the eClass standard[10], standardizing procurement, storage, production and sales within and between companies.

The ECLASS dictionary is based on international standards:

- The data model is defined according IEC 61360/ISO 13584-42.
- The identifiers of the classes and properties are based on ISO 29002-5.

[8] https://webstore.iec.ch/publication/6225

[9] https://en.wikipedia.org/wiki/ECLASS

[10] https://www.eclass.eu/

3.4.9 AML IEC 62714 – Engineering data exchange format for use in industrial automation systems engineering – Automation Markup Language

IEC 62714-1:2018[11] is a solution for data exchange focusing on the domain of automation engineering. The data exchange format defined in the IEC 62714 series (Automation Markup Language, AML) is an XML schema-based data format and has been developed in order to support data exchange in a heterogeneous engineering tools landscape. The goal of AML is to interconnect engineering tools in their different disciplines, e.g. mechanical plant engineering, electrical design, process engineering, process control engineering, HMI development, PLC programming, robot programming, etc.

AutomationML describes real plant components as objects encapsulating different aspects. An object can consist out of other sub-objects and can itself be part of a bigger composition. It can describe a screw, a claw, a robot or a complete manufacturing cell in different levels of detail. Typical objects in plant automation comprise information about topology, geometry, kinematics and logic, where logic comprises sequencing, behaviour and control.

3.4.10 PackML

PackML (Packaging Machine Language) is an industry technical standard for the control of packaging machines, as an aspect of industrial automation. PackML was created by the Organization for Machine Automation and Control (OMAC) in conjunction with the International Society of Automation (ISA). The primary objective of PackML is to bring a common "look and feel" and operational consistency to all machines that make up a Packing Line (note: can be used for other types of discrete process) PackML provides.

3.5 Communication layer

The Communication layer is used to apply a uniform format to information and data passed through it. The services used to control the Integration layer are also contained[12]. "IEEE or 3GPP communication standards specify the physical layer and the medium access control sub-layer for user data traffic. If no higher layers of the Internet such as IP, TCP or HTTP should or can be used

[11] https://webstore.iec.ch/publication/32339

[12] Sharpe, R., Van Lopik, K., Neal A., Goodall, P., Conway, P.P., & West, A.A. (2019). An industrial evaluation of an Industry 4.0 reference architecture demonstrating the need for the inclusion of security and human components. *Computers in Industry*, *108*, 37-44.

for industrial communication systems, corresponding standards for services, protocols and profiles are available in the IEC 61158-1 and IEC 61784-2 standards series. Industrial radio communication systems are standardized in IEC 62591:2016 (WirelessHART), IEC 62601 (WIA-PA), IEC 62734 (ISA100a) and IEC 62948 (WIA-FA). Additionally, the IEC 62657-2 series of standards on coexistence management for radio communication solutions could be mentioned[13].

3.5.1 IEC 62541 – OPC Unified Architecture

The standard IEC 62541 specifies the OPC-UA model, which is one of the most important industrial communication protocols. It is created by the technical committee TC 65/SC 65E - Devices and integration in enterprise systems. The OPC Unified Architecture standard series defines the information model associated with Devices. More specifically, the IEC 62541-100:2015[14] part describes three models which build upon each other:

- the (base) Device Model intended to provide a unified view of devices.
- the Device Communication Model which adds Network and Connection information elements so that communication topologies can be created.
- the Device Integration Host Model which adds additional elements and rules required for host systems to manage integration for a complete system. It allows reflecting the topology of the automation system with the devices as well as the connecting communication networks.

The entire series of standards describes different aspects of OPC-UA. IEC 62541-1 presents the concepts and overview of the OPC Unified Architecture and serves as the basis for further specification. Following parts are IEC 62541-2 – security model, IEC 62541-3 Address Space Model, IEC 62541-4 services, IEC 62541-5 Information Model, IEC 62541-6 Mappings, IEC 62541-7 Profiles, IEC 62541-8 Data access, IEC 62541-9 Alarms and Conditions, IEC 62541-10 Programs, IEC 62541-11 Historical access, IEC 62541-12 Discovery and global, IEC 62541-13 Aggregates, IEC 62541-14 PubSub and IEC 62541-100 Device interface.

[13] German Standardization RoadmapIndustrie 4.0 version 4, https://www.dke.de/resource/blob/778208/31b06bb4ef2d64fe58c0a1525ed73d23/german-standardization-roadmap-industry-4-0-version-4-data.pdf

[14] https://webstore.iec.ch/publication/21987

3.5.2 IEC 61784 – Industrial communication networks

IEC 61784-1:2019[15] defines a set of protocol specific communication profiles based primarily on the IEC 61158 series, to be used in the design of devices involved in communication in factory manufacturing and process control. This edition includes update of the dated references to the IEC 61158 series, to IEC 61784 2, to the IEC 61784 3 series, to the IEC 61784-5 series and to the IEC 61918.

3.5.3 IEC 61850:2020 – Communication networks and systems for power utility automation

IEC TS 61850:2020[16] is intended for any users but primarily for standardization bodies that are considering using IEC 61850 as a base standard within the scope of their work and are willing to extend it as allowed by the IEC 61850 standards. This standard provides guidelines for individual steps, such as:

- the management of product-level standards based on IEC 61850.
- the management of transitional standards based on IEC 61850.
- the management of private namespaces based on IEC 61850 data.
- the development and management of IEC 61850 profiles for domains.

From a technical point of view, this standard refers to the appropriate parts of the series which host the requirements for recommendations, lists all possible flexibilities offered by the standards and defines which flexibilities are allowed/possible per type of extension cases.

On the process side, the standard covers the initial analysis of how existing IEC 61850 object models and communication services may be applied in new or specific domains, the purpose and process for using transitional namespaces, the management of standard namespaces and the development of private ones.

3.5.4 REST – RDF Simple Data Interface Protocol

This standard[17] indicates simple ways for using HTTP operations to read and alter information exposed as RDF graphs, following the REST architectural style. Many types of systems can act as

15 https://webstore.iec.ch/publication/59887

16 https://webstore.iec.ch/publication/6028

17 https://www.w3.org/2001/sw/wiki/REST

servers for this protocol, including both domain=specific applications, such as CAD, GIS, finance, and general storage systems, such as RDF quadstores, SQL databases and filesystems. This protocol may be implemented in parallel to other interfaces (SOAP, SPARQL, etc), providing an easy-to-implement standard interface to some or all of the same underlying features.

This protocol applies to "Graph-State Resources" (GSRs), which are Resource which have their state exposed on the Web as sets of RDF triples, also known as RDF graphs. These are the REST elements of this protocol. REST's design is based on a Web server exposing a view of internal state as on or more RDF graphs.

3.5.5 ANSI/MTC1.4 – 2018 – MT Connect

The ANSI/MTC1.4-2018[18] is a data and information exchange standard based on a data dictionary of terms describing information associated with manufacturing operations. The standard also defines a series of semantic data models that provide a clear and unambiguous representation of how that information relates to a manufacturing operation. More specifically, the semantic data models provide the required information to fully characterize data with both a clear and unambiguous meaning and a mechanism to directly relate that data to the manufacturing operation where the data originated.

Although the MTConnect standard has been defined to specifically meet the requirements of the manufacturing industry, it can also be readily applied to other application areas as well.

3.5.6 ISO/IEC 19464:2014 – Information Technology – Advanced Message Queuing Protocol (AMQP) v1.0 specification

ISO/IEC 19464:2014[19] defines the Advanced Message Queuing Protocol (AMQP), an open internet protocol for business messaging. It defines a binary wire-level protocol that allows for the reliable exchange of business messages between two parties. AMQP has a layered architecture and the standard is organized as a set of parts reflecting that architecture:

- Part 1 defines the AMPQ type system and encoding.
- Part 2 defines the AMPQ transport layer, an efficient, binary, peer-to-peer protocol for transporting messages between two processes over a network.

[18] https://www.mtconnect.org/standard-download20181

[19] https://www.iso.org/standard/64955.html

- Part 3 defines the AMPQ message format.
- Part 4 defines how interactions can be grouped within atomic transactions.
- Part 5 defines the AMPQ security layers.

3.5.7 Message Queuing Telemetry Transport (MQTT[20])

MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT). It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. MQTT today is used in a wide variety of industries, such as automotive, manufacturing, telecommunications, oil and gas, etc.

3.5.8 IEEE FIPA-ACL

The IEEE FIPA (Foundation for Intelligent Physical Agents) specifications represent a collection of standards which are intended to promote the interoperation of heterogeneous agents and the services that they can represent. The Agent Communication Language (ACL) is a proposed standard language for agent communications.

The standard defines a set of performatives, also called Communicative Acts, and their meaning (e.g. ask-one). The content of the performative is not standardized, but varies from system to system. To make agents understand each other they have to not only speak the same language, but also have a common ontology as a part of the agent's knowledge base.

3.6 Integration layer

The scope of the integration layer is to integrate the assets into the world of information. The integration layers' main purpose is to provide all physical assets to the other layers in order to create events in the form of so-called administration shells. Those shells represent the foundation for further processing and therefor provide information to do so. To show the context of each asset, the integration layer also provides the usage and integration of network components or passive ones like barcodes QR-codes etc.

[20] https://mqtt.org/mqtt-specification/

3.6.1 ISO 11354 - Advanced automation technologies and their applications — Requirements for establishing manufacturing enterprise process interoperability

The purpose of ISO 11354 standard series is to specify a Framework for Enterprise Interoperability (FEI) that establishes dimensions and viewpoints to address interoperability barriers, their potential solutions, and the relationships between them.

ISO 11354 applies to manufacturing enterprises but can also apply to other kinds of enterprises. It is intended for use by stakeholders who are concerned with developing and deploying solutions based on information and communication technology for manufacturing enterprise process interoperability. It focuses on, but is not restricted to, enterprise (manufacturing or service) interoperability.

There are two parts to ISO 11354 that we highlight here:

1. *ISO 11354-1:2011, Advanced automation technologies and their applications — Requirements for establishing manufacturing enterprise process interoperability — Part 1: Framework for enterprise interoperability*

   ISO 11354-1:2011 specifies the following:

   - viewpoints for addressing stakeholder concerns for the exchange of entities (information objects or physical objects) at the operational levels of enterprises at which interoperability is required;
   - a framework for structuring these stakeholder concerns (business, process, service, data), the barriers relating to enterprise interoperability (conceptual, technological, organizational) and the approaches to overcome barriers (integrated, unified, federated), with contents identifying the various kinds of solutions available to enable interoperability[21].
2. *ISO 11354-2:2015 Advanced automation technologies and their applications — Requirements for establishing manufacturing enterprise process interoperability — Part 2: Maturity model for assessing enterprise interoperability*

   ISO 11354-2:2015 specifies:

   - levels to represent the capability of an enterprise to interoperate with other enterprises;

[21] https://www.iso.org/standard/50417.html

- measures for assessing the capability of a specific enterprise to interoperate with other enterprises;
- methods for combining these measures into two kinds of overall assessment:
- maturity level by concern and barrier, and
- assessment relative to four designated maturity levels;
- a method for representing concern and barrier overall assessments in a graphical form and for identifying where capabilities are required to achieve desired higher levels of interoperability.

3.6.2 ISO 15745 Industrial automation systems and integration — Open systems application integration framework

ISO 15745 defines an application integration framework - a set of elements and rules for describing integration models and application interoperability profiles[22].

ISO 15745-1:2003 defines the generic elements and rules for describing integration models and application interoperability profiles, together with their component profiles - process profiles, information exchange profiles, and resource profiles.

This standard is applicable to industrial automation applications such as discrete manufacturing, process automation, electronics assembly, semiconductor fabrication, and wide-area material handling. It may also be applicable to other automation and control applications such as utility automation, medical and laboratory automation and others.

ISO 15745-2:2003 defines the technology specific elements and rules for describing both communication network profiles and the communication related aspects of device profiles specific to ISO 11898-based control systems. ISO 15745-2:2003 describes technology specific profile templates for the device profile and the communication network profile[23].

ISO 15745-3:2003 defines the technology specific elements and rules for describing both communication network profiles and the communication related aspects of device profiles specific to IEC 61158-based control systems. ISO 15745-3:2003 describes technology specific profile templates for the device profile and the communication network profile. Profiles for ISO/IEC 8802-3-based control systems are outside the scope of ISO 15745-3:2003[24].

[22] https://www.iso.org/standard/30418.html
[23] https://www.iso.org/standard/32973.html
[24] https://www.iso.org/standard/33820.html

ISO 15745-4:2003 defines the technology specific elements and rules for describing both communication network profiles and the communication related aspects of device profiles specific to Ethernet-based control systems. ISO 15745-4:2003 describes technology specific profile templates for the device profile and the communication network profile[25].

3.6.3 IEC 62264 Enterprise-control system integration

IEC 62264 is an international standard for enterprise-control system integration. International standard for enterprise-control system integration in terms of:

- information exchanges between applications performing business and manufacturing activities
- object models and attributes definition
- technology independent model that is used for exchanging transaction messages

IEC 62264 consists of the following parts detailed in separate IEC 62264 standard documents:

- Part 1:2013 Object Models and Attributes of Manufacturing Operations (First edition 2003-03) [26]
  IEC 62264-1:2013 describes the enterprise-control system integration and defines the hierarchy models in terms of functional hierarchy, role-based equipment hierarchy and physical asset equipment hierarchy.
- Part 2:2013 Object model attributes (First edition 2004-07)
  In conjunction with IEC 62264-1, IEC 62264-2 specifies generic interface content between manufacturing control functions and other enterprise functions. It defines the method of object modelling and their attribute values[27].
- Part 3:2016 Activity models of manufacturing operations management (First edition 2007-06)
  IEC 62264-3 defines activity models of manufacturing operations management that enable enterprise system to control system integration. The activities defined in this document are consistent with the object models definitions given in IEC 62264-1[28].
- Part 4:2015 Objects models attributes for manufacturing operations management integration

[25] https://www.iso.org/standard/33443.html
[26] https://webstore.iec.ch/publication/6675
[27] https://webstore.iec.ch/publication/6676
[28] https://webstore.iec.ch/publication/33511

IEC 62264-4 defines object models and attributes exchanged between manufacturing operations management activities defined in IEC 62264-3[29].

- Part 5:2016 Business to manufacturing transactions
  IEC 62264-5 defines transactions in terms of information exchanges between applications performing business and manufacturing activities associated with Levels 3 (Manufacturing Operation and Control) and 4 (Business Planning and Logistics). The exchanges are intended to enable information collection, retrieval, transfer and storage in support of enterprise-control system integration[30].
- Part 6:2016 Messaging Service Model
  IEC 62264-6 defines a technology independent model for a set of abstract services that is located above the application layer of the OSI model, and that is used for exchanging transaction messages based on the transaction models defined in IEC 62264-5. The model, which is called the Messaging Service Model (MSM), is intended for interoperability between manufacturing operations domain applications and applications in other domains[31].

3.6.4 IEEE 2660.1-2020 - IEEE Recommended Practice for Industrial Agents: Integration of Software Agents and Low-Level Automation Functions

This recommended practice[32] describes approaches to solve the interface problem when applying industrial agents, namely, integrating intelligent software agents with low-level automation devices in the context of cyber-physical systems, are described in this recommended practice.

3.6.5 VDI/VDE 2653 - Multi-agent systems in industrial automation

This standard[33] provides selected architectures for multi-agent systems (MAS) and selected patterns for field level control in automated production systems and energy systems to enable CPPS or Industry 4.0 characteristics. First classification criteria of MAS architectures and agent patterns based on implemented and conceptual MAS in industry and research are introduced. They might be used as blueprints for the design and realization of MAS applications. The standard

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[29] https://webstore.iec.ch/publication/23943
[30] https://webstore.iec.ch/publication/25465
[31] https://webstore.iec.ch/publication/59706
[32] https://standards.ieee.org/standard/2660_1-2020.html
[33] https://www.vdi.de/en/home/vdi-standards/details/vdivde-2653-blatt-4-multi-agent-systems-in-industrial-automation-selected-patterns-for-field-level-control-and-energy-systems

gives advice on how to implement agent-based systems and by providing patterns, it serves as an orientation guide for software developers when implementing agent-based applications.

3.7 Descriptions of Systems

According to the concept of the digital factory (IEC TS 62832-1), a physical or logical object that has an actual or perceived value for an organization and is therefore managed is called an asset. It is closely related to the asset administration shell.

3.7.1 IEC 62832 CD 2 Part 1

Following the definition of the asset, it is understood as a physical or logical object which is owned or managed by an organization which has an objective or perceived value for the organization. The standard addresses the utilization phase of such assets and the related product facilities, their design, construction, commissioning, operation and maintenance. For the identification of concepts, it uses identifiers according to ISO 29002-5. The structured asset class of the digital factory IEC 62832 contains the digital factory (DF) asset class, the DF asset class header, the DF asset class body, the DF asset header and the DF asset body.

The most important distinction here is the separation between the header and body. The specification of data elements makes a reference to IEC 61360 properties, as described in section 3.4.6.

3.7.2 ISO 29002-5

The standard ISO 29002-5, as defined by the technical committee ISO/TC 184/SC4 Industrial data, specifies the data elements and syntax for an unambiguous identifier for an asset administration shell. The item is called an “international registration data identifier” (IRDI), as specified in ISO/IEC 11179-5. An administered item can be a concept or concept information element in a concept dictionary. It includes such things as terminology (terms, abbreviations, definitions, images, symbols), assignment of a concept to a class of similar concepts (the concept type) and reference to source documents.

3.7.3 IEC 61508

The standard IEC 61508 specifies functional safety requirements. It contains of several parts, each considering different aspects for functional safety. IEC 61508-1 Generic requirements: defines the activities, documentation, management and validation related to each phase of the safety lifecycle; IEC 61508-2 Requirements for E/E/PE systems: specifies how to define the specification of the safety requirements and the activities to be carried out during the design and implementation of the product; IEC 61508-3 Software Requirements: Same as Part 2 but applied to software; IEC 61508-4 Definitions and abbreviations: provides definitions and abbreviations of terms used in the standard; IEC 61508-5 Examples of methods for the determination of SIL: provides methods for the calculation of SIL levels for E/E/PE safety systems; IEC 61508-6 Guidelines for the application of Parts 2 and 3: provides mainly a guideline for quantitative analysis; IEC 61508-7 Overview of techniques and measurements: provides descriptions of techniques used in safety engineering and software. This standard is used for the safety specification in the asset administration shell.

3.7.4 IEC 62443

The standard IEC 62443, created by the technical committee TC 65 – industrial process measurement, control and automation, is a technical specification which defines the terminology, concepts and models for Industrial Automation and Control Systems (IACS) security. It establishes the basis for the remaining standards in the IEC 62443 series. It is used for the security submodel of the asset administration shell.

3.7.5 IEC 61131 – Programmable controllers

The International Standard IEC 61131 describes programmable logic controllers (PLCs). Enabling the users to have a standardized programming language able of passing a complete program or parts of that program between different development environments. A program is consisted of program organization units (POUs), but also of user-defined data types, global and external declarations and other elements besides the POUs. The exchange of POUs developed in one of the textual languages, i.e. instruction list (IL) and structured text (ST) or the textual representation of sequential function charts (SFC) is possible, because a syntax description of these languages is part of the IEC 61131-3 standard. The objective is to extend the reuse of programmed solutions both for textual languages and graphical languages, i.e. function block diagram (FBD) and ladder diagram (LD) or the graphical representation of SFCs. It defines a solution independent eXtensible Markup Language (XML) based exchange format, to be supported by interfaces of different kinds of software tools. The usage of the XML exchange format should provide more than a simple export/import from one development environment to another. Besides that, it also provides the ability to transfer graphical representation information, e.g. the position and size of function blocks and how they are connected.

4 Cross-cutting topics

4.1 AI in industry

4.1.1 Standardization bodies in AI

Different strategies and initiatives drive the progress of AI with significant acceleration in nowadays. However, such progress needs to be monitored and regularized in order to avoid some of the risks that the development of this technology brings to the current and future landscape. A non- standardized regulation in this competition for the most remarkable breakthrough within the global AI community can derive in important consequences for human health and social risks given the impact that AI has in our lives every day. As a result, AI policy goals need to be defined and international standards are an essential tool for that. In order to achieve efficiently advanced AI-based systems and facilitate trust among states and researchers, international standards address these issues supporting policy goals. This way, the main consequences of global governance among AI development can be summarized as:

- Support AI policy goals
- Facilitate trust among states and research efforts
- Encourage efficient development of increasingly advanced AI systems

Having in mind the risks that the continuous development of AI might bring and the fact that this issue deserves coordinated global governance responses, another question is about the actors of the current AI standards development.

In the particular case of AI, there is a remarkable number of software standards widely adopted by researchers and companies around the world. **Tensorflow**, **PyTorch** or **OpenAI Gym** are nowadays standard frameworks in research, education and industry. However, the development of these frameworks ignores the global perspective that the so-called standardization bodies have to monitor the evolution of AI technology. Currently, the main standard bodies developing AI standards include:

4.1.1.1 ISO/IEC JTC 1/SC 42

The Joint Committee JTC1 is an established collaboration between ISO and IEC with the aim of fostering AI standardization and providing guidelines to JTC 1, IEC and ISO committees. The collaboration platform is organized in nine working groups, namely:

- ISO/IEC JTC 1/SC 42/AG 2 AI Systems Engineering

- ISO/IEC JTC 1/SC 42/AHG 1 Dissemination and outreach
- ISO/IEC JTC 1/SC 42/AHG 2 Liaison with SC 38
- ISO/IEC JTC 1/SC 42/JWG 1 Joint Working Group ISO/IEC JTC1/SC 42 - ISO/IEC JTC1/SC 40: Governance implications of AI
- ISO/IEC JTC 1/SC 42/WG1 Foundational standards
- ISO/IEC JTC 1/SC 42/WG 2 Data
- ISO/IEC JTC 1/SC 42/WG 3 Trustworthiness
- ISO/IEC JTC 1/SC 42/WG 4 Use cases and applications
- ISO/IEC JTC 1/SC 42/WG 5 Computational approaches and computational characteristics of AI systems

4.1.1.2 IEEE Standards Association (SA)

The IEEE SA is a leading global organization that supports and encompasses standards development during their full lifecycle in different industries and technologies. IEEE standards are developed by volunteer working groups with the aim of driving technological innovation in a global scale. The IEEE SA fosters different Initiatives, including the Artificial Intelligence Systems (AIS) platform that focus on the development of different approaches and solutions for the application of AIS principles and frameworks. Other Initiatives related with AI include The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems and The IEEE Applied Artificial Intelligence Systems (AIS) Risk and Impact Framework Initiative.

4.1.1.3 ITU

Another standard body that is expected to grow in the incoming years is the ITU, which traditionally played a relevant role in the development of standards in information and communication technologies.

4.1.2 Standards

To date, the main work done by both bodies, ISO/IEC JTC 1 Standards Committee on Artificial Intelligence CS-42 and IEEE SA´s AI Standards Series, can be classified in two main blocks: Products and Processes. The following lists give some examples of the current development (done and being done) of standards for AI development within these two main blocks.

Product

- Foundational Standards: Concepts and terminology (**SC 42 WD 22989**)
- Framework for Artificial Intelligence Systems Using Machine Learning (**SC 42 WD 23053**)
- Transparency of Autonomous Systems (defining levels of transparency for measurement) (**IEEE P7001**)
- Personalized AI agent specification (**IEEE P7006**)

- Ontologies at different levels of abstraction for ethical design (IEEE P7007)
- Wellbeing metrics for ethical AI (**IEEE P7010**)
- Machine Readable Personal Privacy Terms (**IEEE P7012**)
- Benchmarking Accuracy of Facial Recognition systems (**IEEE P7013**)
- Certification for products and services in transparency, accountability, and algorithmic bias in systems (**IEEEECPAIS**)
- Fail-safe design for AI systems **(IEEE P7009**)

Process

- Model Process for Addressing Ethical Concerns During System Design (**IEEE P7000**)
- Data Privacy Process (**IEEE P7002**)
- Methodologies to address algorithmic bias in the development of AI systems (**IEEE P7003)**
- Process of Identifying and Rating the Trustworthiness of News Sources (**IEEE P7011**)
- Certification framework for child/student data governance (**IEEE P7004**)
- Certification framework for employer data governance procedures based on GDPR (**IEEE P7005**)
- Ethically Driven AI Nudging methodologies (**IEEE P7008**)

4.1.2.1 Published Standards

ISO/IEC JTC 1/SC 42 has 6 standards already published, which are outlined in the following sections.

4.1.2.1.1 ISO/IEC 20547 series – Information technology – Big data reference architecture

In the last years, ISO/IEC JTC 1/SC 42 has published 5 standards focused on the field of big data under the **ISO/IEC 20547** series. These standards aim to foster a standardized approach for developing and implementing big data architectures, providing a big data reference architecture (BDRA). In addition, the **ISO/IEC 20546:2019 Information technology – Big data** provides a terminological foundation and conceptual overview in the field of big data.

4.1.2.1.2 ISO/IEC TR 24028:2020 Information technology – Artificial Intelligence – Overview of trustworthiness in AI

This standard surveys topics related to trustworthiness in AI systems, including:

1. Approaches to establish trust in AI systems through transparency, explainability, controllability, etc.

2. Engineering pitfalls and typical associated threats and risks to AI systems, like data poisoning, adversarial attacks, model stealing, hardware-focused threats to confidentiality and integrity and privacy threats. Possible mitigation techniques and methods are also addressed.
3. Approaches to assess and achieve availability, resiliency, reliability, accuracy, safety, security and privacy of AI systems.

The specification of levels of trustworthiness for AI systems is out of the scope for this document.

4.1.2.2 Standards Under Development

Besides the standards already published by IEEE and ISO/IEC/JTC 1/SC42 for AI systems and related topics, there is a current effort on developing new standardization approaches within the field of AI, covering AI governance, AI ethical issues, the development and implementation of AI systems and applications and fostering explainable AI:

4.1.2.2.1 IEEE P2863 – Recommended Practice for Organizational Governance of Artificial Intelligence

This recommended practice specifies governance criteria such as safety, transparency, accountability, responsibility and minimizing bias, and process steps for effective implementation, performance auditing, training and compliance in the development or use of artificial intelligence within organizations.

ISO/IEC/JCT 1 is also developing standards in this direction via the following standards:

- ISO/IEC DIS 38507 Information technology — Governance of IT — Governance implications of the use of artificial intelligence by organizations.
- ISO/IEC DTR 24027 Information technology — Artificial Intelligence (AI) — Bias in AI systems and AI aided decision-making
- ISO/IEC AWI TR 5469 Artificial intelligence — Functional safety and AI systems
- ISO/IEC CD 23894 Information Technology — Artificial Intelligence — Risk Management
- ISO/IEC AWI TR 24368 Information technology — Artificial intelligence — Overview of ethical and societal concerns

One relevant topic related to transparency and ethics deals with the need for building personalized AI, which incorporates the influence of individual humans to avoid the lack of transparency that may arise as a result of machine-to-machine communication between AI systems. One of the main purposes here is to establish shared social norms and ethical principles and process personal information at a machine-readable level while mitigating the ethical risks. The **IEEE P7006 Standard for Personal Data Artificial Intelligence (AI) Agent**, still not published, gives a description of the technical elements needed to build and grant access to personalized AI comprising inputs, learning, ethics, rules and values which are controlled by individuals.

Another domain which is captioning significant attention in standardization efforts is eXplainable Artificial Intelligence (XAI). The main purpose of XAI is to provide intuitive or heuristic explanations of the decisions made using AI. Conventional AI techniques usually have an inherent black-box nature which may lead to biased, harmful, unfair or inopportune conclusions. As a result, XAI has emerged with the aim of ensuring the explainability of the models for stakeholders while meeting the applicable requirements regarding privacy, safety, accountability, fairness and regulations.

The standards covering XAI topics are mainly from IEEE and are still under development:

4.1.2.2.2 IEEE P2894 - Guide for an Architectural Framework for Explainable Artificial Intelligence

This guide establishes an architectural framework and application guidelines for the adoption of XAI. In particular, the guide addresses the following points:

1. Description and definition of XAI
2. Categorization of XAI techniques
3. Application scenarios for which XAI techniques are required
4. Performance evaluations of XAI in real application systems

4.1.2.2.3 IEEE P2976 - Standard for XAI – eXplainable Artificial Intelligence - for Achieving Clarity and Interoperability of AI Systems Design

This standard describes compulsory/optional requirements and limitations that must be fulfilled by an AI system, method, application or algorithm to be recognized as explainable. The focus is on providing a unified and high-level methodology for engineers and scientists to facilitate the implementation of explainable AI systems with improved interoperability. In addition, the standard defines both partially explainable and fully/strongly explainable AI to enable the classification of products and includes an XML Schema with the requirements and constraints.

Also, regarding XAI, the ISO/IEC JTC 1/SC 42 Technical Committee is preparing the *ISO/IEC AWI TS 6254 Information technology – Artificial intelligence – Objectives and methods for explainability of ML models and AI systems.*

Furthermore, there are ongoing standardization efforts which aim to provide generic frameworks for dealing with data and knowledge in AI systems, such as the *ISO/IEC WD 5392 Information technology — Artificial intelligence — Reference architecture of knowledge engineering* which is being developed also by ISO/IEC JTC 1/SC 42, the *IEEE 1872-2015 – IEEE Standard Ontologies for Robotics and Automation*, and the following one by IEEE regarding data attributes:

4.1.2.2.4 IEEE P2975 - Standard for Industrial Artificial Intelligence (AI) Data Attributes

This standard describes attributes in industrial AI data including data source, type, ownership, sampling frequency, traceability, privacy attributes for modelling, sampling, shareability and its usability in AI techniques. The standard provides a generic data framework to facilitate data classification, association and mapping with the aim of value creation and a common understanding of this data among all stakeholders.

Moreover, there is also a special interest in standards that provide frameworks dedicated to federated and shared AI systems, in which data is distributed across repositories from different devices or organizations and its aggregation may result in regulatory, ethical or competitive concerns. While in federated Machine Learning (ML) the models are trained by each source and then shared, but not the data, in shared ML there is data sharing but in an encrypted way and the model is trained by a trusted third party and then shared. One standard for federated ML is the *IEEE P3652.1*, for which there is an approved draft version, and the *IEEE P2830* for shared ML, however it is not published yet.

4.1.2.2.5 IEEE P3652.1 - Guide for Architectural Framework and Application of Federated Machine Learning (Approved Draft version)

Federated ML refers to a ML framework that allows a collective model to be built from data which is distributed across repositories owned by different organizations or devices. This guide specifies a blueprint for data usage and model building in a federated setting while meeting applicable privacy, security and regulatory requirements. The architectural framework includes the following points:

- Description and definition of federated ML
- Categorization of federated ML and application scenarios of each category
- Performance evaluation of federated ML
- Associated regulatory requirements

4.1.2.2.6 IEEE P2830 - Standard for Technical Framework and Requirements of Trusted Execution Environment based Shared Machine Learning

This standard provides a framework and architectures for shared ML specifying functional components, security requirements, workflows, technical requirements and protocols.

On the other hand, there are also several standardization efforts in progress regarding evaluation of ML and Deep Learning models, such as the following list of standards under development by the ISO/IEC JTC 1/SC 42 Technical Committee:

- ISO/IEC WD TS 4213 Information technology — Artificial Intelligence — Assessment of machine learning classification performance
- ISO/IEC WD 5259 series - Data quality for analytics and ML
- ISO/IEC TR 24029 series - Artificial Intelligence (AI) — Assessment of the robustness of neural networks
- ISO/IEC AWI 25059 - Software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Quality model for AI-based systems

Also relevant regarding this topic is the standard IEEE P2841, which is described in the next section.

4.1.2.2.7 IEEE P2841 – Framework and Process for Deep Learning Evaluation

This standard describes best practices for the development and implementation of deep learning algorithms. In particular, the document proposes ways to assess the scope, terms and definitions, assessment index system, assessment process and requirements, design, implementation and operation phases. The standard defines a framework and criteria for the evaluation of algorithm reliability and quality of the resulting software systems, including the examination of code implementation and the influence of objective function, training data, adversarial examples, hardware and software dependences and environmental data.

Finally, besides the standards under development cited above, there are additional standards being developed focus on the deployment of AI systems and applications, which include:

- ISO/IEC WD 5338 Information technology — Artificial intelligence — AI system life cycle processes
- ISO/IEC WD 5339 Information Technology — Artificial Intelligence — Guidelines for AI applications
- ISO/IEC DTR 24372 - Information technology — Artificial intelligence (AI) — Overview of computational approaches for AI systems

This standard has yet to be published.

4.2 The Human in the workplace

The human operator is an essential asset in the MAS4AI system. When humans, with their abilities, skills, performance and limits form an integral part of design approach, efficient, flexible and human centered work systems are created. This paragraph details relevant standards for the human operator in the workplace.

4.2.1 Directives – guidelines – standards

On a European level, there are directives with respect to health and safety at work. These directives are binding documents; however, they only provide general directions towards human centered work systems. Guidelines and standards provide more detailed but are non-binding documents. Developing standards generally takes a lot of time, further they are based on an agreement between involved stakeholders. Particularly with ergonomic standards, they should not be limiting if design allows to go beyond a standard.

Framework Directive (89/391/EEC) establishes general principles for managing safety and health[34]. As an elaboration, individual directives 89/654/EEC and 89/655/EEC set requirements for safety and health for workplaces and work equipment. The first directive is also known as the workplace directive. It is concerned with the safety of the workplace environment but does not mention organization of work or workload.

Besides the directives mentioned above, there is the machine directive 2006/42/EC. This directive is aimed at safe design of machinery and contains only a few general directions on ergonomics in Annex I, section 1.1.6. More guidance on ergonomics with respect to machinery can be found in the "Guide to application of the Machine Directive 2006/42/EC[35]" .

In the following sections 3.8.1 and 3.8.2 relevant standards (harmonized and non-harmonized) for the human operator in the manufacturing work system are listed. In 3.8.3 relevant frameworks/standards/methods for skills and competences are described.

4.2.2 Ergonomic standards

In this section we will list the state of the art of ergonomic guidelines and international standards that are available to aid in the design and evaluation of work (physical, cognitive, social, organizational and environmental aspects). Ergonomics can be practiced on a micro and macro level. Micro-ergonomics focusses on optimizing the human machine interface (see 3.8.2). On a

[34] https://osha.europa.eu/en/safety-and-health-legislation
[35] https://ec.europa.eu/docsroom/documents/38022

macro level (macro-ergonomics), the system boundaries are drawn wider including also management practice, people relationships and the whole set of tools that are provided to workers. The ISO organization provides a list of relevant guidelines that fall under the direct responsibility of ISO technical committee 159 who's scope is standardization in the field of ergonomics. The European Committee for Standardization (CEN) has a similar technical committee on ergonomics: CEN/TC 122. They have created a family of harmonized standards, largely together with ISO.

Relevant standards with respect to macro-ergonomics are:

- ISO 6385:2016 (Ergonomics principles in the design of work systems). ISO 6385 describes an integrated approach for the design of work systems (e.g., machines, robots, production lines) taking into account human operators and technological and social requirements.
- ISO 27500 and 27501, prepared by ISO TC 159 in collaboration with CEN TC122, provide recommendations for managers to create human centered organizations based on seven principles, such as create meaningful work and make 'accessibility and usability' strategic business objectives.

4.2.3 Human machine interface/interaction

For the design and evaluation of the human machine interface, work tasks and the working environment there is a large body of standards. For almost every ergonomic aspect, a standard exists. Relevant standards for human machine interface are listed below.

- ISO 9241 is a multi-part standard from ISO covering ergonomics of human-computer interaction. The standards under 9241 cover different aspects of human-computer interaction including:
  - an overview of guidelines for human-centered design of interactive systems (ISO 9241-210: 2019),
  - principles for the presentation of information for the three main modalities (visual, auditory, tactile/haptic) of ICT applications (ISO 9241-112:2017) and
  - guidance on software individualization for different user characteristics (ISO 9241-129:2010).
- ISO/TS 18152:2010 is not yet a standard but a technical specification covering the "Ergonomics of human-system interaction – Specification for the process assessment of human system issues". The definition of 'system' applied in this document, is not limited to a mechanical or software system, it also applies to products and services. Its predecessor ISO/PAS 18152 is cited in ISO/IEC/IEEE 15288, the reference model for

systems engineering, as "the means to address human-system issues in the system lifecycle".

- ISO 10075:2017 describes principles for the design and evaluation of mental workload
- CEN 894 specifies general principles for human interaction with displays and control actuators, to minimize operator errors and to ensure an efficient interaction between the operator and machines.

4.2.4 Skills frameworks

A skills-based approach might be beneficial to support the transition from one industry to another. In this approach, people are hired based on their skills and competences instead of their accomplished degrees and certificates. Skills-ontologies are a great way to support intersectoral mobility and promote sustainable employability at large. Several skills-ontologies are developed in order to facilitate this approach, such as O*NET (USA) and ESCO (EU).

O*NET[36] is an Occupational Information Network. The ONET content model provides a framework that describes worker-oriented descriptors (worker characteristics, worker requirements and experience requirements) and job-oriented descriptors (occupational activities, workforce characteristics and occupation specific information).

ESCO[37] is a classification framework of European Skills, Competences, Qualifications and Occupations that are relevant for the European labor market, training and education. ESCO is being gradually developed and will be continuously updated. ESCO v1 was released in 2017 and contains around 3,000 occupations, 13,500 knowledge, skill and competence concepts and a framework for the qualifications pillar. ESCO is a European Commission project, run by DG EMPL.

4.3 Data privacy

Data privacy is arguably one of the most important considerations in any organization's compliance program. This is also one of the themes that runs through EU law. It is such an important topic that it is modified periodically in private data protection. It has become a necessity to replace the Data Protection Directive 95/46/EC by introducing new regulations in the form of GDPR. The first directive was created in 1995. At that time, the Internet was

[36] https://www.onetcenter.org/
[37] https://ec.europa.eu/esco/portal

developing and spreading fast. Therefore, as a result of this situation some theoretical possibilities emerged soon. The emergence of the digital economy, the data explosion and the technologies that contributed to this evolution have made that the possible threats noticed and signaled earlier have become real. The processing of large amounts of data and the high degree of autonomy and decentralization of self-organizing systems in Industry 4.0 are factors that can become problematic in the context of privacy and personal data protection. Privacy and data protection issues concern IBAC: **Internet of Things (IoT), Industrial Internet of Things (IIoT), Blockchain, Artificial Intelligence (AI) and Cybersecurity**.

It is the aim of Blockchain to build trust in the network, but undeniably, there are some important issues concerning the privacy of the data stored in it. IoT and IIoT, in turn, evolves and becomes a source of data to referred to as to smart data. Some of this data is still protected by GDPR, but huge part of this data is processed in mixed data sets. Finally, a topic of AI should be mentioned and discussed as it evokes significant ethical concerns which come up in numerous ways and situations (fig. 1).

Ownership and use of data generated in an industrial context are major areas of concern. When it is personal data, protection is dealt with in the GDPR, together with the ePrivacy Directive. The data generated from a manufacturing environment can be highly variable and unpredictable in its volume. Seemingly non-personal data may turn into personal data when related to a natural person. **If non-personal data can be related to an individual in any way, causing them to be either directly or indirectly identifiable, the data must be considered as personal data**. The humans in smart factories are directly tracked. Even if the sensor does not explicitly identify who is wearing it, it is still likely that identification will be possible by cross-referencing the sensor's data with a shift sheet. It's not important if this information is stored - merely the gathering and transmission of this data will qualify as a processing under GDPR, even identification ceases to be possible in the future.

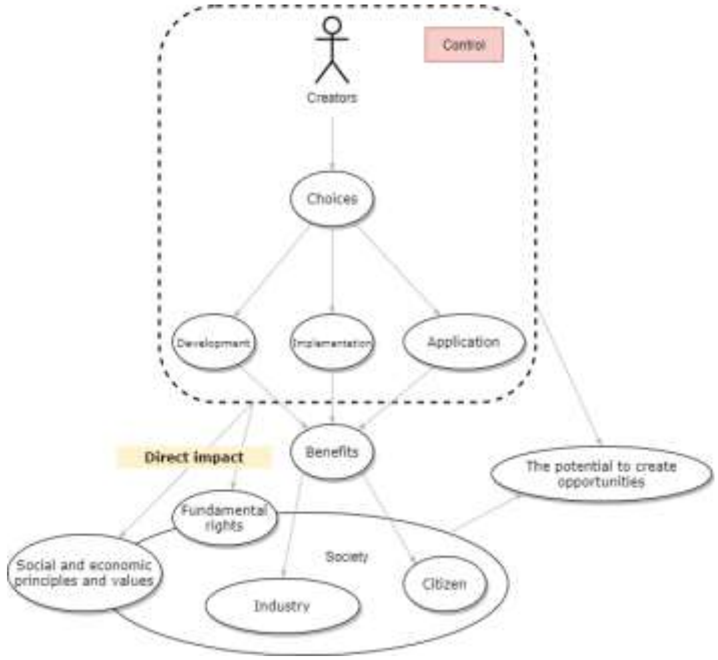

Figure 4 Why UE law wants to control the creators (Author: R. Prabucki).

Taking into account accountability principle (*Article 5.2 GDPR*) and privacy by design (*Article 25.1 GDPR*) rule it is necessary to establish in every case of designing the process, component, tool or service if any personal data will be processed and if the answer is affirmative, the risk assessment must be done.

Taking into account the nature, scope, context and purposes of processing as well as the risks of varying likelihood and severity for the rights and freedoms of natural persons, the controller shall implement appropriate technical and organizational measures to ensure and to be able to demonstrate that processing is performed in accordance with GDPR (Article 24.1 GDPR). The **risk-based approach** is crucial for the evaluation of all solutions implemented with regard to the protection of personal data.

Excessive surveillance is strictly related to the invasion of the **employees' privacy**. Data collected for evaluation of a worker can lead to discrimination and social exclusion. This is not only unacceptable on ethical grounds, but also prohibited by UE law, among others based on GDPR and national laws of the Member States, especially in the field of labor law.

A careless approach to data protection legislation carries enormous financial risks: EUR 20 million or 4% of their total global turnover from the previous financial year, whichever is higher. Violation of the principles of privacy protection also creates the risk of pursuing claims for damages by data subjects in court proceedings, the risk of criminal liability in some cases, but also - which for many entities may be the most serious problem - the risk of losing their reputation as a result of an information security incident.

The legal team cannot, in the context of privacy issues, be limited solely to GDPR monitoring and tracking. Privacy is a much broader concept, touching on many pieces of legislation. A broader view can also result in assistance on, for example, security or ethical grounds (**Error! Reference source not found.**).

Regulations and standards	Source	Action
EP Resolutions		
European Parliament resolution of 20 October 2020 with recommendations to the Commission on a framework of ethical aspects of artificial intelligence, robotics and related technologies (2020/2012(INL))	https://www.europarl.europa.eu/doceo/document/TA-9-2020-0275_EN.html	Monitoring required
European Parliament resolution of 20 October 2020 with recommendations to the Commission on a civil liability regime for artificial intelligence (2020/2014(INL))	https://www.europarl.europa.eu/doceo/document/TA-9-2020-0276_EN.html	Monitoring required
European Parliament resolution of 20 October 2020 on intellectual property rights for the development of artificial intelligence technologies (2020/2015(INI))	https://www.europarl.europa.eu/doceo/document/TA-9-2020-0277_EN.html	Monitoring required
Regulations and directives		
GDPR	https://eur-lex.europa.eu/eli/reg/2016/679/oj	Action required
ePR	https://eur-lex.europa.eu/eli/dir/2002/58/oj	Possible action required
Cybersecurity	https://eur-lex.europa.eu/eli/reg/2019/881/oj	Possible action required
CJEU case law		
CURIA	https://curia.europa.eu/jcms/jcms/j_6/en/	Monitoring required
International standards		
ISO/IEC JTC 1/SC 27/WG 5 "Identity management and privacy technologies	https://www.iso.org/committee/45306.html	Monitoring required
CEN-CENELEC/JTC 13/WG 5 "Data Protection, Privacy and Identity Management"	https://standards.cen.eu/dyn/www/f?p=CENWEB:7:0::::FSP_ORG_ID:2416754&cs=140A091203C84C7307DB4D06AB289BE3E	Monitoring required

Table 2 Examples of sources of legal information that can be applied to the project.

5 Analysis of standards

5.1 Analysis results

In this section, we will apply our analysis metrics to a selection of standards. Below we have listed all standards that have come to the fore as a result of investigation by all partners.

Standard	Market adoption	Openness; potential for MAS4AI involvement	Applicability to MAS4AI core topics
RAMI: Function			
IEC/ISO 62264 - Enterprise Control System	x		x
IEC 61512 – Batch control	x		
ISO/IEC 42010 – Systems and software engineering – Architecture description	x		
IEC 61499 – Function blocks	x		x
RAMI: Information			
RDF – Resource Description Framework	x		x
OWL – Web Ontology Language			x
WSDL – Web Services Description Language	x		
SPARQL – SPARQL Query Language for RDF	x		
RFC8259 – The JavaScript Object Notation (JSON) Data Interchange Format	x		x
XML – Extensible Markup Language	x		
ISO 13584-4/IEC 61360 – Classification and product description	x	x	x
IEC 61987 – Industrial-process measurement and control – Data structures and elements in process equipment catalogues	x		x
eCl@ss/eClass – Reference-data standard for the classification and unambiguous description of products and services	x	x	x
IEC 62714 – Engineering data exchange format for use in industrial automation systems engineering – Automation Markup Language	x	x	X
PackML	x		x
ISO/IEC 19788-7:2019 – Information technology – Learning, education and training – Metadata for learning resources	x		
ISO 16684-1:2019 – Graphic technology – Extensible metadata platform (XMP)	x		
ISO/IEC 15944-10:2013 – Information technology – Business operational view – Part 10: IT-enabled coded domains as semantic components in business transactions	x		

ISO 1087:2019 – Terminology work and terminology science - Vocabulary	x		
ISO/IEC 1179 – Metadata Registry (MDR)	x		
ISO 21597-1:2020 – Information container for linked document delivery – Exchange specification	x		
RAMI: communication			
IEC 62541 – OPC Unified Architecture	x	x	x
IEC 61784 – Industrial communication networks	x		x
IEC 61850:2020 – Communication networks and systems for power utility automation	x		x
REST – RDF Simple Data Interface Protocol	x		X
ANSI/MTC1.4 – 2018 – MT Connect	x		x
ISO/IEC 19464:2014 – Information Technology – Advanced Message Queuing Protocol (AMQP) v1.0 specification	x		
Message Queuing Telemetry Transport (MQTT)	x		
IEEE FIPA-ACL	x		x
ISO 18000-7 – Information technology – Radio frequency identification for item management – Part 7: Parameters for active air interface communications at 433 MHz	X		
IEEE 802.15.1 – Bluetooth LE	x		
IEEE 802.15.4 - ZigBee	x		
IEEE 802.11 – Wireless Local Networks	x		
ANSI/MTC1.4 – 2018 – MT Connect	x		
RAMI: Integration			
ISO 11354 - Advanced automation technologies and their applications — Requirements for establishing manufacturing enterprise process interoperability	x		
ISO 15745 Industrial automation systems and integration — Open systems application integration framework	x		
IEC 62264 Enterprise-control system integration	x		
IEEE 2660.1-2020 - IEEE Recommended Practice for Industrial Agents: Integration of Software Agents and Low-Level Automation Functions	x		x
VDI/VDE 2653 - Multi-agent systems in industrial automation	x		x
RAMI: systems			
IEC 62832 CD 2 Part 1	x	x	x
ISO 29002-5	x		
IEC 61508 - functional safety requirements	x		
IEC 62443 - Industrial communication networks - IT security for networks and systems	x		x
IEC 61131 – Programmable controllers	x	x	
AI in industry			

ISO/IEC 20547 series – Information technology – Big data reference architecture	x	
ISO/IEC TR 24028:2020 Information technology – Artificial Intelligence – Overview of trustworthiness in AI	x	x
Human in the workplace		
ISO 6385:2016	x	x
ISO 27500 and 27501	x	x
ISO 9241: ergonomics of human-computer interaction	x	x
ISO/TS 18152:2010: "Ergonomics of human-system interaction	x	x
ISO 10075:2017	x	x
CEN 894	x	x
O*Net / ESCO	x	x
Data privacy		
GDPR	x	x
ISO/IEC JTC 1/SC 27/WG 5 - Identity management and privacy technologies		x
CEN-CENELEC/JTC 13/WG 5 - Data Protection, Privacy and Identity Management		x

5.2 Analysis summary

Based on the analysis in the table above, we would like state the following observations:

- *Mature, open standardization processes:* The overview in the analysis table shows that almost all standards listed can be considered mature and relevant in terms of market adoption. All standards are managed by open organizations, that have a well-established standardization process and allow participation in their process.
- *Potential for involvement from MAS4AI:* At the same time, the scope of many standards goes far beyond the scope of the project: many standards are very generic (e.g. RDF, Bluetooth LE, Enterprise Control Systems), apply to many use cases across many domains and are therefore not attractive candidates to get involved in from MAS4AI.
- *Lack standardization on the functional level:* MAS4AI aims to integrate and deploy advanced AI components, which provide functionalities to the production facilities and may complement or replace conventional components on a functional level according to the requirement gathering. I.e. Industrial components such as MES, which are currently very static may be replaced by dynamical and more flexible AI-Components in the near future. The same holds for Quality assurance (product), predictive maintenance (station) and optimization on the control level. From our investigation and the table above, it is

worth noting that standardization efforts on the functional level of the RAMI hierarchy currently seem to be underrepresented.

- *Lack of maturity in AI standardization :* from the investigation standards we can conclude that standards for AI in manufacturing are still rare and only few have reached some level of maturity: many of these efforts are however still in their infancy and in draft status of the standardization process at best.
- *Diffciulty of positioning AI and agent standardization in RAMI:* we have chosen RAMI 4.0 as the grounding for our system. It is however not entirely obvious, where and how to integrate the AI technology in this stack. The same hold for MAS-technology.

From this analysis we can conclude that the combination of level of adoption, relevance to core topics of MAS4AI and openness and potential for MAS4AI involvement of the organisation applies to a limited number of standards. We have considered IEC organizations to be more accessible from the european MAS4AI perspective:

- IEC 61360 – Standard data element types with associated classification scheme
- ISO 13584 – Industrial automation systems and integration – Parts library
- IEC 62541 – OPC Unified Architecture
- IEC 62714 – Engineering data exchange format for use in industrial automation systems engineering – Automation Markup Language
- eCl@ss/eClass – Reference-data standard for the classification and unambiguous description of products and services.

6 Conclusion

6.1 Next steps

Standardization white spots for MAS4AI should present themselves as opportunities for meaningful contribution of project results to relevant standardization organizations. Since the main goal of the project is deployment of AI agents in order to collaborate and create a modular workflow, we will focus our recommendations on standardization actions directly on the topics related to formally describing the agent, making assets and agents interoperable and support of the human worker.

Collaboration means that the agent needs to be able to exchange data via standardized interfaces with standardized semantics. The AAS is the primary way to achieve this. Since the AAS is an established meta-model standard but is still evolving as a standard for operational interaction, we think that one of the main contributions of MAS4AI is foreseeable in providing extensions and potentially new models for the concept of the AAS.

6.2 Recommendations for standardization action

6.2.1 Standardize agents via AAS

The project needs to investigate to what extent and how models and submodels of AAS need to be created and/or existing (sub)models need to be extended:

- What specific requirements multi-agent systems in general and multi-agent systems with AI-agents related to data collection, pre-processing, learning and inference bring to development of these AAS models.
- What new (sub)models need to be created in order to have representations for all required agents in MAS4AI (e.g. for the human operator)
- What current AAS models need extension of their (sub)models in order to adequately represent the required functionality in MAS4AI.

This requires definition of semantics in terms of AAS concept definition, definition of submodels, mandatory/optional properties, etc.

Support and advancement of these activities takes place in IEC/TC WG24.

6.2.2 Extend the property types for AAS models

The property types of the AAS represent the details of the semantics of assets in MAS4AI. States and configuration parameters for software agents, dynamic data and functions of assets need to be considered and reflected in property types of the AAS models. Creation of new AAS models or the extension of existing AAS models may lead to creation of new property types, whose semantics need to be defined.

Support and advancement of these activities takes place in IEC 61360.

6.2.3 Provide mapping onto the Communication layer

In order to create communication interoperability for the MAS4AI agents, the AAS needs to be mapped onto a communication protocol. OPC-UA is an important industrial communication protocol and a prime candidate for mapping of the AAS models. This requires creation of OPC-UA information models that correspond with the AAS models.

Support and advancement of these activities takes place in IEC 62541.

7 References

[1] German Standardization Roadmap Industrie 4.0 version 4, 2020, https://www.dke.de/resource/blob/778208/31b06bb4ef2d64fe58c0a1525ed73d23/german-standardization-roadmap-industry-4-0-version-4-data.pdf

[2] openMOS, Deliverable: D1.3 - Detailed Review and Evaluation of Relevant Standardisation Activities Report, 2016

[3] DIN SPEC 91345:2016-04, Reference Architecture Model Industrie 4.0 (RAMI4.0), English translation

[4] DIMOFAC MS2: Approach for Developing a Common Information Model (CIM), 2020

8 Appendix A – longlist of use case standards

This appendix contains all standards that have been listed as part of an investigation of the requirements for standards in the use cases from the perspective of the use case owners.

Use case 0: Smart Factory testbed demonstrator			
Standard id	**Standard name**	**Organisation**	**How this standard is applied in your daily operations?**
IEC62541:1-100	OPC Unified Architecture	TC 65/SC 65E - Devices and integration in enterprise systems	The OPC-UA standard describes the standardized interface protocol of the SF modular testbed demonstrator. It contains the standards which describes the concepts, security, address space, identification and registration of services, device interfaces, machine safety states, access history, discovery, access levels and pub sub interfaces.
DIN-ISO12100	Safety of machinery - General principles for design - risk assessment and risk reduction	ISO/TC 199/WG5 - Allgemeine Gestaltungsleitsätze für Maschinen und Risikobeurteilung / Deutsches Institut für Normung (DIN)	The standard describes how the general safety related design principles of the modular demonstrator are handled. It is only on a general level due to the research aspect of the demonstrator, not process specific.
EN ISO 13849-1	Safety of machinery - Safety-related parts of control systems	NA 095-01-03 GA - Gemeinschaftsarbeitsausschuss NASG/NAM/DKE: Steuerungen // CEN/TC114 // ISO/TC199 Sicherheits von Maschinen und Geräten	The standard EN ISO 13849-1 describes the safety requirements / performance level description of the machinery and is used in the SF demonstrator related to research questions of automatic safety certification / risk identification, together with TÜV

Use case 1: Automotive industry demonstrator			
Standard id	**Standard name**	**Organisation**	**How this standard is applied in your daily operations?**
IEC62541:1-100	OPC Unified Architecture	TC 65/SC 65E - Devices and integration in enterprise systems	The OPC-UA standard describes the standardized interface protocol on machine level. VW is interested in integrating this standard in their systems landscape

Use case 2: Contract manufacturing demonstrator			
Standard id	**Standard name**	**Organisation**	**How this standard is applied in your daily operations?**
ISO 9001:2015	Quality management systems - requirements	ISO	All organizationally relevant processes are tested against this.
ISO 13485:2016	Medical devices - Quality management systems - requirements for regulatory purposes	ISO	We must commit ourselves to this for the development and production of machines and products within the medical market.
ISO 3834-2:2006	Quality requirements for fusion welding of metallic materials - part 2: Comprehensive quality requirements	ISO	Certification according to this standard is indispensable for the organization and execution of welding activities within the defense market.
EN 12899:2007	Fixed, vertical road traffic signs - fixed signs	EN	Within the 'infrastructure' department, development and production of this type of signs is in accordance with these two standards
ISO 2768:1990	General Geometric Tolerances and Technical Drawings	ISO	This is the most commonly used standard for defining geometric tolerances for sheet metal and machining
ISO 13920:1996	Welding - General tolerances for welded constructions - Dimensions for lengths and angles - Shape and position	ISO	This is the most commonly used standard for defining geometric tolerances for welding
ISO 4063:2009	Welding and allied processes - nomenclature of processes and reference numbers	ISO	This standard is used in welding work for both implementation and development
ISO 2553:2019	Welding and allied processes - symbolic representation on drawings - welded joints	ISO	This standard is used in welding work for both implementation and development
Machinery Directive 2006/42/EC		EC	This standard is applied in the development of machines for our customers, which require a CE mark.

Use case 3: Bicycle industry demonstrator			
Standard id	**Standard name**	**Organisation**	**How this standard is applied in your daily operations?**
ISO 2859-1:1999	Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection	ISO/TC 65	Standard is describing sampling procedures for inspection by attributes. The acceptance quality limit (AQL) indicates the worst acceptable quality level. For the determination of sample size and allowable defect quantities statistical tools from the standard ISO 2859-1 - AQL tables - are used.
ISO 16474-3:2013	Paints and varnishes — Methods of exposure to laboratory light sources — Part 3: Fluorescent UV lamps	ISO/TC 35/SC 9	On BV site this standard is being used for exposing coatings to fluorescent UV lamps, heat and water in apparatus designed to reproduce the weathering effects that occur when materials are exposed in actual end-use environments to daylight, or to daylight through window glass. Parts are being tested in UV testing machine.
ISO 9227:2017	Corrosion tests in artificial atmospheres — Salt spray tests	ISO/TC 156	The neutral salt spray (NSS) is being applied for parts; testing their corrosion resiststance.
ISO 11243:2016	Cycles — Luggage carriers for bicycles — Requirements and test methods	ISO/TC 149/SC 1	Carriers are being tested according to this standard and main requirement from suppliers that carriers must comply with this standard, otherwise, carriers cannot be used EU.
ISO 8098:2014	Cycles — Safety requirements for bicycles for young children	ISO/TC 149/SC 1	Different safety requirement come when speaking about bikes which are designed to children. Thus, standard is used for testing children bikes. Also, all parts must comply to it.
EN 15194:2017	Cycles - Electrically power assisted cycles - EPAC Bicycle	CEN/TC 333	This European Standard is intended to cover electrically power assisted bicycles of a type which have a maximum continuous rated power of 0,25 kW, of which the output is progressively reduced and finally cut off as the EPAC reaches a speed of 25 km/h, or sooner, if the cyclist stops pedalling. Just mechanical part is being tested in BV.
ISO 4210: 1-10 (2014, 2015, 2020)	Safety requirements for bicycles	ISO/TC 149/SC 1	Standards from 4210:1 to 4210:10 are applied in our bicycle testing laboratory. Each of the standard part provided needed testing methodology and requirements for each bicycle part (frame, fork, lights, etc.). Bikes, which are made in BV are tested according to these tests and bikes should

			comply all requirements that could be sold in EU.
LST EN 15532:2009	Cycles - Terminology	CEN	This European Standard defines a description of common terms and symbols used in the field of bicycles.

Use case 4: Bearings production demonstrator			
Standard id	**Standard name**	**Organisation**	**How this standard is applied in your daily operations?**
ISO 9001:2015	Quality management systems - requirements	ISO	All organizationally relevant processes are tested against this.
IATF 16949:2016	International Standard for Automotive Quality Management Systems	International Automotive Task Force (IATF)	External certification. The organization works according to this standard
ISO 14001:2015	International standard that specifies requirements for an effective environmental management system (EMS)	ISO	External certification. The organization works according to this standard
ISO 1101:2017	Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out	ISO	Standard for geometrical product specification and tolerances

Use case 5: Woodworking industry demonstrator			
Standard id	**Standard name**	**Organisation**	**How this standard is applied in your daily operations?**
ISO 19085-1:2017	Woodworking machines — Safety	ISO/TC 39/SC 4	ISO 19085-1:2017 gives the safety requirements and measures to reduce risks related to woodworking machines arising during operation, adjustment, maintenance, transport, assembly, dismantling, disabling and scrapping and which are common to machines used in the woodworking industry. It is applicable to woodworking, stationary and displaceable machines when they are used as intended and under the conditions foreseen by SCM.
ISO 19085-3:2017	Woodworking machines — Safety requirements — Part 3: Numerically	ISO/TC 39/SC 5	ISO 19085-3:2017 gives the safety requirements and measures for numerically controlled (NC) boring machines, NC routing

	controlled (NC) boring and routing machines	machines and NC combined boring/routing machines (as defined in 3.1). ISO 19085-3:2017 deals with all significant hazards, hazardous situations and events, relevant to the machines when they are operated, adjusted and maintained as intended and under the conditions foreseen by the SCM including reasonably foreseeable misuse. Also, transport, assembly, dismantling, disabling and scrapping phases have been considered.

9 Appendix B – longlist of standards

This appendix provides a list of standards that have emerged from the investigation but were deemed to be only partially relevant of the core topics of MAS4AI.

9.1 Function layer

9.1.1 IEC 61512 – Batch control

This standard provides models and terminology and data structures and guidelines for language, applicable to batch control. It provides an object model of production information and defines batch history exchange tables. It also enables a detailed definition for batch production records. It consists of a description and object model of batch production record contents. The intended use of this batch production record standard is to provide a reference model for developing applications for the storage and/or exchange of batch production records. Implementations based upon this standard will allow retrieval, analysis, and reporting of selected batch production record data.

9.1.2 ISO/IEC 42010 – Systems and software engineering – Architecture description

This standard addresses the creation, analysis and sustainment of architectures of systems using architecture descriptions. A conceptual model of architecture description is established. It makes usage of architecture viewpoints, architecture frameworks and architecture description languages in order to codify conventions and common practices of architecture description.

9.2 Information layer

9.2.1 ISO/IEC 19788-7:2019 – Information technology – Learning, education and training – Metadata for learning resources

The primary purpose of the ISO/IEC 19788 series is to facilitate: (1) the description of a learning resource by providing a standards-based approach to the identification and specification of the metadata elements required to describe a learning resource, e.g. as a metadata learning resource (MLR) record; and (2) the search, discovery, acquisition, evaluation, and use of learning resources, for instance by learners, instructors or automated software processes.

The ISO/IEC 19788 series is modularly structured with all subsequent parts corresponding to a specified set of user requirements for the identification and specification of metadata elements having a particular focus and intended use in the description of a learning resource. This includes categories of metadata elements focused on technical perspectives, pedagogical aspects, availability and intellectual property aspects, bindings, etc.

This standard part maps the different constructs to machine readable/understandable entities. This document also proposes global (non-linguistic) identifiers for MLR entities and localized (linguistic) identifiers for the same MLR entities.

9.2.2 ISO 16684-1:2019 – Graphic technology – Extensible metadata platform (XMP)

This standard edition defines two essential components of XMP metadata:

- Data model: The data model is the most fundamental aspect. This is an abstract model that defines the forms of XMP metadata items, essentially the structure of statements that XMP can make about resources.
- Serialization: The serialization of XMP defines how any instance of the XMP data model can be recorded as XML.

9.2.3 IEC 61360-1:2017 – Standard data element types with associated classification scheme

IEC 61360-1:2017 specifies principles for the definition of the properties and associated attributes and explains the methods for representing verbally defined concepts with appropriate data constructs available. It also specifies principles for establishing a hierarchy of classification from a collection of classes, each of which represents a technical concept in the electrotechnical domain, or a domain related to electrotechnology. This edition includes the following significant technical changes with respect to the previous edition:

- support of advanced constructs such as
  - conditions and constraints,
  - blocks,
  - cardinality,
  - polymorphism,
  - generic and restricted enumerations, and
  - mapping;
- extended list of data types;
- harmonization with IEC 62656-1;
- support of IEC TS 62720 and of coded units;
- harmonization of semantic and administrative data among the various information objects;
- use of UML for data modelling;
- enhanced definitions and descriptions;
- introduction of examples of higher-level constructs such as block, cardinality, or polymorphism as guidance for the user of the IEC 61360 series.

9.2.4 ISO/IEC 15944-10:2013 – Information technology – Business operational view – Part 10: IT-enabled coded domains as semantic components in business transactions

The primary purpose of ISO/IEC 15944-10:2013 is the provision of integrated approach for the key concepts and their definitions as well as rules pertaining to "coded domains". It does so in a systematic and rules-based manner. It defines a methodology and tool for an IT-enabled approach to existing widely used standards, specifications, authority files, pick-lists, etc., of a "codes representing X" nature, i.e. as ISO/IEC 15944-10:2013 compliant coded domains, involving the making of (legally-binding) commitments, based on common business practices.

A key purpose of ISO/IEC 15944-10:2013 is to maximize and state very explicitly the level of "intelligence" at the highest and most precise required level with respect to the semantics of the actual data being interchanged among autonomous parties in a business transaction. Here the use of coded domains presents a simple and very pragmatic approach at the data element, i.e. semantic component level. It focuses on the development of intelligently coded data elements as part of coded domains. This involves rule-based, structured and pre-defined values whose purpose and use has been clearly stated and unambiguously defined (thereby facilitating an IT-enabled approach).

9.2.5 ISO 1087:2019 – Terminology work and terminology science - Vocabulary

The main purpose of this standard is to provide a systematic description of the concepts related to terminology work and terminology science and to clarify the use of the terms in this field. Its target group comprises standardizers, terminologists, other individuals involved in terminology work, terminology users as well as researchers and professionals dealing with terminology science and/or natural language processing.

The terminological entries are listed in a systematic order under several general headings.

- entry number
- preferred term(s)
- admitted term(s)
- abbreviated form(s)
- definition
- example(s)
- note(s)

9.2.6 ISO/IEC 1179 – Metadata Registry (MDR)

This part of ISO/IEC 11179 contains both principles and rules. Principles establish the premises on which the rules are based. A naming convention is a convention (a set of rules) about names. Many naming conventions have much in common, whether it is defining a method of specifying names for common usage across application systems or developing an organization's internal policy on the choice of XML tags for data interchange.

The goal of any naming convention is to allow development of names for items that have maximum clarity and transparency of meaning, combined with concision, demanding minimal effort of interpretation by the end user, subject to the constraints of the system under which the items are processed.

The naming principles and rules described in this part of ISO/IEC 11179 apply primarily to names of concepts, data element concepts, conceptual domains, data elements, and value domains, but can be extended to any registry content. Differing naming conventions may be applied to different sets of designable items.

9.2.7 ISO 21597-1:2020 – Information container for linked document delivery – Exchange specification

The ISO 21597-1:2020 standard[38] defines an open and stable container format to exchange files of a heterogeneous nature to deliver, store and archive documents that describe an asset throughout its entire lifecycle. The container format includes a header file and optional link files that define relationships by including references to the document or to elements within them. The header file, along with any additional RDF(S)/OWL files or resources forms a suite that may be directly queried by software. The link references may be interpreted by the recipient applications interactively by the recipient.

This standard is suitable for all parties dealing with information concerning the built environment, where there is a need for exchanging multiple documents and their interrelationships, either as part of a process or as contracted deliverables.

9.3 Communication layer

9.3.1 ISO 18000-7 – Information technology – Radio frequency identification for item management – Part 7: Parameters for active air interface communications at 433 MHz

ISO 18000-7:2008[39] defines the air interface for radio frequency identification (RFID) devices operating as an active RF tag in the 433 MHz band used in item management applications. The purpose of ISO 18000-7:2008 is to provide a common technical specification for RFID devices. This standard defines the forward and return link parameters for technical attributes including operating efficiency, channel accuracy, occupied channel bandwidth, maximum power, spurious emissions, duty cycle, data coding, and where appropriate, operating channels, frequency hop rate, hop and spreading sequence and chip rate. ISO 18000-7:2008 further defines the communications protocol in the air interface.

[38] https://www.iso.org/obp/ui/#iso:std:iso:21597:-1:ed-1:v1:en

[39] https://www.iso.org/standard/43892.html

9.3.2 IEEE 802.15.1 – Bluetooth LE

The IEEE 802.15.1[40] standard is an additional resource implementing Bluetooth devices. IEEE 602.15.1 defines the lower transport layers (L2CAP, LMP, Baseband and ratio) of the Bluetooth™ wireless technology. Additionally, this standard specifies a clause on SAPs which includes a LLC/MAC interface for the ISO/IEC 8802-2 LLC and a normative annex providing a Protocol Implementation Conformance Statement (PICS) proforma. Additionally, an informative high level behavioural ITU-T Z.100 Specification and description language (SDL) model for an integrated Bluetooth MAC Sublayer is specified.

9.3.3 IEEE 802.15.4 - ZigBee

The IEEE 802.15.4[41] was chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity. The standard includes the following features:

- Data rates of 250 kbps, 40 kbps, and 20 kbps.
- Two addressing modes; 16-bit short and 64-bit IEEE addressing.
- CSMA-CA channel access.
- Automatic network establishment by the coordinator.
- Fully handshake protocol for transfer reliability.

9.3.4 IEEE 802.11 – Wireless Local Networks

The IEEE 802.11[42] standard specifies the requirements for 5G Indoor Hotspot and Urban test environments of the enhanced Mobile Broadband (eMBB) usage scenario. The standard establishes a foundation for an advanced Wi-Fi technology capable of supporting 5G network performance. Successful evaluation of IEEE 802.11 demonstrates the ongoing evolution of IEEE 802.11™ to meet wireless capacity demands being driven by remote video streaming and cloud access.

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[40] https://www.ieee802.org/15/pub/TG1.html

[41] https://www.ieee802.org/15/pub/TG4.html

[42] https://www.ieee802.org/11/

10 Appendix C – standardization organizations

This appendix provides an overview of relevant international organizations.

IEC - International Electrotechnical Commission	
IEC/TC 65	**Industrial-process, measurement, control and automation** To prepare international standards for systems and elements used for industrial process measurement, control and automation. To coordinate standardization activities which affect integration of components and functions into such systems including safety and security aspects. This work of standardization is to be carried out in the international fields for equipment and systems.
IEC/TC 65/WG 16	**Digital Factory** Definition of the Digital Factory framework, which specifies model elements and rules for creating and managing digital representations of production systems. These digital representations include role-based requirement information as well as physical equipment information and are based on well-defined semantics.
IEC/TC 65/WG 23	**Smart Manufacturing Framework and System Architecture** The task of WG 23 is to establish a framework for Smart Manufacturing (SM) concepts and standards within the scope of TC 65 and in particular: • Identification of SM concepts relevant for TC65, and analysis of their relations with TC 65 standards; • new technologies (e.g. AI, edge, cloud, IIoT) • data exchange and management • new communication technologies
IEC/TC 65/WG 24	**Asset Administration Shell for Industrial Application** Work on Asset Administration Shell in the scope of industrial applications and especially of Smart Manufacturing. Define how to represent an asset of the real world in the information world by the Asset Administration Shell containing structures, properties and services.

ISO – International Organization for Standardization	
ISO/TC 184	**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.

ISO/IEC	
ISO/TC 184 – IEC/TC 65/JWG 21	**Smart Manufacturing Reference Model(s)**

ISO/IEC JTC 1 - Joint Technical Committee for Information Technologies	
ISO/IEC JTC1/SC 42	**Artificial Intelligence**
ISO/IEC JTC1/AG 8	**Meta Reference Architecture and Reference Architecture for Systems Integration**
ISO/IEC JTC1/AG11	**Digital Twin**

CEN – European Committee for Standardization	
CEN/TC 310	**Advanced Automation technologies and their applications** Standardization in the field of automation systems and technologies and their application and integration to ensure the availability of the standards required by industry for design, sourcing, manufacturing and delivery, support, maintenance and disposal of products and their associated services.

CENELEC – European Committee for Electrotechnical Standardization	
CLC/TC 65X	**Industrial-process measurement, control and automation** Contributes, supports and coordinates the preparation of international standards for systems and elements used for industrial process measurement, control and automation at CENELEC level. To coordinate standardisation activities which affect integration of components and functions into such systems including safety and security aspects.
CLC/TC 65X/WG 02	**Smart Manufacturing** Tasked with observing the Smart Manufacturing activities on IEC, ISO and other standardization bodies and fora. WG2 will act as the TC 65X contact for the CEN-CLC-ETSI Coordination group.

IEEE – Institute of Electrical and Electronics Engineers	
IEEE P2806	**System Architecture of Digital Representation for Physical Objects in Factory Environments** This standard defines the system architecture of digital representation for physical objects in factory environments. The system architecture describes the objective, important components, required data resources and basic establishing procedure of digital representation in factory environments.

ETSI	
TC SmartM2M	**Smart Machine-to-Machine Communications** Developing standards to enable M2M services and applications and certain aspects of the Internet of Things (IoT).

OneM2M	
WG1	**Requirements and Domain Models (RDM) Working Group**

OPC Foundation	
OPC UA	**OPC Unified Architecture (UA)** The OPC Unified Architecture (UA), released in 2008, is a platform independent service-oriented architecture that integrates all the functionality of the individual OPC Classic specifications into one extensible framework.

AutomationML	
AutomationML	Develops and maintains an open, neutral, XML based, and free industry data representation standard which enables a domain and company crossing transfer of engineering data.

ECLASS	
Eclass	Data standard for the classification and unambiguous description of products and services using standardized ISO-compliant properties.

W3C	
WoT	**Web of Things** The Web of Things (WoT) provides a set of standardized technology building blocks that help to simplify IoT application development by following the well-known and successful Web paradigm. This approach increases flexibility and interoperability, especially for cross-domain applications, as well as enabling reuse of established standards and tools.