GERMAN STANDARDIZATION ROADMAP
INDUSTRIE 4.0

VERSION 5

STANDARDIZATION COUNCIL
INDUSTRIE 4.0

PUBLISHED BY

DIN e. V.

Am DIN-Platz
Burggrafenstr. 6
10787 Berlin
Tel.: +49 30 2601-0
Email: info@din.de
Website: www.din.de

DKE German Commission for Electrical, Electronic & Information Technologies

Merianstraße 28
63069 Offenbach am Main
Tel.: +49 69 6308-0
Email: service@vde.com
Website: www.dke.de

Photo credit:
Cover: VDE
Chapter entry pages:
Pugun & Photo Studio (S. 5),
kras99 (S. 9, 15, 39, 43), Alex (S. 83) – stock.adobe.com

January 2023

FOREWORD

Prof. Dr. Dieter Wegener
Chair SCI 4.0 Advisory Board
DKE Vice President

Chairman DIN FOCUS.ICT
Speaker ZVEI-Führungskreis Industrie 4.0

Dear Reader,

In recent years, Industrie 4.0 has evolved from a theoretical concept to a field-tested approach. The first products and services using a Digital Twin in line with the Industrie 4.0 concept of the Asset Administration Shell are available on the market. The first submodel templates are already available for the Asset Administration Shell as an "integration plug for digital ecosystems", and thus the first use cases can be implemented.

Policy-makers in Germany and Europe have recognized the strategic importance of digital ecosystems for achieving future goals. That is why several initiatives have been launched to further expand the digital ecosystem. One example is the Ecodesign Regulation for sustainable products proposed by the EU Commission on 30 March 2022. This regulation calls for a Digital Product Passport (DPP) for which there is an opportunity and a need to apply the concepts of Industrie 4.0, as is proposed for the "DPP4.0". With the DPP4.0, the vision of digital ecosystems based on European values becomes a bit more tangible.

The 2030 Vision for Industrie 4.0 of the Plattform Industrie 4.0 formulates a holistic approach to the shaping of digital ecosystems for the development and orientation of Industrie 4.0. This document centres on the following strategic fields of action:

1. **Interoperability**, which should enable seamless collaboration and flawless data exchange between all actors.
2. **Autonomy**, the freedom of all to make decisions without becoming dependent on individual actors.
3. **Ecological and social sustainability**, which are fundamental cornerstones of social value orientation.

This requires standards and integration, a uniform regulatory framework, decentralised systems and artificial intelligence.

The 5th edition of the German Standardization Roadmap Industrie 4.0 builds on the 4th edition of the Roadmap: with the aim of achieving interoperability, that is, standardized machine-to-machine and human-to-machine communication in networked digital ecosystems. The "Standardization Council Industrie 4.0" (SCI 4.0), together with DIN and DKE, has taken on the task of developing normative recommendations for action on Industrie 4.0.

As Chair of the Advisory Board I am pleased to see that the Standardization Council Industrie 4.0 continues to perform this important, bundling function at national and international level for industry-relevant topics. The Standardization Roadmap Industrie 4.0 is gaining attention not only in Germany, but internationally as well.

As an example, artificial intelligence (AI) is becoming increasingly important due to the diversity of existing and potential application areas. The fact that artificial intelligence enables new processes and dynamic design options still raises the question of whether or how the corresponding standards, specifications and guidelines can be adapted. For example, in terms of functional safety for partially certified methods and systems, there are insufficient or no answers to questions about the use of AI systems in dynamic decision-making processes.

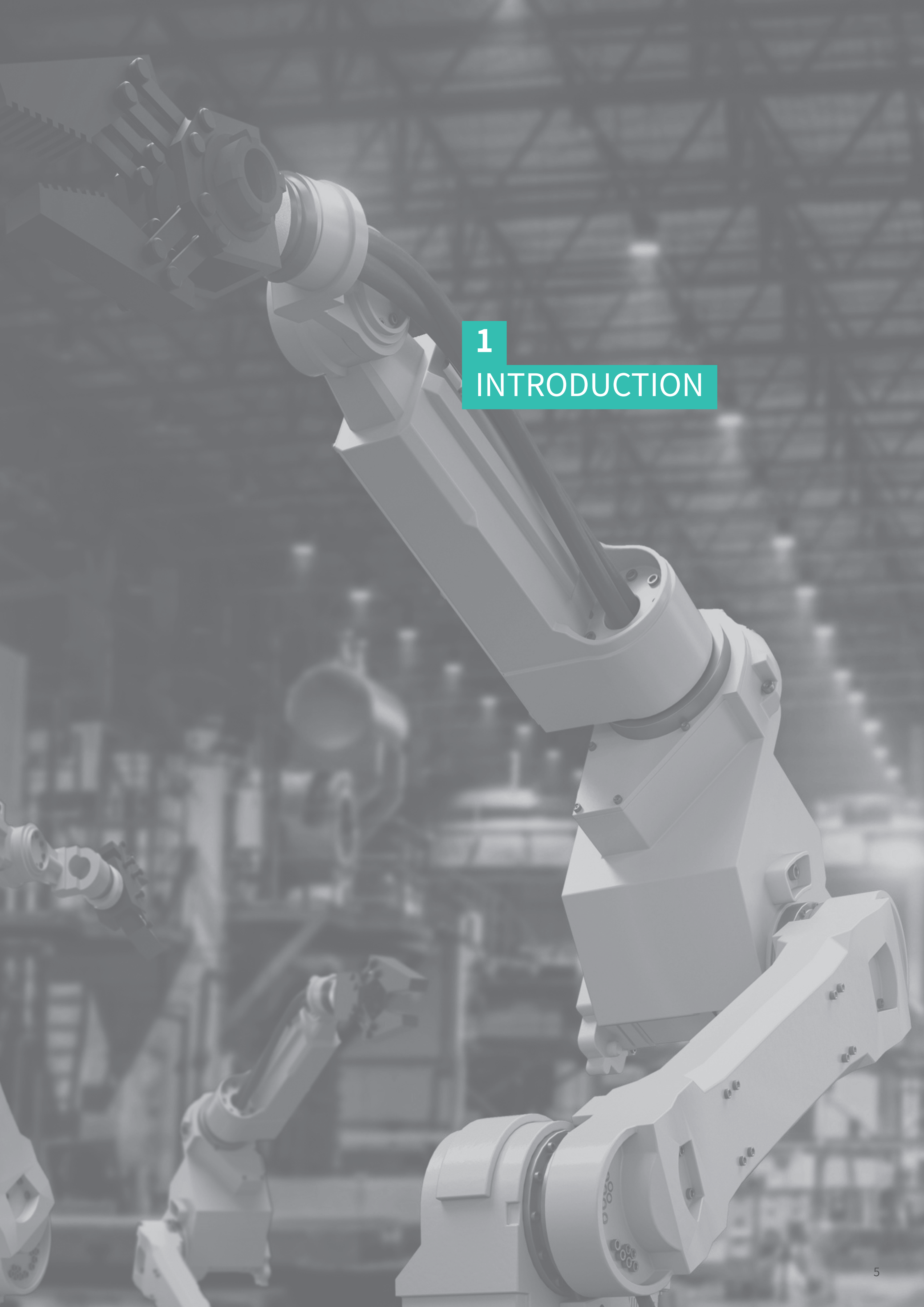
Machines are not intended to replace humans, but to make their work easier or to give them the opportunity to concentrate on more important things. Thus, humans, their knowledge and their needs are at the centre of the development of the Standardization Roadmap Industrie 4.0.

I am always fascinated by the high degree of participation and the willingness of the experts to devote themselves to this “project Standardization Roadmap Industrie 4.0”. Without the willingness to contribute their knowledge and commitment, we would not be able to celebrate our “Version 5” today. With this in mind, I would like to take this opportunity, also on behalf of the SCI 4.0 Advisory Board, to thank all authors and participants for their tireless efforts.

The task now is to implement the recommendations for action with vigour and, in parallel, to further develop the standardization strategy for Industrie 4.0 in a targeted manner.

I wish all readers an exciting read.

Prof. Dr. Dieter Wegener
Chair SCI 4.0 Advisory Board
DKE Vice President
Chairman DIN FOCUS.ICT
Speaker ZVEI-Führungskreis Industrie 4.0



1 INTRODUCTION

1.1 Needs in the innovative research field Industrie 4.0

In Germany, it was recognized at an early stage that Industrie 4.0 is a joint project that requires close coordination among all players. This concerns both the development of basic concepts and technology development to market maturity. Based on this insight, organizations from the environment of the Plattform Industrie 4.0 were founded for the purpose of collaborative technology development. For the organization of standardization, this means that cooperation with these organizations must be defined and implemented. This differs from "classic" competitive technology development, in which the development of a technology to market maturity takes place at the companies or market players independently of one another and is then followed by a standardization of requirements through standards and specifications.

1.2 Status quo of the implementation of the recommendations of the Standardization Roadmap Industrie 4.0

As was regularly emphasized in previous editions, the Standardization Roadmap Industrie 4.0 was conceived as a "living" document from the very first edition and is accordingly understood as a basis for discussion that is to be continuously updated at regular intervals. With the Progress Report [1] on the fourth edition of the Standardization Roadmap Industrie 4.0 [2], an overview was recently compiled that provides an up-to-date summary of the implementation status of the recommendations for action formulated in the fourth edition. At the same time, the Progress Report [1] provided an outlook on the direction the fifth edition (this edition) was to take.

Industrie 4.0 is currently in the transition from the concept phase to the implementation phase. Numerous initiatives have been launched to support a practical application of the developed concepts and the ramping-up of Industrie 4.0: the Industrial Digital Twin Association (IDTA) as a technology driver for the Asset Administration Shell, the InterOpera project as support for the start-up of the development of submodels of the Asset Administration Shell, CATENA-X as a driver for a data space for automotive production, COMDO as a project (see Chapter 5.1.1) for the end-to-end use of semantic features of ECLASS and IEC CDD, to name just a few examples. The "Manufacturing-X" initiative, which was in the process of being established at the time of publication of this Roadmap, is intended to implement the cross-industry data space for Industrie 4.0 which is included in the German government's digital strategy.

With the successful implementation of IEC 63278-1 [1] "Asset Administration Shell for industrial applications – Part 1: Asset administration Shell structure", an important standardization project has now been consolidated internationally in order to make the Asset Administration Shell the central "integration plug" for digital ecosystems and to anchor it further in international standardization. With the additions to the IEC 63278 series of standards of IEC 63278-2 [2] "Information meta model" and IEC 63278-3 [3] "Security provisions for Asset Administration Shells", further foundations are currently being laid for using and standardizing the concept of the Asset Administration Shell.

Likewise, sustainable developments are increasingly being driven forward and normatively implemented. One example of this is the Digital Product Passport, which will support the industrial Circular Economy over the long term. Based on the Asset Administration Shell structure described in IEC 63278-1, a decentralized approach was enabled to provide access to user-friendly websites of manufacturing companies and standardized machine-readable information about the product via a product identifier, according to IEC 61406 "Identification Link". Each submodel represents a standardized data set for a specific use case, for example for the transmission of technical data or product documentation. In further submodels, regulatory requirements, service information or even environmental information can be standardized, as well as digitally stored and retrieved. In this way, the structure of the Digital Product Passport can also be used to develop new digital business models.

1 IEC 63278-1 "Asset Administration Shell for Industrial Applications – Part 1: Asset administration shell structure"

2 IEC 63278-2 "Asset Administration Shell for Industrial Applications – Part 2: Information meta model"

3 IEC 63278-3 "Asset Administration Shell for Industrial Applications – Part 3: Security provisions for Asset Administration Shells"

1.3 Looking ahead: Recommendations for action for further work in standardization

The topics of **sustainability, resilience, interoperability** and technological **autonomy** are increasingly becoming the focus of Industrie 4.0 standardization. The aim of this standardization must be to create the preconditions so that the potential for realizing these strategic goals of Industrie 4.0 can be fully leveraged.

The **fifth edition of the German Standardization Roadmap Industrie 4.0** is based on a holistic understanding of sustainability. This is achieved through the simultaneous implementation of ecological, economic and social goals. It is therefore necessary to also consider the interactions of these aspects for the holistic realization of **sustainability**. In this way, the ecological dimension of sustainability can be advanced with the help of digitalization and can contribute to improving resource and energy efficiency, as well as reducing emissions. In addition, Industrie 4.0 will lay the foundations for a climate-friendly Circular Economy. In social terms, the digitalization of work will place new demands on the education and training of specialists and managers, as well as on the organizational and global framework conditions – especially against the backdrop of new forms of collaboration between humans and machines. These ecological and social aspects can only be achieved if they interact with the economic dimension of sustainability.

In addition to the aspects of sustainability, the resilience of value networks and technological autonomy in Industrie 4.0 are becoming more of a focus of standardization. The Corona pandemic in particular, and most recently the war in Ukraine, have clearly highlighted the importance and necessity of resilient value networks. The prerequisites for ensuring **data autonomy** while reducing dependence on “hyperscalers” may lie in the science-based and proactive design of (international) autonomous **data spaces**. They form the basis for the exchange of data in accordance with the European legal and value system for the purpose of realizing data-driven and scalable business models. In order to enable interoperability and thus multilateral data exchange, standardization and certification processes, as well as appropriate **IT security** for Industrie 4.0 are above all necessary.

Industrie 4.0 has shown that it is a backbone for innovation, especially in times of crisis. Both **integration** topics (for example, data spaces and artificial intelligence in Industrie 4.0, taking account of traceability, trustworthiness and ethics) and application topics (for example, sustainable, CO_2-neutral production through Industrie 4.0) must be addressed. We will deal with these topics in the following chapters.

Digitalization not only affects industry, but also standardization work. For example, the Corona pandemic and geostrategic conflicts have once again highlighted the need for more flexible and responsive standardization processes. As a consequence, standards organizations will have to introduce modern technologies in the form of user-friendly digital platforms more frequently and more rapidly in order to increase the speed of development[4].

4 See the CEN-CENELEC Report

2
PRINCIPLES AND REQUIREMENTS FOR THE DESIGN OF DIGITAL ECOSYSTEMS

To help readers get started with the topic of standardization for Industrie 4.0, the Roadmap's structure is discussed below and some basic terms are explained, such as "digital ecosystem". The fifth edition of the Standardization Roadmap Industrie 4.0 consists of a total of 10 chapters, which can be roughly divided into three sections:

Section 1 comprises Chapter 1 to 4 and forms the basis of the German Standardization Roadmap Industrie 4.0. Terminology and concepts are described, e.g. industrial data spaces, and the status quo of ongoing or completed initiatives is also discussed. In addition, a summary of the recommendations for action can be found in Chapter 3.

Section 2 comprises Chapter 5 and 6 in which the current main topics are addressed. Various aspects, such as the Asset Administration Shell, are described, and arguments are presented as to why there is a need for standardization of these aspects.

Section 3 (from ANNEX A on) contains additional information such as the Bibliography and an overview of relevant publications and activities in the field of Industrie 4.0.

Some basic terminology is discussed in the following sections.

2.1 Digital ecosystems in Industrie 4.0

From a standardization perspective, there are four aspects that are central to any digital ecosystem in the current context:

1. **Semantics** as the foundation of interoperable digital systems.
2. The concept of "**industrial data spaces**", which creates additional value based on data while maintaining and ensuring data autonomy, data security and data integrity for stakeholders.
3. "**Human-centred Industrie 4.0 systems**" as the basis of human-centred work design, as well as its various aspects (e.g., work equipment, work environment).
4. The idea of "**sustainable and ecological aspects of Industrie 4.0**," i.e., the implementation of climate and environmental goals with an industrial focus. This includes, on the one hand, the monitoring and reduction of emissions from industrial facilities and, on the other hand, preventive environmental protection with regard to products and their environmental effects.

These four aspects are discussed in greater detail below.

2.2 Semantics as the foundation of interoperable digital ecosystems

In standardization, **semantics** is seen as being the foundation of interoperable digital ecosystems.

A closer look shows that there are very different views of the concept of semantics in the context of digitalization, making a common understanding difficult. These differences are due, among other things, to the fact that very different disciplines, such as linguistics, philosophy, or even computer science, make independent contributions to the concept of semantics.

One example is the "realistic" understanding of the semantics of a symbol as a three-way relation between the sound or word, the thing signified, and the ideas triggered by the sound. This is contrasted, for example, with the "use theory", which sees the meaning of exchanged symbols in the rules of interaction, which in computer science corresponds to the view that information is given its meaning by its processing.

Precisely because of the central role semantics plays in achieving **interoperability**, it is essential for the standardization strategy to arrive at a more uniform understanding aimed at the specific use case of efficiently establishing interoperability.

This primarily concerns interoperability with regard to digital ecosystems, as these form the basis for a variety of data-driven services and functionalities for industry. The interaction of systems takes place on underlying digital platforms. On these platforms, a bond between sender and receiver systems of processes can be a priori completely unknown, but still have to cope with the same interaction tasks. At this point, the standardization of semantic expressiveness can serve as an important element for establishing interoperability to support interaction capabilities between systems in digital ecosystems. In the field of Industrie 4.0, there are now a large number of individual standards with which interoperability between systems can be achieved. To achieve a common understanding, it is important how knowledge can be described, exchanged, and comprehended or processed. A common understanding, preferably in the form of standards, on how to share this knowledge is therefore needed.

2.3 Autonomy of industrial data spaces

The topic of **data spaces** is discussed in the context of the digital economy. This pursues the overarching goal of creating additional value based on data while maintaining and ensuring **data autonomy, data security,** and **data integrity** for stakeholders. For this purpose, data spaces offer participants shared, trusted transaction spaces (security domains), via which data can be made available and jointly evaluated or managed. This creates a generally accepted basis for data exchange and use based on a decentralized or centralized infrastructure for provision, evaluation and management. Examples exist in the "data economy" or "platform economy" proposals of the associations.

A data space defines technical, legal and business principles [3]. There are already numerous examples in the manufacturing industry today where companies are creating additional value based on data. A common challenge of all these examples is often to improve their respective economic scalability. By offering common technical, legal, and business principles, data spaces offer the potential here to deliver specific value across examples in a consistent manner using a data space. This makes it easier to transfer specific examples to other applications. In addition, data spaces also offer the potential to open up new applications. The following topics in particular are worth mentioning here:

→ going from mass production to customer-specific production,
→ reliable and resilient value chains,
→ data-driven business models,
→ the Circular Economy,
→ supply chain transparency.

These are based on the broad and distributed use of data, but also beyond that they are based on the fundamental problem of data use in the area of tension between data security and the protection of intellectual property rights (IP) with the simultaneous need for collaboration across company and business unit boundaries.

However, the specific requirements of the stakeholders involved in data autonomy, data security and data integrity are very much dependent on the use case, so that in addition to the technical characteristics of a data space, the cost-benefit ratio associated with it in the individual case must also always be considered. Thus, a data space – in addition to offering suitable characteristics – must assert itself economically in the interplay of market requirements and regulatory framework conditions.

2.4 Social sustainability – human-centred Industrie 4.0 systems

Following the sociotechnical approach, the interactions between social and technical components must be taken into account in the design and standardization of work systems. Accordingly, technological changes such as the introduction of Industrie 4.0 systems always require organizational adjustments and have an impact on work tasks, activities and employees [4]. Such a human-centred perspective can prevent "technical constraints" that may arise when elements of Industrie 4.0, such as innovative assistance systems, are introduced without taking into account standardized aspects and defined specifications of human-centric work design [5].

It should be noted at this point that fundamental principles of occupational health and safety law must be considered in conjunction with standards for the operational implementation and evaluation of Industrie 4.0 systems. Information on this subject can be found in the policy paper on the role of standardization in the health and safety of workers at work [6].

The fundamentals of human-centric work design and its various aspects (e.g. work equipment, work environment) were considered in greater depth and related to Industrie 4.0 in Version 4 of the Standardization Roadmap Industrie 4.0 [2]. These fundamentals are still valid and serve as a framework for the consideration of individual topics, which are selected as examples due to their topicality and importance for the human-centric design of Industrie 4.0 and are described in the subchapters of this Roadmap and are supported by new recommendations for action (see Chapter 3).

Recommendations for action on the topic of "**human-centred Industrie 4.0 systems**", which were formulated in the Roadmap V4 [2] and not mentioned in the Progress Report [1], are taken up in this Version 5 in summarized form in the individual subchapters.

2.5 Sustainable and ecological aspects of Industrie 4.0

The topics of ecological **sustainability** and **digitalization** are current top trends and are often referred to in combination as a double transformation or "twin transformation".

With the publication of the **European Green Deal**, the European Commission has committed to a new growth strategy. This aims to make the EU a fair and prosperous society with a modern, resource-based and competitive economy, with zero net greenhouse gas emissions in 2050 and economic growth decoupled from resource use [10]. Digital technologies are seen as a crucial prerequisite for achieving the Green Deal's sustainability goals [10].

As the world's largest single market, the European Union, together with its member states, can set standards that apply to global value chains and can also be applied in digital ecosystems. At the same time, sustainability commitments can be continuously strengthened within the framework of EU trade agreements with third countries, for example through the inclusion of standards [10].

To successfully implement the "twin transformation", sustainability aspects must be digitally recorded and made available in the form of data and information. Only an automated, standardized, nearly cost-neutral "running" of sustainability data in digital ecosystems will lead to a widespread application and a significant impact on the climate, environment, and sustainability.

Consequently, with regard to the topic of "sustainable and ecological aspects of Industrie 4.0", there are various cross-references to the aspects of interoperability and autonomy of industrial data spaces and thus to all subchapters of Chapter 5 "Standardization aspects in the key topics".

2.6 Overview of aspects

The Standardization Roadmap Industrie 4.0 serves as a guide for industry to create a coordinated transition to a digital ecosystem. From a German perspective, the three fields of action **interoperability**, **autonomy** and **sustainability** are of central importance for a digital ecosystem, as outlined in the 2030 Vision for Industrie 4.0 (see Figure 1).

Figure 1: Strategic fields of action in Industrie 4.0 as a vision for 2030
(Source: © Plattform Industrie 4.0/INFOGRAFIK PRO GmbH) as in (BMWK 2019b)

Autonomy guarantees competitiveness in digital business models through free room for design and self-determination. This requires a solid digital infrastructure, data security and the promotion of technology development that reduces dependence on individual suppliers and solution providers through diversification.

The goal of **sustainability** is to safeguard modern industrial value creation and thus the standard of living. This requires good jobs and education, social participation and climate protection.

Interoperability is the basis for cooperation and open eco-systems. It requires a regulatory framework, decentralized systems and artificial intelligence, as well as standards and integration. Interoperability is thus essential and forms one of the basic building blocks of autonomy.

The three fields of action provide an important and long-term orientation for the further initiatives and activities of all players in industry, science, politics and society. For each of the three fields of action, there are a number of sub-aspects for which there is still a need for action with regard to their standardization. In the context of this Roadmap, the focus is on those sub-aspects that are of primary interest for the respective field of action from a current perspective.

The **need for standardization in terms of interoperability** comprises the following sub-aspects:

→ properties and their system integration in industrial applications for the smooth exchange of information between the individual players in a supply chain;
→ reference architecture models for implementing the structural framework for the smooth implementation of Industrie 4.0 scenarios;
→ semantics and properties, i.e., interpretable interactions at interaction points, e.g., at human-machine interfaces;
→ the Asset Administration Shell as an implementation of the Digital Twin for Industrie 4.0 serves as the basic concept of the Asset Administration Shell;
→ industrial communication, communication methods of networked systems;
→ functional safety in Industrie 4.0 as part of overall safety and thus as a prerequisite for flexible production facilities;
→ Artificial intelligence in industrial automation, also with regard to human-machine interaction.

Standardization needs in terms of the autonomy of industrial data spaces:

→ industrial security focuses primarily on the holistic protection of information technology in production systems, machinery and equipment against sabotage, espionage or manipulation;
→ privacy, especially with regard to data protection;
→ trustworthiness, i.e., of data within the supply chain;
→ establishment of access mechanisms as “rules of the game” for autonomous multilateral data sharing.

Need for standardization in terms of sustainability:

→ sustainability aspects in Industrie 4.0; sustainability through data quality;
→ sustainability modules at a glance, e.g., fixed and mobile facilities, processes, etc.;
→ aspects of social sustainability and recommendations for action in the design and operation of Industrie 4.0 facilities.

Of course, the respective sub-aspects can also be of importance for the other two fields of action. In these cases, a cross-reference has been noted in the relevant chapter.

3 RECOMMENDATIONS FOR ACTION OF THE STANDARDIZATION ROADMAP INDUSTRIE 4.0 (VERSION 5)

5.1.1 Characteristics and their system integration in industrial applications

[RE 5.1.1-1 V5] Sociotechnical system design

It should be made clear at an appropriate point in the standards relating to Industrie 4.0 value creation systems that a human-centric design of Industrie 4.0 work systems requires early consideration of sociotechnical aspects, a requirements engineering derived from this for the overall value creation system and its individual components, and the earliest possible involvement of workers in the Industrie 4.0 value creation system in a key user role (ideally as design partners). In this context, the experience of workers from comparable Industrie 4.0 value-added systems and networks already in use can and should be recorded, documented and used for the more human-friendly design of the respective Industrie 4.0 system currently being developed, and introduced by means of suitable knowledge and experience management.

[RE 5.1.1-2 V5] Selection and presentation of complex information for employees

Complex information should be selected and presented in a way that employees can understand and process it. Various selection and visualization options (e.g., type and amount of information) can be supportive. The principles of ergonomic design should be taken into consideration. If data is processed and presented by artificial intelligence algorithms, this is to be made transparent. This relates to the standards DIN EN ISO 9241-112 and DIN EN 894-1 and standardization in the field of artificial intelligence, among other things.

[RE 2.7-22 V4] [RE 2.7-24 V4] ➡ [5.1.1-2 V5]

[RE 5.1.1-3 V5] Minimum standards for the consideration of sociotechnical aspects

The formulation of minimum standards for the consideration of sociotechnical aspects is to be examined in various generic standards on ergonomics and work design. The relevant statements regarding the design of work systems are currently scattered across numerous standards. This means that operational planners find it more difficult to find these statements and to take sufficient account of them when planning Industrie 4.0 solutions. To this end, the overview of the relationships in ergonomics standardization should also be improved.

Against this background, it is recommended that operational planners be provided with a document containing a summary of all process-relevant statements regarding Industrie 4.0. This should first be implemented in a guide to work system design for Industrie 4.0 solutions.

[RE 2.7-1 V4] [RE 2.7-2 V4] ➡ [RE 5.1.1-3 V5]

[RE 5.1.1-4 V5] Review of standards in relation to the overall system design process

It must be examined whether and in what way existing standards with normative statements on the process of work system design can be used as a reference in this respect, and what need there is for supplements and amendments to these existing standards (in particular DIN EN ISO 6385; DIN EN ISO 10075 Part 2; DIN EN ISO 13407; DIN EN ISO 27500).

[RE 5.1.1-5 V5] Adaptive, dynamic allocation of tasks between humans and machines

Since a rigid allocation of tasks (division of functions) between humans and machines in many cases does not provide adequate opportunities for perception, situation assessment, influence, result feedback, and any resulting opportunities for learning and competence development, the division of functions should ideally be designed in a dynamic-adaptive manner. In any case, this division of functions should be transparent and designed in such a way that employees can understand and influence it. It may have to be taken into account that different employees may be working in one work system (in parallel and synchronously or also asynchronously). A procedure for the process-accompanying evaluation of adaptive task allocation with special attention to safety, security and psychosocial effects of employees is to be developed and integrated into standardization. It must also be taken into account that machines can record and evaluate body dimensions etc. for dynamic adaptation to humans. This results in a need for supplements or amendments to standards such as DIN EN 614-2, ISO/TS 15066, DIN EN ISO 10218, DIN EN 894-1,3, DIN EN ISO 29241-2, DIN EN ISO 10075-2, DIN EN ISO 11064-1,5,7, DIN EN ISO 13861, C standards for machines, ISO/TS 15066, standards on artificial intelligence (ISO/IEC JTC1 SC42), DIN EN ISO 9241-110, -112, DIN EN ISO 11064-5, DIN EN ISO 11064.

[RE 2.7-4 V4], [RE 2.7-11 V4], [RE 2.7-12 V4], [RE 2.7-14 V4], [RE 2.7-15 V4], [RE 2.7-16 V4], [RE 2.7-20 V4], [RE 2.7-23 V4] ➡ [RE 5.1.1-5 V5]

[RE 5.1.1-6 V5] Design of the learning process of assistance systems

The process of employees teaching collaborative robots as a special case of dynamic task allocation should be ergonomically designed (e.g. expectation-compliant, error-tolerant and self-describing). ISO/TS 15066 and DIN EN ISO 10218-2 require revision, for example.

[RE 2.7-25 V4] ➡ [RE 5.1.1-6 V5]

[RE 5.1.1-7 V5] Design of the selection of assistance systems

When designing the selection of assistance systems, care must be taken to ensure that they are a good fit with the characteristics of the employees as well as the characteristics of the task. Otherwise, undesirable, negative effects on cognitive and physical demands, as well as the quality of task processing are possible. In addition, it should be seen that sufficient room for manoeuvring remains with the employees, and that the use of assistance systems is not accompanied by a loss of skills. Assistance systems open up new kinds of opportunities for professional participation, especially for people with disabilities. Displays of assistance systems should be oriented to the task design. DIN EN ISO 894-2 and DIN EN 11064-2, for example, and standards on the design of assistance systems require amendment.

If (mobile) assistance systems are used to perform monitoring and control activities that are dynamic and cannot be paused, the impact of these dynamics on control options must be taken into account. The DIN EN 894, DIN EN ISO 9241 and DIN EN ISO 11064 series require amendment.

[RE 2.7-18 V4], [RE 2.7-19 V4] ➡ [RE 5.1.1-7 V5]

[RE 5.1.1-8 V5] Characteristics and properties

An important step in the plug-and-produce concept is the coordination of requirements and the assurance of device characteristics. With this in mind, extended instance-related attributes are to be covered by standards.

[RE 2.3-7 V4] ➡ [RE 5.1.1-8 V5]

[RE 5.1.1-9 V5] Standardized input of maintenance information

Standardization of the interfaces of Industrie 4.0 components (facilities and products) for the input of current maintenance information, e.g., on the basis of iiRDS (repairs, maintenance, conversions) into the systems of condition monitoring and predictive maintenance. In the industrial environment, assets can also include intangible things such as concepts, patents, procedures or processes. Charcteristics of conceptual assets, such as planning documents, should be included as standardized dictionary entries.

[RE 2.3.19-1 V5]

[RE 5.1.1-10 V5] Properties of conceptual assets in standardized dictionaries

Properties of conceptual assets such as planning documents should be included in standardized dictionaries such as the Common Data Dictionary of IEC/SC 3D, e.g., the specifications in VDI 2770. Additionally, planning documents should be communicable between humans and machines/Industrie 4.0 components.

[RE 2.3-5 V4] ➡ [RE 5.1.1-10 V5]

[RE 5.1.1-11 V5] Sustainable and consistent harmonization of properties between ECLASS and CDD

Given the fundamental importance of standardized semantics for Industrie 4.0 components, a multiple coexistence of different standards for the same semantics is not acceptable, since it prevents the overlapping interaction between Industrie 4.0 components. Parallel developments as in certain places today in IEC, ISO and ECLASS must be coordinated: The activities to harmonize the properties must be accelerated in the ECLASS and IEC committees involved. In particular, the existing properties should be brought to the same semantic and syntactic level and adapted. Standardized mechanisms and procedures for specifying new properties must be synchronised between ECLASS and CDD to avoid further differences in properties. Ideally, the publishers of properties (and other structural elements e.g., classes, values and units) have interlocked their standards after the harmonization steps to such an extent that semantically identical elements have the same name and code, i.e., mean the same thing. Common content should be kept and processed identically in all databases or managed in a common database in order to structurally prevent the content from being divergent. The main publishers are IEC, ECLASS and in future probably also ISO. The results should be made publicly available.

[RE 2.5-2 V4] ➡ [RE 5.1.1-11 V5]

[RE 5.1.1-12 V5] Standardized dictionaries

Existing fieldbus profiles, companion specifications and other specifications that define device and component properties should be transferred into standardized dictionaries, such as ECLASS and IEC CDD. Furthermore, they should be presentable in a suitable semantic way (e.g. graphically/algebraic).

[RE 2.3-4 V4] ➡ [RE 5.1.1-12 V5]

5.1.2 Reference architecture models

[RE 5.1.2-1 V5] Industrial cloud platforms

An open, distributed, real-time and secure operating system, standardization activities for a flexible and extensible architecture for future requirements of cognitive services, real-time applications and data marketplaces should be taken up in the relevant committees. Hybrid cloud platforms, IIoT applications and cyber-physical architectures should be investigated as core elements. Uniform life cycle management of all IT resources, means of production and technical building equipment are just as much a part of this as the creation of an integrated infrastructure for real-time capable, cross-domain value-added networks for the AI-supported, autonomous production of the future.

[RE 2.3-23 V4] ➡ [RE 5.1.2-1 V5]

5.1.3 Semantics and characteristic

[RE 5.1.3-1 V5] Human-machine interface

In order to enable task- and activity-related process modelling of the dynamic human-machine functional division postulated here (and all other value creation processes with an active role for humans in the process) in the Digital Twin as a planning tool for Industrie 4.0 value creation networks and the associated Industrie 4.0 work systems, a project should be initiated to supplement the Industrie 4.0 reference architecture model with a type of activity process module according to work and organizational psychology standards.

[RE 5.1.3-2 V5] Human-machine interface

It should be examined in which way the approach described in **[RE 5.1.3-1 V5]** can be elevated to a standard (supplementing and adapting/updating existing standards such as ISO 6385, ISO 10075 Part 2, ISO 13407, ISO 16982, ISO 18529, ISO 27500 or integration in other/new, Industrie 4.0-related or also AI-related standards).

[RE 5.1.3-3 V5] Ensuring effective normative infrastructures

It is recommended that joint efforts by ISO, IEC and CEN/CENELEC as well as the national committees be made to go through the digital transformation process from document-centric standards to digital value-added services for content of the standards in order to make preparations in the infrastructures at an early stage and to ensure the future of consensus-based standardization. Active participation in international standardization bodies is therefore important.

[RE 5.1.3-4 V5] Semantics in the context of the Digital Twin

ISO/IEC JTC 1/SC 41/WG 6 should explain the connection between semantics and the Digital Twin in a cross-domain normative way.

[RE 5.1.3-5 V5] Industrie 4.0 language

The existing VDI/VDE 2193 (Part 1 and Part 2, "Language for I4.0 Components") is available as a guideline and forms an essential basis for interoperability between Industrie 4.0 components. It is recommended to bring this Inustrie 4.0 language to international standardization.

[RE 2.4-5 V4] ➡ [RE 5.1.3-5 V5]

[RE 5.1.3.-6 V5] Tools of semantics

It is recommended that tools of semantics be developed, i.e., tools and artefacts that can be used to analyze, define, describe, or cyber-physically engineer a product. These should be standardized according to their use (e.g., provision in combination) and characteristics.

[RE 5.1.3-7 V5] Quality criteria for ontologies

The requirements for existing ontologies should be fundamentally reviewed. To this end, quality criteria for ontologies should be developed to enable a clear identification of ontology concepts (e.g., avoidance of homonyms and synonymous concepts).

5.1.4 Tools for implementing the Digital Twin

[RE 5.1.4-1 V5] Use the Asset Administration Shell concept consistently and standardize it internationally

To support the processes described above, such as maintenance functions and storage of knowledge in a life cycle record, the assets must be able to exchange data with production systems and plant operators via standardized interfaces with standardized semantics. This will be achieved via the Asset Administration Shell concept, if the Asset Administration Shells or their generic submodels, as well as their communication between Industrie 4.0 components, are defined in standards. It is recommended to support and advance the activities of IEC/TC 65/WG 24 with respect to the IEC 63278 series.

[RE 2.3-1 V4] [RE 2.3.2 V4] ➡ [RE 5.1.4-1 V5]

[RE 5.1.4-2 V5] Synchronizing the concepts of the Asset Administration Shell and the Digital Twin

It is recommended that the concepts currently being developed for both the Digital Twin and the Industrial IoT in ISO/IEC JTC 1/SC 41/WG 6 and for the Asset Administration Shell in IEC/TC 65/WG 24 be synchronized.

[RE 5.1.4-3 V5] ISO/IEC-21823 series in the Industrie 4.0 context

DIN’s NA 043-01-41 IoT and other relevant bodies and committees should carefully review the current standards of the ISO/IEC 21823 series with regard to their direct reference to industry and report back to the mirror committee.

[RE 2.4-3 V4] ➡ [RE 5.1.4-3 V5]

[RE 5.1.4-4 V5] International cooperation in the context of the Asset Administration Shell and the Digital Twin

ISO/IEC JTC 1/SC 41/WG 6, IEC TC 65 and ISO/IEC JTC 1/SC 41/AG 20 should continue their joint collaboration and exchange on the “industrial sector” with regard to the Industrial IoT, the Asset Administration Shell and the Digital Twin with all the associated liaisons.

[AE 5.1.4-5 V5] OPC UA Companion Specifications for implementing the Digital Twin

The semantically standardized information in the OPC UA Companion Specifications should be used to implement the Digital Twin for the production environment. Through interoperable semantics, Digital Twins of production are usable efficiently, both in an industry-specific and a cross-industry manner, and will achieve high value.

[RE 5.1.4-6 V5] OPC UA in the context of the Asset Administration Shell

The Asset Administration Shell concepts should continue to be expanded in the context of OPC UA. For this purpose, further needs for standardized semantics for production information are to be reported to the responsible OPC UA working groups for development. In the sense of the "single source of truth", information from production, such as the products of mechanical and plant engineering, must be standardized at their point of origin using OPC UA Companion Specifications and harmonized in the context of the current IEC/TC 65/WG 24 standards (e.g., the differentiation and complementarity of the two technologies should be described).

[RE 5.1.4-7 V5] Supplement existing standards (ISO 13585-1 or IEC 61360) on semantics

The data formats required in the information world are taken from ISO 13585-1 or IEC 61360. The properties of ECLASS are also coded on this basis. However, Asset Administration Shells and their submodels require additional property types for operational use compared to the purely descriptive characteristics of an asset. These are states and parameters of the assets as well as their measured and actuator values (dynamic data). Commands and entire functions (often called technical functions) must also be described using the same concepts. The concept of properties in today's standards is to be extended by such semantics in the data models to be able to represent dynamic values correctly. For example, this can be done with corresponding new attributes in the ISO 13584/ IEC 61360 data model. Models for functions/commands are to be developed or existing ones defined in standards.

[RE 2.5-1 V4] ➡ [RE 5.1.4-7 V5]

[RE 5.1.4-8 V5] Holistic development of AAS submodels

It is recommended to advance the development and internationalization of the submodels of the Asset Administration Shell in IDTA, ISO and IEC. The application of the submodels should follow the holistic approach as far as possible to enable their applicability in other areas as well.

[RE 5.1.4-9 V5] Digital life cycle record as a submodel of the Asset Administration Shell

The information model for the digital life cycle record is to be mapped as a submodel of the Asset Administration Shell for technical systems. It is further recommended that the DIN 77005 series be brought to international standardization.

[RE 2.3.13 V4] ➡ [RE 5.1.4-9 V5]

[RE 5.1.4-10 V5] Standardization of the AAS submodels

Operational models and appropriate tools are needed for a simulation. Tools and models need common semantics for machine execution and for a comprehensible representation of the characteristics of the considered system in its environment.

[RE 2.3.22 V4] ➡ [RE 5.1.4-10 V5]

[RE 5.1.4-11 V5] Standardization of the AAS submodels

Conditions must be created so that functional requirements (e.g., role and expected function) and their fulfilment (e.g., supported role, provided function) can be included in standardized dictionaries so that the execution of production processes by production systems can be planned.

[RE 2.3-9 V4] ➡ [RE 5.1.4-11 V5]

[RE 5.1.4-12 V5] Digital nameplate

In September 2022, IEC 61406 on the digital nameplate (based on DIN SPEC 91406) was published. In addition, modifications should be made to all application standards for machine-readable marking based on VDE V 0170-100:2021-02 “Digital nameplate”.

[RE 2.3-11 V4] [RE 2.3.12 V4] ➡ [RE 5.1.4-12 V5]

[RE 5.1.4-13 V5] Standardization of the AAS submodels and properties

Preparatory activities for the standardization of submodels of the Asset Administration Shell are to be initiated. The integration should be done in coordination with IEC/TC 65/WG 24. A submodel must be standardized in its basic properties, which means that there must be both basic/obligatory properties and basic/obligatory functions that can be extended by Industrie 4.0 partnerships via individual properties and functions. This means that, for example, the same mandatory properties and functions must be available for different assets when considering energy, so that, requirements, e.g., for all components of a system or systems of a plant can be easily consolidated or controlled in the same way. Specific additions remain possible.

[RE 2.3-8 V4] ➡ [RE 5.1.4-13 V5]

5.1.5 Industrial communication

[RE 5.1.5-1 V5] Heterogeneous industrial networks

New standards for global mobile network technologies should be configured or existing standards expanded in such a way as to enable a seamless transition between local industrial networks and industrial mobile radio networks. Starting points for the standardization of such heterogeneous, industrial networks can be the documents of the 5G-ACIA for the integration of Ethernet, TSN and OPC UA in 5G.

[RE 2.6-1-V4] ➡ [RE 5.1.5-1 V5]

[RE 5.1.5-2 V5] Network management

Services and interfaces for the management of the various industrial communication networks should be specified uniformly and from an application perspective. Account must be taken of the need to distinguish between the provision of networks (management services) and the provision of communications services (control services).

[RE 2.6-2-V4] ➡ [RE 5.1.5-2 V5]

[RE 5.1.5-3 V5] Integration of communication devices in Industrie 4.0

Communication devices with adaptive functions for device and network management are to be modelled as Industrie 4.0 components. Appropriate properties and services are to be specified for a communications submodel of an Asset Administration Shell.

[RE 2.6-3 V4] ➡ [RE 5.1.5-3 V5]

[RE 5.1.5-4 V5] Data traffic models

For the planning of communication networks (wired and wireless) a model is to be developed with which industrial data communication scenarios can be specified.

[RE 2.6-4 V4] ➡ [RE 5.1.5-4 V5]

[RE 5.1.5-5 V5] Reliability assessment of communication networks and services

Standards for the reliability assessment of communication networks and communication services are to be developed, which allow a quantitative, transparent and contractually secure assessment from the perspective of industrial applications at the interface between provider and user.

[RE 2.6-5 V4] ➡ [RE 5.1.5-5 V5]

[RE 5.1.5-6 V5] Evaluation of real-time communication

Parameters and methods for the evaluation of industrial real-time communication systems (wired and wireless) are to be summarized and uniformly defined in a standard.

[RE 2.6-6 V4] ➡ [RE 5.1.5-6 V5]

[RE 5.1.5-7 V5] Validation and testing

Communication standards for Industrie 4.0 are to provide test specifications that can be used to demonstrate the performance, conformity and interoperability of products.

[RE 2.6-7 V4] ➡ [RE 5.1.5-7 V5]

[RE 5.1.5-8 V5] Frequency spectra

Efforts to obtain a worldwide harmonization of frequency spectra for industrial automation applications should be actively assisted by experts in measurement and automation technology. Industry associations and the Plattform Industrie 4.0 should formulate arguments and requirements for administrations (e.g. BNetzA in Germany) for consideration in frequency use planning. These should be internationally coordinated. The regulation applicable to Germany for frequency allocations for local frequency use in the 3,700-3,800 MHz frequency range should apply worldwide in the interests of international harmonization. It is also recommended to harmonize the concepts for non-public industrial network operation and for cooperative network operation with a public network operator.

[RE 2.6-8 V4] ➡ [RE 5.1.5-8 V5]

[RE 5.1.5-9 V5] Standards for non-public mobile local area networks for industry

New standards for global mobile network technologies should be configured or existing standards expanded in such a way that the use of a non-public local industrial network is also possible. The starting point should be the 5G-ACIA's White paper "5G non-public networks for industrial scenarios".

[RE 2.6-9 V4] ➡ [RE 5.1.5-9 V5]

[RE 5.1.5-10 V5] Seamless convergence of (heterogeneous) industrial networks with 5G networks

Using the network slicing concept, it is possible to virtualize non-public industrial 5G subnets in public 5G networks to serve applications and services with Industrie 4.0-specific communication requirements. However, to enable the seamless integration of (heterogeneous) industrial networks with 5G networks, open interfaces between the two types of infrastructure still need to be defined. Attention needs to be paid to the ability to position assets with the 5G infrastructure.

[RE 2.6-10 V4] ➡ [RE 5.1.5-10 V5]

[RE 5.1.5-11 V5] 3GPP-specified mobile communications systems

With reference to the rapidly progressing specification process for mobile communications systems in 3GPP, publications on many aspects of communication are emerging in the 5G-ACIA. These publications can also help to reassess industrial communication from the point of view of its use for Industrie 4.0. Topics such as the integration of TSN and OPC UA in 5G, data traffic modelling or the assessment of the reliability of communication networks and communication services can be a source of information for future standardization projects. It is therefore recommended to pay attention to the work of the 5G-ACIA.

[RE 2.6-A1 V4] ➡ [RE 5.1.5-11 V5]

[RE-5.1.5-12 V5] Security in industrial communication

It is recommended to develop and advance an agreed and accepted security model. The content should be integrated in the fieldbus standards.

[RE 5.1.5-13 V5] Single Pair Ethernet (SPE)

It is recommended to advance the integration of SPE (Single Pair Ethernet) into fieldbus standards. Relevant standards should be included by IEEE in IEC 61158-2.

[RE 5.1.5-14 V5] Advanced Physical Layer (APL)

It is recommended to advance the integration of the APL (Advanced Physical Layer) into relevant fieldbus standards. The technical specification (IEC TS 63444) is a first step and an integration of the content into IEC 61158-2 should follow.

[RE 5.1.5-15 V5] Consistent standardization for industrial location management

Industrial location management requires the consistent standardization of the following aspects:

(1) technologies for determining location data;

(2) formats for location data;

(3) agreements on data storage (central/decentralized);

(4) protocols for data transport;

(5) applications and visualization tools.

[RE 2.6-11 V4] ➡ [RE 5.1.5-15 V5]

5.1.6 Functional safety in Industrie 4.0

[RE 5.1.6-1 V5] Functional safety in the engineering process

The implementation of the Industrie 4.0 concepts described in Version 4 of the Standardization Roadmap Industrie 4.0 leads to a further modularization of plants and components with great effects also on the engineering process. It should be considered how Industrie 4.0 concepts can also take into account plant safety and functional safety issues. This can be done by extending the concept of the Asset Administration Shell to a "safe Asset Administration Shell". In this respect, the "Module Type Package (MTP)" initiative deserves special mention, as this initiative not only considers Industrie 4.0 aspects in the area of automation technology in general and functional safety in particular, but also describes fundamental ways in which Industrie 4.0 principles can be successfully applied in the construction of plants for amorphous production.

[RE 3.5-1 V4] ➡ [RE 5.1.6-1 V5]

[RE 5.1.6-2 V5] Safety and security standardization activities

The work on safety and security should be further deepened and made more concrete. This should be done as part of the revision of IEC TR 63069 or IEC TR 63074, for example. Further work should keep the new Machinery Regulation in particular in mind and address its information security requirements.

[RE 3.5-4 V4] ➡ [RE 5.1.6-2 V5]

[RE 5.1.6-3 V5] Standardized procedures and methods for on-time risk management throughout the life cycle

Standardized procedures and methods should be developed to enable on-time risk management throughout the life cycle without compromising the confidentiality of the technical documentation. In accordance with the most recent German-Chinese agreements, a guideline should first be developed ("Sino-German white paper on functional safety in I4.0" – described in Version 4 of the Roadmap), which sensitizes the stakeholders with regard to the possible repercussions (increases in risk or compromise of risk-reducing measures) of different Industrie 4.0 application scenarios on plant safety. Furthermore, the possibility of making safety- and security-relevant accompanying documents digitally exchangeable, for example via a digital nameplate, should be sought.

[RE 3.5-2 V4] ➡ [RE 5.1.6-3 V5]

[RE 5.1.6-4 V5] Design requirements for human-machine interfaces with potentially dangerous or safety-relevant systems

Design requirements for interfaces for interactions with potentially dangerous or safety-relevant systems go beyond usability design. Aspects of functional safety and the interaction of human and technical reliability must be taken into account. Relevant standards to be examined are: DIN EN ISO 13849-1, 2, DIN EN ISO 26800, DIN EN 894, DIN EN ISO 9241-11, -210.

[RE 2.7-21 V4] ➡ [RE 5.1.6-4 V5]

5.1.7 Artificial intelligence in industrial automation

[RE 5.1.7-1 V5] Standardized terminology and definitions in the context of AI and Industrie 4.0

Definitions of terms in existing (international) standards with a focus on "Artificial intelligence" are to be continuously checked for consistency with regard to their applicability in Industrie 4.0 and – where necessary – harmonized and/or clarified for industrial automation. Identified inconsistencies and obstacles to application are to be dealt with in the corresponding standards committees. The scope of documents (specifications, standards as well as regulatory acts) should be clearly defined. Existing regulation needs to be made stricter in this regard. Also in the development of AI-based systems, the resulting common and consistent basic understanding of the terms as well as the interrelationships of concepts used, with special consideration of the use of AI methods, represents an important basis for interdisciplinary collaboration in the development of industrial AI systems.

[RE 4.1-1 V4] ➡ [RE 5.1.7-1 V5]

[RE 5.1.7-2 V5] Consistent application of existing terminologies and definitions in the context of AI and Industrie 4.0 (esp. in regulatory activities)

Since a regulation, its core aspect and (sub-)systems to be regulated to which a regulation is to apply, is ambiguous and partly contradictory in the normative context, it is neither possible to regulate in a targeted manner nor to address adequately on the basis of standardization mandates ("standardization requests"). Therefore, it is recommended to use existing definitions of AI (and, if applicable, methods [RE 5.1.7-6 V5]) or quality requirements (see [RE 5.1.7-7 V5]) consistently (also in the regulatory context) or, if necessary, to strive for appropriate adaptations of existing standardized definitions; but not to create one's own (partly orthogonal to existing definitions) formulated references. Likewise, a clear demarcation from existing standards, e.g., for high-risk AI systems and safety, should be made where appropriate.

See also [RE 3.5.3 V4]

[RE 5.1.7-3 V5] Strengthening of education and training regarding the standardization of (software) innovation for engineering professions

Artificial intelligence largely comprises software-centric innovations and solutions. Understanding innovation concepts in software-intensive systems and the role of standardization in general, and for such systems in particular, are of essential industrial importance. Strengthening of vocational and academic training with regard to innovation and standardization is necessary. To this end, the first initiatives have already been initiated by DIN and DKE at national level. These should be further strengthened and corresponding initiatives (research and funding) should be pushed and supported politically.

[RE 5.1.7-4 V5] Strengthening the coupling of (research) innovation and standardization

Strengthening and promoting the participation of national institutes for standardization in research projects in order to facilitate a comparison between the normative and scientific state of the art, and to accompany the national or international introduction of new (scientific) findings in an advisory and consolidating capacity. In larger scientific initiatives (consisting of several research projects), a (synchronization and orchestration) project with a normative focus should also be considered (in addition to a frequently used scientific exchange platform and synchronization). Furthermore, at European level this would achieve multilateral exchange between national standards institutes for standardization and science, and thus also a leverage effect through Europe's basic federal structure in international standardization.

[AE 2.2-A1 V4] ➡ [RE 5.1.7-4 V5]

[RE 5.1.7-5 V5] Further and continuous updating of a standardization map and derivation of strategies for action

An initial map for standardization activities for AI in the context of Industrie 4.0 was drawn up based on the recommendations for action from the previous Version 4 of the Standardization Roadmap Industrie 4.0. In order to take advantage of the various recommendations for action described in the Standardization Roadmap for AI, the development and continuous updating of a standardization map for artificial intelligence in general, and for AI in industrial applications in particular, is recommended. In particular, the exchange with other international standardization activities of ISO, IEC and at European level (e.g. the Stand.ICT.eu project or the artificial intelligence Focus Group) should be actively promoted.

[RE 4.1-6 V4] ➡ [RE 5.1.7-5 V5]

[RE 5.1.7-6 V5] Criteria for the classification and evaluation of AI systems

A uniform location and assessment framework for AI methods should be developed by horizontal standardization bodies. Appropriate classifications of the autonomy of technical systems, necessary metrics for evaluation methods for Industrie 4.0 as well as further requirements, concepts and methodologies should be addressed by vertical standards committees and should be introduced in standards committees in an appropriate manner. Characteristics of the AI methods with respect to quality features (see [RE 5.1.7-7 V5]) should be taken into account. A precise definition of AI methods, their quality criteria or quality parameters, and a clear demarcation from other (normative) definitions should be ensured. In terms of Industrie 4.0, any inconsistencies with vertical and relevant horizontal standards are to be examined and addressed appropriately within standardization.

[RE 4.1-3 V4] ➡ [RE 5.1.7-6 V5]

[RE 5.1.7-7 V5] Quality description, test methods and conformity assessment of AI-based systems in Industrie 4.0

AI is seen as a tool that can change the quality, such as reliability, trustworthiness, security/safety, etc. of (sub)systems. Thus, a definition of universal criteria and workflows for acceptance and comparison of the performance of AI-based systems is necessary A description of essential work steps in the (engineering) workflow and the application of evaluation criteria, in particular for highly critical systems, in accordance with the draft AI Act of the EU, must be defined normatively, taking into account relevant, already existing standards (see also [RE 5.1.7-8 V5]), and should in particular include the definition of individual process steps for development, test, acceptance, operation and maintenance, taking into account the description of the structure of the system and the subsystems as well as the AI-based parts and their influence on quality criteria. For this purpose, a uniform definition and description of the meaning for characteristic (quality) features such as acceptance, reliability, predictability, controllability, explainability, cybersecurity (security), functional safety (safety) and uncertainty are necessary (see also [RE **5.1.7-1 V5], [RE 5.1.7-2 V5]** and **[RE 5.1.7-6 V5]**).

[RE 5.1.7-8 V5] Strengthening vertical standardization relating to artificial intelligence

Stronger integration of existing standardization activities (e.g., electrical engineering, automation, especially in IEC and ISO) and existing AI standardization activities (essentially in ISO/IEC JTC 1/SC 42). To this end, it is recommended that standardization activities be shifted to the corresponding (subject-specific, possibly vertical) bodies in ISO and IEC. Greater involvement of ISO/IEC JTC 1/SC 42 in AI-related standardization activities in ISO and IEC is recommended.

[RE 4.1-7 V4] ➡ [RE 5.1.7-8 V5]

5.2.1 Data spaces

[RE 5.2.1-1 V5] Securing Industrie 4.0 – Suitability of regulation-related standardization for cybersecurity in the EU.

The focus of security standardization in support of European regulation at CEN/CENELEC under the New Legislative Framework (NLF) is currently on the work on cybersecurity for radio equipment (RED). It is to be expected that the upcoming "Cyber Resilience Act" will result in extensive security-related work at CEN/CENELEC, which will be of great importance in the form of horizontal security standards for Industrie 4.0 security, and this globally, beyond the European area. Any regional differences in cryptography (and also data protection) may force the possibility of profiling and agile implementations of security standards, especially for communication on a global level.

[RE 3.2-1 V4] ➡ [RE 5.2.1-1 V5]

[RE 5.2.1-2 V5] Globally interoperable identity management and security functions to protect and control data spaces

Only international standards on data spaces can guarantee and secure global collaboration. European solution building blocks such as eIDAS must be supplemented globally or made accessible and accepted.

5.2.2 Industrial Security

[RE 5.2.2-1 V5] Standardized security development process for integrators and operators

IEC 62443-4-1 defines a security engineering process for component suppliers; this must be expanded to take into account the other parties that form part of the value added network, such as machinery construction companies, operators and integrators, in order to make it possible to implement comprehensive and consistent security architectures within the sense of "security engineering".

[RE 3.2-7 V4] ➡ [RE 5.2.2-1 V5]

[RE 5.2.2-2 V5] Generic interface for security elements in embedded systems

The implementation of cryptographically based security functions in Industrie 4.0 devices must be protected against attacks. High security levels can be achieved by integrating suitable security hardware. However, the diversity and complexity of the assemblies available on the market with their special boundary conditions lead to high integration costs and thus to a relatively high application threshold for manufacturers and integrators, especially for SMEs. A "Generic Trust Anchor API", which would be supported by many hardware manufacturers as a uniform programming interface, can provide help.

[RE 3.2-8 V4] ➡ [RE 5.2.2-2 V5]

[RE 5.2.2-3 V5] Global infrastructure to support key management

The "ZeroTrust" principle aims to implement end-to-end security architectures that cover both the IT and OT areas of a company (or an entire Industrie 4.0 application scenario). Here it is important that the resulting security mechanisms are as globally interoperable as possible and are supported by suitable infrastructures for key management, for example.

[RE 5.2.2-3 V5]

[RE 5.2.2-4 V5] Industrie 4.0 security management processes

The increasing networking within the framework of Industrie 4.0 requires coordinated and cooperative processes and standards for security management, which can interact across domains. This includes:

→ Support of security management for dynamically reconfigurable automation systems (plug and automate)
→ Integration of the Digital Twin in security management
→ Secure dynamic patch management
→ Uniform, machine-readable format for vulnerability information
→ Continuous compliance monitoring
→ Resilience, business continuity
→ Security event handling
→ Supply chain security

[RE 3.2-10 V4] ➡ [RE 5.2.2-4 V5]

[RE 5.2.2-5 V5] Establishment of an SBOM as a necessary information artefact in the software supply chain (for Industrie 4.0)

Consideration of existing standards ISO/IEC 5962:2021, SPDX and OWASP CycloneDX Software Bill of Materials (SBOM) standard and consideration of regulatory requirements (US: EO 14028 section 4 (e); EU: CRA and NIS2.0)).

[RE 5.2.2-6 V5] Guideline "Security-Training"

IT security aspects must already be considered in the planning and development phase of products and systems ("security by design"). Employees in production need additional IT security knowledge, as production and IT worlds merge and competence requirements fundamentally change. Essential organizational and process-specific security aspects must be considered in the corresponding standards for their implementation. Suitable guideline standards for "security training" must be derived from this.

[RE 3.2-11 V4] ➡ [RE 5.2.2-6 V5]

[RE 5.2.2-7 V5] Security for the Asset Administration Shell

Each manifestation of an Asset Administration Shell requires security mechanisms for integrity, access/confidentiality, and verifiable processing in operations along the value chain. Continuation of the work within IEC/TC 65.

[RE 5.2.2-8 V5] Security standards for the exchange of type and instance information of Asset Administration Shells

Online and offline options are to be provided for the exchange of type or instance information. A data format for transfer files is proposed. Mechanisms for ensuring authenticity and confidentiality must be defined and established as global standards. Access APIs are to be defined. This must be coordinated with the concepts for secure identities (see **[RE 5.2.2-11 V5]**) and access control (see **[RE 5.2.2-9 V5]**).

[RE 3.2-6 V4] ➡ [RE 5.2.2-8 V5]

[RE 5.2.2-9 V5] Access, roles and authorization mechanisms for Industrie 4.0

Access to and use of data and resources within the framework of Industrie 4.0 cooperations require standardized rules. Existing concepts, such as IEC 62351, can serve as a starting point. Boundary conditions governing implementation include scalability and the potential for representation in the form of specific vertical requirements.

[RE 3.2-5 V4] ➡ [RE 5.2.2-9 V5]

[RE 5.2.2-10 V5] Security for agile systems

Definition of standards for technical negotiation of security profiles (based on capabilities and characteristics) for Industrie 4.0 communication or cooperation of entities in different security domains, which are sometimes regulated differently.

This includes the:

→ Identification and authentication of the partners involved (requirements and solutions)
→ Evaluation of the trustworthiness of cooperation partners
→ Technical support for information classification and requirements for handling appropriately classified data
→ Especially when using AI methods: Their quality must be ensured; methods of assessment are important and must be developed (research)
→ Topic quality certificates
→ Definition trustworthiness profile – capabilities, supply chain, traceability, (cloud trustworthiness), trustworthiness framework (ISO/IEC JTC 1/SC 41).

[RE 3.2-3 V4] ➡ [RE 5.2.2-10 V5]

[RE 5.2.2-11 V5] 5G Security for Industry

Features and possibilities of 5G require the possibility of dynamic, flexible and scalable security architectures. On the basis of suitable industrial use cases, it must be possible to derive the security requirements taking into account existing security standards such as ISO/IEC 27001 and IEC 62443 within the framework of the 5G standards.

→ Industrial security guidelines must be implementable, especially for Industrie 4.0-based cross-company communication.
→ Application of IEC 62443 and ISO/IEC 27001 must be possible, especially in in-house operations.
→ The protection of meta data of the communication of devices, machines and plants must be guaranteed. This applies in particular to data that can be collected by the telecommunications provider via the signalling channel.
→ Industry-compatible security requirements should be actively incorporated into the 5G standardization process.

[RE 3.2-9 V4] ➡ [RE 5.2.2-11 V5]

[RE 5.2.2-12 V5] Security infrastructure for secure inter-domain communication

Secure communication requires secure identities (identifiers and attributes) and anchors of trust. Generating and administering secure identities and securing their trustworthiness require a secure infrastructure. The requirements for this include factors such as scalability, resilience, profitability, long-term fitness for purpose, and (user-defined) trustworthiness beyond local legal jurisdictions and independent of local jurisdictions. Cross-domain governance structures to support secure Industrie 4.0 communication must be defined and standardized.

This will require the close cooperation of all industrial stakeholders. The possible use and integration of national and regional solutions (such as eIDAS) must be examined with the help of the regulatory authorities and tested in field trials/pilot projects.

[RE 3.2-2 V4] ➡ [RE 5.2.2-12 V5]

5.2.3 Privacy

[RE 5.2.3-1 V5] Protection of personal data within value networks

Definition of process standards for the protection of personal data within value networks up to the protection of personal data required for individualized products with batch size 1, etc.:

→ Rules for classifying data and information, also in the respective context (contexts are very relevant because they massively influence the sensitivity and meaningfulness of data, e.g., an article number in an internet order seems harmless until it can be linked to a drug product database for example, which then shows that the product is a cancer drug or a psychotropic drug, for example. The knowledge that the format of the article number indicates a medical device is also significant).
→ Rules for the exchange of classified data and information (which data may be passed on where under which circumstances, what the recipient may do with it, when it must be deleted, if necessary);
→ Methods of evaluating the trustworthiness of cooperation partners. Examples of mechanisms are manufacturer declarations, certificates, auditing.

[RE 3.3-1 V4] ➡ [RE 5.2.3-1 V5]

[RE 5.2.3-2 V5] Handling of personal or person-related data for employees

Large scale data collection, storage and processing will be an essential part of Industrie 4.0. Protection targets in this context include availability, integrity, confidentiality and legally compliant handling of the data. For employees, the handling of personal or person-related data collected, for example, when using assistance systems, is particularly relevant. DIN EN ISO 27500, ISO 924 ff. and ISO 26800, for example, require supplements or amendments.

[RE 2.7-6 V4] ➡ [RE 5.2.3-2 V5]

[RE 5.2.3-3 V5] Relationship between data protection standards and Industrie 4.0 scenarios

The fitness for purpose of existing standards that relate to Industrie 4.0 scenarios must be clarified:

→ In the case of automated communication across domain boundaries (e.g., as the boundaries between jurisdictions), the relevant data protection requirements and associated security requirements derived from them must be harmonized.
→ Access control standards must be able to manage resources in a domain-oriented manner in order to ensure that the respective level of data protection is taken into account, especially for cross-border data transfers in the value chain, for example from the EU to third countries whose level of data protection has or has not been recognized as equivalent to that of the EU, especially since such recognition can be granted or withdrawn. The domain-oriented administration of access control standards must functionally cover these recognition dynamics. Data protection standards must apply to "intelligent" home appliances (household appliances, toys, etc.) produced in Industrie 4.0 processes and their communication needs (including back to the manufacturer).

[RE 3.3-3 V4] ➡ [RE 5.2.3-3 V5]

[RE 5.2.3-4 V5] Privacy compliant auditing

Definition of standards for privacy-compliant auditing processes that process personal data and/or work at risky interfaces in a manner compatible with data protection, including

→ methods for data-saving (e.g. aggregated) logging
→ methods for local processing and evaluation of sensitive data so that they can be aggregated or deleted afterwards.

[RE 3.3-2 V4] ➡ [RE 5.2.3-4 V5]

5.2.4 Trustworthiness

[RE 5.2.4-1 V5] Definition of process standards for the trustworthiness of collaboration within an Industrie 4.0 value network

These include:
- → the standardization of "trustworthiness capability profiles"
- → methods of evaluating the trustworthiness of cooperation partners (examples of mechanisms are: manufacturer declarations, certificates, auditing)
- → rules for the exchange of classified data and information
- → minimum security requirements for B2B
- → integration of processes and components
- → compliance with regulatory provisions

[RE 3.4-1 V4] ➡ [RE 5.2.4-1 V5]

[RE 5.2.4-2 V5] Machine-readable profiles for trustworthiness

Machine-readable profiles for trustworthiness are the prerequisite for the automated implementation of **[RE 5.2.4-1 V5]** and **[RE 5.2.4-3 V5]**.

[RE 5.2.4-3 V5] Define standardized trustworthiness management mechanisms along the value chain (chain of trust)

The trustworthiness of value contributions along the supply chain can change over the life cycle of the product.
This requires the management of a chain of trust, in part because of government regulations that go beyond bilateral relationships between suppliers and customers.

5.3.2 Overview of sustainability modules

[RE 5.3.2-1 V5] "Sustainability building blocks"

It is recommended to define different standard modules for digital data acquisition and further processing with regard to the implementation of a digital, automated acquisition and assessment of sustainability aspects in Industrie 4.0 systems. These standard modules can then be flexibly aggregated into larger information units as needed.

[RE 5.3.2-2 V5] Climate and environmental data on (industrial) plant

Climate, environmental data and other ecological sustainability aspects of (industrial) plant and production facilities should be recorded, presented and made comparable in a standardized form.

[RE 5.3.2-3 V5] Social sustainability aspects at production facilities

Social sustainability aspects of (industrial) plant and production facilities should be recorded, presented and made comparable in a standardized form.

[RE 5.3.2-4 V5] Digital sustainability passport for (industrial) plant and production facilities

Ecological and social sustainability aspects of (industrial) plant and production facilities should be combined in a uniform and clearly structured digital sustainability passport, without mixing up the data on ecological and social sustainability.

[RE 5.3.2-5 V5] Climate and environmental data on mobile plant

Climate, environmental data and other ecological sustainability aspects of mobile plant or means of transportation should be recorded, presented and made comparable in a standardized form.

[RE 5.3.2-6 V5] In-house processes

It is recommended to develop and establish a standardized format for describing in-house processes and for sharing process information with third parties.

[RE 5.3.2-7 V5] Linear processes across plant and sites

It is recommended to develop a standardized format for the description of primarily linear processes across (industrial) plant and sites, which defines as an integral part a standardized methodology for the exchange of data or information in the process or between the cooperating actors.

[RE 5.3.2-8 V5] Circular process across assets

It is recommended that a standardized format for describing circular processes across assets be developed that defines, as an integral component, a standardized methodology for data sharing in the circular process or among collaborating actors.

[RE 5.3.2-9 V5] Climate and environmental data on the product

Climate and environmental data directly related to products should be collected, presented and made comparable in a standardized form.

[RE 5.3.2-10 V5] Digital sustainability passport for products

It is recommended that a standardized, modular format be developed and established for the content and structure of the digital sustainability passport for digitally documenting and making available climate, environmental data and other sustainability aspects for products.

[RE 5.3.2-11 V5] Digital ecosystem/network

There should be standards for the sustainability assessment of digital ecosystems or networks, focusing on the assessment of the network as a whole.

5.3.3 Aspects of social sustainability and recommendations for action

[RE 5.3.3-1 V5]

The increasing possibilities to organize work independent of time and place lead to a further spread of mobile work, which was strongly accelerated by the corona pandemic. The design options for mobile work differ substantially from those for stationary work. DIN EN ISO 9241-1:1997 for example, requires supplements or amendments. It is recommended that data be collected on the prevalence of mobile/location-independent work in the production environment in order to be able to assess the relevance of specific aspects, including data transmission issues, for standardization. Use cases relating to location-independent work with the need to operate work equipment, etc. and the transfer of information to people working at different locations should be included in the standardization of assistance systems such as data glasses. In particular, delays in the transmission of video and audio data can reduce performance in locally separated work (e.g., troubleshooting) and increase the cognitive load on users.

[RE 2.7-7 V4] ➡ [RE 5.3.3-1 V5]

[RE 5.3.3-2 V5]

It must be examined how the requirements of inclusive work design, i.e., the design of Industrie 4.0 work systems geared to the specific capabilities, requirements and the needs of workers with different disabilities, and the inclusion of people with disabilities in the system design process (early and appropriate participation), can be taken into account by supplementing and expanding the existing standards or by considering them separately. It should also be examined whether the standardization of assistance systems, user interfaces, etc. can take up the provision of information in at least two sensory channels and in simple language.

6.1 Requirements in the open source context

[RE 6.1-1 V5] Strengthen cooperation of standardization with open source communities

It is recommended to strengthen the cooperation of standardization with open source communities. Here, specifications (e.g., DIN SPEC or VDE SPEC) within the framework of Industrie 4.0 can offer a good opportunity for piloting.

[RE 3.1-1 V4] ➡ [RE 6.1-1 V5]

[RE 6.1-2 V5] Identify synergies and create points of contact

In order to accelerate the spread of Industrie 4.0, the development of open source implementations should be promoted to an even greater extent. Synergies must be identified here and points of contact created (e.g., through a DIN DKE OSPO) that make it easy to use and collaborate on open source projects, particularly in interaction with standardization.

[RE 3.1-2 V4] ➡ [RE 6.1-2 V5]

[RE 6.1-3 V5] Mutual involvement

The potential of open source and standardization working together must be better exploited and activities must be thought together. It is therefore recommended that standardization be more closely involved in open source projects. Likewise, open source solutions should be increasingly considered in standardization activities (in the area of Industrie 4.0).

6.2 Requirements in the context of use cases

[RE 6.2-1 V5] Justification of standardization activities through use cases

In principle, all standardization projects should be justified on the basis of examples/business scenarios/use cases. The IEC 63283-2 use case collection can be used as input for this purpose. If it is found that use cases are missing in IEC 63283-2, such missing use cases should be reported to IEC/TC 65/WG 23 TF Use Cases.

[RE 6.2-2 V5] Supplementation of IEC 63283-2 to include data space use cases

Analyse the results of **[RE 6.2-1 V5]** to determine the extent to which IEC 63283-2 can and should be supplemented by “data space” use cases (responsible body: IEC/TC 65/WG 23 TF Use Cases)

[RE 6.2-3 V5] Systematic preparation of use cases

Systematic preparation of examples/business scenarios/use cases for the provision, evaluation and management of data in the manufacturing industry (responsible bodies: e.g., Gaia-X community, ZVEI data economy working group, VDMA platform economy working group, etc.).

Commentary: This recommendation for action also includes, in particular, the detailing of the topics mentioned in the “Industrial data spaces” chapter of the Standardization Roadmap Industrie 4.0 Version 5, where data spaces offer the potential to open up new applications.

[RE 6.2-4 V5] Recommendations for action for standardization

Derivation of recommendations of action for standardization from the requirements for standardization formulated in the IEC/TC65/WG 23 Use Cases (responsible body: IEC/TC 65/WG 23 TF Gap analysis and recommendations for standardization actions)

[RE 6.2-5 V5] Analysis of use case collections

Screening of existing and emerging use case collections from e.g., ISO/IEC JTC 1/SC 41, ISO/IEC JTC 1/SC 42 with regard to a completion of the IEC/TF 65/WG 23 use cases (responsible body IEC/TC 65/WG 23 TF Use Cases)

[RE 6.2-6 V5] Supporting the task force “Smart Manufacturing Use Cases” of IEC/TC 65/WG 23

The task force “Smart Manufacturing Use Cases” of IEC/TC 65/WG 23 (IEC TR 63283-2 “Industrial-process measurement, control and automation – Smart manufacturing – Part 2: Use cases”) should be actively supported by Germany in order to obtain a consistent and representative collection of use cases for Industrie 4.0. This will help the task force to establish itself as the central hub for a systematic consolidation of the many different use cases in the Industrie 4.0 environment.

[RE 2.1-1 V4] ➡ [RE 6.2-6 V5]

[RE 6.2-7 V5] International coordination on use case descriptions

The various concepts that formulate use cases based on more detailed descriptions such as the IIRA template should be continued. Examples are the joint activities with China and Japan, selected activities of Labs Network Industrie 4.0 (LNI 4.0), as well as activities at European Union level, such as those planned in particular in the context of artificial intelligence within the AI-PPP4.

[RE 2.1-2 V4] ➡ [RE 6.2-7 V5]

[AE 6.2-8 V5] Use of the term "use case"

Efforts should continue to be made to avoid overloading the term "use case" unnecessarily. It is not the aim to prescribe a uniform understanding, but it is recommended that activities position themselves in relation to the understanding formulated in this Standardization Roadmap Industrie 4.0 so that this can be further enhanced.

[AE 2.1-A1 V4] ➡ [AE 6.2-8 V5]

[RE 6.2-9 V5] Use cases for work organization and design

Work organization and design are central elements and success factors of a work system Use cases should be described which characterize the target image for work organization and task structure and which measures are planned to involve users. A further core component of work system design is the task-appropriate, ergonomic design of work equipment (e.g., in accordance with DIN EN ISO 6385). The relevant use cases should therefore describe the means by which this requirement should be implemented. Because sociotechnical use cases typically imply new competence requirements, it should be described how the need for competence and competence development should be determined or at least estimated in which way the design of the Industrie 4.0 component(s) should contribute to competence maintenance, competence development and learning/development-promoting design of Industrie 4.0 work systems, and which other ways of competence maintenance, competence development and learning/development-promoting design of Industrie 4.0 work systems should be considered and designed. It is valuable for forward-looking work design to employ use cases to describe and assess possible physical and mental hazards and their prevention.

[RE 2.7-3 V4] ➡ [RE 6.2-9 V5]

6.3 Requirements in the context of machine-readable standards

[RE 6.3-1 V5] Adaptation of Industrie 4.0 mechanisms, principles and ontologies for the digitalization of standards and standardization

Industrie 4.0 concepts and mechanisms, such as the Reference Architecture Model Industrie 4.0 (RAMI 4.0) and Asset Administration Shell, are to be further investigated and applied in the context of the digitalization of standards and standardization. In principle, the challenges of Industrie 4.0 are transferable to the digitalization of standards and standardization, so that alignment or compatibility of the targeted solutions should be ensured. A first step could be the identification and integration of Industrie 4.0-relevant information units, as well as semantic mechanisms into the standards information model (SIM).

[RE 6.3-2 V5] Use of fragmented standards information in the context of Industrie 4.0 applications

To effectively take advantage of SMART standards and the envisaged information model (SIM), target systems of fragmented and semantic information must be prepared to use such information. It is therefore necessary to work out how digital standard content can be imported, processed and reused in the context of the Asset Administration Shell and other Industrie 4.0 systems. A first step could be the development of a submodel for standards, which can represent both the document-based and the fragmented (provision-based) information from standards in different stages of expansion.

[RE 6.3-3A V5] Use and consolidation of reference definitions (IEV etc.)

In order to establish the uniqueness of terms, a 1:1 correspondence between designation and definition should be aimed at. For this purpose, the reference definitions in IEV (IEC 60050), which already represent a consolidated state of standardization terminology, should be used with as few changes as possible. If a new definition is unavoidable, participating committees should be identified, definitions coordinated, and the IEV supplemented or corrected as part of new IEC TC 1 projects.

[RE 2.4-4 V4] ➡ [RE 6.3-3A V5]

[RE 6.3-3B V5] Systematic comparison of all relevant standard definitions

Both in the extension of the IEV (IEC 60050) and in standardization projects in the technical committees, all relevant term entries from valid standards should be collected in order to promote the reuse of definitions. Terminology databases and tools for structuring the relevant entries should be used. Technical bodies should explain deviations from other standards in Notes.

[RE 6.3-3C V5] Software-supported assistance with systematic matching

The collection of all relevant term entries within IEC/TC 1 and other technical bodies should be database-driven to ensure completeness. In order to make the possible options manageable and to make an informed choice, computer assistance should be used to support text comparisons, pre-structure definitions, and point out rule violations.

[RE 6.3-3D V5] Software-supported assistance of formal checking

In order to prevent formal terminological discrepancies, the formal requirements for creating definitions according to the ISO/IEC Directives, Part 2:2021, ISO 10241-1:2011 (confirmed 2022), and ISO 860:2022 and ISO 704:2022 should be considered. The verification of compliance with the requirements should be systematic and, if possible, supported by tools.

[RE 6.3-4 V5] Skills for standards users

Review of the necessary skills for the development and use of Industrie 4.0-relevant SMART standards

Note: It should be noted here that **[RE 2.7-5 V4]** on the topic of “leadership” is no longer addressed in the current Roadmap, as no concrete possibility of standardization has been identified. **[RE 2.7-9 V4]** on the subject of “lifelong learning” is also no longer taken up, as a corresponding guideline has been drawn up in the “Arbeitswelt Industrie 4.0” expert committee of the VDI/VDE Society for Measurement and Automation Technology. Furthermore, **[RE 2.7-28 V4]** on the topic of “Design of work environments, work spaces and work stations” is no longer included in the current version, as this topic concerns legal aspects. See also Version 4 of the Standardization Roadmap Industrie 4.0 [2].

4 STAKEHOLDER AND STANDARDIZATION ENVIRONMENT

4.1 Classification and environment of standardization in Germany, Europe and internationally

The following chapter briefly presents the environment of standardization in Germany, Europe and internationally. A complete overview of the current standardization environment can be found in the Annex.

4.2 In Germany

Plattform Industrie 4.0 was founded in 2013 to implement the German Industrie 4.0 standardization strategy. This was followed by the establishment of the Standardisation Council Industrie 4.0 (SCI 4.0) and the Labs Network Industrie 4.0 (LNI 4.0). As shown in Figure 2, the interaction of the three organizations forms a quick-reacting and interwoven structure of strategy, conception, testing and standardization. The collaboration between the partners in the various test centres makes it possible to generate market-relevant requirements. Validated outcomes are then incorporated directly into the standardization process via the SCI 4.0. The findings and concepts defined by Plattform Industrie 4.0 are also taken into account and carried across into international standardization in a suitable focused manner via the SCI 4.0. This will accelerate the development of marketable products and ensure Germany's leading position in Industrie 4.0 concepts.

Plattform Industrie 4.0 was created by the three industrial associations BITKOM, VDMA and ZVEI and is currently under the leadership of the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Federal Ministry of Education and Research (BMBF). Plattform Industrie 4.0 brings together representatives from industry, the scientific sector, trade unions, politics and consumer groups, in order to work towards achieving a shared future for Germany as an industrial location. In terms of subject matter, it focuses on the fields of research and innovation, the security and safety of networked systems, legal frameworks, work, and further education and training. Of course, all in addition to standardization. The German standardization organizations DIN and DKE are involved in these working groups and support the Plattform Industrie 4.0 in applying their outcomes to the process of standardization, especially on an international level.

Together with the industrial associations BITKOM, VDMA and ZVEI, DIN and DKE founded the **Standardization Council Industrie 4.0 (SCI 4.0)**. The SCI 4.0 is responsible for orchestrating standardization activities and, in this role, acts as a point of contact in connection with all matters relating to standardization in the context of Industrie 4.0. In collab-

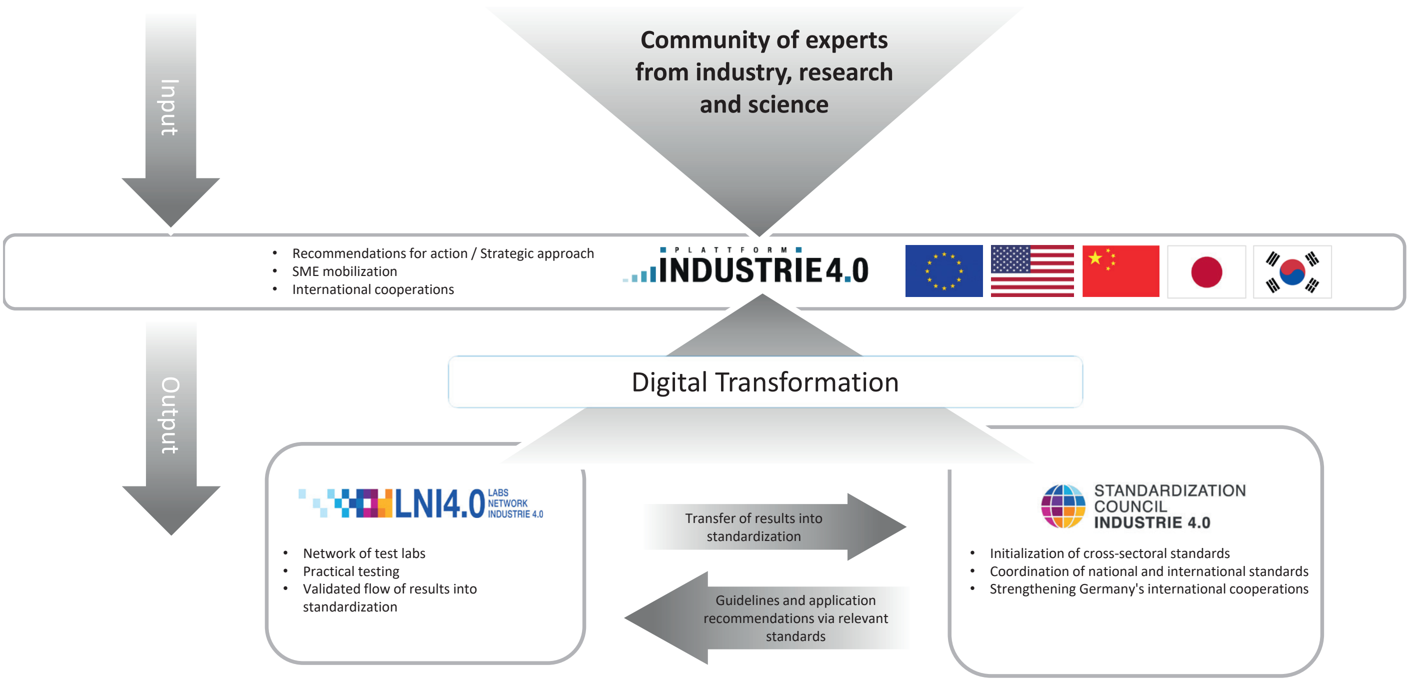


Figure 2: Network of central actors (Source: according to SCI 4.0)

oration with the Plattform Industrie 4.0, the SCI 4.0 brings German stakeholders together and represents their interests in international bodies and consortia. SCI 4.0 also supports the concept of practical testing in test centres by initiating and carrying out new standardization projects that fulfil the needs that have been identified.

The **Labs Network Industrie 4.0 (LNI 4.0)** was set up by companies of the Plattform Industrie 4.0, together with BITKOM, VDMA and ZVEI. New technologies, business models and use cases in Industrie 4.0 can be tested in the test centres, and their technical and economic feasibility can be examined before they are launched on the market. This means that LNI 4.0 offers an ideal laboratory and experimental environment, particularly for small and medium-sized enterprises. Thanks to close collaboration with the SCI 4.0, new Industrie 4.0 solutions, and the standards and technical rules they draw on, can be tested. In turn, the results flow directly into the further development of standards and specifications – nationally and internationally.

4.3 International

Here is an overview of relevant European and international committees and important coordinating bodies:

→ CEN/TC 310 “Advanced Automation technologies and their applications”,
→ CEN/TC 319 “Maintenance”,
→ CEN/TC 438 “Additive Manufacturing”,
→ ISO/TC 184 “Automation systems and integration”,
→ IEC/TC 65 “Industrial-process, measurement, control and automation”,
→ ISO/IEC JTC 1 “Information Technology”,
→ ISO/IEC JTC 1/SC 41 “Internet of Things and Digital Twin”,
→ ISO/IEC JTC 1/SC 42 “Artificial Intelligence”,
→ ISO/TC 307 “Blockchain and distributed ledger technologies”.

4.4 Coordinating bodies – smart manufacturing

Under German leadership, the ISO/TMBG/SMCC [5] “Smart Manufacturing Coordinating Committee” has actively promoted international work on the topic of Industrie 4.0. The goal is to coordinate the work in an interdisciplinary manner and to develop implementation recommendations, in particular with regard to generating a common international approach. At the same time, a national mirror committee was implemented at DIN in order to offer interested parties a national platform for playing a significant role in shaping international work.

IEC/SyC SM [6] “System Committee Smart Manufacturing”, chaired by Germany, is located directly under the Standardization Management Board (SMB) of IEC and started its work in 2018. Alongside coordinating standardization activities, the tasks of IEC/SyC SM are to identify gaps and overlaps, especially relating to the collaboration between relevant standards organizations and consortia. Due to the substantive overlaps that exist within the work of ISO/TC 184 [7] and IEC/TC 65 [8], the two bodies formed the ISO/IEC Joint Working Group 21 (ISO/IEC JWG 21) [9] “Smart Manufacturing Reference Model(s)” in July 2017. Germany and Japan jointly lead ISO/IEC JWG 21. The aim is to bring about the harmonization of existing reference models and to develop smart manufacturing reference models, especially with regard to various aspects such as life cycles and the technical and/or organizational hierarchies relating to assets. Furthermore, the development of a fundamental architecture for smart manufacturing components as an essential part of the virtual representation of assets is planned (Industrie 4.0 components).

The CEN-CENELEC-ETSI “Coordination Group on Smart Manufacturing” (SMa-CG [10]) was founded in 2019 and is led by DIN/DKE. The Coordination Group advises on ongoing European activities related to smart manufacturing and synchronizes the position of CEN, CENELEC and ETSI vis-à-vis SDOs and other third parties on standardization.

5 ISO/TMBG/SMCC “ISO Smart Manufacturing Coordinating Committee” (SMCC)

6 IEC/SyC SM “System Committee Smart Manufacturing”

7 ISO/TC 184 Automation systems and integration

8 IEC/TC 65 Industrial-process measurement, control and automation

9 ISO/IEC JWG 21Joint Working Group 21 “Smart Manufacturing Reference Model(s)”

10 SMa-CG CEN-CENELEC-ETSI “Coordination Group on Smart Manufacturing”

5 STANDARDIZATION IN THE KEY TOPICS

5.1 Aspect 1: Interoperability

5.1.1 Characteristics and their system integration in industrial applications

In a digital ecosystem, companies from different industries, such as suppliers, logistics companies and manufacturers, are interconnected in a complex value adding system. To provide their value proposition, companies use various technical systems such as factories, plant, tools, variable software and control systems, engineering tools or even simple screws.

For the **interoperability** of technical systems in the industrial production environment [11], [12], [13], the exchange of information between systems plays an essential role. In particular, heterogeneous systems should have the ability or **characteristics** to interact independently and purposefully, without the help of external entities (see also Chapter 5.1.3). In order to classify a system and express the data and information by simple values, properties or characteristics are used for this purpose.

5.1.1.1 Technical systems

As is well known, Industrie 4.0 is about the development of intelligent **technical systems** [14] that can adapt to their environment and the needs of their users during operation [15], as well as about an ever more extensive and thus absolutely efficient integration of a wide variety of technical subsystems into the emerging digital business processes. If one understands “intelligence” as meaning “problem-solving competence”, one can also attribute intelligence to technical systems insofar as they solve problems defined for a human being or an organization. Such systems should be able to easily and comprehensively structure, process, store and exchange data with other systems.

Since the interaction and communication between systems are subject to constant interactions in these relationships (see Figure 3), the goal of Industrie 4.0 standardization is to identify ways in which such systems can be built independently of each other and still operate in a fully interoperable manner.

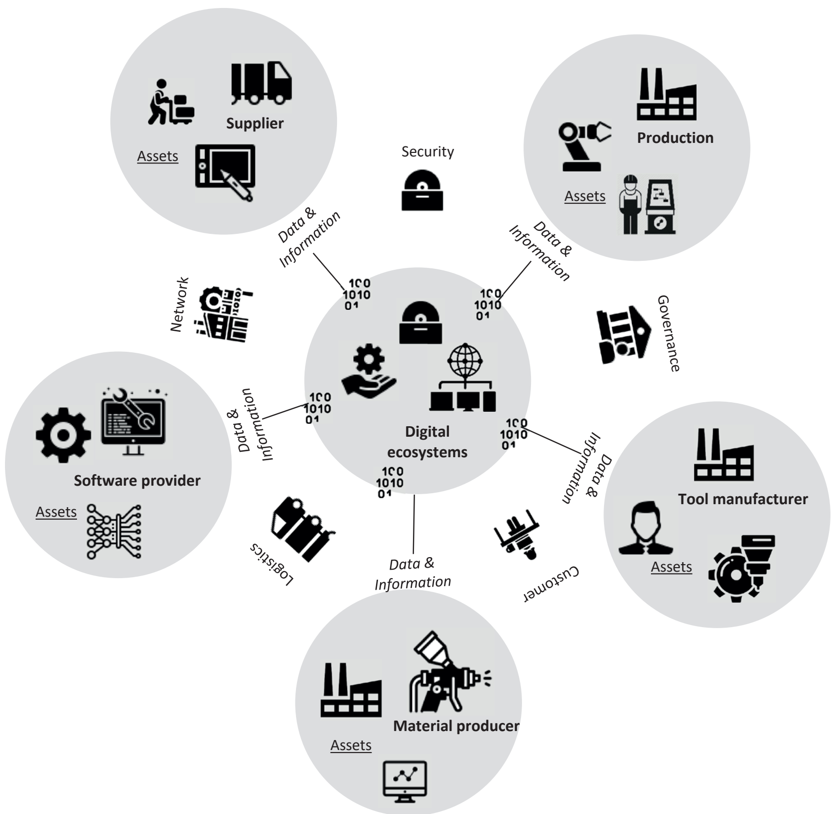


Figure 3: Assets and interoperability in the industrial production environment (Source: O. Meyer, Fraunhofer IPA)

Interoperability in the industrial production environment describes the ability of autonomously and independently operating heterogeneous systems to work together in a targeted manner without the help of external influences from the physical or real world and to exchange information unambiguously [15] (see also Contribution to semantic interoperability in Chapter 5.1.3). In the context of Industrie 4.0, we talk about "**assets**", which are not just any technical systems, but objects that have a value for an organization (see IEC TS 62443-1-1:2009 [11] and ISO/IEC 20924:2021 [12]).

5.1.1.2 Requirements on assets as sociotechnical systems

Architecturally, all assets can be described in their complex interrelationships using the Reference Architecture Model Industrie 4.0 [12]. If the interactions between humans and machines or plants in a technical system are included, we speak of a **sociotechnical system** [16] Since Industrie 4.0 value networks are, by their very nature, systems of systems, this has consequences not only in terms of technologically understood interoperability, but also in terms of the human-centred design of Industrie 4.0 work systems. Such consequences arise in particular for the area of system design, where an integrated view and design of technology, organization and person (sociotechnical system design) is indispensable. This results in recommendation for action [RE 5.1.1-1 V5].

One of the typical properties of Industrie 4.0 value networks is that they consist of a system of systems and therefore have a high degree of inherent complexity. This will be intensified due to the continued high pace of technological innovation and the increased dynamics of change (up to and including disruptive innovations). As described above, dealing with this complexity of Industrie 4.0 value creation networks is a major challenge for the humane design and configuration of Industrie 4.0 work systems, even in the requirements definition and target planning phase with regard to the overall system. For the micro level of design (e.g. design of assistance systems, human-machine interfaces) this means: Particularly with the goal of designing work that is conducive to learning, it is important to carefully weigh up the use of artificial intelligence, automation and assistance systems (such as data glasses or tablets) on the one hand and the creation of scope for action and decision-making, learning requirements and development incentives on the other. Accordingly, the blanket statement that complexity should always be reduced does not apply; instead, a differentiated view is necessary. The selection and presentation of complex information should also be balanced [RE 5.1.1-2 V5].

In the sense of a prospective or preventive work design, this holistic-integrative perspective is to be adopted at the very beginning. But even if elements of Industrie 4.0 are subsequently integrated into existing systems, social aspects should be taken into account in addition to technical ones as early as the requirements determination phase (sociotechnical requirement engineering). Version 4 of the Standardization Roadmap Industrie 4.0 [2] pointed out that work designers need assistance in dealing with this complex requirement. The German standards committee NA 023-00-06 AA "Ergonomics for work design and product design for integrated and intelligent digitalization" is therefore currently working on a project to support company work designers with the aim of providing orientation knowledge [RE 5.1.1-3 V5].

Workers should be valued and taken into account in their role as future key users of the Industrie 4.0 system of work systems as development and design partners who, with their experiential knowledge, make a critical contribution to the usability and humane design of the respective work system.

For the overall process of system design, instead of the conventional waterfall model of (iterative) requirements definition, development, realization and implementation, an agile iterative approach is required in view of the technological, ecological, global economic and socio-cultural development dynamics, because this is the only way to guarantee a process and result quality that corresponds to the state of the art and to the sociotechnical requirements [RE 5.1.1-4 V5].

There are different possibilities for dynamic task allocation (division of functions) between human and machine (e.g., task allocation is adjusted on a daily basis based on algorithms and specified by the system vs. task allocation is determined on a daily basis by the operator). These are associated with different psychosocial effects (e.g., experience of self-efficacy). The allocation of tasks, however, is contrary to the usual process of determination in advance of task processing by planners without any possibility for employees to influence it and should therefore be made transparent

11 IEC TS 62443-1-1:2009 "Industrial communication networks – Network and system security – Part 1-1: Terminology, concepts and models"

12 ISO/IEC 20924:2021 "Information technology – Internet of Things (IoT) – Vocabulary"

and comprehensible for employees. A procedure for the process-accompanying evaluation of adaptive task allocation with special attention to safety, security and psychosocial effects of employees is to be developed and integrated into standardization [RE 5.1.1-5 V5]. This is also related to the topic of data protection.

A solution can be classified as a human-centred design of an Industrie 4.0 work system if the dynamic design of the human-machine division of functions when working with a digital assistance system keeps the human in the process, depending on the situational conditions, the current task and the available knowledge and skills of the worker, and if the human retains scope for action and decision-making, learning and development opportunities. There is a high probability that, in addition to the aspects of "work design conducive to learning" and "prevention/maintenance of human work ability", this will simultaneously result in a higher overall reliability of the Industrie 4.0 value creation process, because the workers are and remain in a position to react to deviations and unexpected system states proactively and appropriately to the situation. In this way, errors can be avoided that can have major consequences for humans and the environment, especially in high-risk plants [RE 5.1.1-5 V5], [RE 5.1.1-6 V5], [RE 5.1.1-7 V5].

5.1.1.3 Properties and a common language for Industrie 4.0

Each asset has certain characteristics or properties that are described in the information world, and the terms "characteristic", "feature" and "property" are often used interchangeably. To achieve clear semantics, the terms "feature" and "property" are used in the following text. In this context, a **feature** is a characteristic of an asset observed in the physical world that can also be used, for example, to classify the asset. A **property** is a defined representation of such a feature in the information world. The use of internationally standardized properties is recommended.

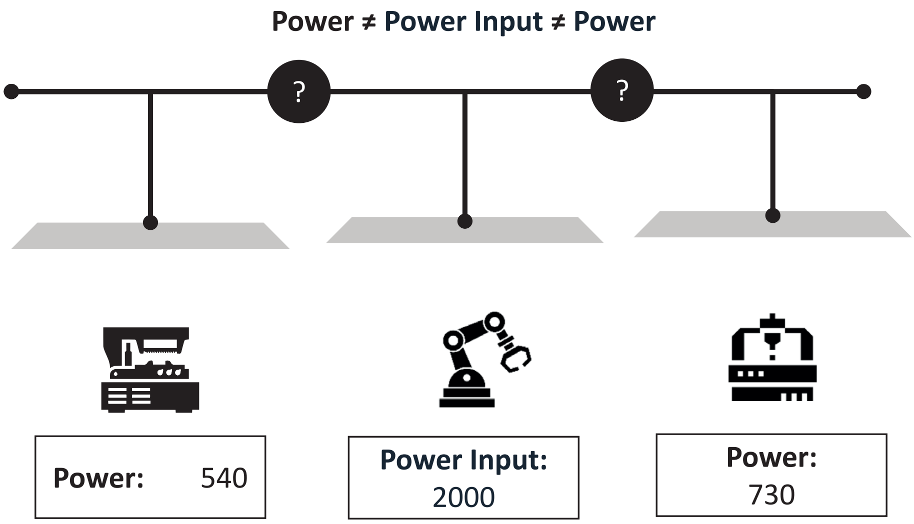
Each feature is permanently assigned to an asset. For example, the features of an asset are defined by its components, materials and geometry, which can be fully described by properties. In particular, the ability of an information technology system to capture information and communicate across system boundaries with the least loss of content is enabled by the use of standardized properties. The concept of semantic interoperability postulates that the exchange of expressions of features, in the sense of **standardized properties**, enables the receiving systems to interpret the data in a factually correct manner and to use them in subsequent processes such as orders, production orders and maintenance information.

The description of the characteristics of an asset is an essential prerequisite for its representation. Here, the definition and designation of the feature, its value specifications of use, identification, as well as the schema of the transmitted data in the form of a (binary) data technical representation with attributes and references are considered. Information in such a form makes it possible to capture the asset in the physical world as a list of features with the information and mirror it into the virtual world.

However, it is not sufficient to describe an asset by means of features only. In order for an asset to exchange information with another asset (see Figure 4), a **common language** [17] **based on semantics** (see also Chapter 5.1.3), which includes the interaction mechanisms, must be defined to provide a unified model for processing information. While it is sufficient for humans to vaguely interpret the information based on their experience and knowledge for interacting in their environment and to be able to modify their assumptions about their actual context of action at any time, machines can only function properly if their context of action is unambiguous [18]. This means that it is essential for the execution of computer-aided processes across companies, such as development, manufacturing or sales processes, that such features and variable process states are clearly defined beyond the operational information world. Only in this way can computers on both sides decode the transmitted information and understand each other.

Other important normative activities for production rely on semantic interface standards such as OPC UA [20] for machine and plant engineering products used in discrete and continuous production. The data exchange between assets includes semantically standardized information from the life cycle phase of production, as well as related necessary information, e.g., identification. There are two classes of interface standards. Domain-specific standards define specific information of the individual machine and component types, such as robotics, machine tools, injection moulding machines. The interface standards series "OPC UA for machinery" defines cross-domain information based on selected use cases, such as status monitoring, results transfer or job and energy management. The goal is a comprehensive semantic description of production information for the Digital Twin of production.

Figure 4: "Lingua franca" as the greatest challenge of Industrie 4.0 (Source: O. Meyer, Fraunhofer IPA acc. to [1])



As of 2022, the OPC UA interface standards for machine and plant engineering products include around 60 specifications [21] that have been published as open source. Some 600 companies [13], organizations, and various sector committees worldwide are involved in developing a uniform language for production as a de facto standard for interoperable communication of production information from production to cloud systems [14] (see also [AE 5.1.4-5 V5]).

5.1.1.4 Creation of standardized dictionaries for mapping characteristics

The methodology for mapping characteristics is defined by standards. Properties that fulfil the interoperability requirements are standardized, for example, via **dictionary entries** of the ECLASS Content Development Platform (CDP) [22], in IEC by IEC 61360-4 Common Data Dictionary [15] (IEC CDD) or in ISO/TC 184/SC 4 [16]"Industrial data" by ISO 22745 [17].

There are currently efforts to transfer the plug-and-play concept that is familiar from information technology to automation technology in order to achieve what is known as plug-and-produce. An important step in the plug-and-produce concept is the coordination of requirements and the assurance of device characteristics [19] [RE 5.1.1-8 V5]. The concept of the IEC 62832 [18] series "Digital factory framework" is to describe relationships between property-value statements of different assets and comparing them in an automated way will be further explored at this point. Further similar activities should be considered:

→ harmonization of ECLASS and IEC CDD (see also [RE 5.1.1-11 V5]);
→ comprehensive description of system components in IEC CDD;
→ definition of standardized models from the domain by means of future description by IEC working groups;
→ development of a mapping procedure from OPC UA Companion Specification to a property description (see also [AE 5.1.4-5 V5]) and [RE 5.1.4-6 V5])).

Another focus in the standardization of properties is the **documentation and exchange of relevant to maintenance** and information over the life cycle of an asset [RE 5.1.1-9 V5]). An ultimate goal is therefore to standardize the appropriate vocabulary for technical documentation. This work will be continued within the framework of the iiRDS standards and VDI 2770 Part 1 [19] [RE 5.1.1-10 V5]). The joint work of the iiRDS consortium with the VDI committee has been actively pursued in recent years to ensure compatibility between the two standards. For this purpose, necessary preparations for the translation of VDI 2770 Part 1 into different languag-

13 VDMA "Overview of OPC UA working groups"
14 VDMA "Global production language based on OPC UA"
15 IEC 61360-4 "Common Data Dictionary"
16 ISO/TC 184/SC 4 "Industrial data"
17 ISO 22745 series "Industrial automation systems and integration – Open technical dictionaries and their application to master data"
18 IEC 62832 series "Digital factory framework"
19 VDI 2770 Part 1 "Operation of process engineering plants – Minimum requirements for digital manufacturer information for the process industry – Fundamentals"

es were examined in 2022 and an international NWP (New Work Proposal) application was submitted to IEC/TC 3/WG 28[20]. The project has started under German leadership as IEC PAS 63485 ED1[21] "Intelligent Information Request and Delivery Specification (iiRDS) – A process model for information architecture".

In the IEC work is currently being carried out in IEC TC 65/SC 65E/WG 2[22] and IEC SC 3D[23]. IEC TC 65/SC 65E/WG 2 is developing the methods for standardizing the descriptions of intelligent assets in manufacturing and specifies how the asset descriptions can be used for electronic data exchange between two computer systems, for example a customer system and a supplier system, using features and lists of features. The definition, structuring and identification of classes and properties, structural designs of product data, dictionaries and ontologies, publication of information, and maintenance and quality control of the IEC CDD will continue to be carried out in IEC SC 3D [RE 5.1.1-12 V5]).

The extension of current standards to include semantics has been actively progressing in recent years (see also [RE 5.1.4-7 V5]). The Whitepaper "Modelling the semantics of data of an Asset Administration Shell with elements of ECLASS", published in 2021, describes the requirements for the ECLASS Dictionary (including semantic requirements for use of certain data types). The ECLASS Association has started a project to implement these requirements and has begun to define data structures to support interoperability. It is expected that these modifications and data structures will be published in the next release of ECLASS 13.0.

In IEC, IEC SC 3D has started work to update the basic definitions of IEC Dictionary and to support the semantic requirements for the IEC Dictionary. New projects were initiated in 2022:

→ IEC 61360-1[24]: The 4th edition of the standard is to be revised as the 5th edition, and the methods and requirements from the semantic work are to be considered. For example, the support "dynamic property" is also discussed.
→ IEC 61360-6[25]: The 1st ed. will be revised, and an improved guideline for the definition of semantic content in the IEC CDD will be developed.
→ IEC 61360-7 DB[26]: A new product data dictionary has been released that provides data structures that can be used equally across many different domains.

5.1.1.5 Intentions to harmonize properties in the global normative environment

The parallel developments that can be seen today in some places in IEC, ISO and ECLASS need to be further coordinated by activities to **harmonize the properties** between the bodies involved [RE 5.1.1-11 V5]. In this context, the joint project COMDO (One COMmon Data RepOsitory for Smart Manufacturing), initiated by ECLASS and IEC together with ISO at the end of 2020, was actively pursued with the aim of realizing the development of a single common data repository. Again, progress was made on current implementation approaches for a common repository (see Figure 5) to develop a plan for implementation across relevant use cases [RE 5.1.1-12 V5] (see also [RE 5.1.4-7 V5]). The next step is to submit a feasible proposal for implementation to the technical steering committees of the project partners (IEC/SMB, ISO/TMB, ECLASS Board).

20 IEC/TC 3/WG 28 "Intelligent Information Request and Delivery specification (iiRDS) – A Process Model for Information Architecture"

21 IEC PAS 63485 ED1 "Intelligent Information Request and Delivery Specification (iiRDS) – A Process Model for Information Architecture"

22 IEC TC 65/SC 65E/WG 2 "Product properties & classification"

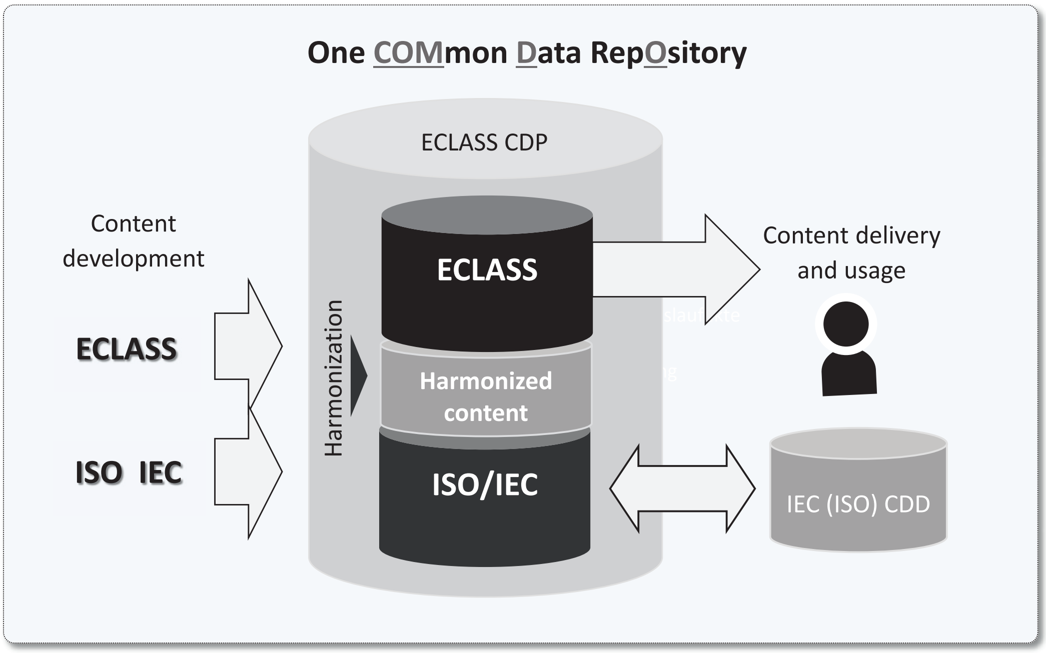
23 IEC SC 3D "Classes, Properties and Identification of products – Common Data Dictionary (CDD)"

24 IEC 61360-1 5th ed. "Standard data element types with associated classification scheme – Part 1: Definitions – Principles and methods"

25 IEC 61360-6 2nd ed. "Standard data element types with associated classification scheme for electric components – Part 6: CDD modelling guideline for the use of concepts"

26 IEC 61360-7 DB "Data dictionary of cross-domain concepts"

Figure 5: Harmonization of properties in the COMDO project (Source: O. Meyer, Fraunhofer IPA acc. to COMDO)



5.1.2 Reference architecture models

Reference architecture models provide necessary tools and artefacts and set structural frameworks for the smooth implementation of Industrie 4.0 scenarios. Reference architecture models play a special role in digital ecosystems in particular, as they ensure the integration and interaction of technical objects in the value chain.

The architecture of a software system is essentially understood as the system's structure in the sense of the compositional relationships of its interacting components (see ISO/IEC/IEEE 42010[27] as well as results from the Progress Report [1] on [RE 2.2-1 V4] and [RE 2.2.-2 V4]). Above all, knowledge of the effects of these relationships enables the architect to efficiently implement requirements in technical systems [23]. Therefore, reference architectures in the sense of generally accepted principles of structuring (software) systems can be very helpful for systematizing the process of implementing requirements and understanding them, and accordingly play an important role in standardization.

27 ISO/IEC/IEEE 42010 "Systems and software engineering – Architecture description"

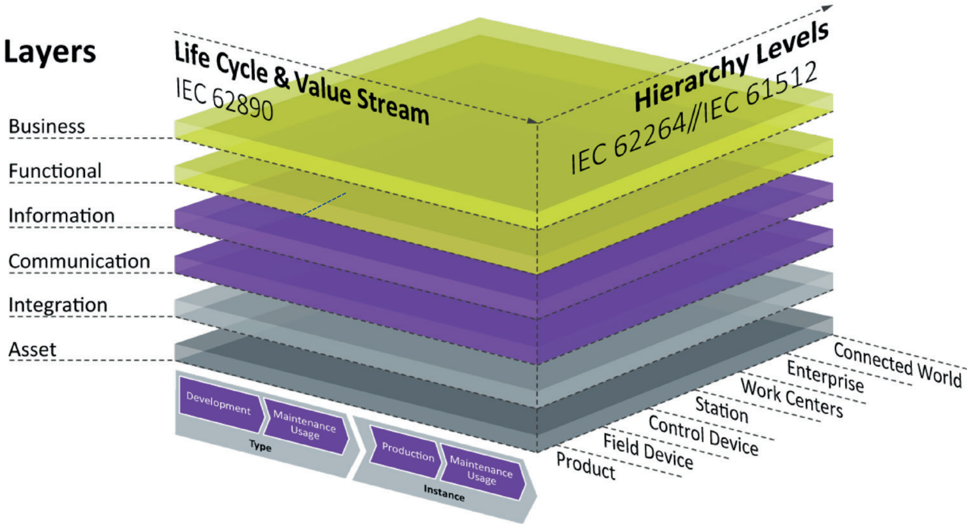
5.1.2.1 New requirements for reference architecture models for Industrie 4.0

The modelling of such reference architectures is usually not only done at the system level, but also includes the regulatory level, which ultimately aims to capture the development of a technical system in its life cycle according to predefined rules. By using both levels, different patterns can emerge. These are often captured as models and are the necessary reference point for an architect to build the complete architecture (e.g., company IT architecture, cloud architecture, IoT architecture, etc.). Conformity with the rules is the basic prerequisite and the starting point for interoperability in the value chain. This enables the architect to describe systems both in their individual parts and in their complexity (see also results from the Progress Report [1] on [RE 2.2-3 V4]).

The **Reference Architecture Model Industrie 4.0 (RAMI 4.0)** [12] is a three-dimensional consolidation of the most important aspects of Industrie 4.0. The concept has been published as IEC PAS 63088 and publication as an international standard is in preparation. It ensures that all participants in Industrie 4.0 adopt a common perspective and build a shared understanding.

As Figure 6 shows, the three axes map all the essential aspects of Industrie 4.0. These axes make it possible to classify an object, such as a machine, in the model. Thus, highly flexible Industrie 4.0 concepts can be described and implemented

Figure 6: Reference architecture model Industrie 4.0 (RAMI 4.0) (Source @ Plattform Industrie 4.0 and ZVEI)



with RAMI 4.0. The reference architecture model allows a step-by-step migration from today's world to the Industrie 4.0 world. Full details on this topic are described in Version 4 of Standardization Roadmap Industrie 4.0 [2].

Semantic interoperability in particular plays an essential role with regard to RAMI 4.0 (Chapter 2 as well as Chapter 5.1.3) [12], [24]. RAMI 4.0 and the description elements of the semiotic triangle can be directly related to each other. The (x-)axis of RAMI 4.0 from type development to instance usage is declared by semantic means (from the semantic domain in the semiotic triangle as a "typograph"). The (y-)axis of RAMI 4.0, which includes the product in its networked entrepreneurial, technical world, i.e., safety and security zones, is realized with physical, technical means (from the semiotic domain of things (devices, machines, etc.)). The (z-)axis of RAMI 4.0, which includes the system architecture, can be captured by linguistic-ontological means, used in standards, because it is about the integration, communication, information derivation, functions and business processes in which the assets, i.e., the semantically and physically considered things, are used and in which they are embedded.

The "life cycle and value stream" axis is understood in the semiotic triangle as a stepwise semantic change from concept to product and thus is described by semantic means (e.g., graph-based artefacts or modal logics).

5.1.2.2 Current work in the environment of the Industrial Internet of Things

A smart and networked factory, e.g., in the sense of the IEC 62832 series "Digital factory framework", builds on the Internet of Things (IoT) and the vision of the Digital Twin (see also Chapter 5.1.4). Such a factory is a production facility in which all "things" – e.g., industrial equipment, buildings, household appliances, or cars – are networked in the sense of the IoT and are able to process different types of information, exchange the information interoperably and semantically correctly in the value chain, as described in the previous section.

In manufacturing, we usually speak of the Industrial IoT (IIoT). This starts with connecting sensors and devices to a network and collecting data that can significantly improve productivity by optimizing production processes or logistics in conjunction with software systems such as ERP or physical assets. Sensors are needed to capture the collection of various actual data sets and to track current production information. The actual data sets can be compared by the Digital Twin with the target data sets in real time.

The networking aspects, as well as the reference architectures underlying the IoT, are being actively standardized in ISO/IEC JTC 1/SC 41[28] "Internet of Things and Digital Twin". In this context, many standards are currently listed by ISO/IEC JTC 1/SC 41, which provide the important

28 ISO/IEC JTC 1/SC 41 "Internet of Things and Digital Twin"

building block for the development of intelligent systems. In Germany the working committee of the same name, DIN NA 043-01-41 AA[29], is making a significant contribution to the development of these standards (see also [RE 5.1.4-3 V5], [RE 5.1.4-4 V5]):

→ ISO/IEC 30141:2018[30], 1st ed. (2018-08-30) "Internet of Things (IoT) – Reference architecture", is currently being developed;
→ ISO/IEC 21823[31]series "Internet of Things (IoT) – Interoperability for IoT systems", the first four parts of which have already been published;
→ ISO/IEC 30165:2021[32], 1st ed. (2021-07-06), "Internet of things (IoT) – Real-time IoT framework";
→ ISO/IEC TR 30176:2021[33], 1st ed. (2021-11-04), "Internet of Things (IoT) – Integration of IoT and DLT/blockchain: Use cases";
→ ISO/IEC 30162:2022[34], 1st ed. (2022-02-07), "Internet of Things (IoT) – Compatibility requirements and model for devices within Industrial IoT systems";
→ ISO/IEC 30147:2021[35], 1st ed. (2021-05-28), "Internet of Things (IoT) – Integration of IoT trustworthiness activities in ISO/IEC/IEEE 15288 system engineering processes".

5.1.2.3 Cloud computing and industrial cloud platforms in standardization

The IoT generates large amounts of data that can be processed, analysed and made available to users. This process takes place in a continuous feedback loop, usually performed either by humans or by intelligent software such as machine learning or artificial intelligence in near real-time. Local computing power and data availability are usually required in order for users to benefit from faster and more reliable services. This can be achieved in the context of edge computing, i.e., close to the user's physical location or data source, and can bring significant benefits to an organization, such as the use of sensitive applications and low latency to save bandwidth. Edge computing enables an organization to distribute a common pool of resources across a large number of sites and scale a centralized infrastructure to meet the demands of a growing number of devices and data. In conjunction with IoT and **cloud computing**, for example, an IoT gateway can send data between the edge, the cloud, or the central data centre for further local processing.

Industrial cloud platforms (e.g. based on IoT architectures) and cloud computing play a central role in the design of digital ecosystems. IoT solutions of the cloud-based platform, such as remote management of heterogeneous smart objects (sensors, actuators, modules) that are not bound to specific communication protocols or networks for networking with the service platform, can come into play in the current energy crisis. The ISO/IEC JTC1 Advisory Group on Systems Integration Facilitation (SIF)[36] [25], established in 2016 to promote expertise in the JTC1 committee and to take advantage of standardization in the area of systems integration for complex market requirements, therefore recommends further standardization work or exchange with the International IoT Security Round Table on the Internet of Things and edge computing and their impact on the Sustainable Development Goals and the European Green Deal [26] (see also Chapter 5.3).

To establish a high level of trust and improve interoperability and portability of infrastructures, data, and services, other initiatives also contribute to the concepts of data sharing and data autonomy. For example, the basic principles for autonomous data sharing based on open standards, such as the development of a reference architecture (e.g., International Data Spaces Association IDSA [27]), the research, development, and application of value-based trusted technologies such as artificial intelligence, data technologies, and robotics (e.g., Big Data Value Association BDVA [28]), and the necessary tools for machine-level interoperability (e.g., umati [29] based on OPC UA, the Open Platform Communications Unified Architecture [16]) are advanced within the framework of Gaia-X.

29 DIN NA 043-01-41 AA "Internet of Things (IoT) and Digital Twin"
30 ISO/IEC 30141:2018 "Internet of Things (IoT) – Reference architecture"
31 ISO/IEC 21823 series "Internet of Things (IoT) – Interoperability for IoT systems"
32 ISO/IEC 30165:2021 "Internet of things (IoT) – Real-time IoT framework"
33 ISO/IEC TR 30176:2021 "Internet of Things (IoT) – Integration of IoT and DLT/blockchain: Use cases"
34 ISO/IEC 30162:2022 "Internet of Things (IoT) – Compatibility requirements and model for devices within Industrial IoT systems"
35 ISO/IEC 30147:2021 "Internet of Things (IoT) – Integration of IoT trustworthiness activities in ISO/IEC/IEEE 15288 system engineering processes"
36 JTC 1 Advisory Group on Systems Integration Facilitation (SIF)

Such Interdisciplinary collaboration must fundamentally be built on a flexible and extensible rule-based framework architecture [RE 5.1.2-1 V5]. This should enable a universally accepted framework for current and future requirements for cognitive services, real-time applications, data sovereignty, marketplaces and many other requirements in a digital ecosystem. To this end, the Gaia-X ecosystem, for example, makes its normative contribution to regulatory, industry, and technical standards, known as the "architecture of standards" [30], available to participants in such an ecosystem. This set of rules, formulated in new release of the Gaia-X architecture [31], among other things, promises a high level of interoperability and security.

5.1.3 Semantics and characteristics

The need for standardization with regard to **semantics** requires special attention in the introduction and use for human-enabled Industrie 4.0 systems.

Industrie 4.0 systems can be suitable for humans if they can perform interactions that are suitable for humans, i.e., are 'interpretable', at their points of interaction or at human-machine interfaces.

5.1.3.1 Semantic interoperability

In reference architecture models (e.g. RAMI 4.0), interoperability is usually defined on communication layers for the exchange of information and data in terms of content. At the same time, not all models provide for a separate layer for **semantic interoperability**, which includes both semantic and syntactic aspects. Semantic interoperability thus includes formats and meaning of exchanged data with each other. Interoperability is called "semantic" between machines and processes if the meaning of the exchanged information between the machines and processes can be maintained.

That is, semantic interoperability includes the ability to communicate of data formats AND between processes originating from different domains, for example when a continuous measurement process delivers measurement values to a storage process (see also IEC white paper "Semantic interoperability: challenges in the digital transformation age" [32]). Then there must be a common understanding between the measurement and storage process to be able to communicate or synchronize. There must also be compatibility between the producer and user representation of the measurement data, e.g., if an analogue measuring device is connected to a digital memory, the analogue values must be mapped to the digital values for a certain working range and vice versa, if necessary.

When considering the **human-machine interface,** it is important to note that machine interpretations and interpretations that are appropriate for humans are different. "Appropriate for humans" means that humans can and may express a certain expertise appropriate to them and make their own decisions. On a formal level, interaction that is appropriate for humans means that signs, sentences, and symbols can be exchanged between humans and machines that can be semantically interpreted by humans and machines in comparable ways, possibly based on standards, but in any case based on a shared semantic representation, e.g., FOL or by means of graph-theoretic concepts.

The machine's ability to interpret (machine-machine interface) differs from humans' ability to interpret in that the machine requires a language and rules (e.g., blueprint) to be interpreted in order to be able to execute or control processes interoperably, i.e., in an environment- and time-dependent manner, whereas the human can cognitively cope with a mathematically precise, axiomatic declarative process description. However, it is assumed that the human worker or user of a machine has the necessary qualification to do so.

In order to be able to design Industrie 4.0 work systems in a way that is conducive to learning and thus appropriate for humans, it is imperative to design information flows and human-system interfaces in a comprehensible manner at the level of the overall system. In addition, the provision of suitable assistance systems must support the familiarization and understanding of the system, and the worker's ability to perceive the context when a job requires it [RE 5.1.3-1 V5], [RE 5.1.3-2 V5].

5.1.3.2 Requirements for the forms of representation of semantics

The need to semantically label requested characteristics concerns first and foremost standardization itself. The digitalization of standards into machine-interpretable and directly linkable and analyzable documents and content requires not only suitable semantic labels, i.e., ontologies for describing standards documents, but also appropriate tools and processes with which the content can be generated, managed and applied. Related issues are addressed, for example, in the DKE Digital Standards Initiative or SemNorm.

The Digital Standards Initiative IDiS [33]sees itself as a community whose task is to develop a common understanding (and benefit) of digital standards and the associated digital transformation of standardization with industry, and to formulate a common vision of digital standards on the basis of the use cases collected (see also Chapter 6.3 on SMART Standards [33]).

In the DIN CONNECT project **SemNorm** [37] a "Guide to the creation of executable semantic standards" has been developed. "Executability" of a standard means an operational model of data and processes of the CP asset that can be transferred to a computer and executed symbolically. "Semantics" of a standard means a declarative model whose axioms and process variables can be "read" by humans and analysed in the model.

Both models, the operational and the declarative model, are represented in a domain-specific language, e.g., for Industrie 4.0 production systems. The associated changes in tool chains and work processes require sufficient preparations for effective anchoring in the infrastructures of the respective stakeholders, i.e., standards organizations as issuing bodies or companies as users. It is therefore recommended to make preparations in the infrastructures at an early stage, i.e., to identify and address adaptation and expansion needs in order to be able to respond adequately to the requirements of future digital standards [RE 5.1.3-3 V5]. The aim of standardization is to provide operational and declarative artefacts for formulating an Industrie 4.0 ontology for the production of industrial products.

A model or a **form of representation** is being searched for, which integrates both formats, the operational and the declarative representation. While the executability of a specification represented in operational semantics can be realized by means of IT of a production plant, the declarative semantics of an Industrie 4.0 production process represents the non-operational knowledge of the CCM user, manufacturer, supplier, e.g., of a production plant, represented as dynamically evolving process graphs.

Physics or technology, ontology or standards, and semantics or interoperability form the **three representing (semiotic) domains** that define for a "thing" or asset the architecture, the cooperative behaviour, the data types and possibly used technologies such as

artificial intelligence, Internet of Things, the cloud, edge computing, etc. The relations between the semiotic domains are called morphisms and have the meaning of semantic assignments of artefacts from the three disjointed domains: (1) semantics/human, (2) ontology/standards and (3) thing/asset.

5.1.3.3 Semantics in the context of the Digital Twin

The **Digital Twin** represents the image of a cyber-physical system (asset). The Digital Twin is thus an autonomous digital asset that "mirrors" the behaviour of the cyber-physical asset. Mirroring here means the analytical reflection of the cyber-physical asset behaviour with semantic means. That is, the Digital Twin allows, in parallel with the cyber-physical asset process, both information on different life cycle phases of an asset and an analysis of the behaviour of the cyber-physical asset, if necessary, a timely validation or simulation in the model, to be performed and the results fed back to the cyber-physical asset, if necessary for correction.

The goal of standardization is to provide the semantic artefacts (elsewhere called tools) needed for semantic model building (to be applied as in a puzzle) to construct an executable model for analysis and simulation. The Digital Twin has these and other tools to analyse the semantic model and provide the resulting data to the cyber-physical asset. By delivering semantic data from simulation and analysis, the Digital Twin is involved in the organization and structuring of a data space that is compatible with cyber-physical assets. In the current standards of ISO/IEC JTC 1/ SC 41/ WG 6 [38] "Digital Twin" (see Chapter 5.1.4), little attention is currently paid to explaining the relationship between semantics and the Digital Twin, which would now be urgently required to support technical implementation as a normative basis [RE 5.1.3-4 V5].

37 See VDE DINCONNECT Projekt SemNorm, #602608 (2022)

38 ISO/IEC JTC 1/ SC 41/ WG 6 "Digital Twin"

5.1.3.4 I4.0 language

In production which is to meet the requirements of the Industrie 4.0 concept, interactions between the Digital Twins are required. Increased flexibility goes hand in hand with further modularization, decentralization and also an increase in asset autonomy. The Digital Twin provides the information technology part of the process. The exchange of Industrie 4.0 components (asset and Digital Twin) therefore requires a standardized form. This is made possible by the I4.0 language [34], which has been defined in VDI/VDE 2193. This language thus makes it possible to exchange the vocabulary required by ontologies and to enable interoperable behaviour of Industrie 4.0 components. Therefore, it is recommended to bring the **I4.0 language** to international standardization [RE 5.1.3-5 V5].

The artefacts used in a specification or "semantic standard" consist of representational elements of operational or declarative semantics, an "**I4.0 language**" for normative requirements, and the constructive elements of machine-specific I4.0 engineering. For example, one or more semantic graph trajectories of a manufacturing process can be identified with a symbol or phrase in a specification or standard.

The set of current trajectories against the background of the cyber-physical system specification by means of a type graph then corresponds exactly to the modelled or required semantics that can also be observed in the extensively implemented manufacturing process.

Thus, a "human-appropriate interoperation" with machines may only become clear with the cyclic successive application of the three morphisms: An ontological symbol denotes a state of a manufacturing process, this is defined by the intended semantics, e.g. by means of interpretation of a submodel of the Asset Administration Shell (see Chapter 5.1.4). The submodel updates the parameters of the technical cyber-physical asset that is in a certain state, about which a Digital Twin performs analyses, where necessary.

The models that humans can share cognitively and machines can share operationally can ideally be interpreted by a Digital Twin (rather than generic IT). A Digital Twin has analytical capabilities, e.g., by simulating a semantic model and its synchronization of states between model and technical process in real time. To synchronize, a Digital Twin can be loosely or closely coupled with its machine (OT) processing process. While a close coupling is to be executed within narrow time limits, a loose coupling is dependent on the environment and can therefore perform e.g., a SCADA tool-supported graphical analysis. With the placement of the Digital Twin in the semantic domain, the Digital Twin, in addition to its machine expression, also becomes an asset that can be administered via submodel identification and specification through the Asset Administration Shell.

5.1.3.5 Tools for semantics for Industrie 4.0

"Tools" are understood here as all aids and artefacts that can be used for the analysis, definition, description or, in cyber-physical engineering, for the manufacture of a product, and therefore their use and characteristics are to be made available in a standardized, i.e., combinable manner [RE 5.1.3.-6 V5]. The combinability of the standardized tools and artefacts is methodically achieved by setting up the communication or collaboration capability in a cyber-physical asset in a network-like distributed manner. The smallest building blocks of the **collaborative condition monitoring** (CCM) network consist of unlimitedly combinable three-party stakeholder relationships (called **fractals**) between the machine operator, machine supplier, and machine component manufacturer. Each of these stakeholders can participate in other subnetworks.

The CCM data space represents the current state in the entire CCM network. It exploits the semantic analysis capability of data and process spaces on the secure basis of combinable artefacts based on operational theories such as graph theories, data type theories logics or semantic rules, etc.

The goal of standardization is to identify the various semiotic categories of artefacts and their characteristic properties, consisting of technical, semantic, or even safety-critical artefacts. The artefacts within one category, e.g., those contained in a library, can be combined with each other.

5.1.3.6 Ontologies

Ontologies are linguistically formulated requirements for products, or for the manufacture of products, that can be verified in their context. For this search criteria are needed (ontology search points), with which a unique identification is possible. For example, IEC 63278-1[39] 1st ed. “Asset Administration Shell for industrial applications – Part 1: Asset Administration Shell structure” states that data models are defined based on ontologies. The semantics of the actual data are generally documented by references to these ontologies (see also [35] and [36]).

Ontologies come from different application domains and are to be used in context. Examples of such ontologies are materials science ontologies, which enable the selection of materials for specific uses based on standard properties, ontologies in the construction industry, or **product data dictionaries**, which standardize the representation of products in electronic catalogues.

In order for ontology-based data to be particularly effective in the planning and documentation of production systems, the underlying ontologies must meet certain minimum quality requirements. For example, concepts defined in the ontology should be globally uniquely identified or special properties should be defined based on uniquely specified data types and with compatible physical units (see IEC 62832[40] series). Concepts in the ontology should be clearly delineated and uniquely identifiable (e.g., avoiding homonyms and synonymous concepts). Concepts or artefacts used in an ontology need a clear definition, and the relationships between artefacts should be clearly defined. It is therefore recommended to standardize quality criteria for ontologies in order to be able to select the ontologies to be used according to these quality criteria [RE 5.1.3-7 V5].

5.1.4 Tools for implementing the Digital Twin

5.1.4.1 Asset Administration Shell

The basic concept of the **Asset Administration Shell** (AAS) is based on the idea of semantic interoperability. In particular, this involves the ability of machines, devices and sensors to interact with each other and communicate with humans in Industrie 4.0. As a result of the resulting digital relationships, smart Industrie 4.0 systems [14], which combine physical objects with data and intelligence to function in a digital ecosystem, are emerging. To make real-world properties available in the information world, modelling tools are needed that provide the necessary flexibility for data exchange between assets, especially when heterogeneous manufacturer data is exchanged in the upgrade network. This is often referred to as a universal “integration plug” [37], which is to be used for data exchange along the value chain and thus establishes interoperability in the digital ecosystems.

In the Asset Administration Shell, the data in the information world are not detached, but are created in a structured manner in the form of submodels with the properties defined there. This results in the ability to process, model, retrieve, find, or forward information in a standardized manner according to the interoperability requirements of a digital ecosystem. Thus, on the one hand, each Asset Administration Shell is unambiguously and sufficiently described in its relationships to other Asset Administration Shells by its submodels and, on the other hand, the properties in the Asset Administration Shell can be unambiguously assigned to an asset (see also **Chapter 5.1.1** and **Chapter 5.1.3**). The asset and the associated Asset Administration Shell together form the “Industrie 4.0 component” [12] (see **Figure 7**).

In the context of the **Digital Twin** (see also **Chapter 5.1.2** and **Chapter 5.1.3**), the Asset Administration Shell is referred to as an implementation based on the international standard, which defines it as a “digital representation of an asset”. Digital Twins of assets play a central role in Industrie 4.0. Via Digital Twins, all data and information can be exchanged, stored and made available to the different actors throughout the entire life cycle [38] (see **Figure 8**).

In practice, we currently frequently observe that different manufacturers create individual Digital Twins for their respective components. For example, component manufacturer A would develop a Digital Twin for the engine in a vehicle and component manufacturer B would develop one independently for the transmission. This makes it difficult to get an overall view of the vehicle. Specifications for appropriate formats, access rights and interfaces are necessary to achieve the desired interoperability here (see also [RE 5.1.3-4 V5]).

The data obtained from the Digital Twins can also benefit product planning as well as product development, as they can contribute to better market analysis (for new products) as well as product improvement (for existing products). These topics are currently being dealt with by VDI/VDE-GMA / GPP 7.10 [39].

39 IEC 63278-1 1st ed. “Asset Administration Shell for industrial applications – Part 1: Asset Administration Shell structure”

40 IEC 62832-1:2020 “Industrial-process measurement, control and automation – Digital factory framework – Part 1: General principles”

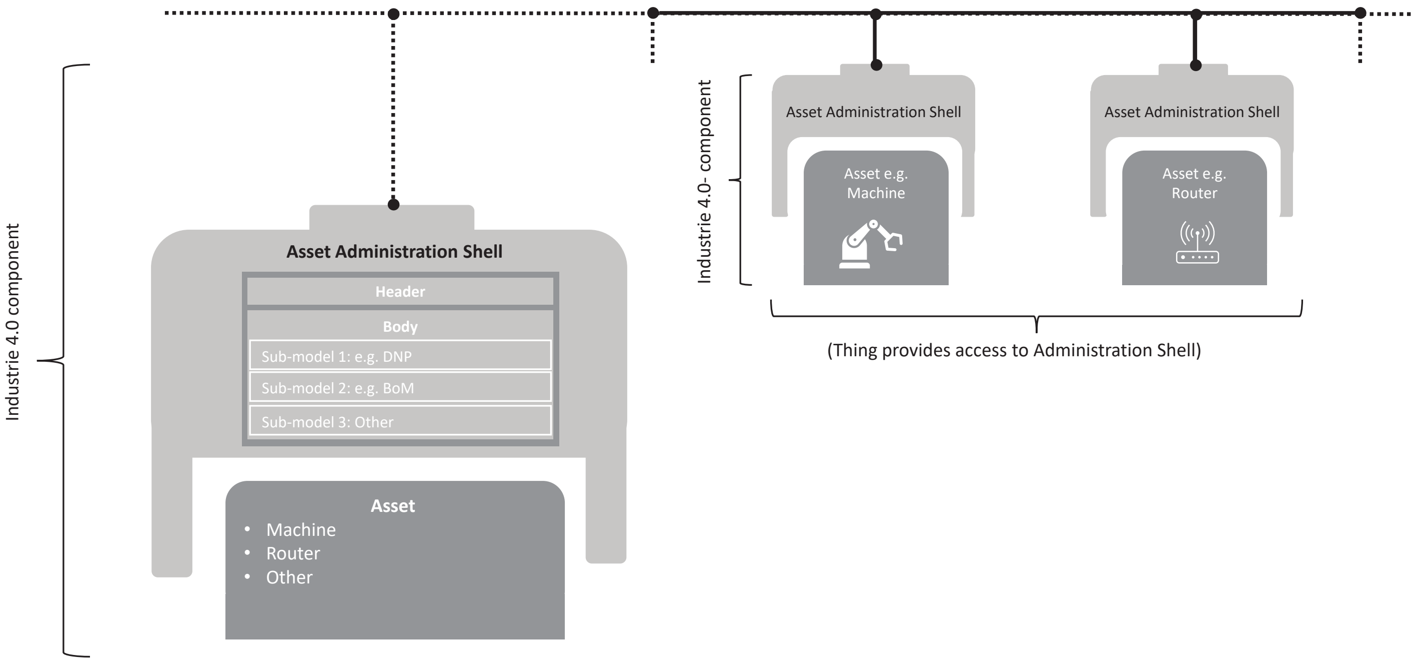


Figure 7: Asset Administration Shell as part of the Industrie 4.0 component (Source as in: Fraunhofer IPA)

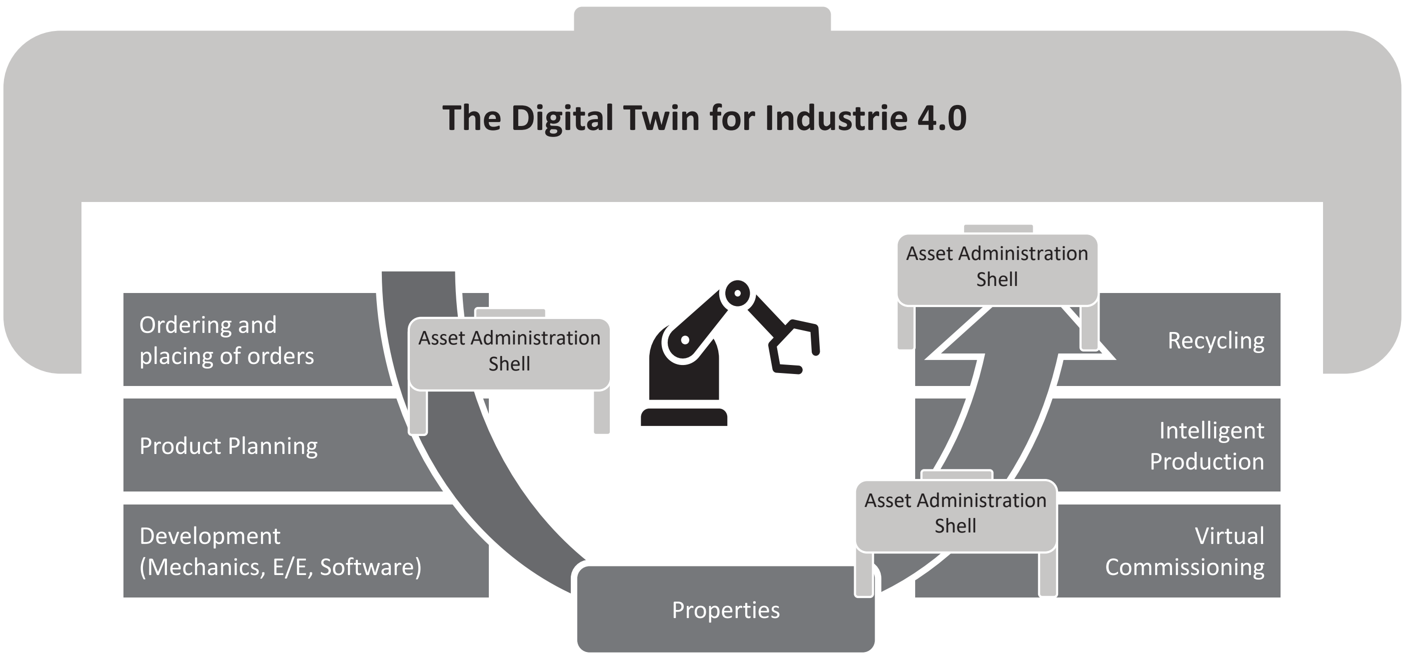


Figure 8: Asset Administration Shell and Digital Twin in value creation (Source: acc. to IDTA and Plattform Industrie 4.0)

5.1.4.2 Need for action in international cooperation

The idea is technically taken up by the international standards series IEC 63278[41] "Asset Administration Shell for industrial applications" of IEC/TC 65/WG 24[42] "Asset Administration Shell for Industrial Applications", which aims at an interoperable implementation of a Digital Twin in the industrial field. IEC/TC 65/WG 24 has been very active in recent years. Work on IEC 63278-1 has advanced with strong support from Germany, and the standard is in the last stages of publication, which is planned for 2023. With the current projects IEC 63278-2[43] "Information meta model" and IEC 63278-3[44] "Security provisions for Asset Administration Shells", further foundations are currently being laid for using and standardizing the concept of the Asset Administration Shell.

In Germany, the development of the Asset Administration Shell is being led by Plattform Industrie 4.0, industry associations, the German consortia of industrial and IT companies, science and political institutions, and the IDTA [40]. Current work includes the standardization of submodels to enable reuse and further detailing of the concept in the work of IEC/TC 65/WG 24. Furthermore, in order to accelerate the end-to-end use of the Asset Administration Shell and the roll-out of the submodels, the Asset Administration Shell concept must be actively standardized. Therefore, it is still recommended to support the activities of IEC/TC 65/WG 24 with regard to the development of the IEC 63278-series of standards on the Asset Administration Shell and to promote this work internationally [RE 5.1.4-1 V5].

In addition to the Internet of Things (see also Chapter 5.1.2), Digital Twins are also seen as paving the way for intelligent overall solutions ("smart everything"), as these are based on measured values that create an image of an object in the digital world. In this context, the sensors provide the necessary data streams that enable mirroring into the virtual world through data synchronization and transaction (see ISO/IEC JTC 1/SC 41 2021 Business Plan). The concept of the Digital Twin is currently being standardized in detail (after the dissolution of ISO/IEC JTC1/SC 41/AG 27 "Digital Twin Strategy" in summer 2022, see **HE 2.3-2 V4** [2]) in the international committee ISO/IEC JTC 1/ SC 41/ WG 6. In Germany these activities are actively mirrored in the work of DIN NA 043-01-41. For example, the ISO/IEC committee is not only looking at Digital Twins in an industrial context, but is examining their global application across multiple sectors. Data from multiple Digital Twins can thus be combined for a composite view over a set of real-world objects, such as a ship, bridge, building, factory, supply chain, or city.

Many normative projects are currently being initiated in connection with the Digital Twin that still need to be aligned with the current developments in IEC/TC 65/WG 24 [RE 5.1.4-2 V5]:

→ PNW JTC1-SC41-333 ED1 1st ed. "Digital Twin – Reference architecture"
→ PWI JTC1-SC41-6 "Guidance for IoT and Digital Twin use cases"
→ PWI JTC1-SC41-7 "Digital Twin – Maturity model"
→ PWI TR JTC1-SC41-11 "Digital Twin – Correspondence measure of DTw twinning"
→ ISO/IEC 20924 ED3 CDM "Internet of Things (IoT) and Digital Twin – Vocabulary"
→ ISO/IEC TR 30172 1st ed. DTR "Digital Twin – Use cases"
→ ISO/IEC 30173 1st ed. CD "Digital Twin – Concepts and terminology"

With regard to the consistency of standards concerning the Asset Administration Shell, current work on the ISO/IEC 21823 series, in particular ISO/IEC 21823-1[45] "Internet of Things (IoT) – Interoperability for IoT systems – Part 1: Framework", is being carried out by IEC/TC 65/WG 24. The "interoperability" context in the drafts of the current standards for the Asset Administration Shell is to be examined in coordination with ISO/IEC JTC/SC 41 and, if necessary, adapted. At national level this activity is being supported by national mirror bodies such as DIN NA 043-01-41 and DKE/AK 931.0.16[46] "Asset Administration Shell for Industrial Applications" [RE 5.1.4-3 V5] (see also [RE 5.1.3-4 V5] for further recommendations for action regarding semantics).

41 IEC 63278 series "Asset Administration Shell for industrial applications"

42 IEC/TC 65/WG 24 "Asset Administration Shell for industrial applications"

43 IEC 63278-2 "Asset Administration Shell for industrial applications – Part 2: Information meta model"

44 IEC 63278-3 "Security provisions for Asset Administration Shells"

45 ISO/IEC 21823-1 "Internet of Things (IoT) – Interoperability for IoT systems – Part 1: Framework"

46 DKE/AK 931.0.16 "Asset Administration Shell for Industrial Applications"

A special topic of focus is the design of the collaboration between all players in the field of the Digital Twin for industry. ISO/IEC JTC 1/SC41/WG 20[47] "Sectorial Liaison Group (SLG 1) on Industrial sector" is making a significant contribution to the harmonization of standards in the industrial sector. The list of liaisons in industry-relevant bodies currently suggested by WG 20 is extensive: IEC TC 65, IEC TC 65/WG 24, IEC/SyC SM, ISO/TC 10, ISO/TC 39, ISO/TC 39/SC 10, ISO TC 184/IEC TC 65, ISO/IEC JWG 21, ISO TC 184/SC 1, ISO TC 184/SC 4, ISO TC 184/SC 5, ISO TC 261 and ISO TC 299. In the context of the Digital Twin, initial recommendations have been formulated by ISO/IEC JTC 1/SC41/WG 20 in order to improve cooperation between ISO/IEC JTC/SC 41 and IEC TC 65[48] "Industrial-process measurement, control and automation" and to initiate joint work, for example in the form of a Joint Advisory Group for the vertical "smart manufacturing" topic [RE 5.1.4-4 V5].

5.1.4.3 OPC UA and companion specifications as tools for implementing a Digital Twin

In the context of the Digital Twin, the stakeholders involved in the OPC UA are facing the challenge of establishing the definition of "grammar" and "vocabulary" for the exchange of information as a uniform language for production (see also "**Study on interoperability in mechanical and plant engineering: The global language of production as a basis for Industrie 4.0**" [41]) and contributing to the implementation of the Digital Twin. Accordingly, attention is focused on the semantic description of information in production to enable the Digital Twin of production and, in contrast to the Digital Twin of the final product, to address the digital representation of the means of production in its operation. Due to the ongoing digitalization, the relevance for standardized semantics for production information continues to increase (see also [RE 5.1.1-11 V5] and [RE 5.1.3-4 V5]). Currently, around 40 working groups are actively developing further interface standards. The harmonization activities of "OPC UA for machinery" are particularly gaining considerable relevance.

In addition to using the data in the Asset Administration Shell, the production information can also be used and processed independently directly in further systems and IT environments. In this sense, the use of the OPC UA companion specifications plays an important role for the implementation of the Digital Twin [AE 5.1.4-5 V5].

47 ISO/IEC JTC 1/SC41/WG 20 "Sectorial Liaison Group (SLG 1) on Industrial sector"

48 IEC TC 65 "Industrial-process measurement, control and automation"

5.1.4.4 OPC UA in interaction with the Asset Administration Shell

The OPC UA standard [20] has long been established as the open interface standard (IEC 62541 series "OPC Unified Architecture") as the solution for the manufacturer-independent exchange of product data in production. The umati – universal machine technology interface [29] initiative is contributing to further global acceptance and increased adaptation of open source technologies. Umati enables the cross-sectoral testing of OPC UA interface standards in mechanical and plant engineering, as well as the global exchange in the associated community.

In addition, the desired data can be requested from any authorized location by means of the Asset Administration Shell. This is made possible by a standardized communication interface, for example on the basis of OPC UA. In contrast to the Asset Administration Shell, which represents a central information node for the entire product life cycle, information in OPC UA is communicated interoperably in real time. In this way, both dynamic information and information of longer-term relevance can be communicated between the Asset Administration Shell and the OPC UA interface. For this purpose, long-term concepts are to be developed in cooperation with the OPC Foundation and IEC/TC 65/WG 24 in order to exclude the duplication of information on several levels [RE 5.1.4-6 V5].

5.1.4.5 Standardization activities with regard to semantic data modelling

The importance of a standardized dictionary as one of the fundamental aspects of creating meaningful Asset Administration Shells has increased over the past few years. In this context, important activities have been initiated at international level in IEC TC 65/SC 65E/WG 2 in 2022 to support Asset Administration Shell submodels to complement existing standards for semantics [RE 5.1.4-7 V5].

To meet the requirements of the Asset Administration Shell in a semantic context, the white paper "Modelling the Semantics of Data of an Asset Administration Shell with Elements of ECLASS" examines the semantic requirements for use of specific data types. The document identifies the necessary structures missing in the conceptual data model of ECLASS. Furthermore, the white paper lists suggestions for the further development of the ECLASS data model and describes the cases in which necessary elements of the Asset Administration Shell metamodel are not supported by either IEC 61360-4 "Common Data Dictionary" or ECLASS. Proposals for the extension of the ECLASS data model are being formulated for the identified gap.

Based on the findings of the white paper, the ECLASS Association has begun to define data structures to support Asset Administration Shell submodels in the new project. The proposal to define universally applicable data structures for use in smart manufacturing was accepted with the project PNW 65E-928 ("IEC 6xxxx DB – Common data concepts for smart manufacturing"). These data structures are defined in IEC 61360-7 "DB – Data dictionary of cross-domain concepts" and can be used, for example, to define Asset Administration Shell submodels. As a first submodel, the "digital nameplate" submodel is to be supported by corresponding data structures.

In parallel with the activities at ECLASS, IEC/TC 3/SC 3D is also investigating necessary extensions to the data model. First prototypical submodel templates of the Asset Administration Shell have already been realized in the "IEC Common Data Dictionaries" (CDD).

5.1.4.6 Paths to the holistic development of submodels for interoperability

Data modelling is a central component of the Asset Administration Shell concept. While the asset exists as a physical (or virtual) component in the real world, the Asset Administration Shell represents it in the information world using defined models. Here, the Asset Administration Shell has a defined structure with a distinct meta-information model. In addition to the most important basic information about the asset, an Asset Administration Shell contains **submodels** (see Figure 9). These allow the mapping of a description of properties, parameters and variables of an asset. An Asset Administration Shell can contain several submodels that can fulfil different functionalities.

In recent years, numerous preparatory activities have been created for the standardization of submodels of the asset administrative shell. For this reason, not only were the recommendations for the internationalization of further parts of the IEC 63278 series of standards (see also [RE 5.1.4-1 V5]) actively promoted and implemented, but preliminary work was also started in IEC/TC 65/WG 24 on setting up corresponding structures for the development of submodels. To this end, IDTA has also been actively working on bringing together the development strands for the industrial Digital Twin and developing them together with industry as an open technology solution based on the Asset Administration Shell.

Over the past two years, IDTA has been committed to accelerating the establishment of the Digital Twin in industry through the joint development of the submodels. In this sense, the IDTA network is experiencing very rapid growth. Among these, the proactive strategy to build cooperations with other relevant initiatives and consortia such as the Digital Twin Consortium [42], the Digital Data Chain Consortium (DDCC), the Open Manufacturing Platform (OMP) and others is particularly noteworthy [40], [42].

The coordination of standardization within the framework of work in IEC/TC 65/WG 24 is carried out by IDTA "WG Submodels". This working group now supports about 30 submodel projects and has already published some important submodels such as "Digital nameplate for industrial equipment", "Inclusion of Module Type Package (MTP) Data into Asset Administration Shell", "Generic Frame for Technical Data for

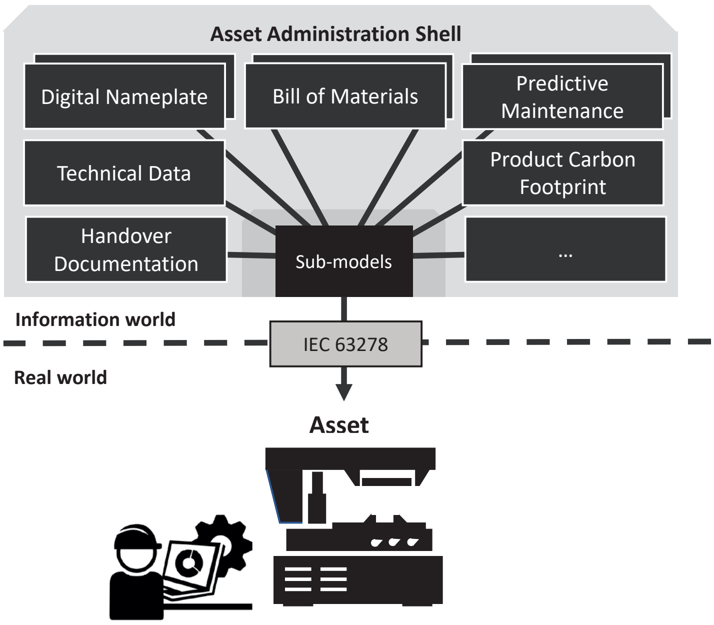


Figure 9: Holistic development of asset administration shell submodels (Source: O. Meyer, Fraunhofer IPA)

Industrial Equipment in Manufacturing" and "Submodel for Contact Information" [43].

Current activities are primarily directed at the development of basic submodels for industrial use. However, submodels are to be developed for further aspects such as different structures, communication, integration, but also for other sectors, since the currently available submodels are not yet sufficient for comprehensive Industrie 4.0 solutions, e.g., in a complex plant or Asset Administration Shell networks [RE 5.1.4-8 V5]. In addition, methodological knowledge must also be deepened, broadened and expanded in order to bring the necessary expertise to the facilitation of the development of submodels and enable them to be implemented at the next stage of development. Here, for example, the IDTA is working closely with the InterOpera [44] funding project to develop interoperable submodels for industry and thus to create a common basis for the further development of the standard. The aim is to develop 50 submodels of the Asset Administration Shell on the basis of concrete, practical use cases. In this context, the project results are to be used in standardization to address the Technical Committees (TC) and other bodies with regard to their references to applications in order to create further specific submodels.

All standardization stakeholders are encouraged to work with IDTA to develop the submodels that are still lacking and to contribute to ongoing activities.

→ **Standardization of submodels for technical documentation**

As Version 4 of the Standardization Roadmap Industrie 4.0 [2] shows, there is still a need for a standardized exchange format for digital technical documents. Since several standards such as iiRDS and VDI 2770 have become established as exchange formats for digital technical documentation (see also [RE 5.1.1-10 V5]), intensive work has been done to align these and transfer them to the Asset Administration Shell world as a submodel. Activities on the development of submodels on the basis of iiRDS have been successfully initiated in InterOpera. These activities aim to implement a more uniform representation of the extended technical documentation (complementary to the IDTA submodel "handover documentation" already present in the review) [43] in order to make the content semantically accessible and interchangeable, as well as usable by multiple providers. Further work is currently being carried out within the framework of the international project IEC PAS 63485 ED1 in IEC TC 3/ WG 28.

The concept of the Asset Administration Shell is a very comprehensive approach that tries to solve the complexity of mapping all properties and views with different submodels. A somewhat different objective is pursued by the approach of the digital life cycle record according to the DIN 77005[49] series of standards "Life cycle record of technical objects". The focus here is on the standardized structuring of digital asset documentation and the resulting possible joint processing of digital life cycle records by the various actors in the life cycle of an asset and their software systems, for example enterprise resource planning systems (ERP), document management systems (DMS) or product data management systems (PDM).
In contrast to the concept of the Asset Administration Shell, where all data, i.e., data on the current status of an asset, can be stored, the concept of the digital life cycle record is limited to the relevant information of an asset that is needed by the different actors in the respective life phases of an asset. Accordingly, the focus is on a more horizontal approach across the entire asset life cycle.
With DIN 77005-1[50], requirements for a life cycle record for technical objects have already been formulated.
Based on this, an information model for object-related documented information was defined in DIN 77005-2[51] "Life cycle record of technical objects – Part 2: Digital life cycle records". The digital life cycle record as in DIN 77005-2 can be realized as a submodel of the Asset Administration Shell [RE 5.1.4-9 V5]. However, it is also possible to implement the digital life cycle record as a stand-alone approach in Industrie 4.0. A draft of DIN 77005-2 has been available since 2022-08.

→ **Standardizing submodels in the area of simulations**

With regard to [RE 5.1.4-10 V5], in 2022, on the initiative of the Plattform Industrie 4.0 "SG AAS submodel simulation", a corresponding application for the creation of the "provision of simulation models" submodel was submitted in a public enquiry phase, developed and published at the end of 2022. The submodel can be used to provide simulation models from "suppliers" across manufacturers for use by an "integrator" and "operator". In addition, models can be requested from the manufacturer by potential users. The submodel supports searching, querying

49 DIN 77005series "Life cycle record of technical objects"

50 DIN 77005-1:2018-09 "Lifecycle record of technical objects – Part 1: Structural and content-related specifications"

51 DIN 77005-2 "Lifecycle record of technical objects – Part 2: Digital lifecycle record"

and providing simulation models for an Industrie 4.0 component. The model includes information about the simulation purpose, integration into a simulation environment, and administration.

→ **Standardization of submodels for functional requirements (capability and skills)**
In the meantime, work on the Asset Administration Shell submodels for capturing standardized capability descriptions has likewise begun in several IDTA working groups [RE 5.1.4-11 V5]. Capabilities are technology-neutral descriptions of functions, i.e., independent of the way in which they are implemented ("capability" or "skill"). The core task here is to describe these capabilities on the one hand as requirements in the process description, and on the other hand also as capabilities of the devices. Ideally, these should be automatically compared and brought into line with each other.

→ **Standardizing submodels in the identification of assets**
IEC/SC 65E[52] "Devices and integration in enterprise systems" is a committee that has implemented both recommendations [RE 5.1.4-12 V5]. VDE V 0170-100 has been brought into international standardization as IEC 63365[53] 1st ed. "Digital nameplate – Digital product marking" and DIN SPEC 91406 has been published internationally as IEC 61406 "Identification Link – Unambiguous biunique machine-readable identification".
Used in the Asset Administration Shell, the "digital nameplate for industrial equipment" submodel acts as the link between the physical asset and the Asset Administration Shell. The digital nameplate thus contributes to the goals of the European Green Deal for 2050 [26] and supports the new approach to asset labelling (see also Chapter 5.3).

Currently, many preparatory measures still need to be initiated and carried out in order to standardize the submodels of the Asset Administration Shell. Although IDTA's current focus is on developing basic submodels for industry, InterOpera [44] is looking outside the box to cover a broader range of use cases from different industries. For example, specific but frequently used submodels are also considered and valuable experience is gained [RE 5.1.4-13 V5]. With the project results, Technical Committees (TC) and other bodies in standardization are to be approached depending on their relevance in order to create further specific submodels.

52 IEC/SC 65E "Devices and integration in enterprise systems"

53 IEC 63365 ED1 "Digital nameplate – Digital Product Marking"

5.1.5 Industrial communication

End-to-end and seamless communication is an essential aspect of Industrie 4.0 and in this context, with a view to **industrial communication**, the terms converged network and time sensitive network (TSN) are becoming increasingly important.

5.1.5.1 Converged networks in industrial communication

Converged networks bring IT, OT and fieldbuses together in one physical network. This promotes flexibility and simplification of installation and means cost savings on the one hand, but requires quality of service (QoS) for the respective services on the other. Each service, each packet is transmitted with its QoS. Standards and specifications are essential for converged networks. Not only interoperable protocols, but also network configuration must follow standards and be uniform. The latter enables a seamless transition between wired and wireless communication.

Communication standards by IEEE are paving the way and setting important accents with TSNs. Layer 2 is being prepared for the requirements of converged networks. TSNs are mentioned today, or will be mentioned in the future, in connection with 5G and Wifi (also: wireless fidelity). Interface standards such as OPC UA will also incorporate TSNs into their respective standards.

A converged network is aware of its resources and capabilities, and enables quality of service for the requirements of subscribers in the network. Network configuration becomes part of the network to a certain extent. TSNs and profiles are the answer to these requirements and look at latency, availability, resource management and time synchronization.

Industrial communication for Industrie 4.0 benefits from convergent networks.

The recommendations for action listed in this chapter follow the basic idea of converged networks and provide support in:
→ interoperable protocols;
→ interoperable configurations;
→ enabling and simplifying transitions between wired and wireless networks;
→ uniform test specifications.

TSN (IEEE 802.1 TSN Taskgroup) and IEC/IEEE 60802[54] "TSN Profile for Industrial Automation" (IEEE 802.1 Profile 60802, IEC Profile 60802) in particular are connecting elements of **heterogeneous, industrial networks.** Standardization work is in full swing with the outlook to publish the first edition in 2023. Other publications such as the white paper "Integration of 5G with Time-Sensitive Networking for Industrial Communications" by the 5G-ACIA [45] and the technical paper "OPC UA for Field eXchange (FX)" [46] by the OPC Foundation show the connection to converged networks. Wifi with TSN is planned and will follow this approach [RE 5.1.5-1 V5].

The recommended action formulated in Version 4 of the Standardization Roadmap Industrie 4.0 [2] [RE 5.1.5-2 V5] with regard to services and interfaces for **network management** of the various industrial communication networks will become even more important. Here, it is still necessary to specify these uniformly and from the application perspective. At present there are few activities to report. Against the backdrop of converged networks, opportunities are emerging that fulfil this recommendation for action.

This modelling is the basis for effective coexistence management of different (radio) communication solutions, which can take into account not only the "sensitivities" of the communication, but also those of the application [RE 5.1.5-3 V5]. For example, **Asset Administration Shell modelling** allows the application to adaptively respond to changes in communication and vice versa (example: instead of stopping, a driverless transport vehicle slows down when the connection goes bad). A working group has been established in IDTA to develop an asset administrative shell submodel. It is planned to then transpose the submodel into an IEC Standard within WG24.

There are no known activities in the field of **communication network planning** so far. Scenarios can be the basis for uniform test specifications according to which networks can already be tested in the simulation phase. Data communication characterization also always plays a role in the never-ending, ever-new use case investigations. Agreeing on something here seems to be an effective step – even if the scenarios are not incorporated into a formal test specification, but "only" an agreement is established [RE 5.1.5-4 V5].

A national guideline has now been developed for the **reliability assessment** requirements. VDI/VDE Guideline 2192[55] "Interoperability in Industrie 4.0 systems – Quality of services – Characteristic parameters and influencing quantities" should be developed into an International Standard [RE 5.1.5-5 V5].

On both sides (provider and end user), there is currently a great deal of uncertainty when it comes to negotiating service level specifications (SLS), which are intended to supplement the technical side of a service level agreement (SLA). For example, it must be negotiated who measures what and how, and who is responsible for which aspects. An international agreement would be ground breaking. The term SLS as a complement to an SLA was discussed by the 5G ACIA in a white paper of the same name, "Service Level Specifications (SLSs) for 5G Technology-Enabled Connected Industries" [47].

The evaluation of industrial **real-time communication systems** is becoming increasingly important for companies. A national guideline follows this recommendation for action – VDI/VDE Guideline 2185 Blatt 4[56] "Radio-based communication in industrial automation – Metrological performance rating of wireless solutions for industrial automation applications", describing parameters and methods for evaluating industrial radio communication systems. An international approach to the evaluation of industrial real-time communication systems has been launched with IEC 61360-7 "DB – Data dictionary of cross-domain concepts" [RE 5.1.5-6 V5]**.**

An application-oriented, communications technology-neutral **test specification** is the prerequisite for a sustainable solution that will also endure for future developments in communications technologies. The fieldbus consortia have joined forces [48] and are starting to create a test specification for IEC/IEEE 60802. It is further recommended to integrate this content in an International Standard as well. IEC/IEEE 60802 is in preparation [RE 5.1.5-7 V5]**.**

54 IEC/IEEE 60802 "TSN Profile for Industrial Automation"

55 VDI/VDE-Guideline 2192 "Interoperability in Industrie 4.0 systems – Quality of services – Characteristic parameters and influencing quantities"

56 VDI/VDE Guideline 2185 Blatt 4 "Radio-based communication in industrial automation – Metrological performance rating of wireless solutions for industrial automation applications"

5.1.5.2 5G system in Industrie 4.0

Worldwide harmonization of spectrum aspects is addressed in the 5G-ACIA white paper "5G for connected industries and automation." [49] Concrete work on global harmonization of this topic has not yet begun. It is recommended that this approach be pursued [RE 5.1.5-8 V5].

There is still a need for standards related to non-public mobile local area networks for industry [RE 5.1.5-9 V5] (see 5G ACIA white paper "5G Non-Public Networks for Industrial Scenarios" [50]).

For the seamless merging of (heterogeneous) industrial networks with 5G networks, standards are still needed that describe their architectures for different types of infrastructures and the required interfaces [RE 5.1.5-10 V5]. Details are not yet uniformly regulated (e.g., handover between public and non-public network).

One possible approach is in combination with the recommendation in [RE 5.1.5-11 V5] to start work in IEC SC 65 TC 65C/WG 16 [57] "Digital Factory". There is a proposal in IEC SC 65 TC 65C/WG 16 to describe requirements for the application of 3GPP-specified mobile radio systems for industrial automation. Standardization work on this has not yet started, but it is recommended to do so.

5.1.5.3 Security in industrial communication

The increasing volume of communication in the Industrie 4.0 environment, especially with regard to interoperability in digital ecosystems, requires consideration of **security** aspects to ensure sufficient reliability and security against attack. With referencing in further technical standards (e.g., OPC UA, 5G-ACIA) the importance of IEC/IEEE 60802 "TSN Profile for Industrial Automation" (IEEE 802.1 Profile 60802, IEC Profile 60802) will increase. The current draft 1.4 of the profile is being supplemented by sections on a security model. These follow a security-by-design approach – secure converged networks [RE-5.1.5-12 V5]. The current draft of the profile is being supplemented by sections on a security model. See Chapter 5.2.2 for further aspects on security.

57 TC 65C WG 16 "Digital Factory"

5.1.5.4 SPE and APL – answers to the requirements of the process industry

Requirements of the process industry for the physics of Ethernet has led to extensions of the IEEE 802.3 standards. Single pair Ethernet (SPE) takes into account the environment, topology and requirement of the sensor market. Since the basis is Ethernet, the advantages are a reduction of gateways, flexibility regarding protocols, power delivery etc.. This facilitates integration into OT networks and supports Industrie 4.0. Current IEEE standards (e.g., IEEE P802.3dg 100 Mb/s long-reach single pair Ethernet) standardize requirements for link speeds and segment length. In addition, it is recommended to include the relevant standards from IEEE in IEC 61158-2 [58] "Industrial communication networks – Fieldbus specifications – Part 2: Physical layer specification and service definition" [RE 5.1.5-13 V5].

Further requirements arise from the project Ethernet Advanced Physical Layer (APL) [51]. A white paper "Ethernet – To the Field" [52] explains the connections and details. In summary, a two-wire Ethernet – comparable to SPE – supplemented with features for explosive areas, as well as simplified installation and power delivery, and brings with Ethernet the advantages of common protocols and services for sensors and field devices. The result of the project is currently being incorporated into a technical specification (IEC TS 63444 [59] ED1. "Industrial networks – Ethernet-APL Port Profile Specification") at IEC. An integration into relevant fieldbus standards is desirable [RE 5.1.5-14 V5].

5.1.5.5 Industrial location management

The localization of objects is an important requirement in Industrie 4.0, especially with regard to transparency of the increasingly dynamic and mobile production processes. Among other things, location data helps to optimize the flow of materials, minimize search times, and make more efficient use of mobile operating equipment and production areas. In this way, this data can have a lasting effect on securing the future of industrial production in countries with high labour, material and energy costs.

58 IEC 61158-2 "Industrial communication networks – Fieldbus specifications – Part 2: Physical layer specification and service definition"

59 IEC TS 63444 ED1 "Industrial networks – Ethernet-APL Port Profile Specification"

The options for collecting, managing and providing location data are manifold and range from radio-based methods to optical positioning technologies. For this reason, harmonization is necessary at various levels [RE 5.1.5-15 V5]. This includes both the standardization of different localization technologies and the subsequent processing and provision of the location data. In this context, the open locating standard omlox [53] – which is managed as a technology group within the PROFIBUS user organization – is already a very advanced initiative for harmonizing industrial location management. From omlox, harmonization with the Asset Administration Shell, in the semantics of machine data (OPC Foundation), the integration of localization technologies in industrial buildings (BuildingSmart) and seamless location in outdoor environments, e.g. in logistics (OpenGeospatial Consortium) have already been initiated. The preliminary work of omlox can certainly make a valuable contribution in the above-mentioned aspects.

5.1.6 Functional safety in Industrie 4.0

We begin with a definition of **safety**. This is freedom from unacceptable risks of physical injury or harm to human health, either directly or indirectly as a result of damage to property or the environment.

Functional safety is the part of overall safety that depends on a system or piece of equipment providing correct responses to its input states. An over temperature protection device that uses temperature sensors in the windings of an electric motor to shut down the motor before it can overheat is an example of functional safety. Providing special insulation to withstand high temperatures is not an example of functional safety, although it is still an example of safety and could protect against precisely the same hazard. Neither safety nor functional safety can be determined without assessing the systems as a whole and the environment acting on them (DIN EN 61508 (VDE 0803) Supplement 1:2005-10 [60] "Functional safety of electrical/electronic/programmable electronic safety-related systems").

60 DIN EN 61508 (VDE 0803) Beiblatt 1: 2005-10 "Functional safety of electrical/electronic/programmable electronic safety-related systems"

5.1.6.1 Principles of functional safety in Industrie 4.0

In order to be able to follow the principles of **functional safety**, the actual functions must already be considered during development: For example, a motor should rotate and open a valve. A crucial question at this point is what a malfunction would look like (motor turns in the wrong direction and closes the valve instead of opening it) and how the problem could be prevented.

According to this principle, all possible eventualities are documented – from a simple and superficial level to a very deep and detailed one. A method for reducing systematic errors that has been known for years and is constantly being developed further is the "V-model" (see Figure 10).

This iterative process model was originally designed for the design and development of software and is now also used for the design of mechatronic systems. In addition to the software development process, which is divided into development phases, the V-model compares these phases with test phases and thus defines a procedure for quality assurance.

Starting from the customer requirements, the functional and technical specifications become increasingly more detailed on the left-hand side until an implementation can take place. Each implementation is tested against the specifications on the left using the test steps shown on the right.

Figure 11 shows a practical application of the V-model.

In the process, the various implementation steps are mapped within the framework of digitized processes. Depending on the individual situation, the individual life cycle phases can be separated.

In the technical implementation of the defined safety function as well as its operation, the implementation process is divided into the areas hardware, software and test. This allows the use of automated test processes during both the implementation and the operation of the plant. This approach allows comprehensive digitization of SIS construction and operation while reducing functional safety costs.

The basic prerequisite for consistent modularization in production is a uniform description of the information of the individual modules. For this purpose, an Asset Administration Shell submodel "Inclusion of Module Type Package (MTP)

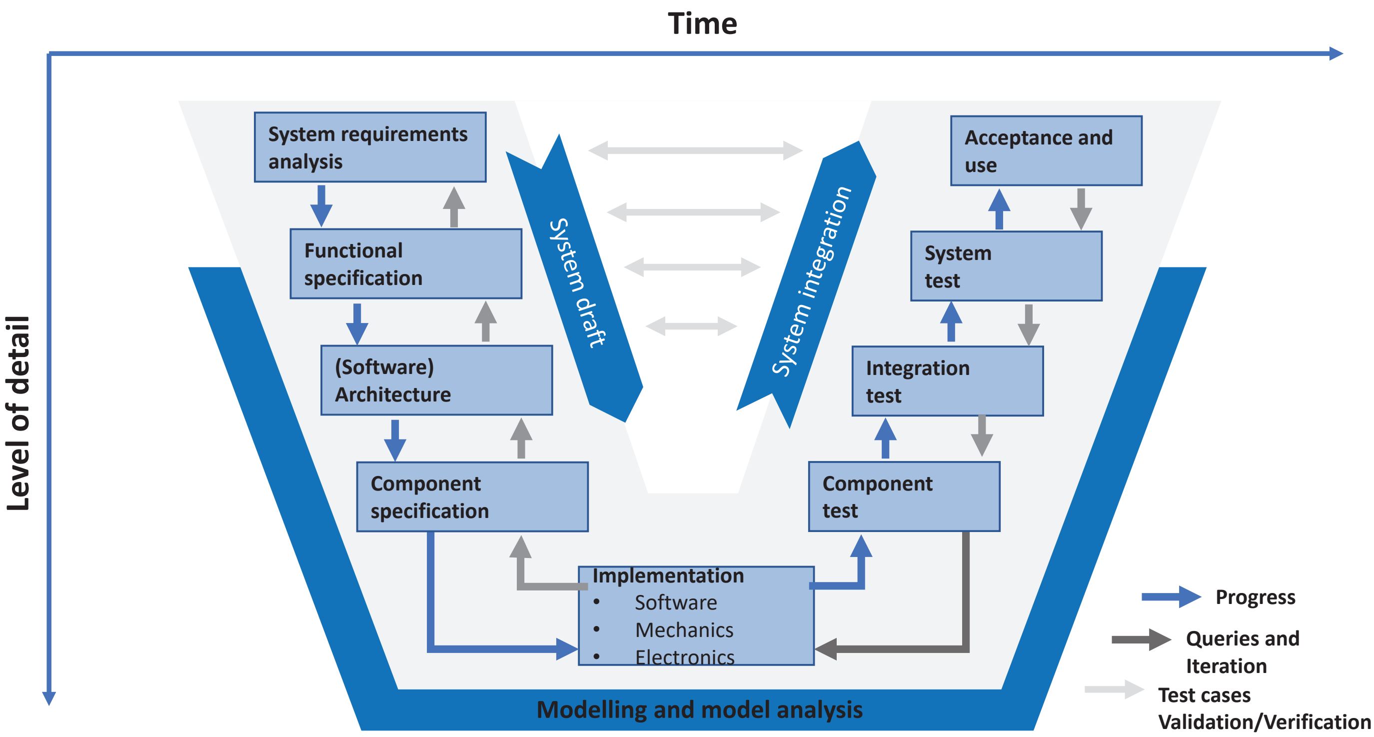


Figure 10: V-Modell: an iterative process to reduce systematic errors
(Source: V-Modell: VDI 2206:2004-06 – VDI Gesellschaft Produkt- und Prozessgestaltung)

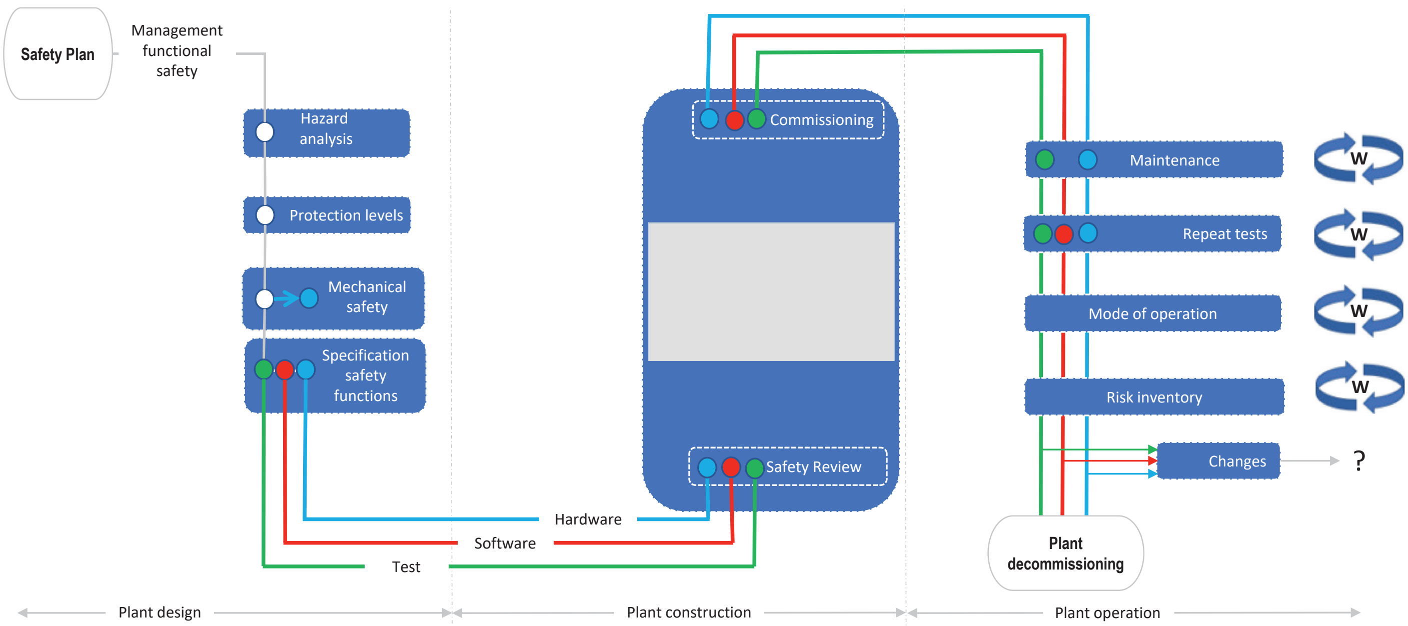


Figure 11: Practical application of the V-model

Data into Asset Administration Shell" was developed at IDTA in 2022 [43], which regulates such a description uniformly and via the cross-industry and cross-manufacturer standard "MTP" (module type package) [RE 5.1.6-1 V5].

5.1.6.2 Functional safety and cybersecurity

"**Functional safety**" and "**cybersecurity**" are mutually interdependent and standardization work in this area should be made more in-depth and given greater detail [RE 5.1.6-2 V5].

Because "security" and "safety" are both expressed in German as "**Sicherheit**", there is often a question of what the difference is between the two concepts of functional safety and cybersecurity.

The difference is clearer in English: **Functional safety** protects people from machines and **cybersecurity** protects machines from people (see Figure 12).

The English language is therefore much more precise with regard to these definitions and descriptions of the terms than the German language. For experts and users, this distinction is simple and quite self-evident – laypersons in this field, on the other hand, do not always understand directly at first whether safety or security is meant.

A key statement that has come up repeatedly in recent years is: "**If it' s not secure, it' s not safe.**"[61] This means that if a plant is not protected against attacks from the outside, the protection of humans from the machine can also no longer be ensured.

It cannot be ruled out – especially at interfaces – that safety and security measures influence each other. This becomes particularly relevant when a holistic risk assessment or risk evaluation has to be set up for a complex system. This includes a safety risk evaluation and a security risk evaluation. For holistic risk assessment, a professional exchange of both representatives takes place, which should show which requirements or measures in the respective area could also have an impact on the other area [RE 5.1.6-3 V5].

Consideration of human-centred design criteria for Industrie 4.0 systems is closely linked to the functional safety of these systems, since a design oriented to the needs and

61 [In German: Wenn es nicht sicher ist, ist es gefährlich.]

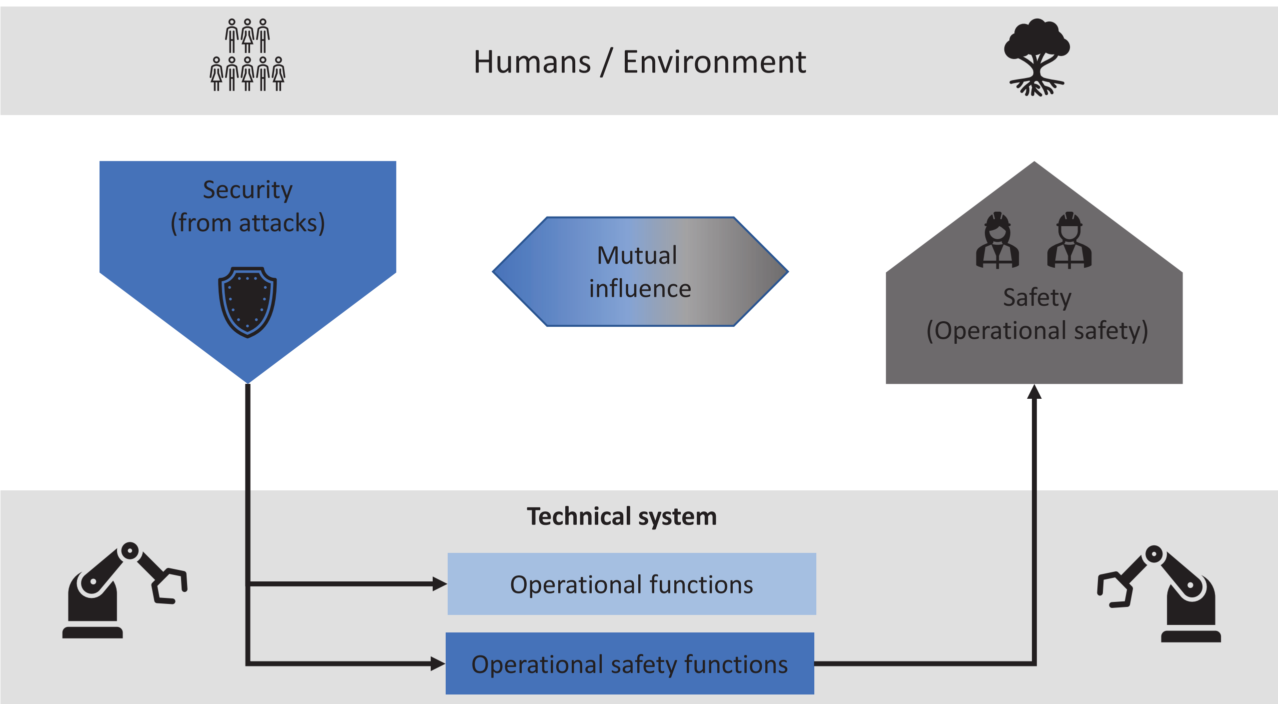


Figure 12: Difference between safety and security (Source: DKE)

capabilities of human operators can help prevent errors and accidents. The design of interfaces is to be given special consideration. The following recommendation for action from Version 4 of the Standardization Roadmap Industrie 4.0 [2] is therefore taken up again at this point [RE 5.1.6-4 V5].

5.1.6.3 IEC 61508: The series of International Standards on functional safety

The scope of the IEC 61508[62] series of standards (see Figure 13) covers conception, planning, development, realization, commissioning, maintenance and modification through to decommissioning and deinstallation. If the requirements of the standards series are implemented consistently, the result is a management system for the safe development and operation of products and plants. In addition, there are further normative specifications for special product areas.

Each of these areas makes use of standards series whose contents are specifically adapted to the respective fields of application. This is understandable, because the requirements for a product or system in railway applications are completely different from those in the field of medical electrical equipment. However, the basis in the context of functional safety is in any case provided by the IEC 61508 series of standards.

A very good example is the standards series ISO 26262[63] "Road vehicles – Functional safety": It forms an independent set of standards for the automotive industry. The basic ideas originate from the IEC 61508 series of standards (e.g., SIL) and are adapted to industry-specific requirements (e.g., ASIL).

Other current topics on functional safety as well as more detailed information on the subject can also be found on the DKE webpage "https://www.dke.de/de/arbeitsfelder/core-safety/funktionale-sicherheit"

62 IEC 61508 series "Functional safety of electrical/electronic/programmable electronic safety-related systems"

63 ISO 26262 series "Road vehicles – Functional safety"

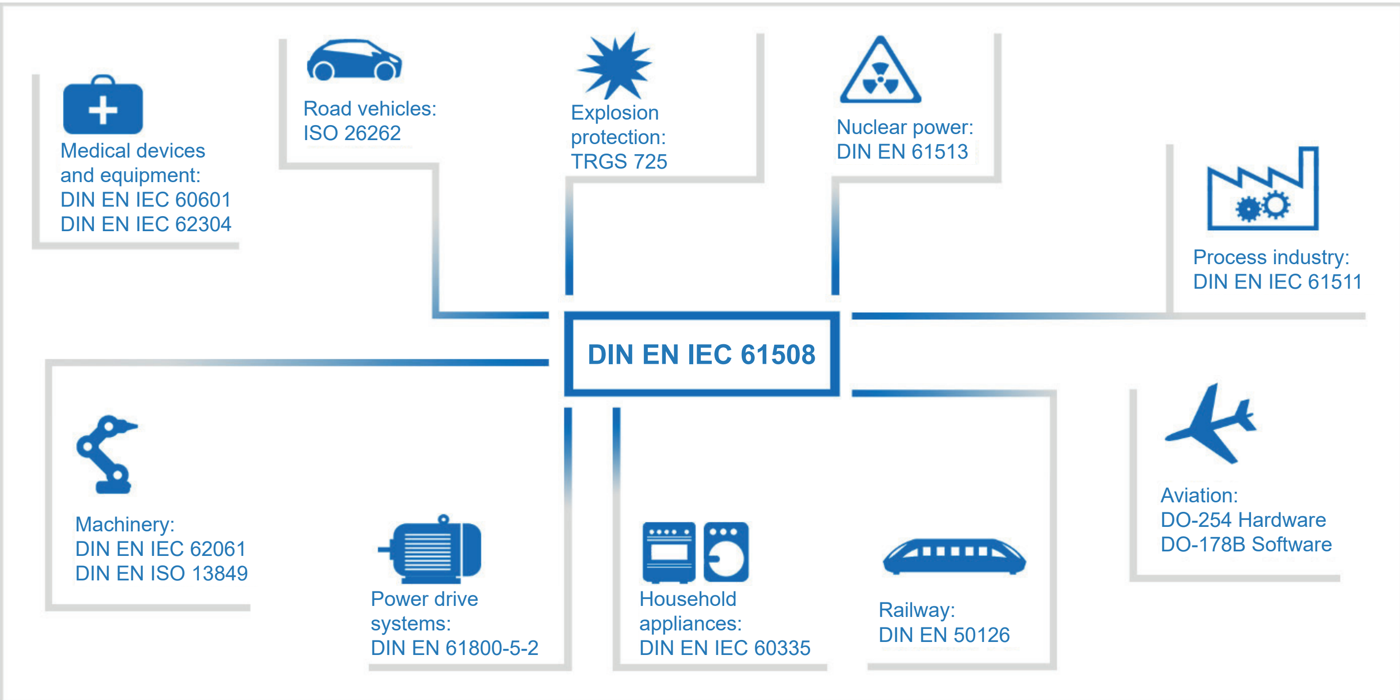


Figure 13: Standards series on functional safety (Source: DKE)

5.1.7 Artificial intelligence in industrial automation

Artificial intelligence (AI) has been ubiquitous for several years now and today's digital world would be unthinkable without it. It permeates increasingly more areas of social and economic life and is changing the way we work, learn, communicate and consume. Today, there are numerous, already existing application examples for AI. The importance of AI is also rapidly increasing in industrial applications. Experts assume that in the future AI will have such a great influence on industrial value creation that companies will hardly be able to refuse to use AI.

The possibilities are many: Speech assistants and chatbots are among them, as are programs for document research, systems for image recognition, industrial robots that interact with humans in the factory, or autonomously driving logistics systems. AI is already used in many companies to optimize processes and ensure their stability, increase productivity, ensure continuous quality of production and reduce energy costs. These are mainly analytical activities that support decision-making processes. The use of artificial intelligence enables adaptation based on observations and existing (background) knowledge instead of rigid, predefined patterns. AI is thus a technology that drives progress and secures economic power and ultimately the prosperity of an entire society. In English, and increasingly in German-speaking countries, the expression industrial artificial intelligence or industrial AI is also used. This includes all fields of application of artificial intelligence in industrial applications or Industrie 4.0 [54], [55].

Standardization of AI is of major importance in Germany and Europe – not least because of the German government's national AI strategy [56], [57] and the European Commission's strategy and regulatory activities [58]. In the context of AI, numerous standards and specifications have already been published or are currently being developed – at national and international level, on a consortium basis as well as in full consensus. Due to the disruptive nature of AI, regulatory and legislative authorities around the world are also increasingly concerned with AI and its implications, e.g., on the correct interpretation and validity of the established legal framework in the application of AI.

From the history of artificial intelligence, which began more than 30 years ago in scientific research, it is the "theory and development of computer systems capable of performing tasks that normally require human intelligence, such as visual perception, speech recognition, decision making and translation between languages" [59]. This definition provides the necessary space for research and (scientific) work. Furthermore, this is also particularly technology-independent in that it is based on the goal of realizing (human-like) intelligence with technical systems, which means that any technology for realizing this goal can be subsumed under this topic. A clear distinction as to whether a technology, application or method is artificial intelligence or not is hardly possible on the basis of such a definition – not only for isolated fringe topics. However, when considering concrete technical issues in a normative context, when examining or even redefining legal or regulatory requirements, one faces the challenge of using a definition of AI that delineates the scope of consideration or application more concretely and with less room for interpretation. Ultimately, the definition (of AI) forms the basis for all subsequent considerations of application, regulatory, normative and legislative considerations, specifications and content. If there is no universally accepted definition, or if existing definitions are inappropriate or too imprecise for the work and intent of a group or publication, the typical approach is to create a "custom" definition or redefine or flesh out an existing one to achieve the best possible accuracy and self-reference of documents, e.g., specifications, standards, regulatory guidelines.

However, the change of an underlying definition can also lead to the fact that developed specifications must also be changed, extended or adapted. In addition, content (e.g., from different standards or specifications) based on different definitions cannot be directly applied together. The more different yet concrete the definitions, the more difficult it becomes to identify a consolidation or common application of content; the risk of conflicting content increases and harmonization of content becomes much more difficult. That is the situation we currently face, not least because there is not yet a commonly used definition of AI.

Since 2022, there is now a normative consensus of a definition of artificial intelligence achieved through intensive discussions worldwide: An AI system is an "engineered system that generates outputs such as content, forecasts, recommendations or decisions for a given set of human-defined objectives" (see ISO/IEC 22989[64]). The problem is that this definition is still quite weak and does not directly solve

64 ISO/IEC 22989:2022 "Artificial intelligence – Artificial intelligence concepts and terminology"

the existing problem of different definitions. The national mirror work takes place within the DIN/DKE Joint Committee Artificial intelligence (NA 043-01-42 GA[65]), in which members of the SCI 4.0 Expert Council for artificial intelligence in Industrial Applications are also active as staff members in order to continuously check the consistency of Industrie 4.0 applications. This work should be continued and intensified [RE 5.1.7-1 V5]. At the European level, CEN/CENELEC JTC 21 "Artificial Intelligence" was founded in June 2021, and its national work in Germany also takes place in NA 043-01-42 GA. This has enabled a strategic bundling of national activities and channelling to European and international standardization activities. Efforts to orchestrate, consolidate and harmonize standardization in the context of AI should also be intensified, particularly at European level – not least in the context of European regulatory activities.

High-risk AI systems (as defined by the EU AI Act [60]) can also be systems that are not considered safety systems. However, similar requirements do apply. However, it is unclear whether these high-risk AI systems should be consistently considered as safety systems (in the sense of fail-safe, functional safety, see also **Chapter 5.1.6**) in the future [RE 5.1.7-2 V5].

Standards and specifications are based on the respective applicable standard of technology. AI represents an active research field in which new innovative algorithms and solutions are being developed at ever shorter intervals, as in the case of ever larger transformer models for language processing [61], [62], [63] or text-to-image generators [64], [65], [66]. The state of the art is changing at an increasing rate. One of the resulting positive effects is an increasingly strong, time-shortened link between science and standardization. Thus, research results already frequently flow directly into normative activities within the framework of any (possibly publicly funded) projects or are triggered from scientific initiatives. However, the challenge here is that the sometimes very complex (national and international) coordination, established normative coordination and harmonization mechanisms, relevant committees and liaisons are partly unknown from a scientific point of view, and this often leads to contradictory national signals at international level, particularly in international research projects and their initiatives in standardization – especially vis-à-vis nations with different national standardization policies than Germany and Europe (such as China). In order to make more targeted use of this fundamentally positive development from the point of view of internationally harmonized standardization activities and to enable positive effects for German and European interests, it is therefore necessary to strengthen the links between science and standardization [RE 5.1.7-3 V5], [RE 5.1.7-4 V5].

The "Strategic Advisory Group" of CEN/CENELEC JTC 21 has as one of its goals the development of a standardization roadmap and strategy with a focus on Europe. At international level, an Advisory Group at ISO/IEC JTC 1/ SC 42"Artificial Intelligence" was established in the fall of 2021 to develop a standardization map and an overview of ongoing and published (standardization) projects. Other working groups of the same SC are developing roadmap strategies for further projects in their thematic areas in ad hoc groups. A continuously updated overview of the most important standardization bodies and their structural organization in the context of AI in industrial applications is to be developed nationally on an institutional basis, for example by SCI 4.0 and its Expert Council for artificial intelligence in Industrial Applications [RE 5.1.7-5 V5].

The Standardization Roadmap Industrie 4.0 V4 already described the recommended action for establishing an evaluation framework for AI methods. Based on this recommendation for action, standards and specifications on horizontal AI methods and systems have already been published at international level, including ISO/IEC 5392[66] and ISO/IEC 42001[67]. Through national mirror work in the DIN DKE artificial intelligence Joint Committee, the results of the standards and specifications developed in this way can be reviewed by the SCI 4.0 "Artificial Intelligence" Expert Council in industrial applications with regard to Industrie 4.0 requirements, and vertical standardization work can be initiated on this basis. Due to the positive effects already resulting from the work carried out so far, these activities should be continued and intensified [RE 5.1.7-6 V5]. In this context, additional regulatory activities (see [RE 5.1.7-1 V5] and [RE 5.1.7-2 V5]) and the general quality characteristics of methods (see also [RE 5.1.7-7 V5]) as well as their influence on these should be taken into account or introduced into horizontal standardization on the part of the Industrie 4.0 community.

65 NA 043-01-42 GA "DIN/DKE Joint working committee Artificial intelligence"

66 ISO/IEC 5392 "Information technology – Artificial intelligence – Reference architecture of knowledge engineering"

67 ISO/IEC 42001 "Artificial intelligence management system"

As the application scenarios developed by the Plattform Industrie 4.0 [67], [68] already show, Industrie 4.0 influences the entire life cycle of product development, the use of the product through to recycling, as well as (special and series) mechanical engineering, system integration, (flexible) plant operation including logistics and dismantling, both in greenfield and brownfield sites. The same applies to the possible applications of AI, which is or can be used in principle in every phase and facet of the life cycle of products and production in the context of Industrie 4.0. The development of (mechatronic) products, machines and plants is already characterized by its high level of interdisciplinarity: For example, the development of a machine involves, among others, design engineers for the mechanical design, electrical engineers and, if necessary, fluid engineers for the planning of electrical/electronic and pneumatic or hydraulic aspects, and automation engineers for the control software. Due to the increasing use of information and communication technology in general and AI in particular, this circle is being expanded to include AI experts, computer scientists, data analysts, etc. Accordingly, the challenge arises as to how a systematic (interdisciplinary) development and operation of AI-based solutions as part of such systems is possible. This is also called AI engineering.

As has already been shown in a multitude of works in research [69], [70], [71] and practice [72], [73], an interdisciplinary system development is decisively confronted with the fundamental challenge of elaborating a common (conceptual) understanding or relying on such an understanding. The use of methods and algorithms from the field of artificial intelligence further increases the challenge and thus the need; a uniform common (normatively defined and consistent) terminology taking into account necessary technical terms in industrial automation or Industrie 4.0 would significantly strengthen development and thus cooperation in order to avoid (possibly very cost-intensive) misunderstandings (see also[RE 5.1.7-1 V5]). Systems in the context of Industrie 4.0 are often critical applications and complex systems, which is why a high degree of specific quality criteria such as reliability, trustworthiness, safety and security, and controllability is required. While these requirements and their evaluation or proof of properties (at runtime) of the systems in system development without AI are (often) already addressed by best practices, standards and specifications, accepted procedures and development methods for AI-based systems or subsystems and their evaluation and proof of properties are lacking in industry [RE 5.1.7-8 V5]. This may result in different (quality) requirements in the respective life cycle phases; verifications may also have to be provided prior to a specific phase of the life cycle, such as safety considerations, for example, before a machine goes into productive operation. Not all applications and life cycle phases have identical requirements. Particularly when using learning methods such as machine learning, compliance with specific boundary conditions (e.g., safety) must be ensured over the entire (productive) lifetime of a machine, even if (continual) learning methods are used.

Currently, there is a focus of normative activities dealing with artificial intelligence in horizontal bodies. This is a logical first step for such a disruptive and widely applicable method and technology area as AI. Currently, a large part of the standardization activities on AI are concentrated in ISO/IEC JTC 1/SC 42. However, after an initial orientation phase, which has already taken place, it is apparent that this centralized approach to the standardization of AI results in a large number of dependencies on other standardization activities, in addition to a large number of aspects and topics, some of which are very heterogeneous. This considerably increases the complexity and personnel requirements in the central standardization bodies and makes it much more difficult to ensure consistency with relevant standardization activities outside this central body (especially in subject-specific details) – not least for relevant aspects of AI in Industrie 4.0. For this reason, a reallocation or shift of standardization projects from central AI bodies to the (largely already existing) subject-specific standardization bodies should be sought, e.g., to the bodies of IEC TC 65 (see [RE 5.1.7-8 V5]), as well as a strengthening of orchestrating bodies.

Currently, the topic of AI is often equated with the use of learning methods (subsymbolic AI), such as machine learning. The large research and application area of symbolic AI, which has existed for decades, i.e., processing of explicit knowledge (e.g., by means of mathematical logic) and corresponding reasoning mechanisms, is often disregarded in this context. However, these also play a not insignificant role in industrial automation, since explicit (digital) models are used, for example, in the development process of products, machines and plants, such as MCAD, ECAD, etc. Furthermore, basic (digital) descriptions of physical (sub)systems (e.g., in the form of submodels of the Asset Administration Shell) and access to operational data (API of the Asset Administration Shell) are being developed as part of the development and application of the Digital Twin and the Asset Administration Shell in the context of Industrie 4.0 (see Chapters 5.1, esp. 5.1.3 and 5.1.4). AI methods and algorithms can perform automatic processing based on this information. However, this requires a suitable formal basis for the information provided (see also [RE 5.1.3-4 V5] as well as [RE 5.1.4-2 V5]). Often, software innovations, such as submodels of the Asset Administration Shell, are developed (consortially) within the framework of (agile) standardization due to rapid innovation cycles. In order to ensure (semantic) interoperability, international acceptance and consistency of normative and regulatory boundary conditions and thus enable the application of (symbolic) AI methods in Industrie 4.0, close cooperation, orchestration and exchange between consortial standardization bodies/consortia and standardization are necessary for the successful use of AI in Industrie 4.0 (see also [RE 6.1-1 V5] and [RE 6.1-3 V5]).

AI technology is always related to humans, the organizational environment, and society as a whole. The successful design of AI solutions therefore always considers the sociotechnical system in which the AI is used and interacts with humans. The concept of sociotechnical system design explicitly postulates the need to optimize the use of technology and the organization together, where the task is the unifying element. The basic principle is based on identifying people's needs, analysing them, and using them to design AI solutions that help users complete their tasks in the best possible way. The strengths and weaknesses, and the opportunities and risks of AI thus do not depend solely on the technology and its development, but on the context of its application. The sociotechnical perspective provides this context and must be considered throughout the complete AI life cycle, focusing on specific aspects of the sociotechnical system at each stage of the AI life cycle. The design of an AI solution therefore always requires a systematic approach in which all affected groups of people are involved in a participatory manner (see [RE 5.1.3-2 V5], [RE 5.1.1-4 V5] and [RE 5.2.3-2 V5]). For more in-depth information, please refer to the chapter "Sociotechnical Systems" in the German Standardization Roadmap for artificial intelligence, 2nd edition [74].

5.2 Aspect 2: Autonomy

5.2.1 Data spaces

On the road to greater digital **autonomy**, standards for data spaces play a significant role. Every type of **data space** requires suitable identity management and security features for protection and controlled access. This requires international standards to support and secure global cooperation. European solution building blocks such as electronic Identification, Authentication and trust Services (eIDAS) must be supplemented globally or made accessible and accepted. Security levels must meet the requirements of the supported business models. The necessary specifications include rules for governance as well as technical architectures and the quality of implementations [RE 5.2.1-1 V5], [RE 5.2.1-2 V5].

There is already an opportunity to build on a wide range of technologies, components, standards and preliminary work. With the "building blocks" of the document "Design principles for data spaces", a methodical approach for structuring and **building data spaces** is already available [3] (see Figure 14). The building blocks are divided into the technical areas of **interoperability, trust** and **data value**, as well as **governance**. To build a data space, the building blocks named here must be filled with concrete realizations that meet the requirements of the data ecosystem, such as the Asset Administration Shell as the basis for data models or the eIDAS regulation for identity management. Beyond the building blocks mentioned here, the setting up of concrete and domain-specific data spaces may require further building blocks. Following this model facilitates interoperability between different data spaces.

Standardization can shape data spaces primarily from a technical perspective. On the one hand, existing standards can form the basis for a technical implementation of a data space; on the other hand, the expansion of existing standards and the development of new standards can be useful and necessary due to new requirements in the context of the "digital economy". This first requires a uniform view of the structure or architecture of data spaces, including the necessary uniform definition of terms (glossary). Building on this, there is a need for the concrete definition and standardization of core functionalities, such as a gateway component that realizes the connection of a subscriber to a data space and thus realizes complex functionality and, at the same time, minimum cybersecurity requirements, as well as decentralized identity management including authentication and authorization.

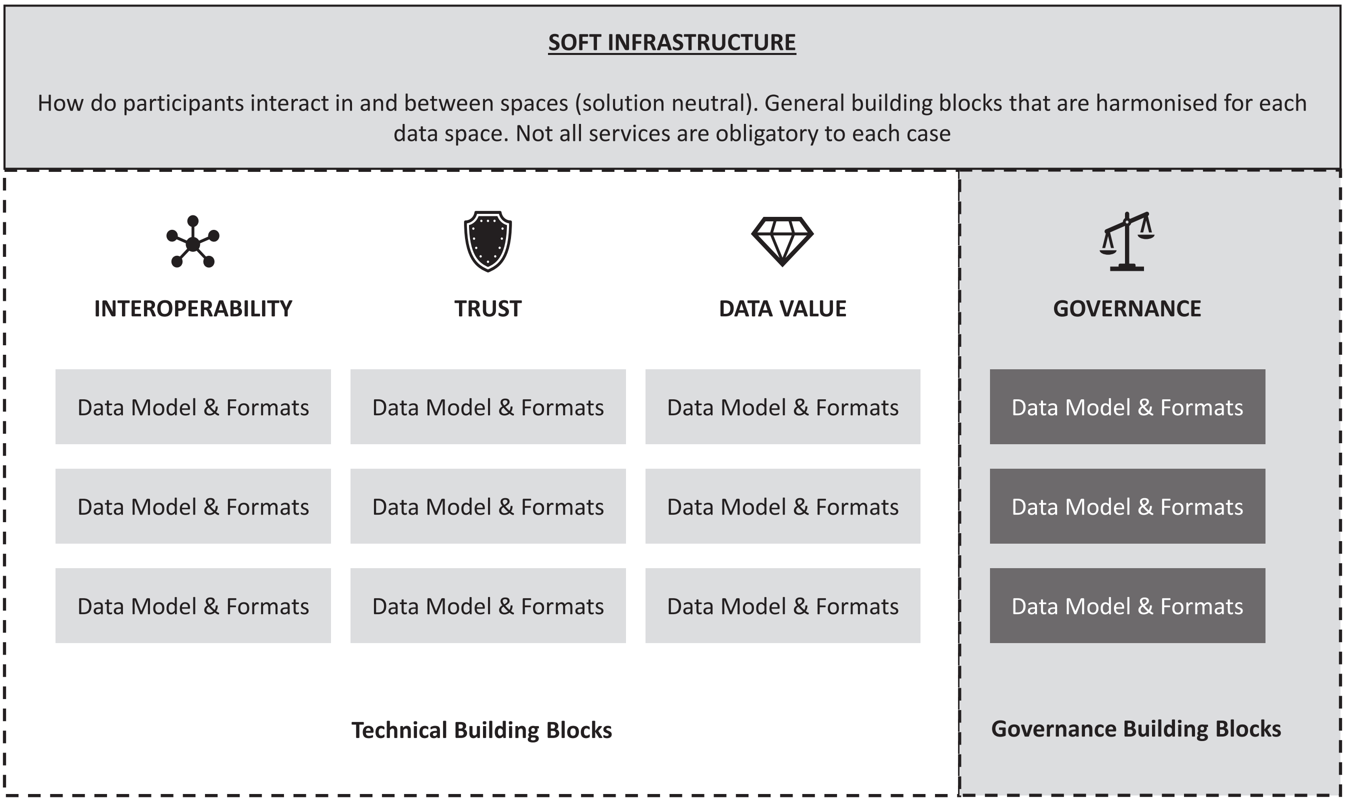


Figure 14: Building blocks for building data spaces acc. to "Design Principles for Data Spaces" (CC-BY-4.0 [3])

Mechanisms for locating data and services are needed to realize data value creation, and other mechanisms are needed to make transactions traceable in a decentralized and cross-enterprise system. These issues need to be brought into the broad standardization landscape. While national (DIN) and international (ISO, CEN-CENELC) standardization bodies are already working on standardizing the requirement, structure, and behaviour of components for data spaces, standardization efforts in other areas must also be coordinated, e.g., work within the W3C on the transition from RDF to RDF-star. In the spirit of international harmonization and cooperation, standardization work must also connect to adjacent topics that deal with data trading (e.g., IEEE P3800 [75]).

In addition to technical standardization activities, other activities are required from the areas of **governance**, legal frameworks, operational foundations and beyond. Here, work is already being done on working principles through various approaches. Examples include the Data Sharing Coalition [76], the SITRA "Rule Book for a fair data economy" [77] or the work of IDSA [27].

Overall, there is a need to be able to communicate the complex situation around standards already in use, standards under development, and lacking standards. This task is already partially addressed by the Data Spaces Business Alliance [78], but should be accompanied by further work.

There are certainly various standards that address data spaces in principle, and also standards that specifically support the objective of data spaces. The impression, however, is that these are more individual activities, while the overarching context is not really transparent. The BDVA [28] TF6.SG6 (Standards) is working here in close collaboration with the Data Spaces Business Alliance DSBA [79] on a common, inclusive and open approach to create transparency and a unified standards agenda for data spaces.

5.2.2 Industrial Security

Information security represents a firmly established industrial and social value. It is a basic requirement for Industrie 4.0 and cooperation within digital ecosystems. Despite all the challenges involved, it creates the high level of trust in Industrie 4.0 worldwide and is an important aspect of trustworthiness along the value chains. This chapter focuses on the topic of security in the sense of "**industrial security**", i.e., the holistic protection of information technology in production systems, as well as the protection of machines and plants against sabotage, espionage or manipulation. Data protection (privacy) and functional safety are covered in Chapter 5.2.3 and 5.1.6.

5.2.2.1 Industrial security as an aspect of interoperability

Increasingly, cyberattacks are used for political purposes, especially in times of political tension and crisis. Attacks are not limited to government agencies or critical infrastructures and can cause great damage: For example, targeted attacks on (niche) producers can bring entire supply chains to a halt, affecting an economy's value creation, prosperity, and defensibility.

Meanwhile, organized crime attacks are being carried out at levels comparable to state-directed attacks. This must be taken into account in risk analyses and requires correspondingly effective defensive measures.

Furthermore, classically available security solutions from the IT and office areas are unsuitable or insufficient for industrial applications. The various security requirements are determined in particular by real-time and robustness requirements, life cycles of industrial components, and requirements for the continuous availability of industrial plants. **Industrial security** also has a much broader meaning than the protection of data and information in traditional data-centric communications security. Industrial security not only affects communicated and stored data and information, but also any assets, be it devices, processes, infrastructures across the entire value chain and the life cycle of the assets involved [RE 5.2.2-1 V5].

In addition to ensuring interoperability and comparability of security levels, future standards should also contribute to overcoming implementation obstacles (see ISO/IEC JTC/SC 41). Such "perceived" obstacles are:

- → Unclear contribution of security investments to value creation: In certain sensitive areas such as critical infrastructures, however, government regulation will increasingly force the implementation of appropriate measures.
- → The lack of generally applicable and industry-compatible implementation standards with moderate certification efforts for trustworthy solutions.
- → Fear of increased system complexity due to security measures that cannot be dealt with in conventional established processes for development and operations.
- → The lack of a standardized assessment of the trustworthiness of value networks for Industrie 4.0, e.g., also with regard to data protection requirements (see also [RE 5.2.4-1 V5] on trustworthiness).
- → The lack of a global trust infrastructure for Industrie 4.0, which, for example, offers the possibility of globally consistent encryption of the transmission of communication and control data.

An important contribution to overcoming implementation barriers for security is the specification "Generic application programming interface for IoT and industrial devices" ISO/IEC TS 30168[68] of ISO/IEC JTC1/SC 41/WG 3[69] "IoT Foundational Standards" [RE 5.2.2-2 V5].

There is an ever increasing need to protect industrial applications and systems directly (i.e., at application level) rather than relying solely (and ineffectively) on network security mechanisms. This means that, if required, end-to-end security or, for example, measures for know-how protection, licensing protection or data protection can be supported and implemented. The "ZeroTrust" principle aims to implement end-to-end security architectures that cover both the IT and OT areas of a company (or an entire Industrie 4.0 application scenario). Here it is important that the resulting security mechanisms are as globally interoperable as possible and are supported by suitable infrastructures for key management, for example [RE 5.2.2-3 V5].

The worlds of secure production and the worlds of secure products belong together. Malicious code can be introduced into the product via compromised production equipment or development tools. Therefore, verification of the security properties of production conditions and their linkage across trusted supply chains is necessary. An important element for the secure management of software along the supply chain is the SBOM (Software Bill of Material). For this purpose, the corresponding submodel was initiated at InterOpera [44] in consultation with IDTA in 2022. The SBOM reliably informs about the libraries, licences, copyrights, etc. used for the creation of the software and supports the management of

68 ISO/IEC TS 30168 1st ed. "Internet of Things (IoT) – Generic Trust Anchor Application Programming Interface for Industrial IoT Devices"

69 ISO/IEC JTC1/SC 41/WG 3 "IoT Foundational Standards"

software updates and the tracking and elimination of newly emerged vulnerabilities and risks [RE 5.2.2-4 V5]. It takes into consideration the existing standards ISO/IEC 5962:2021 “SPDX® Specification V2.2.1”, SPDX and OWASP CycloneDX Software Bill of Materials (SBOM) standard [80] and regulatory requirements [81]. Automatable mechanisms for vulnerability management along the value chain can be supported by this and should be defined as an interoperable standard [RE 5.2.2-5 V5].

Applications supported by artificial intelligence mechanisms require protective functions specifically tailored to them in order to ensure that, in terms of trustworthiness, an application delivers exactly the functionality that the user expects without the possibility of deliberate manipulation of input data or functional components corrupting the result. As a result, the classic integrity protection of data or components and systems is faced with completely new challenges (see ISO/IEC JTC 1/SC 42) (see Chapter 5.1.7).

New concepts, such as the Asset Administration Shell, Digital Twin, blockchain-based infrastructures, quantum technologies, data spaces and trustworthiness, the digitalization of standardization itself, etc., require accompanying security work in the sense of preparing and realizing “security-by-design” [RE 5.2.2-6 V5].

The Asset Administration Shell (see Chapter 5.1.4) describes the Digital Twin for Industrie 4.0 and is standardized at IEC TC 65. Work on security has also been started in IEC/TC 65/WG 24 [RE 5.2.2-7 V5], [RE 5.2.2-8 V5]. The Asset Administration Shell also supports the security of the mapped asset, e.g., by managing digital identities. The Asset Administration Shell can contain data on the supply chain and attestation of the security of the mapped asset, interacting with trust anchors embedded in the asset. Here the generic trust anchor API (ISO/IEC TS 30168) (see also [RE 5.2.2-2 V5]) could play an important role in the implementation. For interaction with the asset, directly or via the Asset Administration Shell, mechanisms for end-to-end security are to be provided to support zero-trust concepts.

The security of the Asset Administration Shell itself must be ensured in order to protect the integrity, authenticity and confidentiality of the data it contains. Access control rules are used for this purpose. A secure Asset Administration Shell can only be realized in a secure and trusted infrastructure. To this end, mechanisms for end-to-end security must be provided to support zero-trust concepts [RE 5.2.2-9 V5] (see also [RE 5.2.2-7 V5]).

5.2.2.2 Security standardization in support of European regulation

The focus of **security standardization** in support of European regulation at CEN/CENELEC under the New Legislative Framework (NLF) is currently on the work on cybersecurity for radio equipment directive (RED). It is to be expected that the upcoming “Cyber Resilience Act” [82] will result in extensive security-related work at CEN/CENELEC, which will be of great importance in the form of horizontal security standards for I4.0 security, and this globally, beyond the European area (see also [RE 5.2.1-1 V5]). The expected regional differences in cryptography (and also in data protection (see Chapter 5.2.3)) will force the possibility of profiling and agile implementations of security standards, especially for communication on a global level [RE 5.2.2-10 V5].

5.2.2.3 5G Security for Industrie 4.0

The **fifth generation of mobile communications (5G)** is intended to meet a wide range of availability, **security** and capacity requirements [RE 5.2.2-11 V5]. Data and its transport between data source and data sink can be dynamically modified and processed. The network is thus becoming intelligent. In the ISO-OSI model the 5G technology can therefore be located at all levels 1 to 7.

5G technology and its use can be clustered in:
→ the installation of 5G components as part of product development,
→ local use of 5G on site and in operation by organizations,
→ the use of 5G services provided by mobile providers.

In the meantime, there is work on TSN security at IEEE, namely IEC/IEEE 60802 “TSN Profile for Industrial Automation”, a profile definition for commissioning/bootstrapping of devices (see also [RE-5.1.5-12 V5]), which incorporate communication security according to the “security-by-design” principle and can be supported by for interdomain communication [RE 5.2.2-12 V5].

5.2.3 Privacy

In the area of data protection, the General Data Protection Regulation (GDPR) [83] has laid essential foundations that also influence standardization globally (for example, in ISO/IEC JTC 1/SC 27/WG 5 [70] "Identity management and privacy technologies"), and further regulations are in preparation.

The ePrivacy Regulation has already been under development since 2014 and is relevant in this context because of the expected protection of location data and also because protection of communications is not negotiable by consent like some regulatory areas of the GDPR.

In addition, regulations such as the Data Act, the Digital Services Act, the Digital Markets Act, and the Data Governance Act [84] are in preparation that affect both technical and economic aspects of data use and data users, and in this respect may raise potential for standards. Thus, these regulations are to be observed [RE 5.2.3-1 V5].

The way in which employees' personal data is handled, as defined in company agreements, for example, can influence the acceptance of Industrie 4.0 systems and satisfaction with them, among other things. The following recommendation for action from Version 4 of the Standardization Roadmap Industrie 4.0 [2] is therefore taken up again at this point [RE 5.2.3-2 V5].

The AI Act plays a special role, since artificial intelligence contributes massively to the use and evaluation of data, and in some cases the data evaluators know more about the respective data subjects than the subjects themselves. Also, with increased performance, through AI capabilities decision assistance can virtually outgrow the role of an assistant. Standardization relevance is already shown by the fact that the EU Commission has started a standardization initiative in connection with the AI Act, interestingly at JTC 1 and not at CEN/CLC (see [RE 5.2.3-1 V5]).

70 ISO/IEC JTC 1/SC 27/WG 5 "Identity management and privacy technologies"

In the course of implementing the GDPR, two aspects are worth noting:

5. The European Data Protection Board EDPB [85] has established itself as the main source of implementation recommendations for the GDPR. It also participates in ISO/IEC JTC 1/SC 27/WG 5 via a cat-C liaison. In this rea spect, it is highly recommended to follow its analyses and recommendations.
6. There are now a large number of standards in ISO/IEC JTC 1/SC 27 [71] "Information security, cybersecurity and privacy protection", mostly in ISO/IEC JTC 1/SC 27/WG 5, which underpin the GDPR. A small number of standards are being refined at CEN/CENELEC JTC 13 or adapted to European needs [RE 5.2.3-3 V5].

The concept of "data ownership" advocated in the Anglo-American world has not caught on because it conflicts too much with the principle of seeing data protection as a fundamental right that cannot be negotiated commercially. The regular weakness of individual users to seriously negotiate terms with large providers, such as Internet service providers, for the use of services and/or in return for the use of personal data may have contributed to this [RE 5.2.3-4 V5].

5.2.4 Trustworthiness

The topic of "**trustworthiness**" is currently finding its way into standardization in various places. A definition and principles of trustworthiness are being dealt with in ISO/IEC JTC 1/WG 13 [72] "Trustworthiness". Trustworthiness with reference to the supply chain of devices is being dealt with in ISO/TC 292/WG 4 [73] "Authenticity, integrity and trust for products and documents". ISO/IEC JTC 1/SC 41 and ISO/IEC JTC 1/SC 42 [74] "Artificial Intelligence" are addressing trustworthiness in relation to the IoT and artificial intelligence. A new group on "Supply Chain Integrity, Transparency and Trust (SCITT)" is currently being formed in the Internet Engineering Task Force (IETF) [86]. At ISO/IEC JTC 1/SC 27/WG 4 [75] "Security controls and services", work is currently being initiated that also con-

71 ISO/IEC JTC 1/SC 27 "Information security, cybersecurity and privacy protection"

72 ISO/IEC JTC 1/WG 13 "Trustworthiness"

73 ISO/TC 292/WG 4 "Authenticity, integrity and trust for products and documents"

74 ISO/IEC JTC 1/ SC 42 "Artificial Intelligence"

75 ISO/IEC JTC 1/SC 27/WG 4 "Security controls and services"

cerns the trustworthiness of "Data Provenance" (PWI 5181) [RE 5.2.4-1 V5]. Within the framework of Gaia-X (see also Chapter 5.1.2), a "trust framework" [87] for the self-description of a service is specified, which is to be included in standardization.

Trustworthiness can refer to a number of different qualities, depending on the context. In the standardization bodies, "characteristics/attributes" such as "authenticity, integrity, resilience, availability, confidentiality, privacy, safety, accountability, usability, sustainability/environmental properties (CO_2 footprint), or compliance to social regulations" are being discussed. Security plays an important role in ensuring the quality of these attributes and providing conclusive evidence, especially along value chains. The trustworthiness expectations and capabilities profile and the trustworthiness expectations and capabilities exchange protocol (TECEP) are currently under discussion [88] . Trustworthiness in the supply chain is proven through verification of claimed capabilities or the trustworthiness expectations and capabilities profile. A decision to enter into a contract can be made based on an assessment of capabilities in relation to expectations, resulting in a trustworthy business relationship. A next step would be a machine-readable definition of profiles for trustworthiness. This solution could also be realized within the framework of the Asset Administration Shell [RE 5.2.4-2 V5].

What is new is the need not only to ensure trustworthiness in the bilateral relationship with the supplier and customer, but also to be able to verify and/or check the qualities backwards along various stations of the value chain ("chain of trust") [RE 5.2.4-3 V5] (see [RE 5.2.4-1 V5]). Automation would make "trustworthiness management" possible and thus enable updated statements on trustworthiness. ISO/TC 292/WG 4 is developing a framework to describe the requirements for such an architecture.

5.3 Aspect 3: Sustainability

5.3.1 Sustainability aspects in Industrie 4.0

The topic of **sustainability** has already been given a permanent place in the Standardization Roadmap Industrie 4.0 with the publication of Version 4 of the Roadmap [2]. Here, the focus was particularly on social and ecological aspects and their fundamental integration in **Industrie 4.0**. With Version 5 of the Roadmap, the topic of sustainability is now considered in a differentiated and in-depth manner and presented in independent chapters. This includes a comprehensive set of new recommendations for action, which are described in detail below.

With regard to the status quo of the standardization of sustainability aspects related to Industrie 4.0, these must be considered separately according to ecological, social and economic aspects.

The environmental sector, which has grown continuously in importance over the past decades, especially with regard to Germany, can boast a large number of standards that are Industrie 4.0-compatible. Examples include the measurement of emissions into the air, the mathematical-statistical evaluation of emission data to determine daily or annual averages of e.g., CO_2, and physical-chemical analysis methods to determine pollutants and pollutant concentrations. Standards in the aforementioned areas have long been established in practice and form an integral part of various legal regulations.

Standards and specifications for the assessment of climate and environmental aspects already exist or are being developed, but so far they have considerable problems with regard to data transparency and quality. In addition, data with completely different reference points (assets) are regularly combined and evaluated, which significantly reduces the further use and significance of the results.

With regard to current standardization activities, the recently published Standardization Roadmap Circular Economy should be mentioned in particular. This Roadmap contains extensive standards research on the key topics of electrical engineering and ICT, batteries, packaging, plastics, textiles, construction and municipalities, as well as digitalization, business models, management, and corresponding recommendations for action to close identified standardization gaps. However, standards from the waste and recycling sector are of limited use in Industrie 4.0 systems geared to the manufacturing of industrial products in collaborative value networks, with the exception of those standards that have a clear product reference.

Furthermore, the InterOpera [44] project should be mentioned, which is working towards a standardized implementation of the Asset Administration Shell in practice. The German Federal Environment Agency has submitted two proposals for submodels – one environmental data set with (industrial) plant reference and one with product reference – which are expected to be published in 2023.

5.3.2 Overview of sustainability modules

5.3.2.1 “Sustainability building blocks”

There are recommendations for action to fully digitally integrate climate, environmental and other sustainability aspects into digital ecosystems and to automate the generation of sustainability assessments.

For the qualitative and quantitative recording and evaluation of sustainability aspects in highly dynamic and flexibly operating digital ecosystems, the data and information required for this must be digitally recorded and managed separately according to assets. The assets available in digital ecosystems, i.e., data reference points, as well as different forms of data aggregation or dissemination, result in the **sustainability modules** described in detail below, which can be flexibly combined with each other as in a “**modular system**” and “assembled” to form larger information units (combination modules; e.g., digital sustainability passport for plants as well as for products). Data quality or minimum quality standards should be defined for each module. The digital information management should be such that the larger information units, i.e., the combined modules, can be broken down again into their “individual parts”, i.e., basic modules. This facilitates error analysis and elimination and is a fundamental element for quality assurance of digitally and automatically generated sustainability outputs. Currently, there are no standards or specifications that could serve as a basis for such basic modules.

The approach or structuring and management of climate, environmental and sustainability information in essence follows a sorting and allocation of data and information to an asset and is consequently based on the approach of the Asset Administration Shell model [RE 5.3.2-1 V5].

In the following, various sustainability standard modules, as explained above, are described in more detail and proposed for implementation (see Figure 15).

5.3.2.2 Sustainability modules for stationary plants

Module: (Industrial)plant/production facility/site and the associated climate data/environmental data/ecological sustainability aspects (Asset: Industrial plant/production facility)
Climate and environmental data are collected for **(industrial) plants/production facilities** on a regular to continuous basis in a standardized form and are also often subject to reporting requirements. This essentially involves emissions to air and water, and waste. As already mentioned above, there are numerous standards and specifications dealing with the measurement of emissions and calculation of pollutant loads, so that the data situation and quality in this area can be classified as comfortable to very good. At the same time, the emission data of an (industrial) plant are largely in one hand or are owned by the plant operator and can be made available accordingly.

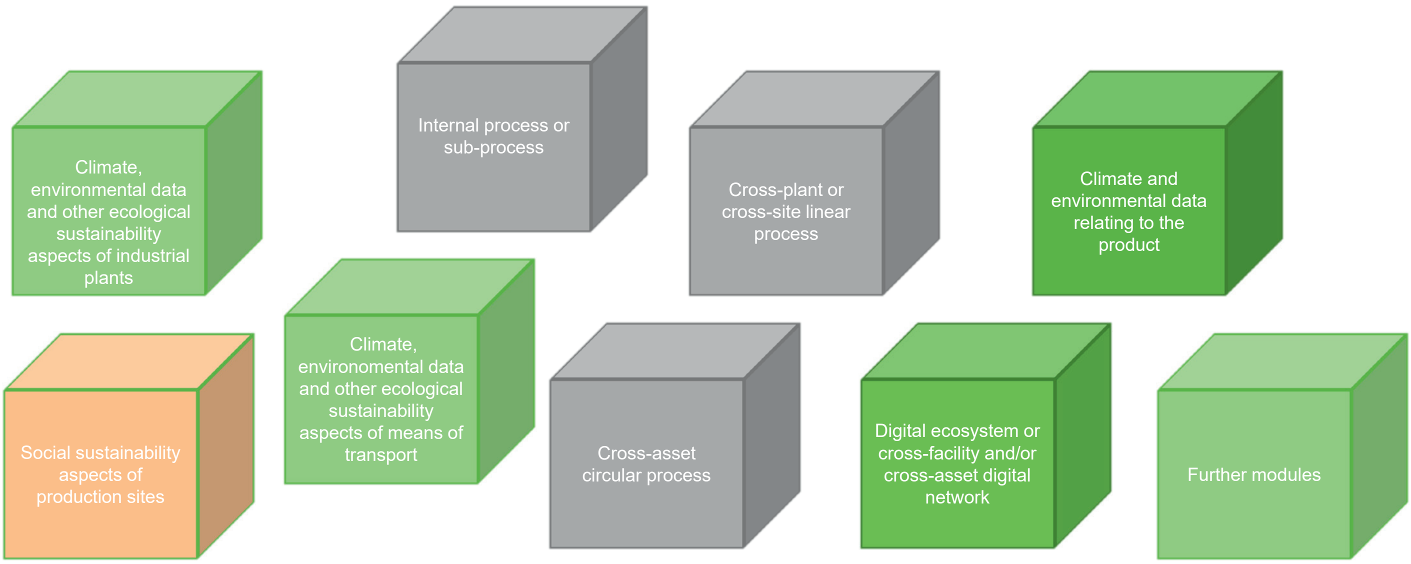


Figure 15: The “sustainability building blocks” comprising various modules (Source: D. Meurer)

With regard to a clear, standardized and thus comparable presentation of emissions and other **environmental sustainability aspects** of (industrial) plants or production facilities, it is recommended that a standardized format for the recording and presentation of facility-related emissions be developed and established in practice.

This also serves the purpose of capturing data only once and then using this digital "source data set" as the basis for all further data uses, including, for example, the various operational reporting obligations [RE 5.3.2-2 V5].

Module: (Industrial)plant/production facility/site and the associated social sustainability aspects (Asset: Industrial plant/production facility)
Analogous to the previously described module on **(industrial) plants/production facilities/sites** with reference to climate, environmental data and ecological sustainability aspects, this basic module focuses on the social sustainability aspects of production facilities (not companies). In all likelihood, data on the social sustainability of production facilities are not yet available in standardized data formats and consistently in digital form (see Chapter 5.3.3).

In order to also regularly record **social sustainability** aspects of (industrial) plants or production facilities, to present them in a clear, uniform form and thus make them comparable, it is also recommended here to develop and implement a standardized format for the presentation and definition of properties of operation-related social sustainability aspects [RE 5.3.2-3 V5].

Combination module: Digital sustainability passport for (industrial)plants/production facilities/sites (Asset: (Industrial)plant/production facility)
The combination of the two basic modules on environmental and social sustainability described above logically results in a **digital sustainability passport for (industrial) plants, production facilities** and, where applicable, sites (see Figure 16), which can be supplemented with the economic sustainability aspects in the future, whereby it must be ensured that the reference point is the (industrial) plant or production facility and not the company.

A consolidation, primarily of the environmental and social sustainability aspects, with regard to (industrial) plants/production facilities and a largely complete as well as clear presentation of all relevant sustainability data would enable a comparability of (industrial) plants and production facilities with regard to their sustainability performance. In the future, such a sustainability passport could also be used for sustainability assessments of production facilities in international value chains. It is therefore recommended to establish a **standardized, digital sustainability passport** for (industrial) plant and production facilities, which consists of the two basic modules on environmental and social sustainability described above [RE 5.3.2-4 V5].

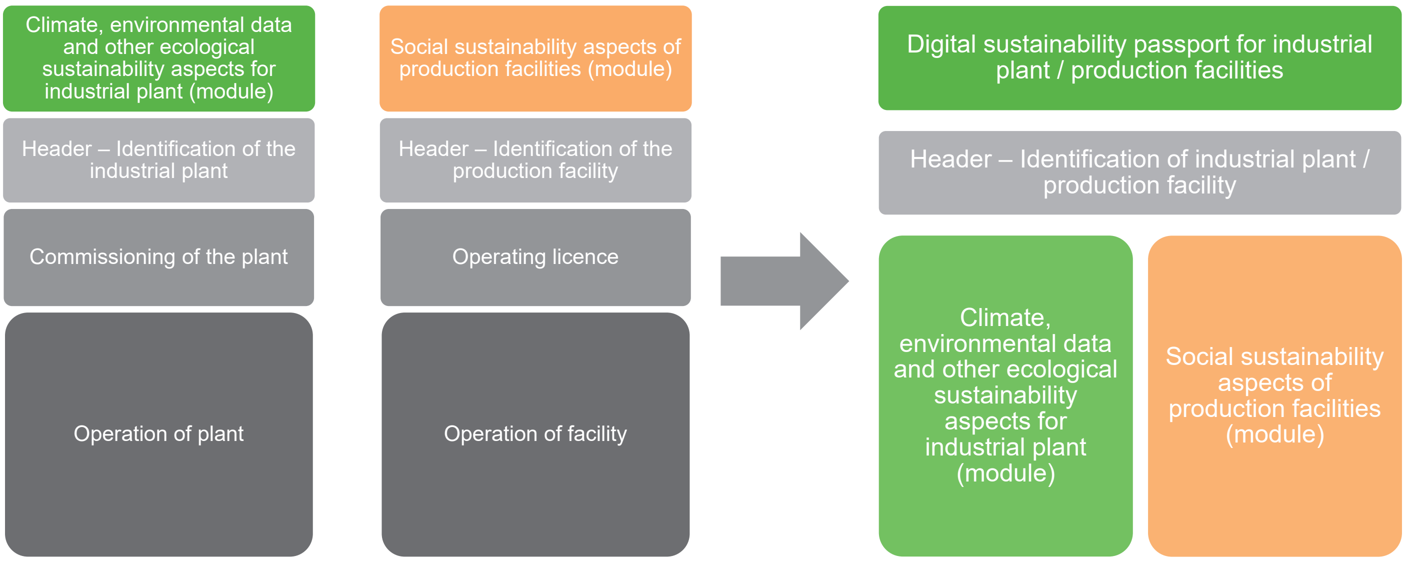


Figure 16: The digital sustainability passport for (industrial) plant and production facilities comprising the modules climate and environmental data for (industrial) plant and social sustainability aspects for production facilities (Source: D. Meurer)

5.3.2.3 Sustainability modules for mobile plant and means of transport

Module: Mobile plant and means of transport and the associated climate data/environmental data/ecological sustainability aspects (Asset: Mobile plant)
Analogous to the basic modules for fixed plant and facilities described above, climate, environmental data and other ecological sustainability aspects can also be assigned to **mobile plant** or means of transport (e.g., motor vehicle, lorry, train, ship, aircraft). The main focus here is on greenhouse gas emissions from fossil fuels. In combination with the modules for fixed plant, i.e., production facilities, and for the product, it is now possible, for example, to display sustainability aspects across entire supply chains [RE 5.3.2-5 V5].

5.3.2.4 Sustainability module for processes

Module: Internal process or sub-process (Asset: Process)
In addition to physical objects, processes can also be viewed as assets in Industrie 4.0 systems and managed digitally. This requires a dedicated description of the process under consideration. **Internal processes or sub-processes** have the advantage that they take place in their entirety in a plant/facility and thus access to the process data is guaranteed to the greatest possible extent. Challenges exist, on the other hand, when process information is passed on to third parties who do not belong to the respective facility or company [RE 5.3.2-6 V5].

ISO 20140 can be cited as an example in which environmentally relevant data in production systems as well as their aggregation and evaluation are standardized internationally.

Module: Cross-plant or cross-site linear process (Asset: Process)
Processes that pass through industrial ecosystems primarily in linear form (e.g., supply chains) are continuous across (industrial) plant or sites due to the length of their information strand. Consequently, the entire process chain consists of a large number of actors or legal entities, which are distributed regionally to worldwide, and are located in a wide variety of countries, resulting in core challenges. Data aggregation along such processes as well as the IT-technical realization do not represent an actual obstacle to implementation, but rather the trustworthy information transfer between the diverse actors, mostly companies, within the process chain. International treaties addressed to states can only provide partial assistance.

Standardization is needed, i.e., agreements between companies that are internationally applicable (e.g., in international supply chains) on the one hand and so transparent and comprehensible on the other that the corresponding standards are sufficiently verifiable for third parties, in particular government institutions, i.e., there is a corresponding acceptance of the standards so that they are then included in international agreements and other legal regulations or are anchored in a legally binding manner [RE 5.3.2-7 V5].

The valid sustainability-relevant data from this process can be used to calculate a product carbon footprint (PCF), a corporate carbon footprint (CCF, site-specific or cross-site) or even the carbon footprint of the entire value chain, depending on what the individual data elements are related to and how they are aggregated. It should not be forgotten that many sustainability parameters beyond CO_2 emissions are and will be relevant, which can also be calculated on the basis of this data.

In addition to several research projects, such as Catena-X, the industrial ESTAINIUM network is being formed in Germany on the basis of a ZVEI showcase, which aims to create a practicable sustainability data exchange network based on open source and decentralized trust technology (distributed ledger) that spans value chains, and to bring it to standardization. Ad-hoc Group 94 “Product carbon footprint data for the electrotechnical sector” (ahG94) was established in the IEC specifically for the standardization of PCF data. An ontology of sustainability-relevant data is being standardized in the second edition of ISO 20140-5, which is currently being developed.

Module: Cross-asset circular process (Asset: Process)
With regard to a digitalized and automated data and IT representation of circular processes (e.g., for implementing the Circular Economy), as well as their holistic evaluation, a wide variety of obstacles to implementation still need to be overcome. Data aggregation and IT-related data transfer in circular processes pose a challenge on the one hand, and on the other hand, there is the confidential, verifiable transfer of information between the actors in the **circular process**, whereby the assets and actors involved are usually distributed across different locations or even countries and thus jurisdictions. The challenges described above cannot be

solved by legal regulations or international treaties; here, too, standardization is the method of choice [RE 5.3.2-8 V5].

5.3.2.5 Sustainability modules for products

Module: Climate and environmental data relating to the product (Asset: Product, directly related to product)
Climate and environmental data on products are collected, presented, and mostly aggregated and documented in very different ways that are not interoperable and consequently not usable in digital ecosystems, neither within thematic departments nor across sectors. Also, legally binding information regarding the approval of products (e.g., hazard statements) is often mixed with voluntary, additional information (e.g., certificates, labels), as are data with direct and indirect product references. With regard to the introduction of a Digital Product Passport envisaged by the EU, it is necessary to establish a standardized preparation and presentation of product-related climate and environmental data that is uniform in terms of content and structure as soon as possible.

This standardized compilation of data for a product also serves the aim of collecting climate and environmental data relating to the product as far as possible only once and then using this digital "source data set" as the basis for further data uses, and to do this as automatically as possible [RE 5.3.2-9 V5].

Combination module: Digital sustainability passport for products (Asset: Product, directly and indirectly related to product)
A digital sustainability passport for products should have diverse information on climate, environmental and other sustainability aspects. Climate and environmental data with direct reference to the product are not sufficient here, but should be supplemented, for example, with data on the supply chain (module: linear process), on recycling (module: circular process) and on locations where it was produced (module: digital sustainability passport for production facilities). The modules described above can be combined with each other.

The goal must be to record and digitally document sustainability data in such a way that it meets all data quality requirements, but especially the specific requirements of Industrie 4.0 systems. In short, product-related sustainability data must be made Industrie 4.0-capable. Only in this way will it be possible to fill out Digital Product Passports automatically during production and to read them with the help of standardized access rights [RE 5.3.2-10 V5].

5.3.2.6 Sustainability module for networks and digital ecosystems

Module: Digital ecosystem or cross-facility and/or cross-asset digital network (Asset: Network)
With the shift towards Industrie 4.0 and production in flexible and locally to globally operating digital production and service networks, company boundaries are becoming increasingly blurred. Today's standardized sustainability assessments mostly refer to the company level or the facility or site level and are not transferable in this form to digital ecosystems or network structures.

The central challenge is the network structure, which is neither a purely linear nor circular process, but consists of diverse, diffuse and yet to be specified network structures with diverse, changing actors. Thus, evaluating a network as a whole is a complex task.

Since a digital ecosystem is composed of a multitude of actors and services, this module is conceived as a combination module consisting of the sum of its actors and services as well as the network itself [RE 5.3.2-11 V5].

5.3.3 Aspects of social sustainability and recommendations for action

Bendel and Latniak [89] consider "orientation knowledge" to be central for company work designers against the backdrop of digitalization. Standardization can make an important contribution here and also promote the transfer of scientific findings into practice by providing concrete support for the aforementioned criteria of humane work design and making design recommendations, among other things. An iterative, explorative process involving experts from various disciplines showed that the relevance of these criteria is also high in the digitalized world of work [90]. It was noted that criteria such as **technical reliability** are particularly sensitive to digitalization, and new criteria such as **inclusiveness, consideration of individuality and diversity**, and **clear responsibilities for occupational health and safety** have been added.

An adaptation and revision of existing standards and addressing new challenges in the context of Industrie 4.0 with the aim of making work safe and healthy are necessary in some cases. A key committee dealing with these issues of safe, ergonomic and stress-optimized design of Industrie 4.0 and artificial intelligence technologies is NA 023-00-06 AA[76] "Ergonomics for work design and product design for integrated and intelligent digitalization". The committee clarifies terms, derives definitions, reviews standards for need of revision, and monitors current activities. The committee's work feeds into the regular revisions of the Roadmap presented here. In addition, impulses are taken to the relevant committees where this makes sense. As mentioned in the Progress Report, the committee is currently working on a project to support company work designers with the aim of providing the previously mentioned orientation knowledge (see Progress Report [1] **[RE 2.7-1 V4]** and **[RE 2.7-2 V4]**).

The Progress Report [1] outlined further significant achievements in addressing the recommendations for action from the previous version of the Standardization Roadmap Industrie 4.0. This relates in particular to the revision of the ISO 10075[77] series of standards "Ergonomic principles related to mental workload" and the forwarding of recommendations to the joint working committee DIN NA 023–00-08 GA[78] "Joint working committee NAErg/NAFuO/NAM: Exoskeletons", which was established in 2021 and is part of DIN's Standards Committee "Ergonomics" .

Human-centred work design can be understood as an aspect of sustainability that comes into play both in the design and operation of stationary Industrie 4.0 plants and in working in and with mobile facilities or means of transport or mobile work. In particular, mobile work in an industrial context poses new challenges for design and evaluation compared to on-site work. In addition to a survey of data on the spread of mobile work in the context of Industrie 4.0, which was accelerated by the corona pandemic, it is therefore recommended that design options for and requirements of, for example, mobile assistance systems be included in standardization [RE 5.3.3-1 V5].

Furthermore, the mandatory rededication of previous face-to-face meetings to virtual meetings due to the pandemic has had the side effect of generating significant cost and time savings. At the same time, it has become clear that interpersonal contact in presence, including brainstorming, trust-building and sensitive decision-making, cannot be completely replaced by communication using digital media.

In summary, it can be stated that a future of standardization collaboration without online meetings and web-based development processes is no longer conceivable. However, there is a clearly identified need for an intelligent mixture of virtual and physical contact, but this is currently reflected in standardization practice in rudimentary form.

The participation of people with disabilities in working life can also be understood as an aspect of sustainability and social justice. In the process of inclusive work design, it is important to actively exploit opportunities for participation and prevention that arise from Industrie 4.0 elements and, at the same time, to avoid specific risks that may be associated with technological changes for people with disabilities or to offer alternative technologies [RE 5.3.3-2 V5].

76 NA 023-00-06 AA "Ergonomics for work design and product design for integrated and intelligent digitalization"

77 ISO 10075 "Ergonomic principles related to mental workload"

78 DIN NA 023–00-08 GA "Gemeinschaftsarbeitsauschuss NAErg/NAFuO/NAM: Exoskeletons"

6
REQUIREMENTS FOR THE DEVELOPMENT OF STANDARDS AND SPECIFICATIONS

6.1 Requirements in the context of open source

Open source already plays an essential role in the context of Industrie 4.0. There are numerous initiatives that show this. This importance is particularly great in the interplay with standardization [RE 6.1-1 V5].

Similar to standards and specifications, open source is about technologies that are developed in collaborative processes and made available openly to all participants in the market. It is therefore also hardly surprising that open source was included as a goal in the German Standardization Strategy: "DIN and DKE establish partnerships and look for ways to cooperate effectively with open source projects and to use open source technologies and methods in standardization." To achieve this goal, DIN has launched an initiative to establish partnerships and is also participating in similar projects at CEN/CENELEC and ISO/IEC. In addition to conceptual developments and piloting, the creation of an "Open Source Program Offices" (OSPO) as a central point of contact at DIN DKE for open source needs is also planned [RE 6.1-2 V5].

In open source projects, source code is collaboratively created and software is developed, which is then made available to the market. All open source software grants users the four basic freedoms that define the term "open source" in terms of content.

→ **Freedom 1:** The basic freedom to be able to use the documents/programs.
→ **Freedom 2:** The freedom to explore and adapt the open source documents/programs to one's own needs. This requires unrestricted access to the open source documents/source code.
→ **Freedom 3:** The freedom to redistribute the open source document/program.
→ **Freedom 4:** The freedom to improve the open source document/program and release those improvements to the public.

The Open Source Initiative (OSI) [91] gives a detailed definition of open source. The OSI is the established organization in the community and is widely recognized, though not an official certification body or binding authority [91].

Publication is subject to certain licence conditions (open source licences) that have been established on the market over the years and that are tailored to the specific conditions and requirements of open source projects. Anyone wishing to use, modify or extend open source software must take a closer look at these various licence conditions, as they specify what obligations arise for the user. The Licence Assistant of the EU Commission [92] provides a good overview on this.

In the context of open source licences, the "copyleft" is a relevant concept. Strong copyleft means that all changes and further developments of an open source software may only be distributed under the same licence. Besides strong copyleft (licences that do not allow any deviation from this principle), there are also less restrictive ones (reciprocal licence) and those that do without copyleft altogether (permissive licence). If the user wants to extend different open source software to a new software, they have to make sure that the licences can be combined in one source code. For example, source code from a project with a GPL licence cannot be used in a project under an Apache v2 licence.

In addition to licences, there are other important aspects that should be considered more closely when using or contributing to open source. On the one hand, a formalized set of processes/rules describing the cooperation of the various partners within an open source project with regard to the handling of rights as well as obligations, policies (e.g., IP, antitrust) and trademarks is helpful. On the other hand, it must be clarified which rights are transferred to the project as a contributing organization. Reciprocal approaches are relatively common here. This means that the same rights must be transferred to the project that the project grants to users under the chosen open source licence.

Below are some ways in which open source projects and standardization can complement each other [RE 6.1-3 V5].

1. **"Traditional" development of specifications:** Involvement of the open source communities in the development of a standard or specification and compliance with the standardization processes laid down by DIN and DKE. In this context, the creation of the standards/specifications is carried out by the open source community in the regular standardization bodies.
2. **Standards development delegated to an open source community operated by a standards organization:** Here, an open source community is formed that develops standards in close cooperation with a standards organization. In contrast to point 1, the preparation takes place outside the standardization bodies.

Table 1: Copyleft categories with examples of licences

Permissive licences	Reciprocal licences	Strong copyleft
→ Apache 2.0 → BSD (Berkeley Software Distribution) → MIT (Massachusetts Institute of Technology)	→ LGPL (Lesser GPL) → MPL (Mozilla Public Licence) → EPL v2(Eclipse Public Licence)	→ GPL (General Public Licence)
These free (permissive) licences do not prescribe under which conditions changes and further developments must be passed on, i.e., they can be licenced as open source or proprietary. A special feature of the Apache 2.0 licence is that it explicitly stipulates the granting of patent rights for use, modification or distribution.	In order to promote the distribution of free libraries, a weakened copyleft licence was created with the LGPL. It allows the linking of free and proprietary software. This category also includes MPL and EPL. Here changes to existing code are subject to copyleft, but independent extensions and new developments may be distributed under a different licence.	The same licence conditions apply for all modifications and further developments of a software as for the original code, i.e., these must also be made available in source code. GPL plays a special role because Linux was written under it. In general, copyleft licences for commercial use have tended to decline.

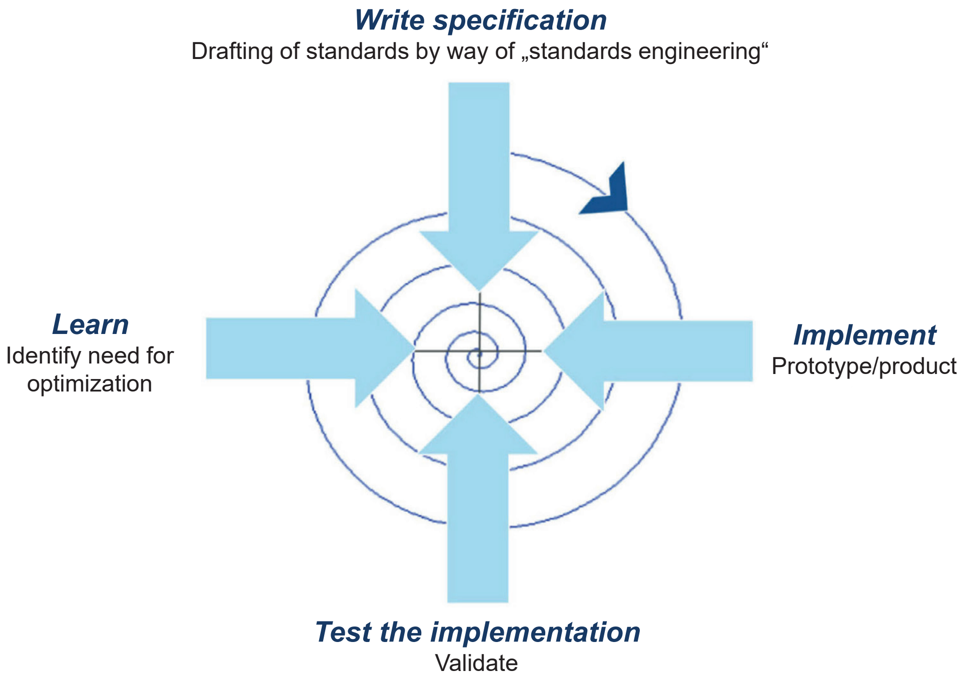
3. **Drawing up of specifications based on open source content: Conventional standardization activities that establish complementary requirements for the use of open source content in a particular situation.**
4. **Input for the development of specifications:** Support of open source communities to evaluate potential developments. The insights will enable an evaluation of approaches and ideas that can then be incorporated into the specification.
5. **The production of open source elements according to the consensus-based approach:** Involvement of standardization bodies with the aim of contributing to an open source community. In a way, this situation is the reverse of point 4. While in point 4 the initiative comes from the open source community, here software is worked on in a standardization body with the aim of supplying an open source community.
6. **Development of "complementary" software under open source licence:** In this model, the corresponding open source software is seen as a complementary activity that does not specify or define the standard, but is an exemplary reference implementation that serves for further developments and implementations of the standard requirements.

This results in the following advantages for the Industrie 4.0 sector:
- → Open source is a suitable way to quickly position technologies and ultimately standards on the market.
- → In the field of interoperability interfaces and similar interoperability technologies, developments are taking place in open source, which, as explained above, are directly available to the market in open source form and which flow back into standardization. It does not need to be explicitly stated that interoperability is a key element for Industrie 4.0.
- → Standardization of existing interfaces can lead to a longer-term availability and stability of such components. In addition to the dissemination of technologies via open source, information on functionalities and in particular on functional gaps flows back into standardization, on the basis of which standardization can react very quickly and specifically. An example of this type of procedure is the "agile standardization" approach presented in Figure 17.

Current initiatives around Industrie 4.0 are presented below that are closely related to open source and standardization:

IDTA: In order to accelerate, validate and demonstrate specification work, IDTA (see Chapter 5.1.4) is driving open source projects related to the Asset Administration Shell together with the Eclipse Foundation. To this end, open source offers

Figure 17: Parallel development – Open source and standardization (Source: DKE)



a collaborative model to spread the technology of the Digital Twin. The Eclipse Digital Twin Top-Level Projekt[79] comprises projects such as Eclipse AASX Package Explorer[80], Eclipse AAS Model for Java (AAS4J)[81], Eclipse AAS Web Client[82] and Eclipse BaSyx (Eclipse BaSyx™), which have realized the concept and specifications of the Asset Administration Shell (e.g., "Details of the Asset Administration Shell – Part 1") and have made them available under an open source licence (e.g., Apache v2.0 or MIT).

Catena-X and GAIA-X: Similar to Gaia-X, specifications and open source play an important role in Catena-X. Although Catena-X is not directly related to standardization, the activities within Catena-X and its findings are incorporated as a contribution to existing specifications or standards (e.g., Asset Administration Shell as a standard for Digital Twins within Catena-X) via collaborations with consortia (e.g., via IDTA). The results of Catena-X are made available as open source with the Eclipse Tractus-X [83] project under the Apache v2.0 open source licence.

Another component for the realization of Gaia-X based data spaces is the Eclipse Dataspace Connector[84], in which a component for the autonomous exchange of data between organizations is developed.

Linking and transferring activities to standardization is a key component in implementing projects (see [RE 6.1-3 V5]). Further unraveling of the environment in terms of self-proclaimed standards should be avoided as a matter of urgency.

6.2 Requirements in the context of use cases

The topic of use cases is dealt with extensively in the IEC 62559[85] series "Use case methodology" and this content is also generally accepted. The challenge with use cases is neither the methodology nor the template, but the practical application of the content described in the respective articles in the operational business environment. Use cases always pursue a purpose or a statement on a specific topic, about which clarity and agreement must be reached in advance. The formulation of high-quality use cases is very time-consuming. The previous versions of the Standardization Road-

79 https://projects.eclipse.org/projects/dt
80 https://projects.eclipse.org/projects/dt.aaspe
81 E Eclipse AAS Model for Java
82 Eclipse AAS Web Client
83 https://projects.eclipse.org/projects/automotive.tractusx
84 https://projects.eclipse.org/proposals/eclipse-dataspace-connector
85 IEC 62559 series "Use case methodology"

map Industrie 4.0 have provided orientation and recommendations for action in this regard.

Whereas in the past, standardization typically took place only after a market launch and thus the scope of application was quite clearly defined, today standardization often starts before a market launch and many theses, ideas and concepts have to be considered under aspects of the solution. Use cases are a possible methodology for the structured elaboration of requirements from the implementation point of view to build a bridge between market requirements, possible solutions and resulting standardization requirements [RE 6.2-1 V5].

As explained in Chapter 5.2.1, data spaces offer great potential for opening up new applications [RE 6.2-2 V5]. However, some issues are currently emerging in standardization around the broad and distributed use of data in a value chain and across company boundaries. This remains a fundamental challenge in using data in the context of enterprise security and IP protection.

There is an internationally agreed collection of almost 50 smart manufacturing use cases (IEC 63283-2 [86] 1st ed. “Industrial-process measurement, control and automation – Smart manufacturing – Part 2: Use cases”). This collection claims to be “representative” for smart manufacturing. The use cases all have a comparable level of detail, are largely complementary to each other, and are each about 5 pages long. The methodology and template of the use cases follow IEC 62559.

It is proposed to update IEC 63283-2 by integrating further use cases, for example through impulses from the AI or Catena-X [RE 6.2-3 V5] environment, but perhaps also from the Standardization Roadmap Industrie 4.0 [RE 6.2-4 V5]. To this end, it is recommended that a screening of existing and emerging collections of use cases be conducted [RE 6.2-5 V5].

In the area of international cooperation, a staff union ensures that German use-case activities are coordinated with the “Smart manufacturing use cases” task force of IEC/TC 65/WG 23 [87] “Smart manufacturing framework and concepts for industrial-process measurement, control and automation” via important international (bilateral) cooperation [RE 6.2-6 V5].

The work on the usage view “Edge Management” as part of the LNI 4.0 test bed and, at the business view level, the results of digital business models, which is being carried out in particular with Japanese cooperation, are worthy of particular mention. [88] In addition, use case discussions have begun in bilateral country collaborations (including those with China, Japan, South Korea) in the context of the Asset Administration Shell, as well as data spaces. It is to be expected that this dialogue will be intensified in the run-up to standardization [AE 6.2-8 V5], [RE 6.2-7 V5].

Feedback regarding various presentations and publications indicates that a consistent separation into a business perspective, an application perspective, and implementation perspectives derived from these is accepted and supported [AE 6.2-8 V5].

Sociotechnical aspects or design examples as part of use cases can support the interdisciplinary cooperation of work designers, engineers, etc., demonstrate positive effects of human-centred design and promote the transfer of abstract requirements for human-centred design through practical approaches to solutions [RE 6.2-9 V5]. Example collections, such as those provided by ifaa , can also be helpful at this point [93].

6.3 Requirements in the context of machine-readable standards

In Version 4 of the Standardization Roadmap Industrie 4.0 [2], the topic of the digitalization of standardization (see Chapter 1.2 in [2]) was introduced and the importance for Industrie 4.0 was highlighted with the recommendation for action [RE 4.1-8A V4] on digitally formulated standards and standards for automated evaluation. The recommendation for action recommended the use of digital standards [89] for an automated evaluation of standards in the Industrie 4.0 environment. To this end, the general availability of such digital standards and the development of suitable evaluation

86 IEC 63283-2 1st ed “Industrial-process measurement, control and automation – Smart manufacturing – Part 2: Use cases”.

87 IEC/TC 65/WG 23 ”Smart manufacturing framework and concepts for industrial-process measurement, control and automation”

88 https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/Edge_Management.html

89 Note: SMART standard is the now internationally established term for digital standards in the context of the digitalization of standards and standardization.

procedures were called for. In the Progress Report [1] on the Standardization Roadmap Industrie 4.0 Version 4, reference was made to the preliminary work of DKE and DIN on the subject of SMART standards. Initial activities were already carried out in 2016 (IEC General Meeting), which then led to the establishment of the Initiative Digitale Standards IDiS [33] in mid-2020, as well as to the formation of numerous working groups at European (CEN and CENELEC) and international (ISO and IEC) level.

6.3.1 Current standardization activities

IDiS is the national stakeholder group in Germany dealing with SMART Standards [33]. The IDiS network is interdisciplinary. The network group is made up of representatives from industry, science and associations from a wide range of sectors. IDiS gives standards users the opportunity to actively participate in current European and international developments on SMART standards and supports DKE and DIN in representing national interests in the international standardization community.

In collaboration with the WG "Technology and Application Scenarios" of the Plattform Industrie 4.0, initial application scenarios were investigated, described and published in two white papers. The white paper "Scenarios for the digitalization of standardization and standards" [94] describes four possible scenarios for the development of a digital standard – from machine readability and machine interpretability to creation and use by means of artificial intelligence. The scenarios also address initial potential areas of application (content usage) in the areas of construction, automation and after-sales, among others. The utility model described in the white paper has since been further discussed in ISO and IEC and accepted as a common basis for describing the basic machine applicability of SMART standards. Another white paper, "Use Cases of SMART Standards," [95] describes which requirements and functionalities digital standards must fulfil. The use cases were created based on collected user stories (about 100 from Germany and Europe), including those from the field of Industrie 4.0.

At **CEN/CENELEC**, numerous pilot projects on the subject of SMART standards have been carried out in recent years. There are currently five work streams (working groups), each dealing with different aspects of SMART Standards, such as the collection and analysis of requirements by standardization experts and users, or the investigation of the impact of SMART standards on the standardization process and related workflows [96].

At international level, **ISO** has formed analogous working groups to those at European level with the subgroups within ISO SMART, and **IEC** has formed similar working groups with the "task forces" of SG 12. These working groups are characterized by a large overlap with the European workstream, both in terms of content and project participants. This ensures a transfer of know-how from the European to the international level (and vice versa), which is crucial if the first SMART standards, or services based on them (Level 3), are to be made available by 2024, and if joint further development towards Level 4 content is subsequently to take place. Since the beginning of 2022, the first joint working groups between ISO and IEC have also started their work in order to exchange results and ensure their harmonization.

Furthermore, initial ideas of an SAM (standard architecture model) and an SAS (standard administration shell) were conceived. Both concepts are based on Industrie 4.0 ideas (RAMI 4.0 and the Asset Administration Shell) and should help to better classify and discuss the functionalities and responsibilities around SMART standards. Following the RAMI model, the SAM assigns activities and functions of SMART standards to different dimensions (application layer, utility level and standard life cycle) in order to further improve understanding and differentiation between applications. The SAS, on the other hand, is more of a technical model and describes how functions and responsibilities can be divided to provide consistent access to SMART Standards content [RE 6.3-1 V5]. In IDiS, the German national community for SMART Standards, a first pilot project (duration approx. 15 months) on the topic of the Asset Administration Shell and a submodel of a digital standard started in mid-2021.

6.3.2 Fragmentation and SIM – Standard Information Model

XML documents (NISO-STS) are already being generated in standardization today which have a fragmentation, albeit a coarse one, which is essentially based on the layout structures of the standard document. However, for systems that are to understand standards content, a corresponding semantic structuring is required. The theoretical basis is the information model for SMART standards developed in project 2 at CEN/CENELEC, which is currently being further developed at IEC (IEC SG 12 – Task Force 3).

The project defines all the essential elements of standardization (requirements, comments, formulas, tables, etc.) and describes the relationships between these elements. In this context, the “provision” rather than the “document” is the central element of standardization. The provision is a self-contained piece of information (definition, note, requirement, recommendation, etc.), which has a corresponding relevance in the context of standardization. A provision can exist in different forms (textual, tabular, expressed as a formula or as a model). This is in line with both the applicable standardization rules (ISO/IEC Directives Part 2) and the most important use case identified so far: the provision of normative requirements in a requirements management system. The SIM also follows the basic idea of Level 3 of the IEC Utility Model, which strives for a semantic capture of all normative information.

The challenges posed by the fragmentation of the standard document are many and profound. Both the current standard development process and the standard application process are document-based. In order to reap the benefits of fragmentation and thus more a targeted information use in the standards application, adjustments must be made across the entire standards process, i.e., from content creation through content management and content delivery to content usage [RE 6.3-2 V5].

6.3.3 Tool support and taxonomies

The extent to which the contents of SMART standards can be made machine-usable and machine-interpretable depends directly on the extent to which it is possible to capture the structured information required for this already during the standards development process, i.e., within the committee work. In turn, the type of structuring and the extent of semantic enrichment determine the difficulty of this task. This is where the information model for SMART standards (SIM) comes into play, defining how standards content is fragmented, networked, and metadata is added.

One of the main goals of the fragmentation of standards is to provide information in a targeted and application-oriented manner. To make this possible in the context of Industrie 4.0 applications as well, the information units relevant for Industrie 4.0 should be identified in standards and taken into account accordingly in the information model (SIM), so that they can already be created in the standard creation process or taken into account in downstream enrichment processes. To this end, the essential semantic concepts as well as the common ontology and taxonomy systems of Industrie 4.0 must be anchored more strongly and sustainably in the standards creation process, such as referencing elements of the CDD or a general integration of feature systems and I4.0 ontologies, the use of semantic IDs, or a link to capability descriptions of products and assets (see [RE 6.3-1 V5]).

The size of the fragments generated has a significant influence not only on the extent to which the content can be made accessible for reliable automated use, but also on the effort required to create them. Thus, as the size of the fragments decreases, the importance of user-friendly tool support that minimizes the additional effort required to capture standards content or manage ontologies and classification systems to be used increases.

6.3.4 Harmonization of terminology

One-to-one terms are a basic requirement for the uniform self-description and interoperability of cyber-physical systems. However, current standardization contains a large number of inconsistencies in the required concepts. In committee work, the reuse of definitions should be encouraged and facilitated by:

1. the use and consolidation of reference definitions (see [RE 6.3-3A V5]),
2. the systematic comparison of all relevant standard definitions (see [RE 6.3-3B V5]),
3. software-supported assistance in this systematic comparison, and (see [RE 6.3-3C V5])
4. software-supported assistance for formal checking (see [RE 6.3-3D V5]).

The national Harbsafe 2 [97] project team has developed a software-based assistance system that can support the harmonization of terminology databases in accordance with the recommendations for action. After the data has been entered, notes are generated in case of inconsistencies with other entries and formal errors in the definition. An overview of the terms based on their meaning spectra and a logical representation of the definitional features are also possible. For this purpose, various machine learning methods are used, which enable automated pre-selection and structuring. The project was presented not only in numerous national committees, but also in international committees, and is now in the utilization phase. The harmonization of terminology inventories in standardization is an important success criterion for the introduction and use of SMART standards and should be continued in a correspondingly focused manner.

6.3.5 New skills for standards and standards users

Another aspect of systemic relevance for the future concerns the definition of the requirements for the changed qualifications of the standardization experts as creators and the standards users as consumers of the digital information. The standardization process itself will be further digitized, and the methods commonly used in industry for information creation (ontologies, knowledge graphs, modelling techniques, formal description forms, pseudo-code, etc.) and for information provision (exchange formats, API access, mapping mechanisms) will increasingly find their way into future standardization work.

The future requirements for the complete execution of the various sub-processes and associated tasks are different – and so are the requirements for the people (or the availability of the necessary competencies in corresponding degrees of proficiency) who have to process the tasks [RE 6.2-6 V5].

6.3.6 Cross-domain references

Modern methods from the field of artificial intelligence, specifically in this case natural language processing (NLP), are the basis for strong improvements in the language understanding of machines in various domains. For this purpose, pre-trained language models (e.g., German BERT) are used, which are trained on a wide variety of texts. Pre-training the models gives them a basic understanding of the domain from which the texts and the information they contain originate.

Language models based on international and German-language standards are being trained in various projects (including a pilot project in IDiS). These pre-trained language models can be refined for different use cases. One of these use cases is, for example, the extraction of relevant standard content (e.g., requirements or product properties), as was investigated, for example, in the DKE DiTraNo project.[90] Furthermore, data sets are being created that contain questions to standards in combination with relevant text passages of the standards as answers. Thus, pre-trained language models can be refined in the form of a specialized model such that they learn to identify and extract appropriate text passages to a question. Moreover, statistical classifiers can identify relevant standards content based on rule-based approaches (as with DIN Software's SNIF tool[91]). Thus, among other things, text passages that do not represent requirements in terms of content, for example, can probably be rejected.

In this sense, it remains to be noted that so far, standards have predominantly been considered via AI, but in this context (also) the application and evaluation of standards by artificial intelligence represents an interesting use case. In this context, AI methods can be used both for support, such as in the identification of semantic information in standards, or they can be viewed as consumers of SMART standards, which can process normative content and possibly also optimize or further develop it in the future (see [74]).

90 https://www.dke.de/ditrano

91 https://www.dinsoftware.de/de/normeninformationen/snif

ANNEX A
STANDARDIZATION ENVIRONMENT INDUSTRIE 4.0

For a detailed, current overview of standards relevant to Industrie 4.0 go to:
https://www.din.de/en/innovation-and-research/industry-4-0
https://www.dke.de/en/areas-of-work/industry

A.1 German standardization bodies in the Industrie 4.0 context

DKE	
DKE/GK 914	Functional safety of electrical, electronic and programmable electronic systems (E, E, PES) for the protection of persons and the environment
DKE/AK 914.0.4	Updating IEC 61508-2
DKE/AK 914.0.6	Cooperation ITEI/Reliability
DKE/K 931	System aspects of automation
DKE/AK 931.0.12	Life Cycle Management
DKE/AK 931.0.14	Smart manufacturing and Industrie 4.0
DKE/UK 931.1	IT security for industrial automation systems
DKE/AK 931.1.3	Functional safety and IT security
DKE/K 941	Engineering
DKE/AK 941.0.2	Automation ML
DKE/K 956	Industrial communication
DKE/AK 956.0.2	Industrial Wireless Networks
DKE/AK 956.0.6	Cooperation ITEI/Radio
DIN	
DIN Standards Committee on information technology and selected IT applications (NIA)	DIN's Standards Committee on information technology and selected IT applications (NIA) develops standards in the IT sector, including selected IT applications. Its annual reports are published on its website.
DIN NA 043-01 FB	Special Division Basic Standards of Information Technology
DIN NA 043-02 FB	Special Division Horizontal Application Standards of Information Technology
DIN NA 043-04 FB	Special Division Information Security
DIN NA 043-04-27 AA	Information Security, Cybersecurity and Privacy Protection
DIN NA 043-01-41 AA	Internet of Things (IoT) and Digital Twin
DIN/DKE NA 043-01-42 GA	DIN/DKE Joint Working Committee Artificial Intelligence

DIN NA 060	Standards Committee Mechanical Engineering
DIN NA 060-30 FB	Steering Committee of the Section Automation systems and integration
VDI/VDE Society for Measurement and Automatic Control	
VDMA	
Companion Specifications	

A.2 European and international standardization in the context of Industrie 4.0

STANDARDS ORGANIZATIONS

IEC – International Electrotechnical Commission	
IEC/TC 65	Industrialprocess, measurement, control and automation
IEC/TC 65/WG 10	Security for industrial process measurement and control – Network and system security
IEC/TC 65/WG 16	Digital Factory
IEC/TC 65/WG 19	Lifecycle management for systems and products used in industrialprocess measurement, control and automation
IEC/TC 65/WG 20	Industrialprocess measurement, control and automation – Framework to bridge the requirements for safety and security
IEC/TC 65/WG 23	Smart Manufacturing Framework and System Architecture
IEC/TC 65/WG 24	Asset Administration Shell for Industrial Applications
IEC/TC 65	Industrialprocess measurement, control and automation
IEC/SC 65A	System Aspects
IEC/SC 65B	Measurement and control devices
IEC/SC 65C	Industrial Networks
IEC/SC 65E	Devices and integration in Enterprise systems
ISO/IEC	
Joint 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 JTC 1/SC 27	Information security, cybersecurity and privacy protection
ISO/IEC JTC 1/SC 27/WG 3	Security evaluation, testing and specification

ISO/IEC JTC 1/SC 27/WG 4	Security controls and services
ISO/IEC JTC 1/SC 31	Automatic identification and data capture techniques
ISO/IEC JTC 1/SC 41	Internet of things and digital twin
ISO/IEC JTC 1/SC 42	Artificial Intelligence
ISO/IEC JTC 1/AG 7	Trustworthiness
ISO/IEC JTC 1/AG 8	Meta Reference Architecture and Reference Architecture for Systems Integration
ISO/IEC JTC 1/AG 11	Digital Twin
ISO – International Organization for Standardization	
ISO/TC 184	Automation systems and integration
ISO/TC 184/SC 4	Industrial data
ISO/TC 108/SC 5	Condition monitoring and diagnostics of machine systems
ISO/TC 261	Additive Manufacturing
ISO/TC 292	Security and resilience
ISO/TC 299	Robotics
ISO/TC 307	Blockchain and distributed ledger technologies
CEN – European Committee for Standardization	
CEN/TC 114	Safety of machinery
CEN/TC 310	Advanced Automation technologies and their applications
CEN/TC 319	Maintenance
CEN/TC 438	Additive Manufacturing
CENELEC – European Committee for Electrotechnical Standardization	
CLC/TC 65X	Industrialprocess measurement, control and automation
CLC/TC 65X/WG 02	Smart Manufacturing
IEEE – Institute of Electrical and Electronics Engineers	
IEEE 802	Time sensitive networks
IEEE P2806	System Architecture of Digital Representation for Physical Objects in Factory Environments
DR_WG	Digital Representation Working Group

ETSI	
3GPP	3rd Generation Partnership Project
ESI	Electronic Signature
ISG SAI	Securing AI
Cyber	Cybersecurity
ISG MEC	Multiaccess Edge Computing
oneM2M	
SmartM2M & SAREf	Smart App Reference Ontology
ITU-T	
FG5GML	Machine Learning for Future Networks including 5G (Focus Group)
IECEE	
IECEE CMC WG 31	Cyber Security Certifications
IECEE OD 2061	Industrial Cyber Security Program Specifies 7 Cyber Security Certifications based on IEC 62443
IECEE OD 2037	ch. 12/Annex 5: Industrial Cyber Security Certificate Structure
IECEE Test Report Forms (TRFs)	TRFs for IEC 62443 parts 24, 33, 41 and 42

A.3 Coordinating bodies

CEN-CENELEC-ETSI	
CEN-CLC-ETSI/SMa-CG Coordination Group on Smart Manufacturing	The CEN-CENELEC-ETSI “Coordination Group on Smart Manufacturing” (SMaCG) was founded in 2019 and is led by DIN/DKE. The Coordination Group advises on ongoing European activities related to smart manufacturing and synchronizes the position of CEN, CENELEC and ETSI vis-à-vis SDOs and other third parties on standardization. Germany holds the secretariat of this Group.
ISO	
ISO/TMBG/SMCC Smart Manufacturing Coordinating Committee (SMCC)	Also under German leadership, the ISO/SMCC “Smart Manufacturing Coordinating Committee” has been actively promoting international work on the topic of Industrie 4.0. The aim here is to coordinate the topic across the board and to develop implementation recommendations, particularly with regard to a joint international approach. At the same time, a national mirror committee was implemented at DIN in order to offer interested parties a national platform for playing a significant role in shaping international work.

IEC	
IEC/SyC SM System Committee Smart Manufacturing	Chaired by Germany, IEC/SyC SM "System Committee Smart Manufacturing" is situated directly under the Standardization Management Board (SMB) of IEC and started its work in 2018. In addition to the coordination of standardization activities and the identification of gaps and overlaps, the tasks of the IEC/SyC lie in particular in the cooperation of relevant standards organizations and consortia.
IEC/SyC COMM Communication Technologies and Architectures	In mid-2019, IEC/SyC COMM "Communication Technologies and Architectures" was additionally created, which emerged from the previous IEC/SEG 7. The tasks of the SyC are standardization in the field of communication technologies and architectures. The SyC aims to coordinate and harmonize activities in the field of communications technologies and architectures. The committee works closely with the IEC committees to support their ongoing work in the area of communications technologies. Another goal is to collaborate with other standards development organizations (SDOs) and industry consortia in the area of communications technologies and architectures.

A.4 Standards Setting Organizations (SSO)

OPC – Unified Architecture
Standard for data exchange as a platform-independent, service-oriented architecture

AutomationML
Open standard for neutral, XML-based data format for the storage and exchange of plant design data

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

NAMUR
Working group 2.8: "Automation networks and services" (Namur Open Architecture NOA)

W3C (see Chapter 2.5.2)
W3C WoT resources W3C WoT Wiki
W3C WoT Interest Group
W3C WoT Working Group
WebRTC deals with the basic real-time capability between things based on a corresponding WoT standard, formal description. WebRTC is standardized by the World Wide Web Consortium (W3C) as an open standard.
WebAssembly A new demand as a replacement for JavaScript in the browser, combined with developments to make it available outside of browsers (spin-off) and thus bring performance for browser-based applications into the performance domain of classic web applications.

WebPerf Performance: the ability to react agilely to different requirements and to implement this with high performance in a unified integration	
WebPayments Introduce integration of payment systems between things, while also allowing them to act autonomously. Question of standards (PSD2, EU, EMV intl. WeChat. Tencent, SCS (China)	
Immersive AR/VR integration in web context likewise only for things, but also between things and people	
Webauthn The expression of a corresponding security architecture based on standards but integrally stored between things, based on a corresponding integration along all model layers both horizontally and vertically (question of views)	
Extensible Web The introduction of extensibility as an integral concept for browsers, later via WASI (WebAssembly System Interface) also for non-browser-based application development as an alternative to Java (bytecode) generation	

A.5 Overview policy (Germany, Europe)

BMWK – Federal Ministry for Economic Affairs and Climate Action
BMBF – Federal Ministry of Education and Research
EC – European Commission
MSP – Multi Stakeholder Platform

A.6 Overview of the current standardization environment

DIN NA 023-00-06 AA “Ergonomics for work design and product design for integrated and intelligent digitalization”
ISO 10075 “Ergonomic principles related to mental workload”
DIN NA 023-00-08 GA “Joint working committee NAErg/NAFuO/NAM: Exoskeletons”
IEC TS 62443-1-1:2009 “Industrial communication networks – Network and system security – Part 1-1: Terminology, concepts and models”
ISO/IEC 20924:2021 “Information technology – Internet of Things (IoT) – Vocabulary”
VDI 2770 Part 1 “Operation of process engineering plants – Minimum requirements for digital manufacturer information for the process industry – Fundamentals”
IEC/TC 3/ WG 28 “Intelligent Information Request and Delivery specification (iiRDS) – A Process Model for Information Architecture”
PWI PAS 3-1 ED1 “Intelligent Information Request and Delivery Specification (iiRDS) – A Process Model for Information Architecture”
IEC 61360-4 “Common Data Dictionary”
ISO/TC 184/SC 4 “Industrial data”

ISO 22745 series “Industrial automation systems and integration – Open technical dictionaries and their application to master data”

IEC/TC 65/SC 65E/WG 2 “Product properties & classification”

IEC SC 3D “Classes, Properties and Identification of products – Common Data Dictionary (CDD)”

IEC 61360-1 5th ed. “Standard data element types with associated classification scheme – Part 1: Definitions – Principles and methods”

IEC 61360-6 2nd ed. “Standard data element types with associated classification scheme for electric components – Part 6: CDD modelling guideline for the use of concepts”

IEC 61360-7 DB “Data dictionary of cross-domain concepts”

ISO/IEC JTC 1/SC 41 “Internet of Things and Digital Twin”

DIN NA 043-01-41 AA “Internet of Things and Digital Twin”

ISO/IEC 30141:2018 “Internet of Things (IoT) – Reference architecture”

ISO/IEC 21823series “Internet of Things (IoT) – Interoperability for IoT systems”

ISO/IEC 30165:2021 “Internet of things (IoT) – Real-time IoT framework”

ISO/IEC TR 30176:2021 “Internet of Things (IoT) – Integration of IoT and DLT/blockchain: Use Cases”

ISO/IEC 30162:2022 “Internet of Things (IoT) – Compatibility requirements and model for devices within Industrial IoT systems”

ISO/IEC 30147:2021 “Internet of Things (IoT) – Integration of IoT trustworthiness activities in ISO/IEC/IEEE 15288 system engineering processes”

ISO/IEC JTC 1/SC 38 “Cloud computing and distributed platforms”

ISO/TMBG/SMCC “ISO Smart Manufacturing Coordinating Committee” (SMCC)

IEC 63278-1 1st ed. “Asset Administration Shell for industrial applications – Part 1: Asset Administration Shell structure”

IEC 62832-1:2020 “Industrial-process measurement, control and automation – Digital factory framework – Part 1: General principles”

ISO/IEC JTC 1/SC 41/WG 6 “Digital Twin”

IEC/TC 65/WG 24 “Asset Administration Shell for Industrial Applications”

IEC/SyC SM “System Committee Smart Manufacturing”

IEC 63278-2 “Asset Administration Shell for Industrial Applications – Part 2: Information meta model”

IEC 63278-3 “Security provisions for Asset Administration Shells”

PNW JTC1-SC41-333 1st ed. “Digital Twin – Reference Architecture”

PWI JTC1-SC41-6 “Guidance for IoT and Digital Twin Use Cases”

PWI JTC1-SC41-7 “Digital Twin – Maturity model”

PWI TR JTC1-SC41-11 “Digital Twin – Correspondence measure of DTw twinning”

ISO/IEC 20924 3rd ed. CDM “Internet of Things (IoT) and Digital Twin – Vocabulary”

ISO/IEC TR 30172 1st ed. DTR “Digital Twin – Use Cases”

ISO/IEC 30173 1st ed. CD “Digital Twin – Concepts and terminology”

ISO/IEC 21823-1 “Internet of Things (IoT) – Interoperability for IoT systems – Part 1: Framework”

DKE/AK 931.0.16 “Asset Administration Shell for Industrial Applications”

ISO/IEC JTC 1/SC 41/AG 20 “Sectorial Liaison Group (SLG 1) on Industrial sector”

IEC/TC 65 “Industrial-process measurement, control and automation”

DIN 77005series “Life cycle record for technical objects”

DIN 77005-1:2018-09 “Life cycle record for technical objects – Part 1: Structural and content-related specifications”

DIN 77005-2 “Lifecycle record of technical objects – Part 2: Digital lifecycle record”

DIN SPEC 91406 “Automatic identification of physical objects and information on physical objects in IT systems, particularly IoT systems”

IEC/IEEE 60802 “TSN Profile for Industrial Automation”

VDI/VDE Guideline 2192 “Interoperability in Industrie 4.0 systems – Quality of services – Characteristic parameters and influencing quantities”

VDI/VDE Guideline 2185 Blatt 4 “Radio-based communication in industrial automation – Metrological performance rating of wireless solutions for industrial automation applications”

IEC/TC 65/WG 16 “Digital Factory”

IEC 61158-2 “Industrial communication networks – Fieldbus specifications – Part 2: Physical layer specification and service definition”

IEC TS 63444 1st ed. “Industrial networks – Ethernet-APL Port Profile Specification”

IEC 61508 series “Functional safety of electrical/electronic/programmable electronic safety-related systems”

ISO/IEC JTC 1/SC 41/WG 3 “IoT Foundational Standards”

ISO/IEC TS 30168 1st ed. “Internet of Things (IoT) – Generic Trust Anchor Application Programming Interface for Industrial IoT Devices”

ISO/IEC JTC 1/SC 27/WG 5 “Identity management and privacy technologies”

ISO/IEC JTC 1/SC 27 “Information security, cybersecurity and privacy protection”

ISO/IEC JTC 1/SC 42 “Artificial Intelligence”

ISO/IEC JTC 1/SC 27/WG 4 “Security controls and services”

ISO/IEC JTC 1/WG 13 “Trustworthiness”
ISO/TC 292/WG 4 “Authenticity, integrity and trust for products and documents”
IEC 62559 series “Use Case methodology”
IEC 63283-2 1st ed. “Industrial-process measurement, control and automation – Smart manufacturing – Part 2: Use Cases”).
IEC/TC 65/WG 23 “Smart Manufacturing Framework and Concepts for industrial-process measurement, control and automation”
IEC 62832series “Digital factory framework”
IEC/SC 65E “Devices and integration in enterprise systems”
IEC 63365 1st ed. “Digital Nameplate – Digital Product Marking”

INDEX OF ABBREVIATIONS

Term	Abbreviation
Advanced Physical Layer	APL
Artificial Intelligence	AI
Common Data Dictionary	CDD
Digital Product Passport	DPP
electronic IDentification, Authentication and trust Services	eIDAS
General Data Protection Regulation	GDPR
Industrial Digital Twin Association	IDTA
Industrial Internet of Things	IIoT
Industrie 4.0	I4.0
Information technology	IT
Intellectual Properties	IP
Intelligent Information Request and Delivery Specification	iiRDS
Labs Network I 4.0	LNI 4.0
Module Type Package	MTP
New Legislative Framework	NLF
New Work Proposal	NWP
Operative technology	OT
Quality of Service	QoS
Reference Architecture Model Industrie 4.0	RAMI 4.0
Single Pair Ethernet	SPE
Standardization Council Industrie 4.0	SCI 4.0
Standards Information Model	SIM
Time Sensitive Network	TSN

INDEX OF AUTHORS

Adolph, Dr. Lars, BAuA – Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Dortmund

Bedenbender, Dr. Heinz, VDI – Verein Deutscher Ingenieure e. V., Düsseldorf

Böll, Dr. Marvin, DKE – Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE, Offenbach

Börkircher, Dr. Mikko, METALL NRW – Verband der Metall- und ElektroIndustrie Nordrhein-Westfalen e. V., Düsseldorf

Brumby, Prof. Dr. Lennart, Duale Hochschule Baden-Württemberg, Mannheim

Czarny, Damian, DKE – Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE, Offenbach

de Meer, Jan, HTW c/o smartspacelab.eu

Faath, Andreas, Verband Deutscher Maschinen- und Anlagenbau (VDMA), Frankfurt

Gayko, Dr. Jens, DKE – Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE, Offenbach

Haack, Daniel, DIN – Deutsches Institut für Normung e. V., Berlin

Hadlich, Dr. Ing. Thomas, Rockwell Automation, Düsseldorf

Holoyad, Taras, Bundesnetzagentur (BNetzA), Mainz

Hörcher, Dr. Günter, Fraunhofer-Institut für Produktions-technik und Automatisierung IPA

Jeske, Dr. Tim, ifaa – Institut für angewandte Arbeitswissen-schaft e. V., Düsseldorf

Jöst, Matthias, omlox

Kirchhoff, Dr. Britta, BAuA – Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Dortmund

Klasen, Dr. Wolfgang, Siemens AG, München

Köpp, Thomas, Verband der Metall- und Elektroindustrie Baden-Württemberg e. V. (Südwestmetall), Stuttgart

Kötter, Wolfgang, GITTA mbH – Gesellschaft für interdisziplinäre Technikforschung Technologieberatung Arbeitsgestaltung mbH, Berlin

Lachenmaier, Dr. Jens, Universität Stuttgart

Laible, Holger, Siemens AG, Nürnberg

Leboucher, Yves , Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Lee, Sascha Man-Son , DKE – Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE, Offenbach

Legat, Dr. Christoph, HEKUMA GmbH, Hallbergmoos

Lindenberg, Uwe, SGS-TÜV, Dortmund

Löwen, Prof. Dr. Ulrich, Siemens AG, Erlangen

Marko, Angelina, BITKOM, Berlin

Meurer, Doris, UBA – Umweltbundesamt, Dessau

Meyer, Olga, Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA, Stuttgart

Müller, Andreas, Schaeffler AG, Nürnberg

Nickel, Peter, Institut für Arbeitsschutz der DGUV (IFA), Sankt Augustin

Olbort, Johannes, Verband Deutscher Maschinen- und Anlagenbau (VDMA)

Orzelski, Andreas, Phoenix Contact GmbH & Co KG, Blomberg

Petschulies, Anna, DIN – Deutsches Institut für Normung e. V., Berlin

Plagge, Michael, Eclipse Foundation Europe

Pröll, Dieter, Siemens AG, Nürnberg

Rannenberg, Prof. Dr. Kai, Goethe-Universität, Frankfurt

Reich, Johannes, SAP, Walldorf

Rudschuck, Dr. Michael, DKE – Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE, Offenbach

Schewe, Frank, Phönix Contact

Schnäpp, Dieter, Universität Braunschweig

Sehnert, Katharina, DIN – Deutsches Institut für Normung e. V., Berlin

Sieber, Peter, HIMA Paul Hildebrandt GmbH, Brühl

Simon, Anja, Labs Network Industrie 4.0

Steinbuss, Sebastian, IDSA

Stock, Dr. Patricia, REFA Fachverband e. V. – REFA-Institut, Darmstadt

Teuscher, Andreas, SICK AG, Waldkirch

Tenhagen, Detlef, HARTING Stiftung & Co. KG, Espelkamp

Underberg, Dr. Lisa, ifak, Magdeburg

Weber Martins, Thiago, SAP

Weber, Ingo, Siemens AG, Karlsruhe

Wegener, Prof. Dr. Dieter, Siemens AG, München

BIBLIOGRAPHY

[1] DIN/DKE and SCI 4.0, **Progress report – German Standardization Roadmap 4.0.** [Online]. Available: https://www.din.de/de/forschung-und-innovation/themen/industrie4-0/roadmap-industrie40-62178 (accessed: Dec. 18 2022).

[2] DIN/DKE, **German Standardization Roadmap Industrie 4.0 – Version 4: DIN and DKE ROADMAP**. SCI 4.0. [Online]. Available: https://www.din.de/de/forschung-und-innovation/themen/industrie4-0/roadmap-industrie40-62178 (accessed: Nov. 1 2022).

[3] L. Nagel and D. Lycklama, "Design Principles for Data Spaces – Position Paper," 2021.

[4] E. Ulich, **Arbeitspsychologie,** 7th ed. Zürich: vdf Hochschulverlag AG an der ETH Zürich, 2020. [Online]. Available: https://vdf.ch/arbeitspsychologie-e-book.html?search=Arbeitspsychologie&description=true

[5] Ulich and Eberhard, "Arbeitssysteme als Soziotechnische Systeme – eine Erinnerung," **Journal Psychologie des Alltagshandelns / Psychology of Everyday Activity, Vol. 6 / No. 1, ISSN 1998-9970**, 2013.

[6] BMAS, **Grundsatzpapier zur Rolle der Normung im betrieblichen Arbeitsschutz.** [Online]. Available: https://www.bmas.de/DE/Service/Presse/Meldungen/2015/grundsatzpapier-normung-betrieblicher-arbeitsschutz.html (accessed: Nov. 1 2022).

[7] United Nations, **United Nations Conference on the Human Environment, Stockholm 1972 | United Nations.** [Online]. Available: https://www.un.org/en/conferences/environment/stockholm1972 (accessed: Nov. 1 2022).

[8] [WCED, **Report of the World Commission on Environment and Development – Our Common Future.** [Online]. Available: https://sustainabledevelopment.un.org/milestones/wced (accessed: Nov. 1 2022).

[9] United Nations, **United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992 | United Nations.** [Online]. Available: https://www.un.org/en/conferences/environment/rio1992 (accessed: Nov. 1 2022).

[10] COM, **640 final: The European Green Deal, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS.** [Online]. Available: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0021.02/DOC_1&format=PDF

[11] Bitkom, **Vorschlag zur systematischen Klassifikation von Interaktionen in Industrie 4.0 Systemen: Hinführung zu einem Referenzmodell für semantische Interoperabilität**. White Paper. [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/Bitkom_Thesenpapier.pdf?__blob=publicationFile&v=5

[12] R. Heidel, M. Hoffmeister, M. Hankel, and U. Döbrich, Eds., **Industrie 4.0: The reference architecture model RAMI 4.0 and the Industrie 4.0 component**. Berlin, Wien, Zürich, Berlin, Offenbach: Beuth Verlag; VDE Verlag, 2019. [Online]. Available: https://www.beuth.de/de/publikation/rami-4-0-and-the-industrie-4-0-component/296158879

[13] Shi-Wan Lin **et al., Architecture Alignment and Interoperability. An Industrial Internet Consortium and Plattform Industrie 4.0 Joint Whitepaper IIC:WHT:IN3:V1.0:PB:20171205.** [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/whitepaper-iic-pi40.pdf?__blob=publicationFile&v=7

[14] B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel, Eds., **Handbuch Industrie 4.0 Bd. 2: Automatisierung,** 2nd ed. Berlin, Heidelberg: Springer Vieweg, 2017.

[15] U. Epple, "Merkmale als Grundlage der Interoperabilität technischer Systeme," **auto**, vol. 59, no. 7, pp. 440–450, 2011, doi: 10.1524/auto.2011.0939.

[16] N. C. Karafyllis, "Soziotechnisches System," in **Mensch-Maschine-Interaktion: Handbuch zu Geschichte – Kultur – Ethik**, K. Liggieri and O. Müller, Eds., Berlin, Heidelberg: J.B. Metzler Verlag, 2019, pp. 300–303.

[17] M. Both, J. Müller, and C. Diedrich, "Automatisierte Abbildung semantisch heterogener I4.0-Verwaltungsschalen durch Methoden des Natural Language Processing," **auto**, vol. 69, no. 11, pp. 940–951, 2021, doi: 10.1515/auto-2021-0050.

[18] C. Diedrich, T. Hadlich, and M. Thron, "Semantik durch Merkmale für Industrie 4.0," in **VDI Springer Reference, Handbuch Industrie 4.0 Bd. 2: Automatisierung**, B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel, Eds., 2nd ed., Berlin, Heidelberg: Springer Berlin Heidelberg, 2017, pp. 417–432.

[19] T. Deppe, L. Nothdurft, and U. Epple, "DIN SPEC 92000 als Enabler für Plug-and-Produce-Konzepte," **atp**, vol. 62, no. 4, pp. 78–85, 2020, doi: 10.17560/atp.v62i4.2461.

[20] OPC UA, **Unified Architecture – OPC Foundation.** [Online]. Available: https://opcfoundation.org/about/opc-technologies/opc-ua/ (accessed: Nov. 1 2022).

[21] OPC Foundation, **List of Documents – OPC Foundation.** [Online]. Available: https://opcfoundation.org/developer-tools/documents/ (accessed: Nov. 4 2022).

[22] ECLASS, **eptos™ – ECLASS ContentDevelopmentPlatform PROD – CDP-7.2.0.** [Online]. Available: https://www.eclass-cdp.com/portal/info.seam (accessed: Nov. 1 2022).

[23] R. Reussner and W. Hasselbring, Eds., **Handbuch der Software-Architektur,** 2nd ed. Heidelberg: dpunkt.verlag, 2009.

[24] J. Reich, L. Zentarra, and J. Langer, "Industrie 4.0 und das Konzept der Verwaltungsschale – Eine kritische Auseinandersetzung," **HMD**, vol. 58, no. 3, pp. 661–675, 2021, doi: 10.1365/s40702-020-00645-4.

[25] JTC1 SIF, **JTC 1 Advisory Group on Systems Integration Facilitation (SIF) – JTC 1.** [Online]. Available: https://jtc1info.org/technology/advisory-groups/jtc1-advisory-group-on-systems-integration-facilitation-sif/ (accessed: Nov. 1 2022).

[26] COMM/DG/UNIT, **A European Green Deal: An official website of the European Union.** [Online]. Available: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_de (accessed: Nov. 1 2022).

[27] IDSA, **Home – International Data Spaces.** [Online]. Available: https://internationaldataspaces.org/ (accessed: Nov. 1 2022).

[28] BDVA, **Home – BDVA Big Data Value Association.** [Online]. Available: https://www.bdva.eu/ (accessed: Nov. 1 2022).

[29] umati, **umati – universal machine technology interface – connecting the world of machinery.** [Online]. Available: https://umati.org/ (accessed: Nov. 1 2022).

[30] Gaia-X, **Architektur der Standards: Gaia-X Architecture Document – 21.12 Release: Gaia-X European Association for Data and Cloud AISBL.** [Online]. Available: https://www.gaiax.es/sites/default/files/2022-01/Gaia-X_Architecture_Document_2112.pdf (accessed: Nov. 1 2022).

[31] Gaia-X, **Gaia-X – Architecture Document – 22.04 Release: Draft.** [Online]. Available: https://gaia-x.eu/wp-content/uploads/2022/06/Gaia-x-Architecture-Document-22.04-Release.pdf

[32] IEC, **Semantic interoperability: challenges in the digital transformation age.** [Online]. Available: https://www.iec.ch/basecamp/semantic-interoperability-challenges-digital-transformation-age (accessed: Nov. 2 2022).

[33] DKE – VDE, **IDiS – Initiative Digitale Standards.** [Online]. Available: https://www.dke.de/de/normen-standards/normung-strategie/deutsche-normungsstrategie/idis (accessed: Nov. 1 2022).

[34] Plattform Industrie 4.0, **I4.0-Sprache – Vokabular, Nachrichtenstruktur und semantische Interaktionsprotokolle der I4.0-Sprache.** [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/hm-2018-sprache.html (accessed: Nov. 2 2022).

[35] OPC Foundation, **OPC 10001-5 Unified Architecture Amendment 5 Dictionary Reference – Release 1.04: OPC UA Online Reference – Online versions of OPC UA specifications and information models.** [Online]. Available: https://reference.opcfoundation.org/ (accessed: Nov. 1 2022).

[36] AutomationML consortium, **AutomationML – The Glue for Seamless Automation Engineering: Whitepaper AutomationML – Part 6: AutomationML Component.** [Online]. Available: https://www.automationml.org/about-automationml/specifications/

[37] DKE, **Verwaltungsschale als Rückgrat der Industrie 4.0 und des Digitalen Zwillings: Fachinformation.** [Online]. Available: https://www.dke.de/de/arbeitsfelder/industry/verwaltungsschale (accessed: Nov. 1 2022).

[38] C. Wagner **et al.**, "The role of the Industry 4.0 asset administration shell and the digital twin during the life cycle of a plant," in **2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation: September 12-15, 2017, Limassol, Cyprus**, Limassol, 2017, pp. 1–8.

[39] VDI, **Digitale Transformation – VDI/VDE-GMA Fachbeirat FB 7 Digitale Transformation – Neuer Fachausschuss VDI/VDE-GMA/GPP 7.10 „Planung und Entwicklung hybrider Leistungsbündel".** [Online]. Available: https://www.vdi.de/fileadmin/user_upload/VDI-Aufruf_7.10-VDI.de.pdf (accessed: Nov. 1 2022).

[40] IDTA, **Home – IDTA – Der Standard für den Digitalen Zwilling.** [Online]. Available: https://industrialdigitaltwin.org/ (accessed: Nov. 1 2022).

[41] VDMA/FKM, **Studie „Interoperabilität im Maschinen- und Anlagenbau": Die Weltsprache der Produktion als Grundlage für Industrie 4.0.** [Online]. Available: https://www.vdma.org/weltsprache-der-produktion

[42] Digital Twin Consortium, **About Us – Digital Twin Consortium is The Authority in Digital Twin™.** [Online]. Available: https://www.digitaltwinconsortium.org/about-us/ (accessed: Nov. 1 2022).

[43] IDTA, **Downloads – IDTA Deutsch.** [Online]. Available: https://industrialdigitaltwin.org/content-hub/downloads (accessed: Nov. 1 2022).

[44] InterOpera, **Startseite – InterOpera – Digitale Interoperabilität in kollaborativen Wertschöpfungsnetzwerken der Industrie 4.0.** [Online]. Available: https://interopera.de/ (accessed: Nov. 1 2022).

[45] 5G-ACIA, **Integration of 5G with Time-Sensitive Networking for Industrial Communications – 5G-ACIA: White Paper.** [Online]. Available: https://5g-acia.org/whitepapers/integration-of-5g-with-time-sensitive-networking-for-industrial-communications/ (accessed: Nov. 1 2022).

[46] OPC Foundation, **Extending OPC UA to the field: OPC UA for Field eXchange (FX): Technical Paper**.

[47] 5G-ACIA, **Service-Level Specifications (SLSs) for 5G Technology-Enabled Connected Industries – 5G-ACIA: White Paper.** [Online]. Available: https://5g-acia.org/whitepapers/service-level-specifications-slss-for-5g-technology-enabled-connected-industries/ (accessed: Nov. 1 2022).

[48] TIACC, **Home | TIACC.** [Online]. Available: https://www.tiacc.net/ (accessed: Nov. 1 2022).

[49] 5G-ACIA, **5G for Connected Industries and Automation (Second Edition): White Paper.** [Online]. Available: https://5g-acia.org/wp-content/uploads/5G-ACIA_WP_5G-for-Connected-Industries-and-Automation-Second-Edition_SinglePages.pdf

[50] 5G-ACIA, **5G Non-Public Networks for Industrial Scenarios: White Paper.** [Online]. Available: https://5g-acia.org/wp-content/uploads/5G-ACIA_5G_Non-Public_Networks_for_Industrial_Scenarios_09-2021.pdf

[51] FieldComm Group, ODVA Inc., OPC Foundation, PROFIBUS Nutzerorganisation e.V, **Ethernet-APL.** [Online]. Available: https://www.ethernet-apl.org/ (accessed: Nov. 1 2022).

[52] Ethernet-APL™, **Ethernet – To the Field: Ethernet-APL™. Ease of adoption. Seamless integration. Simplified installation. Greater range. Valuable data.** [Online]. Available: https://www.ethernet-apl.org/wp-content/uploads/2022/08/Ethernet-APL_Ethernet-To-The-Field_EN_FINAL_June-2021.pdf

[53] omlox, **omlox is an open and interoperable standard that is revolutionizing real-time locating.** [Online]. Available: https://omlox.com/ (accessed: Nov. 1 2022).

[54] J. Lee, **Industrial AI: Applications with Sustainable Performance,** 1st ed. Singapore: Springer Singapore; Imprint Springer, 2020.

[55] Plattform Industrie 4.0, **Industrie 4.0 – KI in der Industrie 4.0: Orientierung, Anwendungsbeispiele, Handlungsempfehlungen: Wegweiser.** [Online]. Available: https://www.bundesregierung.de/breg-de/service/publikationen/industrie-4-0-ki-in-der-industrie-4-0-orientierung-anwendungsbeispiele-handlungsempfehlungen-1769482 (accessed: Dec. 19 2022).

[56] BMWK, **Strategie Künstliche Intelligenz der Bundesregierung: Publikation – Schlüsseltechnologien.** [Online]. Available: https://www.bmwk.de/Redaktion/DE/Publikationen/Technologie/strategie-kuenstliche-intelligenz-der-bundesregierung.html (accessed: Dec. 19 2022).

[57] BMBF, **Home – KI Strategie.** [Online]. Available: https://www.ki-strategie-deutschland.de/home.html (accessed: Dec. 19 2022).

[58] European Commission, **White Paper on Artificial Intelligence: a European approach to excellence and trust | European Commission.** [Online]. Available: https://commission.europa.eu/document/d2ec4039-c5be-423a-81ef-b9e44e79825b_en (accessed: Dec. 19 2022).

[59] Oxford University Press, **artificial intelligence – Quick Reference: The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.** [Online]. Available: https://www.oxfordreference.com/display/10.1093/oi/authority.20110803095426960;jsessionid=812D4FEA8CA56AD4C6A2C104E37A3A57 (accessed: Dec. 19 2022).

[60] European Commission, **Proposal for a Regulation of the European Parliament and of the Council Laying Down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act) and Amending Certain Union Legislative Acts Com/2021/206 Final: 2021/0106(COD).** [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0206 (accessed: Dec. 19 2022).

[61] L. Floridi and M. Chiriatti, "GPT-3: Its Nature, Scope, Limits, and Consequences," **Minds & Machines**, vol. 30, no. 4, pp. 681–694, 2020, doi: 10.1007/s11023-020-09548-1.

[62] A. Vaswani **et al.**, "Attention Is All You Need," Jun. 2017. [Online]. Available: http://arxiv.org/pdf/1706.03762v5

[63] W. Fedus, B. Zoph, and N. Shazeer, "Switch Transformers: Scaling to Trillion Parameter Models with Simple and Efficient Sparsity," Jan. 2021. [Online]. Available: http://arxiv.org/pdf/2101.03961v3

[64] J. Yu **et al.**, "Scaling Autoregressive Models for Content-Rich Text-to-Image Generation," Jun. 2022. [Online]. Available: http://arxiv.org/pdf/2206.10789v1

[65] A. Ramesh, P. Dhariwal, A. Nichol, C. Chu, and M. Chen, "Hierarchical Text-Conditional Image Generation with CLIP Latents," Apr. 2022. [Online]. Available: http://arxiv.org/pdf/2204.06125v1

[66] C. Saharia **et al.**, "Photorealistic Text-to-Image Diffusion Models with Deep Language Understanding," May. 2022. [Online]. Available: http://arxiv.org/pdf/2205.11487v1

[67] BMWi, **Fortschreibung der Anwendungsszenarien der Plattform Industrie 4.0: Ergebnispapier.** [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/fortschreibung-anwendungsszenarien.pdf?__blob=publicationFile&v=8 (accessed: Dec. 19 2022).

[68] BMWi, **Technologieszenario „Künstliche Intelligenz in der Industrie 4.0": Working Paper.** [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/KI-industrie-40.pdf?__blob=publicationFile&v=17 (accessed: Dec. 19 2022).

[69] acatech, **Strategie. Advanced Systems Engineering. Leitinitiative zur Zukunft des Engineeringund Innovationsstandorts Deutschland.** [Online]. Available: https://www.acatech.de/publikation/die-advanced-systems-engineering-strategie/download-pdf?lang=de (accessed: Dec. 19 2022).

[70] acatech, **Engineering smarter Produkte und Services Plattform Industrie 4.0 STUDIE. Michael Abramovici (Hrsg.): Forschungsbeirat.** [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/hm-2018-fb-smart.pdf?__blob=publicationFile&v=5 (accessed: Dec. 19 2022).

[71] W. F. Lawless, Ed., **Systems Engineering and Artificial Intelligence,** 1st ed. Cham: Springer International Publishing AG, 2021.

[72] ZVEI, **AI in Industrial Automation: White Paper.** [Online]. Available: https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2021/April/AI_in_Industrial_Automation/AI-in-Industrial-Automation-White-Paper-NEU.pdf (accessed: Dec. 19 2022).

[73] acatech, **Einordnung der Beispiele der Industrie 4.0-Landkarte in die Anwendungsszenarien.: Forschungsbeirat.** [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/DE/Downloads/Publikation/hm-2018-fb-landkarte.pdf?__blob=publicationFile&v=5 (accessed: 19.12.222).

[74] DIN/DKE, **German Standardization Roadmap Artifical Intelligence. 2nd edition 2.** [Online]. Available: https://www.din.de/resource/blob/891106/57b7d46a1d2514a183a6ad2de89782ab/deutsche-normungs-roadmap-kuenstliche-intelligenz-ausgabe-2--data.pdf (accessed: Dec. 19 2022).

[75] IEEE, **DATA TRADING SYSTEM WORKING GROUP.** [Online]. Available: https://sagroups.ieee.org/3800/ (accessed: Nov. 1 2022).

[76] Data Sharing Coalition, **Home – Data Sharing Coalition.** [Online]. Available: https://datasharingcoalition.eu/ (accessed: Nov. 1 2022).

[77] Sitra, **Rulebook for a fair data economy.** [Online]. Available: https://www.sitra.fi/en/publications/rulebook-for-a-fair-data-economy/ (accessed: Nov. 1 2022).

[78] DSBA, **The Data Spaces Business Alliance – Data Spaces Business Alliance.** [Online]. Available: https://data-spaces-business-alliance.eu/ (accessed: Dec. 18 2022).

[79] DSBA, **The Data Spaces Business Alliance – Data Spaces Business Alliance.** [Online]. Available: https://data-spaces-business-alliance.eu/ (accessed: Nov. 1 2022).

[80] OWASP Foundation – CycloneDX, **OWASP CycloneDX Software Bill of Materials (SBOM) Standard.** [Online]. Available: https://cyclonedx.org/ (accessed: Dec. 19 2022).

[81] NIST, **Executive Order 14028, Improving the Nation's Cybersecurity.** [Online]. Available: https://www.nist.gov/itl/executive-order-14028-improving-nations-cybersecurity (accessed: Dec. 19 2022).

[82] European Commission, **Cyber Resilience Act: Policy and legislation – Publication.** [Online]. Available: https://digital-strategy.ec.europa.eu/en/library/cyber-resilience-act (accessed: Nov. 1 2022).

[83] GDPR, **General Data Protection Regulation (GDPR) Compliance Guidelines.** [Online]. Available: https://gdpr.eu/ (accessed: Nov. 1 2022).

[84] European Commission, **European Data Governance Act.** [Online]. Available: https://digital-strategy.ec.europa.eu/de/policies/data-governance-act (accessed: Dec. 18 2022).

[85] EDPB, **EDPB | European Data Protection Board.** [Online]. Available: https://edpb.europa.eu/edpb_en (accessed: Nov. 1 2022).

[86] IETF, **Home – Internet Engineering Task Force (IETF).** [Online]. Available: https://www.ietf.org/ (accessed: Nov. 1 2022).

[87] Gaia-X, **Introduction | Gaia-X Trust Framework.** [Online]. Available: https://compliance.gaia-x.eu/guide/#latest-release (accessed: Dec. 18 2022).

[88] Plattform Industrie 4.0 and rri, **IIoT Value Chain Security – The Role of Trustworthiness: International Paper.** [Online]. Available: https://www.plattform-i40.de/IP/Redaktion/EN/Downloads/Publikation/IIoT_Value_Chain_Security.pdf?__blob=publicationFile&v=9

[89] A. Bendel and E. Latniak, "Soziotechnisch – agil – lean: Konzepte und Vorgehensweisen für Arbeits- und Organisationsgestaltung in Digitalisierungsprozessen," **Gr Interakt Org**, vol. 51, no. 3, pp. 285–297, 2020, doi: 10.1007/s11612-020-00528-8.

[90] A. Tisch and S. Wischniewski, Eds., **Sicherheit und Gesundheit in der digitalisierten Arbeitswelt: Kriterien für eine menschengerechte Gestaltung,** 1st ed. Baden-Baden: Nomos Verlagsgesellschaft mbH & Co. KG, 2022. [Online]. Available: https://portal.dnb.de/opac.htm?method=simpleSearch&query=Sicherheit%C2%A0und%C2%A0Gesundheit%C2%A0in%C2%A0der%C2%A0digitalisierten%C2%A0Arbeitswelt

[91] Opensource.org, **The Open Source Definition | Open Source Initiative.** [Online]. Available: https://opensource.org/osd (accessed: Nov. 1 2022).

[92] Joinup, **JLA – Find and compare software licenses.** [Online]. Available: https://joinup.ec.europa.eu/collection/eupl/solution/joinup-licensing-assistant/jla-find-and-compare-software-licenses (accessed: Nov. 1 2022).

[93] ifaa, **ifaa-Beispielsammlung „Digitalisierung & Industrie 4.0".** [Online]. Available: https://www.arbeitswissenschaft.net/angebote-produkte/checklistenhandlungshilfen/ue-che-tw-beispielsammlung/ (accessed: Nov. 1 2022).

[94] DIN/DKE, **Szenarien zur Digitalisierung der Normung und Normen: Whitepaper.** [Online]. Available: https://www.dke.de/idis-whitepaper-1-de (accessed: Dec. 19 2022).

[95] DIN/DKE, **Whitepaper. Anwendungsfälle von SMART Standards.** [Online]. Available: https://www.dke.de/resource/blob/2184670/57d8b37f0af3927334664e7cff57502a/idis-whitepaper-2-de---download-data.pdf (accessed: Dec. 19 2022).

[96] CENELEC, **Smart Standards -What is it?** [Online]. Available: https://experts.cenelec.eu/key-initiatives/smart-standards/ (accessed: Nov. 1 2022).

[97] DKE, **Harbsafe2.** [Online]. Available: https://www.dke.de/de/arbeitsfelder/cybersecurity/harbsafe2 (accessed: Nov. 1 2022).

DIN e. V.

Am DIN-Platz
Burggrafenstr. 6
10787 Berlin
Tel.: +49 30 2601-0
Email: info@din.de
Website: www.din.de

DKE German Commission for Electrical, Electronic & Information Technologies

Merianstraße 28
63069 Offenbach am Main
Tel.: +49 69 6308-0
Email: service@vde.com
Website: www.dke.de

January 2023