DIN DKE

PROGRESS REPORT

GERMAN STANDARDIZATION ROADMAP INDUSTRIE 4.0

STANDARDIZATION COUNCIL INDUSTRIE 4.0

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GREETING WORD

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Dear Readers,

We are pleased to present to you in this progress report the current developments and successes in the implementation of the recommendations for action formulated in the 5th edition of the German Standardization Roadmap Industrie 4.0. As an important milestone in the standardization work of national committees, this report provides a comprehensive review of activities and shows progress on the aspects formulated by the Plattform Industrie 4.0 in the 2023 mission statement, such as interoperability, sovereignty, and sustainability for Industrie 4.0.

Many of the activities that have been initiated, such as the harmonization of the development of AAS and other standards for the digital twin, the DPP, new approaches for resilient dataspaces and the standards in the field of artificial intelligence initiated by the EU Data Act, illustrate the importance of strategic and structured standardization. This is the only way to create an open and interoperable Industrie 4.0 ecosystem that meets both national and international requirements.

The progress report shows that the recommendations for action have fallen on fertile ground in the committees and are also having an impact on international standardization. Around 77 of the 113 recommendations formulated were classified as progress - a clear sign that Industrie 4.0 standardization is making faster progress in industrial application and is being used.

Sustainability is an important topic that we want to continue to drive forward. In particular, the introduction of the DPP in combination with the AAS is an excellent example of the combination of digitalization and interoperable implementation of digital twins for sustainable production. The resilience of value chains and the safeguarding of technological sovereignty are also becoming increasingly important as a result of the recent global crises.

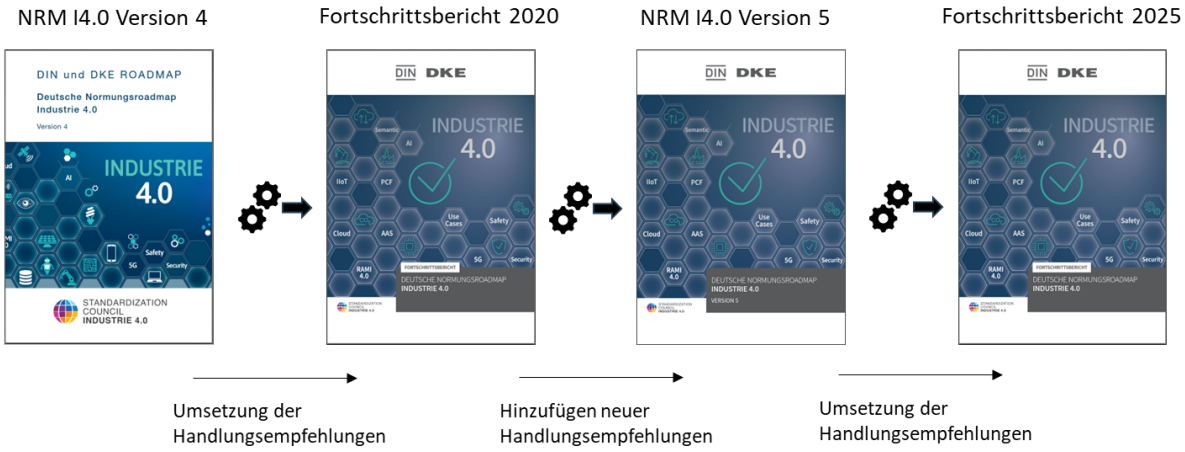
With this progress report, we not only want to document the current status quo, but also provide impetus for further development. We would like to thank all the experts who have supported the implementation of the recommendations for action with their commitment and expertise. Their work is the key to the success of Industrie 4.0.

We invite you to use this progress report as a guide and orientation and look forward to shaping the next steps in standardization for Industrie 4.0 together with you. We wish you an informative and inspiring read!

1 INTRODUCTION

In almost a decade and a total of five editions, the Standardization Roadmap Industrie 4.0 has developed into a central element of German standardization work and is an integral part of the standardization strategy for Industrie 4.0 to support Industry in its digital transformation. Due to its relevance on the international stage, the Standardization Roadmap has been translated into English and is also available in Japanese.

Version 5 of the Standardization Roadmap was published in 2023, and it is therefore time to present the current implementation status of the recommendations for action.



Like the previous editions, the fifth edition of the Standardization Roadmap takes the 2030 vision for Industrie 4.0 as a basis for the design of digital global ecosystems. From a standardization perspective, the focus is on aspects that are of central importance for every digital ecosystem in the current context, such as semantics and properties as the basis of interoperable digital systems, "Industrial Dataspaces" to generate additional added value based on data and "sustainable and ecological aspects of Industrie 4.0", i.e. the implementation of climate and environmental goals with an industrial focus.

2 PROGRESS – ASPECT 1: INTEROPERABILITY

2.1 Properties and their system integration in industrial applications

Recommendation for action	**Minimum standards for the consideration of socio-technical aspects**
[HE 5.1.1-3 V5]	The formulation of minimum standards for the consideration of socio-technical aspects should be examined in various generic standards on ergonomics and work design. As described, the relevant statements on work system design are currently spread across numerous standards, making it difficult for operational planners to locate them and adequately take them into account when planning Industrie 4.0 solutions. In addition, the clarity of the interrelationships in ergonomics standardization should be improved. Against this background, it is recommended that a document be made available to the operational planner in which all process-relevant statements on Industrie 4.0 are summarized. This should initially be realized in a guideline on work system design for Industrie 4.0 solutions.
Progress assessment	Initial approaches are currently being developed in NA 023 BR-03 SO.

Recommendation for action	**Adaptive, dynamic allocation of tasks between man and machine**
[HE 5.1.1-5 V5]	Since a rigid allocation of tasks (division of functions) between man and machine in many cases does not offer adequate opportunities for perception, situation assessment, influence, feedback on results and the resulting opportunities for learning and skills development, the division of functions should ideally be designed to be dynamic and adaptive. In any case, it should be transparent and designed to be comprehensible and influenceable for employees. It may be necessary to consider the fact that different employees may be working in the same work system (in parallel and synchronously or asynchronously). A procedure for process-accompanying evaluation of adaptive task allocation with particular attention to safety, security and psychosocial effects on employees must be developed and integrated into standardization. It must also be taken into account that machines may record and evaluate body measurements etc. for dynamic adaptation to humans. This results in a need for additions or amendments, for example for the standards 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[.
Progress assessment	Needs for updating DIN EN 614-1 are currently being formulated in NA 023 BR-03 SO.

Recommendation for action **[HE 5.1.1-9 V5]**	**Standardized input of maintenance information** Standardization of the interfaces of Industrie 4.0 components (systems and products) for the input of current maintenance information, e.g. based on iiRDS (repairs, maintenance, conversions) in the condition monitoring and predictive maintenance systems. In an industrial environment, assets can also include intangible things such as concepts, patents, procedures or processes. Properties of conceptual assets, such as planning documents, should be included as standardized dictionary entries.
Progress assessment 	The "SMT Intelligent Information for Use" Submodel (formerly "iiRDS Handover Documentation") submitted by the InterOpera project has been under development in the IDTA since June 2024 and deals with the integration of maintenance information in Industrie 4.0-compliant systems, among other things. Based on the IDTA Submodel "Handover Documentation", the VDI 2770 guideline and the iiRDS standard, the Submodel aims to provide interoperable information to describe the iiRDS handover documentation in relation to the asset of the respective AAS. The focus here is on the provision of properties that are ideally interoperable with the help of dictionaries such as ECLASS and IEC CDD. The aim of integrating the standard into the AAS is to make the user documentation available in a standardized format depending on the context, so that the technical documentation can be transferred as intelligent information in a machine-readable format along the value-added network. IEC PAS 63485 "Intelligent Information Request and Delivery - A process model for the exchange of information for use" was published in May 2023, marking an important milestone in the internationalization of the iiRDS concept.

Recommendation for action **[HE 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. In addition, planning documents should be communicable between people and machine/Industrie 4.0 components.
Progress assessment 	IEC/TC 65/SC 65E/AG 4 of IEC/TC 65, which is responsible for the coordination of semantic projects and CDD, has collected the requirements from various working groups (from the perspective of IEC/TC 65) for the IEC CDD and submitted them to SC3D. In future, these tasks of SC 65E/AG 4 will be dealt with in IEC/TC SC 65E /WG 2. Further activities for the standardization of properties in Smart Manufacturing are being conducted in IEC/TC 65/SC 65E/WG 2, such as IEC 63489 "Common data concepts for Smart Manufacturing", including the properties of Nameplates for AAS Submodel Templates, as well as the development of standards for data structures and elements (IEC 61987-100DB). IDTA has also published the "Handover Documentation" Submodel, which uses VDI 2770 Sheet 1 (published in 2020) as a basis.

Recommendation for action **[HE 5.1.1-11 V5]**	**Sustainable and continuous harmonization of properties between ECLASS and CDD** Given the fundamental importance of standardized semantics for Industrie 4.0 components, the coexistence of different standards for the same semantics is not acceptable, as this prevents overarching interaction between Industrie 4.0 components. Parallel developments such as those currently taking place at certain points in IEC, ISO and ECLASS must be coordinated: The activities to harmonize the properties must be accelerated among 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 the specification of new properties must be synchronized between ECLASS and CDD in order to avoid further differences in the properties. Ideally, the publishers of properties (and other structural elements, e.g. classes, values and units) will have dovetailed their standards after the harmonization steps to such an extent that semantically identical elements have the same name and the same code, i.e. mean the same thing. Common content should be managed and developed identically in all databases or managed in a common database in order to structurally prevent the content from diverging. IEC, ECLASS and, in the future, probably also ISO should be mentioned as important publishers. The results should be made publicly accessible.
Progress assessment	IEC and ISO are working on a cooperation for the joint use of the IEC CDD. As soon as these organizational preparations have been completed, ISO-defined content can be mapped in the CDD. A dictionary for the classification of standards (i.e. classification of documents) is planned as one of the first data dictionaries with ISO content. IEC, ECLASS, and ISO are working in the COMDO project (One COMmon. Data RepOsitory for Smart Manufacturing) coordinated by SCI 4.0 on a means for the continuous use of semantic properties of the CDD (Common Data Dictionary) and ECLASS. An internal pilot for the COMDO project was carried out and the findings are currently being processed. Provision of the content of the IEC CDD via the ECLASS Content Development Platform (CDP) is in preparation. Furthermore, IEC revised Annex SK of the internal regulations and thus expanded the possibilities for developing semantic properties of the CDD.
Recommendation for action **[HE 5.1.1-12 V5]**	**Standardized dictionaries** Existing fieldbus profiles, companion specifications and other specifications that define device and component properties should be transferred to standardized dictionaries such as ECLASS and IEC CDD. It should also be possible to represent them in a suitable semantic manner (e.g. graphically/algebraically).
Progress assessment	With regard to the creation of a uniform basis for the consistency of fieldbus profiles, AAS Submodel Templates and OPC UA Companion Specs, discussions are underway between representatives of IDTA, the OPC Foundation, AutomationML, ECLASS and the IEC CDD.

2.2 Reference architecture models

Recommendation for action	Industrial cloud platforms
[HE 5.1.2-1 V5]	An open, distributed, real-time capable and secure operating system, standardization activities for a flexible and expandable architecture for future requirements of cognitive services, real-time applications and data marketplaces should be included in relevant committees. It is recommended that hybrid cloud platforms, IIoT applications and cyber-physical architectures be investigated as core elements. This includes standardized lifecycle management of all IT resources, production equipment and technical building equipment as well as the creation of a consistent infrastructure for real-time capable cross-domain value creation networks for the AI-supported, autonomous production of the future.
Progress assessment 	Ongoing research and development activities continue to focus on the standardization of efficient and innovative cloud infrastructures and on the development of secure and trustworthy cloud-based services. On the one hand, the European Commission is increasingly working in the EU's digital decade to offer European companies and authorities access to secure, sustainable and interoperable cloud infrastructures and services in order to support the development of common European dataspaces. On the other hand, national initiatives such as Caten-a-X, Manufacturing-X and Factory-X are putting the recommendations for interoperability for such ecosystems into practice. Catena-X creates a secure data infrastructure for the automotive industry, which is in line with the recommendations for a flexible and expandable architecture. Manufacturing-X integrates these principles into the entire manufacturing industry and thus supports the creation of cross-domain value networks, as called for in the recommendation. Factory-X is developing specific solutions, such as the "Factory-X Kernel", to integrate cyber-physical systems and IIoT applications, which is in line with the recommendations for investigating hybrid cloud platforms. Furthermore, the cross-sectional project DAVID was initiated at national level to ensure the technological and semantic interoperability of various Manufacturing-X projects based on the AAS. DAVID aims to develop open data ecosystems in the industry and enables the realization of cross-industry use cases. The concepts of the initiatives are being internationalized via the International Manufacturing-X Council (IMX Council). IM-X is in contact with Ad-hoc Group 8 "Data Spaces for Smart Manufacturing" of the IEC System Committee Smart Manufacturing with the idea of coordinating international standardization via this group. In addition, ISO 20151: "Dataspace Concepts and Characteristics" has been included in the work programme of ISO/IEC JTC 1/SC 38 "Cloud Computing and Distributed Platforms" in order to further standardize and develop basic concepts and characteristics of dataspaces. These steps contribute to the creation of a basis for the secure use and exchange of data in various digital environments.

2.3 Semantics and properties

Recommendation for action	**Ensuring effective normative infrastructures**
[HE 5.1.3-3 V5]	It is recommended that ISO, IEC, CEN and CENELEC as well as the national committees make a joint effort to undertake the digital transformation process from document-centric standards to digital value-added services for the content of the standards in order to make preparations in the infrastructures at an early stage and ensure the future of consensus-based standardization. Strong participation in the international committees is therefore important.
Progress assessment 	Research and development work on the digital transformation of standardization is now being carried out internationally and in close coordination with one another. The DKE Digital Standards Initiative (IDiS) is leading the way in Germany, driving forward the digital ecosystem around smart standards with the broad participation of industry and research and in conjunction with international initiatives. This includes work on standardized information models and processes, e.g. using ontologies and AAS. From the USA, for example, NISO is contributing a key building block for XML-based information modelling with the Standards Tag Set (STS). IEC/ISO SMART is a joint IEC and ISO work program for the international promotion of smart standards. This work is being concretized, for example, in the work of IEC SG 12 on Smart Standards incl. IEC SMART Information Model (SIM), but also ISO/IEC JTC 1/SC 32 addresses "Data management and interchange" building blocks in the form of ontologies and document structures. In addition, ISO/IEC JTC 1/SC 41 addresses the digital twin, an essential organizational building block for the merging of standards, which is also dealt with, for example, by the IDTA and the Submodels collected there. At European level, CEN and CENELEC are developing concrete prototypes for future tools in the two key projects "Online Standards Development" and "SMART Standards", in each case in conjunction with the work at ISO/IEC.

Recommendation for action	**Semantics in the context of the digital twin**
[HE 5.1.3-4 V5]	ISO/IEC JTC 1/SC 41/WG 6 should normatively explain the connection between semantics and the digital twin across domains.
Progress assessment 	Semantics in the context of the digital twin refers to the interoperability between digital entities and target entities. Ongoing standardization work focuses on the harmonization of dataspaces, procedures and data formats to efficiently implement the feedback control loops and interoperability concepts. This work is currently being driven forward in the ISO/IEC JTC 1/SC 38 and SC 41 committees for Cloud, Edge Computing and Industrial IoT and digital twin.

Recommendation for action **[HE 5.1.3-5 V5]**	**Industrie 4.0 language** The existing VDI/VDE 2193 (Sheet 1 and Sheet 2, Language of Industrie 4.0 Components) is available as a guideline and forms an essential basis for interoperability between Industrie 4.0 components. It is recommended that the Industrie 4.0 language be transferred to international standardization.
Progress assessment 	A formal language for describing the requirements and properties of industrial products and production processes over the entire life cycle, including refurbishing, has not yet been introduced in semantic standards for Industrie 4.0. The VDE SPEC 90010 Guidance for the creation of executable semantic standards (SemNorm) provides initial approaches for the use of such formal languages, which consist of a declarative part for attribute description and an operational part for defining transformation rules for attributed graphs. VDI 2193 offers further relevant content for describing the interaction and an AAS-based data model, which could be described in the AAS standard IEC 63278 as an additional part. An initiative for implementation could be launched by SCI 4.0.

Recommendation for action **[HE 5.1.3-6 V5]**	**Tools of semantics** It is recommended to develop semantic tools, i.e. tools and artifacts that can be used for the analysis, definition, description or cyber-physical engineering for the manufacture of a product. These should be standardized according to their use (e.g. provision in combination) and properties.
Progress assessment 	The draft standard IEC 63538 of the committee IEC/TC 65/SC 65 E/WG 2 standardizes information models for product life cycles based on the "event" concept. Product components are described with attributes such as <event, raw material, subcomponent>. This approach is compatible with the formal language Common Logic, which uses UML-like graphs. Proof-of-concept examples such as AGG (TUB) and GrGEN.NET (KIT) have been developed in this area, which show that a formal language that uses graph-theoretic (graphical) concepts to represent an Industrie 4.0 semantics/ontology is transferable to platforms with attributive graph grammars. SysML V2, which will be released soon, can also be considered in the context of semantic tools. The Kernel Modeling Language serves as the formal basis, which is based on a representation in first-order logic and promotes machine interpretability. Current Open Source developments for AAS increasingly rely on Open Source tools for the integration of AAS. This is shown by the current status in IDTA's Solutions Hub.

Recommendation for action **[HE 5.1.3-7 V5]**	**Quality criteria for ontologies** The requirements for the existing ontologies are to be fundamentally reviewed. To this end, quality criteria for ontologies are to be developed in order to enable clear identification of ontology concepts (e.g. avoidance of homonyms and synonymous concepts).
Progress assessment 	The DKE (in collaboration with the IEC) is conducting the Harbsafe 2 project, which is concerned with automated quality checks for data dictionaries. The definitions of the elements are checked for consistency and other quality requirements. The results of the project are already being used to improve the terminology in data dictionaries (e.g. IEC 61987 Data Dictionary).

2.4 Tools for implementing the digital twin

Recommendation for action	**Use the Asset Administration Shell concept throughout and standardize it internally**
[HE 5.1.4-1 V5]	To support the processes described above, such as maintenance functions and the storage of knowledge in a life cycle file, the assets must be able to exchange data with production systems and plant operators via standardized interfaces with standardized semantics. This is achieved via the AAS concept if the AAS or their generic Submodels and their communication between Industrie 4.0 components are defined in standards. It is recommended that the activities of IEC/TC 65/WG 24 with regard to the IEC 63278 series be supported and promoted.
Progress assessment 	IEC/TC 65/WG 24 "Asset Administration Shell for Industrial Applications" successfully finalized and published IEC 63278-1 "Asset Administration Shell for industrial applications - Part 1: Asset Administration Shell structure". The publication of this international standard has made a decisive contribution to the international acceptance of this central concept of Industrie 4.0. Since the publication of the 5th edition of the Standardization Roadmap, IEC/TC 65/WG 24 has successfully initiated the standardization projects • IEC 63278-4 ED1 “Asset Administration Shell for industrial applications – Part 4: Use cases and modelling examples” • IEC 63278-5 ED1 “Asset Administration Shell for industrial applications – Part 5: Interfaces” With these new parts of the IEC 63278 series of standards, the first complete description of the AAS concept has been introduced into international standardization. The current challenge is to bring part 2 "Information meta model", part 3 "Security provisions for Asset Administration Shells" and part 5 "Interfaces" to a rapid conclusion, so that these standards can be used to meet the regulatory requirements of the DPP. The provision of sufficient human resources is essential for this. An asset's lifecycle record requires the collection and documentation of information over the entire lifecycle of an asset or product, including documentation, maintenance, sustainability and traceability. The following IDTA Submodels, such as Handover Documentation, Plant Asset Management, Part Traceability, Maintenance Instructions, Carbon Footprint/Product Environmental Data and others, are therefore particularly relevant in the context of an asset's life cycle file. These cover various application areas such as maintenance, production, quality assurance and life cycle management.

Recommendation for action **[HE 5.1.4-2 V5]**	**Synchronization of 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 AAS in IEC/TC 65/WG 24 be synchronized.

Progress assessment	Under German project management, IEC/TC 65/WG 24 is continuously working on the international standardization of the AAS concept. The work currently underway relates to the further development of standards started between 2022 and 2023, such as the IEC 63278 series.
	
	In addition, further topics are planned in IEC/TC 65/ WG 24 to complete the AAS standards and facilitate their application, such as the specification of AAS content for various domains and the development of interaction models for communication between AAS.
	
	ISO/IEC JTC 1/SC 41 is currently developing several Foundational Standards, which are currently in the WD or CD stage and are being tested for synchronization requirements with AAS standardization in IEC TC 65/ WG 24 or WG 23. In detail, these are:
	
	• PWI JTC1-SC41-16 "Digital twin - Extraction and Transactions of Data Products". The following standards for the "digital twin" context are referenced and coordinated at SC41 level between der ISO/IEC JTC 1/WG 6 through liaison with IEC/TC 65 /WG 24 (AAS) and SC41's internal WG 3 (IoT/RA):
	  ○ Basic principles for this as a reference via ISO/IEC 5209 (Data usage - Terminology and use cases) and ISO/IEC 5212 (Data usage - Guidance for data usage) and
	  ○ Interoperability (metadata level for digital twin (see AAS above) as a further reference via ISO/IEC 11179-1 (Metadata registries (MDR) - Part 1 framework) - and ISO/IEC 19763-1 (Metamodel framework for interoperability (MFI) - Part 1 Framework).
	• PWI JTC1-SC41-19 "Digital twin - SC41 PWI 19 Guidelines for digital twin entity modeling " with a focus on interoperability in liaison with ISO/IEC JTC 1 /SC 38 - context "Dataspace" with regard to digital twin (WG6).
	
	The liaison between IEC/TC 65 and ISO/IEC JTC 1/SC 41 has been intensified since the 5th edition of the Standardization Roadmap was published, creating the conditions for synchronizing the activities of the two bodies.

Recommendation for action **[HE 5.1.4-3 V5]**	**ISO/IEC-21823 series in the Industrie 4.0 context** DIN NA 043-01-41 IoT and other relevant bodies and committees should carefully review the current standards of the ISO/IEC 21823 series for direct relevance to industry and provide feedback in the mirror committee.
Progress assessment	Several basic standards are currently being developed in ISO/IEC JTC 1/SC 41, which deal with the (systemic) aspects of "interoperability" (ISO/IEC 21823), among others, and are currently in the WD or CD stage (see [HE 5.1.4-2 V5]).

Recommendation for action **[HE 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 cooperation and exchange on the "industrial sector" with regard to the Industrial IoT, the management shell and the digital twin with all associated liaisons.
Progress assessment	The activities of SC41/AG 20 (SELG1) continue to focus on promoting liaison in/via ISO IEC JTC 1/SC 41 in the industrial sector - especially for IoT and digital twin - to enable a common mutual understanding, both on the part of the consortial rule-setters (e.g. IDTA, OneM2M) and the standardization bodies (IEC, ISO, ETSI) for "Industrial IoT" and "Industrial Digital Twins" standards. To promote standardization in these areas of interest to users/organizations, Cat-C liaisons have been set up in close cooperation. For example, ISO/IEC JTC 1/SC 41 JAG 28 was established following ISO/IEC JTC 1/AG 20 to facilitate exchange and collaboration between the chairs of JTC 1/SC 41 and IEC/TC 65 for all their working groups (and associated JWGs) to enable smooth development and avoid overlap/duplication.
Recommendation for action **[HE 5.1.4-5 V5]**	**OPC UA Companion Specifications for implementing the Digital Twin** The information semantically standardized in OPC UA Companion Specifications is to be used to implement the digital twin for the production environment. As a result, digital twins of production can be used efficiently both within and across industries thanks to interoperable semantics and achieve a high level of value.
Progress assessment	It has been recognized that the digital twin must receive production information in real time. As a result, the OPC UA Companion Specifications are increasingly being implemented in the industry worldwide. Implementation varies in intensity depending on the sector, although there is still room for improvement. VDMA working groups, made up of various industry representatives, develop and publish industry-specific and cross-industry OPC UA communication specifications for mechanical and plant engineering. As of August 2024, there are 109 publications (industry-specific and cross-industry specifications and updates), 62 releases and 13 release candidates (available here: https://www.vdma.org/catalogs) and 38 working groups. Cross-industry solutions in the OPC UA for Machinery basic specification have so far included: machine identification, machine status, operating hours counter, job management, process values and test report transmission. The increasing international relevance can still be seen. For example, certain OPC UA Companion Specifications are also offered as Smart Manufacturing Profiles by CESMII. At the same time, new working groups are also being formed on other continents for the development of new OPC UA Companion Specifications, such as in the area of mining in Brazil. An expansion of the digital twin to the entire production process is also being recorded, as illustrated by battery production, for example, as this is semantically standardized throughout and thus a digital twin of the entire production process will be available. This has the advantage of comparable integration and evaluation of new assets in the digital twin. This also makes it clear that the standardization work regarding the OPC UA Companion Specifications is also progressing with regard to current topics, as confirmed by the standardization work in the field of hydrogen electrolysis.

Recommendation for action **[HE 5.1.4-6 V5]**	**OPC UA in the context of the Asset Administration Shell** The AAS concepts are to be further expanded in the context of OPC UA. To this end, further requirements for standardized semantics for information from production are to be reported to the responsible OPC UA working groups for development. In the spirit 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).
Progress assessment 	In the JWG IDTA/OPC Foundation, a Submodel working group was founded with the aim of developing an OPC UA Server Data Sheet. The provision of implementation details of the OPC UA Server via the Administration Shell is intended to enable developers and users of OPC UA client applications to prepare for the later integration of assets that contain the OPC UA Server. The AutomationML, IDTA, OPC Foundation and VDMA associations and company experts have published a discussion paper about industrial interoperability with a common vision and recommendations for action for industrial interoperability. This paper also describes the interaction between the various technologies. The use of data aggregated using OPC UA in the AAS without duplicating it and storing it directly in the AAS, but only integrating it as a reference, has not yet been sufficiently clarified. An example of a future synergy could be shown in the implementation of the DPP through the combination of OPC UA Companion Specification and the Administration Shell. Furthermore, a clear delineation is required as to which data is relevant for the AAS and which is not (e.g. regarding the requirements for real-time transmission). In future, there should be clarity for each OPC UA Companion Specification as to which attributes should or can be used in a Submodel of the Administration Shell. It is appropriate to identify corresponding use cases and describe them as examples, both to differentiate and to demonstrate synergies.

Recommendation for action **[HE 5.1.4-7 V5]**	**Supplement existing standards (ISO 13585-1 and IEC 61360) for semantics** The data formats required in the information world are taken from ISO 13585-1 and IEC 61360. The properties of ECLASS are also coded on this basis. However, AAS or Submodels require further types of properties for operational use in addition to the purely descriptive properties of an asset. These are states and parameters of the assets as well as their measurement and actuator values (dynamic data). Commands and entire functions (often also called functional functions) must also be described using the same concepts. The concept of properties in today's standards is to extend 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 must be developed, or existing ones must be defined in standards.
Progress assessment 	In the IEC CDD (IEC 61360-4 DB) in the IEC 61987 data dictionary, product descriptions of devices have been and are supplemented by descriptions of variable parameters and dynamic process variables of the devices. Work is currently underway on a revision of IEC 61360-1, for which proposals to support variable values are also being discussed.

Recommendation for action **[HE 5.1.4-8 V5]**	**Holistic development of AAS Submodels** It is recommended that the development and internationalization of the Submodels of the AAS in IDTA, ISO and IEC be promoted. The application of the Submodels should follow the holistic approach as far as possible to enable their applicability in other areas as well.
Progress assessment 	ISO, IEC and IDTA are currently placing great emphasis on the holistic development of digital twin standards. The aim of the joint activities is to standardize not only the interfaces, but also the semantics of the exchanged data. This guarantees that different systems can interpret the same information in the same way. The IDTA and IEC/TC 65/WG 24 contribute significantly to the definition and development of AAS Submodels in the holistic aspect. At IEC/TC 3/SC 3D and IEC/TC 65/SC 65E/WG 2, the projects • IEC 61360-7 “Standard data element types with associated classification scheme - Part 7: Data dictionary of cross-domain concepts”, • IEC 61987-100 „Industrial-process measurement and control - Data structures and elements” und • IEC 63489 “DB - Common data concepts for smart manufacturing” created important prerequisites for the description of AAS Submodels and the semantic properties required for them in international standards. IDTA also ensures that Submodels can be used across different industries, such as the automotive, chemical, mechanical engineering and electronics industries. To support this, IDTA has set up the IDTA portal, which enables the validation of AAS and access to the repository for Submodel Templates. WG 24 is continuing work on the next four parts of IEC 63278 (see [HE 5.1.4-2 V5], [HE 5.1.4-3 V5], [HE 5.1.4-4 V5], as well as [HE 5.1.4-10 V5]), including part 5 on AAS interfaces, which is relevant to the DPP standard. The working group is looking for liaisons with the relevant IEC, ISO, ISO/IEC and other standardization bodies. As part of the cooperation between IDTA, OPC Foundation, CESMII, Digital Twin Consortium, ECLASS, LNI 4.0, VDMA and ZVEI, an exchange of experience is taking place with regard to the development of an optimal system architecture for the upcoming DPP.
Recommendation for action **[HE 5.1.4-9 V5]**	**Digital CV file as a Submodel of the administration shell** The information model for the digital lifecycle file is to be mapped as a Submodel of the AAS. It is also recommended that efforts be made to internationalize the DIN 77005 series of standards.
Progress assessment 	In general, the IDTA develops generic Submodels that can be adapted by companies and organizations. These Submodels cover various application areas such as maintenance, production, quality assurance and life cycle management (see [HE 5.1.4-1 V5]). A central objective of the IDTA is to ensure that the models developed can be implemented not only theoretically but also practically in industry and are based on the international standards of ISO and IEC.

Recommendation for action **[HE 5.1.4-10 V5]**	**Standardization of the AAS Submodels** Operational models and suitable tools are needed for a simulation. Tools and models need a common semantics for machine execution and for the comprehensible representation of the properties of the system under consideration in its environment.
Progress assessment 	The following IDTA Submodels / current work provide tools and operational models that are machine-executable with a common semantics and enable the representation of system properties in their environment: • *Provision of simulation models for the provision of interoperable models for the simulation of systems and virtual commissioning with a focus on engineering data for simulation-based validation prior to implementation*; • *Provision of 3D models for the interoperable representation of 3D data for the simulation of the system under consideration*; • *Value Chain, Material Flow, and Process Simulation with a focus on the simulation of processes, material flows and value chains*; • *Robot Online Programming and Simulation provides tools for simulating and programming robots;* • *P&I Diagrams for machine-readable diagrams for mapping systems and processes;* • *Time Series Data, for example for data for time analysis and simulation of operating processes;* • *Capability Description for the description of the properties and capabilities of resources for simulation-based decisions and* • *Detailed Structure of Production Systems for a structured representation of complex production systems for simulations*.

Recommendation for action **[HE 5.1.4-11 V5]**	**Standardization of dictionaries** Prerequisites 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 can be planned by production systems.
Progress assessment 	The AAS has now been integrated into the CDD and ECLASS concept repositories. The first incorporation of standardized Submodels into the IEC 61360-7 data dictionary took place in the IEC CDD and is available at https://cdd.iec.ch.

Recommendation for action **[HE 5.1.4-12 V5]**	**Digital type plate** IEC 61406 (based on DIN SPEC 91406) for the digital rating plate was published in September 2022. In addition, adjustments are to be made to all application standards for machine-readable marking based on VDE V 0170-100:2021-02 "Digital rating plate".
Progress assessment 	The IEC 61406-1 and IEC 61406-2 standards have recently been published and provide an important basis for standardization in their respective fields. In addition, IEC 63365 was published based on VDE V 0170-100. These standards are coordinated with each other to ensure a consistent and harmonized basis for their application. As part of the ongoing work, it was decided to revise IEC 61406-1 in order to meet current developments and requirements. The basic elements of IEC activities with regard to the standardization of DPP required by the EU are defined in the IEC 63278 standard in conjunction with the IEC 61406 series of standards.
Recommendation for action **[HE 5.1.4-13 V5]**	**Standardization of AAS Submodels and properties** Preparatory activities for the standardization of Submodel Templates of the AAS must be initiated. The integration should take place 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/mandatory properties and basic/mandatory functions that can be expanded via individual properties and functions through Industrie 4.0 partnerships. This means, for example, that the same mandatory properties and functions must be available for different assets in the case of energy considerations, so that they can be easily consolidated or controlled in the same way for all components of a system or systems in a plant. Specific additions remain possible.
Progress assessment 	The IDTA has a working group that deals with the requirements of the basic/mandatory properties and basic/mandatory functions.

2.5 Industrial communication

Recommendation for action **[HE 5.1.5-1 V5]**	**Heterogeneous industrial networks** Standards for global mobile network technologies should be designed or supplemented in such a way that a seamless transition between local industrial networks and industrial mobile radio networks is possible. The 5G-ACIA documents on the integration of Ethernet, TSN and OPC UA in 5G can serve as starting points for the standardization of such heterogeneous, industrial networks.
Progress assessment 	The IEC/IEEE 60802 profile, which is currently under development, is one of the connecting factors of heterogeneous, industrial elements of heterogeneous, industrial networks. A white paper from 5G-ACIA "Integration of 5G with Time-Sensitive Networking for Industrial Communications" and the OPC presentation "OPC UA for Field eXchange" from July 2022 show the interest in finalizing the profile. Publication is planned for fall 2025. The Publicly Available Specification or IEC DPAS 63595 "INDUSTRIAL NETWORKS - 5G COM-MUNICATION TECHNOLOGY - General considerations" is expected to be published in the first quarter of 2025. This document defines radio communication systems based on 5G and subsequent mobile radio technologies that are suitable for industrial measurement and automation applications. This document describes requirements for users, developers and device manufacturers. In particular, the connection with existing and developing industrial communication standards is also described. At the same time, the proposal for a standard entitled IEC 63595 "INDUSTRIAL NETWORKS - 5G COMMUNICATION TECHNOLOGY" is expected. This will also follow the recommendations **[HE 5.1.5-9 V5]**, **[HE 5.1.5-10 V5]** and **[HE 5.1.5-11 V5]**.
Recommendation for action **[HE 5.1.5-3 V5]**	**Integration of communication devices in Industrie 4.0** Communication devices with adaptive functions for device and network management should be modelled as Industrie 4.0 components. Corresponding properties and services must be specified for a communication Submodel of an AAS.
Progress assessment 	In May 2024, the IDTA published the specification IDTA 02022-1-0 "Wireless Communication - Submodel Template of the Asset Administration Shell". The current version of the Submodel contains information on the communication functions of wireless communication devices and characteristics of the frequencies used. Some parts of this Submodel are currently being expanded and developed into separate Submodels, such as the Submodel for antennas. In addition, Submodels for data traffic models (also applies to [HE 5.1.5-4 V5]) and for the evaluation of real-time communication (also applies to [HE 5.1.5-6 V5]) are in preparation.
Recommendation for action **[HE 5.1.5-7 V5]**	**Validation and testing** Communication standards for Industrie 4.0 must provide test specifications that can be used to demonstrate the performance, conformity, and interoperability of products.
Progress assessment 	A test specification for profile 60802 is currently being created within TIACC. As soon as the maturity level of the TIACC documents is sufficient, the content will be formulated in IEC 61802. The draft standard IEC 63595 "INDUSTRIAL NETWORKS - 5G COM-MUNICATION TECHNOLOGY" also contains a section on "Test methods", in which methods for conformance tests, performance tests and for monitoring, diagnosis, and error analysis during operation are described.

Recommendation for action **[HE 5.1.5-12 V5]**	**Security in industrial communication** It is recommended that a coordinated and accepted security model be developed and promoted. The content should be integrated into the fieldbus standards.
Progress assessment	The profile for IEC/IEEE 60802, which is currently under development, is the connecting element of heterogeneous industrial networks. A white paper from 5G-ACIA "Integration of 5G with Time-Sensitive Networking for Industrial Communications" and the OPC presentation "OPC UA for Field eXchange" from July 2022 show the interest in the completion of the profile. A publication is targeted for fall 2025.
Recommendation for action **[HE 5.1.5-13 V5]**	**Single Pair Ethernet (SPE)** It is recommended that the integration of SPE (Single Pair Ethernet) into fieldbus standards be promoted. Relevant standards should be included by IEEE in IEC 61158-2.
Progress assessment	With the support of IEC/TC 65/SC 65C, SPE will be integrated into the fieldbus standards (IEC 61158 and IEC 61784 series) in the 2025-2028 maintenance cycle.
Recommendation for action **[HE 5.1.5-14 V5]**	**Advanced Physical Layer (APL)** It is recommended that the integration of APL (Advanced Physical Layer) into relevant fieldbus standards be promoted. The technical specification (IEC TS 63444) is a first step and integration of the content into IEC 61158-2 is to follow.
Progress assessment	With the support of IEC/TC 65/SC 65C, APL will be integrated into the fieldbus standards (IEC 61158 and IEC 61784 series) in the 2025-2028 maintenance cycle.
Recommendation for action **[HE 5.1.5-15 V5]**	**Uniform standardization for industrial location management** Industrial location management requires uniform standards for the following aspects: • Technologies for determining location data; • Formats for location data; • Agreements on data storage (centralized/decentralized); • Protocols for data transport; • Applications and visualization tools.
Progress assessment	Omlox standard has further increased its presence among member companies and sectors (mechanical engineering, logistics, automotive industry, process industry, etc.). The working group for use cases has now identified more than 340 use cases. The technology is expanding from radio-based methods (UWB, BLE, WIFI, radar, etc.) to image-based methods and ultrasonic localization (accuracy of a few millimetres).

2.6 Functional safety in Industrie 4.0

Recommendation for action **[HE 5.1.6-2 V5]**	**Safety and security standardization activities** The work on safety and security should be further deepened and concretized. This should be done, for example, as part of the revision of IEC TR 63069 or IEC TR 63074. Further work should focus in particular on the new Machinery Directive and address its requirements for information security.
Progress assessment 	IEC TR 63074 has been developed into IEC TS 63074. IEC TR 63069 is currently being developed into a TS. In the revision of TR 63069 to TS 63069, significant concerns that existed from a German perspective were resolved. An additional part for IEC 62443, which is based on TS 63069, is conceivable. The EN 50742 project in TC 44X WG 02 exists for the development of the topic of security (Corruption Section 1.1.9 in the Machinery Ordinance) within the framework of the Machinery Ordinance, with the aim of listing the standard in the Official Journal.
Recommendation for action **[HE 5.1.6-3 V5]**	**Standardized procedures and methods for on-time risk management along the life cycle** Standardized procedures and methods that enable on-time risk management along the life cycle without compromising the confidentiality of the technical documentation should be developed. In accordance with the most recently developed German-Chinese agreements, which are described in the NRM Industrie 4.0 V4, a guideline should first be developed (Sino-German Whitepaper on Functional Safety in I4.0), which sensitizes the stakeholders with regard to the possible repercussions (risk increases or compromising of risk-reducing measures) of various Industrie 4.0 application scenarios on plant safety. Furthermore, the possibility of making safety-relevant accompanying documents digitally exchangeable, for example via a Digital Nameplate, should be pursued.
Progress assessment 	As part of the German-Chinese cooperation, another white paper on the digitalization of functional safety and preventive maintenance is being prepared. The aim is to describe the potential and make it accessible.

2.7 Artificial intelligence in industrial automation

Recommendation for action **[HE 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 should be continuously checked for consistency regarding their applicability in Industrie 4.0 and - if necessary - harmonized and/or specified for industrial automation. Identified contradictions and application hurdles should be brought to the relevant standardization committees. The scope of documents (specifications, norms, standards and regulatory files) should have a clearly defined area of application. Existing regulation must be tightened up in this respect. In the development of AI-based systems, the resulting common and consistent basic understanding of the terms and the interrelationships of the concepts used, with consideration of the use of AI methods, is also an important basis for interdisciplinary cooperation in the development of industrial AI systems.
Progress assessment 	The implementation of this recommendation for action has only made limited progress. The complexity of developing a uniform understanding of terms - especially in an international context - is difficult. The challenge here is that European regulatory requirements, particularly in this context the AI Act, do not use the internationally standardized terms and definitions, but instead introduce their own terminology.

Recommendation for action **[HE 5.1.7-2 V5]**	**Consistent application of existing terminology and definitions in the context of AI and Industrie 4.0 (especially in regulatory activities)** Since regulation, the core aspect to be regulated and the (sub)systems to which regulation is to apply are not clear and are sometimes contradictory in the normative context, it is neither possible to regulate in a targeted manner nor to address them adequately based on standardization requests. It is therefore recommended that existing definitions of AI (and any methods **[HE 5.1.7-6 V5]**) or quality requirements (see **[HE 5.1.7-7 V5]**) are used throughout (including in the regulatory context) or, if necessary, suitable adaptations of existing normative definitions are sought; however, it is not recommended to create your own (sometimes orthogonal to existing definitions) formulated references. A clear demarcation from existing standards, e.g. for high-risk AI systems and safety, should also be made where necessary.
Progress assessment 	The limited progress in **[HE 5.1.7-1 V5]** and the lack of consistent use of standardized terminology in a regulatory context also makes international harmonization more difficult. As a result, there are (in this case negative) interactions between **[HE 5.1.7-1 V5]** and **[HE 5.1.7-2 V5]** regarding their progress. At European level, CEN/CLC/JTC 21 (and correspondingly the national committees, such as DIN/DKE NA 043-01-42 GA "Artificial Intelligence" in Germany) are working intensively on the European Commission's standardization requests with regard to the AI Act. The timeline here is very tight, so it is to be feared that not all the necessary standardization projects can be successfully completed in time and/or that compromises may be necessary in terms of quality (and thus also terminological consistency) and international harmonization.

Recommendation for action **[HE 5.1.7-3 V5]**	**Strengthening training regarding standardization and 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. It is necessary to strengthen vocational and academic training regarding innovation, standardization and standardization. Initial initiatives have already been launched by DIN and DKE at national level. These should be further strengthened, and corresponding initiatives (research and funding) should be politically promoted and supported.
Progress assessment 	Anchoring in education and training is being driven forward. The focus here is on strengthening the systemic understanding of norms and standards for various reasons (e.g. interoperability, regulation, etc.). Efforts are being made, particularly by the national standardization organizations DIN and DKE, but also by other national (standardization) organizations such as VDI and IDTA, to further anchor standardization in education and training. There are already central contact points on the internet with (free) teaching material. For (interested) teachers, the DIN/DKE conference on standardization theory took place for the second time in 2024, where an increasing number of participants can be observed. Numerous community games with didactic preparation of standardization and standardization are already available, such as the IEC Standardization Quest or the DIN game - partly also as an online game like KANelot. However, the current status can only be seen as the first important steps, with a long way to go. In particular, it is clear that the adoption and adoption of teaching content/at teaching institutions (regardless of the type of training in adult education) is stagnating. This is partly due to a lack of expertise among teaching staff and a lack of incentives to specifically address this issue.
Recommendation for action **[HE 5.1.7-4 V5]**	**Strengthening the link between (research) innovation and standardization** Strengthening and promoting the participation of national standardization institutes in research projects to facilitate a comparison between the normative and scientific state of the art and to support the national and 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). At European level, this would also promote multilateral exchange between national standardization institutions and science, and thus also achieve a leverage effect through the federalist basic structure of Europe in international standardization.
Progress assessment 	There is still room for improvement in the transfer of knowledge, particularly with regard to the speed at which new findings from the scientific community are adopted. Particularly in subject areas such as artificial intelligence, which is characterized by rapid technological development, the speed of transfer and consideration of any rapid changes in the state of the art is an important element (also in the context of regulatory activities). Hardly any progress has been made here and there is still significant potential for improvement. However, it can be observed that the presence of normative topics in science (primarily in engineering disciplines and application areas of automation) is increasing. The increasing awareness and importance of individual norms and standards (such as OPC UA, AutomationML and the AAS), which are increasingly being taken up and addressed in scientific publications, is having a positive effect here. Regulatory pressure from the European Commission is also having a positive impact in this context: Topics such as the DPP and the AAS (both also in the context of AI as a data provider) as well as other regulatory aspects are increasingly referenced at scientific events and publications in the technical field and inevitably lead to a stronger presence of normative content.

Recommendation for action **[HE 5.1.7-5 V5]**	**Continuation and continuous updating of a standardization map and derivation of action strategies** Based on the recommendations for action from the previous version 4 of the NRM Industrie 4.0, an initial map of standardization activities for AI in the context of Industrie 4.0 was developed. In order to implement the recommendations for action described in this Standardization Roadmap for AI, the continuation and continuous updating of a standardization map for AI 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 StandICT.eu project or the Artificial Intelligence Focus Group) should be actively promoted, as well as with consortia initiatives and platforms.
Progress assessment 	The closely dovetailed publication of the DIN/DKE Standardization Roadmap Artificial Intelligence in December 2022 and the DIN/DKE Standardization Roadmap Industrie 4.0 - Version 5 in January 2023 is no coincidence: From the perspective of Industrie 4.0, the SCI4.0 Expert Council on Artificial Intelligence in Industrial Applications already ensured thematic dovetailing in advance, as the contributions to both Standardization Roadmaps were jointly developed there. The progress of the implementation of the standardization aspects of Artificial Intelligence was initially carried out by DIN/DKE and coordinated by FOCUS.ICT (as part of a task force). Based on a stringent prioritization of the recommendations for action, the implementation was continuously driven forward and documented by DIN/DKE and SCI4.0. From 2025, DIN/DKE NA 043-01-42 GA will take over the management of the implementation of the recommendations for action assigned to it; recommendations for action in industrial automation (unless already directly incorporated into standardization projects) will remain the administrative responsibility of the SCI4.0 Expert Council on Artificial Intelligence in industrial Applications.

Recommendation for action **[HE 5.1.7-6 V5]**	**Classification and criteria for categorizing and evaluating AI systems** A uniform positioning and assessment framework for AI methods should be developed by horizontal standardization bodies. Suitable classifications of the autonomy of technical systems, necessary metrics for assessment methods for the Industrie 4.0 application area and other requirements, concepts and methodologies should be addressed by vertical standardization bodies and suitably introduced into standardization committees. The properties of the AI methods regarding quality characteristics (see [HE 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. On the part of the Industrie 4.0 application area, any inconsistencies with vertical and relevant horizontal standards should be checked and appropriately addressed within the standardization process.
Progress assessment 	Regarding the core of this recommendation for action - the classification and definition of criteria for the classification and evaluation of AI systems - no fundamental progress can be seen. This is not least due to the high workload of standardization of artificial intelligence regarding the standardization request and the associated, necessary normative activities. The classification currently used - especially in the European context - refers to a risk classification in accordance with the AI Act, but does not meet the objective of this Recommendation for action. Work on quality and quality characteristics of artificial intelligence has already been developed or is currently in progress, both at national level (e.g. DIN SPEC 92001 series) and at European/international level.

Recommendation for action **[HE 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, e.g. reliability, trustworthiness, security, etc. of (sub)systems. Consequently, a definition of generally valid criteria and workflows is necessary for the acceptance and comparison of the performance of AI-based systems. A description of essential work steps in the (engineering) workflow and the application of evaluation criteria, especially for highly critical systems, in accordance with the draft AI Act of the EU must be defined normatively, taking into account corresponding existing standards (see also **[HE 5.1.7-8 V5])** and should in particular include the definition of individual process steps for development, testing, acceptance, operation and maintenance, taking into account the description of the structure of the system and subsystems as well as the AI-based parts and their influence on quality criteria. This requires a uniform definition and description of the meaning of characteristic (quality) features such as acceptance, reliability, dependability, plannability, controllability, explainability, cyber security, functional safety and uncertainty (see also **[HE 5.1.7-1 V5]**, **[HE 5.1.7-2 V5]** and **[HE 5.1.7-6 V5**])
Progress assessment 	Initial progress has been made regarding possible test methods, criteria and procedures for the conformity assessment of artificial intelligence. Most activities are currently taking place at a normative, horizontal level. Initial, specific activities to refine these normative activities regarding Industrie 4.0 are still in their infancy and have not yet made any significant progress.
Recommendation for action **[HE 5.1.7-8 V5]**	**Strengthening the vertical standardization of Artificial Intelligence** Stronger integration of existing standardization activities (e.g. electrical engineering, automation, especially IEC and ISO) and existing AI standardization activities (mainly ISO/IEC JTC 1/SC 42). To this end, a transfer of standardization activities to the corresponding (subject-specific, possibly vertical) committees in ISO and IEC is recommended. Close involvement of ISO/IEC JTC 1/SC 42 in AI-related standardization activities in ISO and IEC is recommended.
Progress assessment 	Progress can be identified regarding the strengthening of vertical standardization and the interlocking of horizontal and vertical standardization of Artificial Intelligence. It can be observed that the establishment of the Joint Committee AI (DIN/DKE NA 043-01-42 GA) as a national mirror of both CEN/CLC/JTC 21 and ISO/IEC JTC1/SC 42 has led to an increasing networking of cross-sectional aspects of standardization in electrical engineering and automation. For example, the topic of "AI and functional safety" is considered both horizontally and vertically in a consolidated manner, as is the topic of "AI and Smart Grid". Structurally, this results in cooperation at national level between the joint committee and corresponding specialist committees at IEC/DKE.

3 PROGRESS - ASPECT 2: SOVEREIGNTY

3.1 Dataspaces

Recommendation for action **[HE 5.2.1-1 V5]**	**Securing Industrie 4.0 - Suitability of regulatory standardization for cybersecurity in the EU** The focus of security standardization to support European regulation at CEN and CENELEC in accordance with the New Legislative Framework (NLF) is currently 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 and CENELEC, which will be of great importance as horizontal security standards for Industrie 4.0 security and this globally, beyond the European area. Regional differences in the requirements for cryptography (and data protection) may force the possibility of profitable and agile implementations of security standards, especially for communication at a global level.
Progress assessment 	Current standardization activities in the area of dataspace-specific security aspects have been taken up in the CEN/CENELEC (JTC 13 and JTC 24) and ISO/IEC JTC 1/SC 27 (WG 4) committees. These activities aim to define and standardize security requirements for dataspaces. In addition, ISO 20151: "Dataspace Concepts and Characteristics" was included in the work program of ISO/IEC JTC 1/SC 38 (see [HE 5.1.2-1]).

3.2 Industrial Security

Recommendation for action **[HE 5.2.2-2 V5]**	**Generic interface for security elements in embedded systems** The implementation of cryptographic-based security functions in Industrie 4.0 devices must be protected against attacks. High levels of security can be achieved by integrating suitable security hardware. However, the diversity and complexity of the modules available on the market with their specific boundary conditions lead to high integration costs and thus to a relatively high application threshold for manufacturers and integrators, especially for small and medium-sized companies. A "Generic Trust Anchor API", which would be supported by many hardware manufacturers as a standardized programming interface, can provide a remedy.
Progress assessment 	The recommendation for action was successfully completed at ISO/IEC JTC 1/SC 41 WG 3. The ISO/IEC TS 30168 specification was published and defines a generic API for the use of Secure Elements in IIoT devices. Various profiles can be used by industrial applications to support cryptography-based security functions. Proof-of-concepts are currently being developed in various projects for different hardware elements in order to incorporate this experience into a future IS version of TS 30168. In addition, the interaction of the GAT API with OPC UA is being clarified in collaboration with the OPC Foundation.

Recommendation for action **[HE 5.2.2-5 V5]**	**Establishment of an SBOM as a necessary information artifact 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).
Progress assessment 	OWASP is currently working intensively on the topic of SBOM (Software Bill of Materials), which also includes hardware and manufacturing aspects. It has been determined that there is no need for additional formats, as the existing solutions are sufficient. However, no contributions have yet been made to the topic of "trustworthiness" in this context. The further development of the SBOM Submodel was taken up by IDTA. The corresponding working group began its work at the start of 2024.
Recommendation for action **[HE 5.2.2-7 V5]**	**Security for the Asset Administration Shell** Each version of an AAS requires security mechanisms for integrity, access/confidentiality and verifiable processing in operations along the value chain. Continuation of the work within IEC/TC 65.
Progress assessment 	Security functions for the AAS are currently being coordinated in the IDTA and IEC/TC 65.
Recommendation for action **[HE 5.2.2-8 V5]**	**Security standards for the exchange of type and instance information from Asset Administration Shells** Online and offline options are provided for the exchange of type or instance information. A data format for exchange files is proposed. Mechanisms for ensuring authenticity and confidentiality are to be defined and established as global standards. Access APIs are to be defined. This must be coordinated with the concepts for secure identities and access control.
Progress assessment 	This recommendation for action is fulfilled by the results of **[HE 5.2.2.-7 V5]**, namely implicitly by the activities within the IDTA and IEC/TC 65.

Recommendation for action	Security for agile systems
[HE 5.2.2-10 V5]	Definition of standards for the technical negotiation of security profiles (based on capabilities and properties) for Industrie 4.0 communication and cooperation between entities in different (sometimes differently regulated) security domains. This includes: • Identification and authentication of the partners involved (requirements and solutions); • Assessment of the degree of trustworthiness of the 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 evaluation are important and must be developed (research); • Topic of quality certificates and • Definition Trustworthiness Profile - Capabilities, Supply-Chain, Traceability, (Cloud Trustworthiness), Trustworthiness Framework (ISO/IEC JTC 1/SC 41).
Progress assessment 	Several standardization activities are currently being driven forward in various committees. Group-based key management is currently being defined in the IETF, in particular as part of the NTP Working Group, which is concerned with ensuring timesynch integrity. In addition, relevant standards such as RFC 3161, the RFC Draft TST Header Parameter and Messaging Protocols (MLS) are being worked on. The topic of Group Key Security is also being further developed as part of IPSec maintenance. AI security is called for in the AI Act for highly critical applications, although the corresponding specifications and requirements are still outstanding. Work in this area is expected in CEN/CENELEC/JTC21 WG5, where the basic security aspects of AI technologies will be further defined and standardized. Standardization work on trustworthiness takes place in particular in the ISO/IEC JTC1/WG 13 (ISO/IEC TS 5723) and ISO/TC 292/WG4 working groups. This work focuses on the development of standards and specifications for the trustworthiness of systems, which is also dealt with in **[HE 5.2.4-3 V5]**.

Recommendation for action **[HE 5.2.2-11 V5]**	**5G Security for Industry** The features and possibilities of 5G require the possibility of dynamic, flexible and scalable security architectures. It must be possible to derive the security requirements on the basis of suitable industrial use cases, taking into account existing security standards such as ISO/IEC 27001 and IEC 62443 as part of the 5G standards. • It must be possible to implement industrial security guidelines, especially for Industrie 4.0-based cross-company communication. • It must be possible to apply IEC 62443 and ISO/IEC 27001, especially for in-house operations. • The protection of metadata from the communication of devices, machines and systems must be guaranteed. This applies in particular to data that can be collected by the telecom provider via the signalling channel. • Industry-compatible security requirements should be actively incorporated into the 5G standardization process.
Progress assessment 	Standardization activities in the area of 5G are currently very active and also include relevant security topics, especially where this is required by regulatory requirements (such as RED and CRA) and market needs. Various government organizations are actively participating in these processes by providing experts to help shape the developments and requirements. In addition, an outlook on the upcoming developments in the area of "6G" is already being provided. Topics such as performance increases, the integration of space technologies and the creation of new services and applications that will be important for future communication technology will be discussed.

Recommendation for action **[HE 5.2.2-12 V5]**	**Security infrastructure for secure inter-domain communication** Secure communication requires secure identities (identifiers and attributes) and trust anchors. The generation and management of secure identities and the assurance of their trustworthiness require a secure infrastructure. Requirements include scalability, resilience, cost-effectiveness, long-term suitability, (user-defined) trustworthiness across local jurisdictions and independent of local jurisdictions. Cross-domain governance structures to support secure Industrie 4.0 communication must be defined and standardized. This requires close cooperation between all industrial stakeholders. The possible use and inclusion of national and regional solutions (such as eIDAS) must be examined with those responsible for regulation and tested in field trials/pilot projects.
Progress assessment 	Concrete work in this area is expected shortly. The driving forces behind these developments are primarily the requirements of "Global Dataspaces" and security-related regulations that have far-reaching effects on global value chains, such as the ESPR and CRA requirements. Joint projects have already been initiated or are being planned between several nations, including collaborations between Japan, Taiwan, Germany and South Korea.

3.3 Privacy

Recommendation for action **[HE 5.2.3-1 V5]**	**Protection of personal data within value creation networks** Definition of process standards for the protection of personal data within value creation networks through to the protection of personal data required for individualized products with batch size 1, among other things: • Rules for classifying data and information, also in the respective context (contexts are very relevant because they massively influence the sensitivity and significance 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, for example, a cancer drug or a psychopharmaceutical. Knowing that the format of the article number indicates a medical product is also significant). • Rules for the exchange of classified data and information (which data may be passed on where and under what circumstances, what the recipient may do with it, when it may have to be deleted). • Methods for assessing the degree of trustworthiness of cooperation partners. Examples of mechanisms are manufacturer declarations, certificates, auditing.
Progress assessment 	Progress in standardization is clearly reflected in two key developments. Firstly, the ISO/IEC 27555:2021 standard, which provides guidelines for deleting personal information, is also expected to be introduced in Germany as DIN EN ISO/IEC 27555 in 2025. This represents an important step towards the standardization of data protection practices. Secondly, there will be a reorganization in the area of data protection for consumers in the context of the Internet of Things (IoT). The previously responsible ISO/PC 317 "Consumer protection: Privacy by design for consumer goods and services" will be replaced by a new committee, JTC 1/SC 44 "Consumer protection in the field of privacy by design".

3.4 Trustworthiness

Recommendation for action **[HE 5.2.4-1 V5]**	**Definition of process standards for the trustworthiness of collaboration within an Industrie 4.0 value creation network** These contain: • Standardization of "Trustworthiness Capability Profiles"; • Method for assessing the degree of 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; • Inclusion of processes and components and • Compliance with regulatory requirements.
Progress assessment 	The ISO 22373 standard is currently in DIS status at ISO/TC 292. A follow-up project to ISO 22373 is expected, which among other things aims to classify "trust levels". In addition, there is a draft within the IETF SCITT working group that deals with the architecture, use cases and API for supply chain integrity.

Recommendation for action **[HE 5.2.4-3 V5]**	**Define standardized mechanisms for trustworthiness management along the value chain (Chain of Trust)** The trustworthiness of value-added contributions along the supply chain can change over the life cycle of the product. This requires the management of a chain of trust, also due to government regulations that go beyond the bilateral relationships between suppliers and customers.
Progress assessment 	In addition to the work in ISO TC 292, basic standards for the terminology in ISO/IEC JTC1/WG 13 are being developed/exist: ISO/IEC 31303- WD- Trustworthiness - Overview and concepts and ISO/IEC 5723-Trustworthiness - Vocabulary (published).

4 PROGRESS – ASPECT 3: SUSTAINABILITY

Recommendation for action **[HE 5.3.2-1 V5]**	**"Sustainability Construction Kit"** It is recommended that various standard modules for digital data collection and further processing be defined with regard to the implementation of digital, automated collection and evaluation of sustainability aspects in Industrie 4.0 systems. These standard modules can then be aggregated into larger information units in a flexible and demand-oriented manner.
Progress assessment 	The various committees and working groups relevant to the area of sustainability were still in the process of being formed at the time the progress report was created. In various projects and initiatives such as Catena-X, Factory-X and InterOpera, aspects of recording the sustainability aspects of products and systems were and are being developed. There is currently no overarching coordination. All experts are cordially invited to participate in the further development of the sustainability aspect.
Recommendation for action **[HE 5.3.2-2 V5]**	**Climate and environmental data on (industrial) facilities** Climate, environmental data and other ecological sustainability aspects relating to (industrial) facilities or operating sites should be recorded, presented and made comparable in a standardized form.
Progress assessment 	As part of the and InterOpera funding project, a proposal for a "Facility Related Environmental Data" Submodel Template was developed and submitted to the IDTA.
Recommendation for action **[HE 5.3.2-6 V5]**	**Internal company process** It is recommended to develop and establish a standardized format for describing internal processes and for passing on process information to third parties.
Progress assessment 	As part of the introduction of the DPP, the exchange of sustainability data along the value chain is of central importance. Work is currently underway on the fundamental structuring of data exchange along the value chain.

Recommendation for action **[HE 5.3.2-7 V5]**	**Cross-plant or cross-location linear process** It is recommended to develop a standardized format for the description of primarily linear, (industrial) plant or cross-location processes, which defines a standardized methodology for data and information exchange in the process or between the cooperating actors as an integral component.
Progress assessment	This includes the work of IEC/TC 111 / JWG 16 on ISO/IEC 82474-1 "Material declaration - Part 1: General requirements" and the work of IEC/TC 111/WG 17 on IEC 63372 - "Quantification and communication of carbon footprint and GHG reduction/avoidance". The national draft of ISO/IEC 82474-1 was published in December 2023 and can expect international publication in Q1/2025. The committee draft of IEC 63372, which was put to the vote, was approved. The committee is discussing whether and which standard content can be transferred to the IEC Common Data Dictionary to be able to carry out the calculation of GHG emissions faster and in a machine-readable manner together with the Product Category Rules (PCR). In particular, the aspect of transferring standard content into machine-readable formats to improve sustainability will require strong synchronization in the standardization of information and data models. At this point, the work of the IDTA should be mentioned, which has already published the "Carbon Footprint" Submodel Template in a first draft for the ecological footprint and the Digital Nameplate for the representation of product data. Furthermore, the IDTA Submodel "Energy Flexibility Data Model" 2025 is being developed to enable optimal energy-flexible operation across systems within industrial companies and to facilitate the communication of energy flexibility between industrial companies and energy market-related services.

Recommendation for action **[HE 5.3.2-9 V5]**	**Climate and environmental data on the product** Climate and environmental data directly related to products should be recorded, presented and made comparable in a standardized form.
Progress assessment	As part of the introduction of the DPP, several ISO and IEC committees are working on the collection of environmental and climate data for products. One example of this is IEC/TC 111 Environmental standardization for electrical and electronic products and systems. A working group to develop a standardized Submodel for recycling will be set up at the IDTA in January 2025.

Recommendation for action **[HE 5.3.2-10 V5]**	**Digital Sustainability Passport for products** It is recommended that a standardized, modular format for the digital documentation and availability of climate, environmental data and other sustainability aspects of products be developed and established for the content and structure of the Digital Sustainability Passport.
Progress assessment	As part of the entry into force of the ESPR and the associated introduction of the DPP, CEN/CENELEC/JTC 24 was founded to develop a standard for the DPP system. ISO and IEC have also initiated activities on the topic of.

5 REQUIREMENTS FOR THE DEVELOPMENT OF NORMS AND STANDARDS

5.1 Requirements in the context of Open Source

Recommendation for action **[HE 6.1-1 V5]**	**Strengthen cooperation between standardization and Open Source communities** It is recommended that cooperation between standardization and standardization with Open Source communities be strengthened. Specifications (e.g. DIN SPEC or VDE SPEC) can offer a good opportunity for piloting in the context of Industrie 4.0.
Progress assessment 	As part of the work, intensive contact was maintained with the relevant Open Source associations and consortia.
Recommendation for action **[HE 6.1-2 V5]**	**Identifying synergies and creating contact points** In order to accelerate the spread of Industrie 4.0, the development of Open Source implementations should be driven forward even more. Synergies must be identified and contact points created (e.g. through a DIN DKE OSPO), particularly in conjunction with standardization, to facilitate the use of and collaboration on Open Source projects.
Progress assessment 	The activities to date have led DIN and DKE to establish a joint contact point for Open Source in standardization (working title: Joint DIN/DKE OSPO). Initial concepts and a project plan have already been presented by DIN.
Recommendation for action **[HE 6.1-3 V5]**	**Mutual integration** The potential for interaction between Open Source and standardization must be better exploited and activities must be considered together. It is therefore recommended that standardization be more closely integrated into Open Source projects. Open Source solutions should also be given greater consideration in standardization activities (in the area of Industrie 4.0).
Progress assessment 	The implementation of concrete Open Source and standardization projects is only taking place hesitantly. This is due to the divergent paradigms and methods used to create content.

5.2 Requirements in the context of use cases

Recommendation for action **[HE 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. If it turns out that use cases are missing in IEC 63282-2, such missing use cases should be reported to IEC/TC 65/WG 23 TF Use Cases.
Progress assessment 	No missing use cases were reported to the IEC/TC 65/WG 23 TF Use Cases.
Recommendation for action **[HE 6.2-2 V5]**	**Addition of "dataspace" use cases to IEC 63283-2** Analyze the results of [HE 6.2-1 V5] to what extent IEC 63283-2 can and should be supplemented by "dataspace" use cases (Responsible: IEC/TC 65/WG 23 TF Use Cases).
Progress assessment 	IEC/TC 65/WG 23 TF Use Cases has analyzed the topic "dataspace", developed further use cases and initiated an ED2 of IEC 63283-2 (status: proposal for CDV submitted to IEC).
Recommendation for action **[HE 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: e.g. Gaia-X community, ZVEI data management working group, VDMA platform economy working group, etc.) Comment: The recommendation for action also includes in particular the detailing of the topics mentioned in the "Industrial Dataspaces" chapter of the NRM Industrie 4.0 V5, where dataspaces offer the potential to open up new applications.
Progress assessment 	The activities have resulted in the Manufacturing-X political initiative and specifically in the application for and approval of the Factory-X project.
Recommendation for action **[HE 6.2-4 V5]**	**Recommendations for standardization** Derivation of recommendations for standardization actions from the requirements for standardization formulated in the IEC/TC 65/WG 23 Use Cases (Responsible: IEC/TC 65/WG 23 TF Gap analysis and recommendations for standardization actions).
Progress assessment 	The IEC/TC 65/WG 23 TF Gap analysis and recommendations for standardization actions task force deals with the recommendations for standardization.

Recommendation for action **[HE 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, SC 42 with a view to completing the IEC/TC 65/WG 23 use cases (responsible IEC/TC 65/WG 23 TF Use Cases).
Progress assessment	There are no concrete use case collections from corresponding committees.
Recommendation for action **[HE 6.2-6 V5]**	**Support for the "Smart Manufacturing Use Cases" task force of IEC/TC 65/WG 23** The "Smart Manufacturing Use Cases" task force 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 from Germany in order to obtain a consistent and representative collection of use cases for Industrie 4.0 in this way. This will help this task force to establish itself as a central hub for the systematic consolidation of the diverse use cases in the Industrie 4.0 environment.
Progress assessment	Only achieved indirectly through participation in the various committees in personal union.
Recommendation for action **[HE 6.2-7 V5]**	**International coordination on use case descriptions** The various concepts that formulate use cases on the basis of more detailed descriptions, such as the IIRA template, should be continued. Examples of this are the joint activities with China and Japan, selected activities of Labs Network Industrie 4.0 (LNI 4.0), but also activities at European Union level, such as those planned in particular in the context of artificial intelligence as part of the AI-PPP4.
Progress assessment	Takes the form of use cases in projects such as Factory-X and the methodology is to be transferred to other projects such as Manufacturing-X projects.
Recommendation for action **[HE 6.2-8 V5]**	**Use of the term "use case"** Furthermore, an attempt should be made not to overload the term "use case" unnecessarily. The aim is not to specify a uniform understanding, but it is recommended that activities position themselves in relation to the understanding formulated in the Industrie 4.0 Standardization Roadmap so that this can be further sharpened.
Progress assessment	Only indirectly through participation in the various committees in personal union.

5.3 Requirements in the context of machine-readable standards

Recommendation for action **[HE 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 the Administration Shell should 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 a harmonization or compatibility of the desired solutions should be ensured. A first step could be the identification and integration of Industrie 4.0-relevant information units and semantic mechanisms into the Standards Information Model (SIM).
Progress assessment	With the support of Industrie 4.0 experts, a first version of the SIM (Standards Information Model) was created and agreed internationally (publication expected Q1 2025); the SIM is used to describe information elements in standards and uses similar semantic mechanisms to the management schema (IEC 63278). The IEC published a report on semantic interoperability, which, among other things, emphasizes the connection between SMART standards and the need for semantic conventions (i.e. standards).
Recommendation for action **[HE 6.3-2 V5]**	**Use of fragmented standard information in the context of Industrie 4.0 applications** To effectively utilize the advantages of SMART standards and the targeted information model (SIM), the target systems of fragmented and semantic information must be prepared for the use of such information. It is therefore necessary to work out how digital standard content can be imported, processed and reused in the context of the AAS and other Industrie 4.0 systems. A first step could be the development of a partial model for standards, which can map both the document-based and the question-based (provision-based) information from standards in different expansion stages.
Progress assessment	Research and development work on the digital transformation of standardization is now being carried out internationally and in ongoing coordination with one another. The DKE Digital Standards Initiative (IDiS) is leading the way in Germany, driving forward the digital ecosystem around smart standards with the broad participation of industry and research and in conjunction with international initiatives. This includes work on standardized information models and processes, e.g. using ontologies and AAS. From the USA, for example, NISO is contributing a key building block for XML-based information modelling with the Standards Tag Set (STS). IEC/ISO SMART is a joint IEC and ISO work program for the international promotion of smart standards. This work is being concretized, for example, in the scope of IEC SG 12 on smart standards including the information model, but ISO/IEC JTC 1/SC 32 also addresses building blocks in the form of ontologies and document structures with "Data management and interchange". In addition, ISO/IEC JTC 1/SC 41 addresses an essential organizational component for the merging of standards with the digital twin, which is also dealt with, for example, by the IDTA and the Submodels collected there. At European level, CEN and CENELEC are developing concrete prototypes for future tools in the two key projects "Online Standards Development" and "SMART Standards", in each case in conjunction with the work at ISO/IEC. The successful implementation can be demonstrated by various examples. These include the development and publication of the IDTA Submodel "Digital Standards Datasheet" (Submodel for describing a standard) at DIN, DKE and IDTA via the InterOpera project. The successful implementation of a pilot, including a web demonstrator, in IDiS, which prototypically implemented a matching of product capabilities and standard requirements based on the AAS (IEC 63278) of a product and associated standards, can be regarded as a further milestone.

Recommendation for action	**Use and consolidation of reference definitions (IEV etc.)**
[HE 6.3-3A V5]	In order to ensure that the terms are unambiguous, a 1:1 correspondence between designation and definition should be worked towards. For this purpose, the reference definitions in the IEV (IEC 60050), which already represent a consolidated state of standardization terminology, should be used as unchanged as possible. If a new definition is unavoidable, the committees involved should be identified, definitions coordinated and the IEV supplemented or corrected as part of new IEC TC 1 projects.
Progress assessment 	The DKE TermAnalyzer and the DKE E-Glossary were developed to facilitate the harmonization of the terminology of IEC standards. The additional consideration of IEV entries is still pending.

Recommendation for action	**Systematic comparison of all relevant standard definitions**
[HE 6.3-3B V5]	A collection of all relevant term entries from the valid standardization should be made both for the extension of the IEV (IEC 60050) and for standardization projects in the technical committees in order to promote the reuse of definitions. Terminology databases and tools for structuring the relevant entries should be used. Technical committees should explain deviations from other standards in the notes.
Progress assessment 	The DKE TermAnalyzer (see HE [6.3-3A]) was applied to the data in the CDD, with suggestions for changes being generated, checked and finally implemented by the IEC committee. The DKE TermAnalyzer was also used as part of the SMARTification process at IEC to optimize the general data quality of terms and definitions in IEC standards. Based on the positive experience gained, it is currently being evaluated whether the TermAnalyzer can be established as a permanently integrated service within the IEC processes in order to continuously integrate proposed changes into the standardization process.

Recommendation for action	**Software-supported assistance with systematic matching**
[HE 6.3-3C V5]	The collection of all relevant term entries within IEC TC 1 and in technical committees should be database-supported in order to ensure completeness. In order to make the number of possible options manageable and to make an informed selection, a computer assistant should be used that supports text comparisons, pre-structures definitions and points out rule violations.
Progress assessment 	Standards are increasingly being created using the new OSD (Online Standards Development) user environment. For this reason, it is not expedient to offer other tools in addition to OSD, such as the e-glossary that has been developed. The focus is now on the integration of data services in OSD. Initial considerations have been made as to how the TermAnalyzer (data service in E-Glossary) can be integrated as a fixed service in OSD and ISO/IEC's SMART.X ecosystem.

Recommendation for action	**Software-supported assistance with the formal examination**
[HE 6.3-3D V5]	To prevent formal terminological deviations, the formal requirements for the creation of definitions in accordance with ISO/IEC Directives, Part 2:2021, ISO 10241-1:2011 (confirmed 2022), and ISO 860:2022 and ISO 704:2022 should be taken into account. The verification of the fulfilment of requirements should be carried out systematically and, if possible, tool supported.
Progress assessment 	See progress **[HE 6.3-3C V5]**
Recommendation for action	**Skills for standards users**
[HE 6.3-4 V5]	Review of the skills required for the creation and consumption of Industrie 4.0-relevant SMART standards.
Progress assessment 	ISO/IEC have established an education and training program for the introduction of OSD (see also [HE 6.3-3C]), which teaches basic skills for the online creation of standards. These will be extended to SMART standards in the future. Initial studies have already been carried out in this context, for example on the question of which new groups of people (personas) need to be addressed and which skills are generally required. Further measures are planned from 2025, including SMART Standards training courses and e-learning.

6 OUTLOOK

The 5th edition of the Standardization Roadmap Industrie 4.0 addressed recommendations for action for cross-cutting topics such as industrial dataspaces, the DPP and ecological aspects in Industrie 4.0. The results of the current progress report suggest the following further developments:

- **The Digital Product Passport:** With the entry into force of the Ecodesign Regulation (ESPR) in July 2022, standardization and standardization activities around the DPP have increased. Among other things, the CEN/CENELEC joint committee "JTC24 - Digital Product Passport - Framework and Systems" was set up to develop the European framework for the DPP as an information system for the circular economy. Due to the importance and potential of the DPP as an information system for product data, there are a number of standardization projects at various national and international levels to make the DPP usable for other areas as well. It must be observed whether the connectivity of DPP4.0, the DPP based on Industrie 4.0 concepts, to the various information systems will be guaranteed.
- **Sustainability and Ecological Aspects of Industrie 4.0:** Industrie 4.0 and the associated technologies play a central role in the circular economy and CO_2 reduction in production. DPP, which enable standardized mapping of information on energy and resource consumption, are an important step towards sustainable production. Industrie 4.0 makes it possible to leverage additional resource efficiency potential. In combination with constructive and process-related approaches, material cycles can be closed over the entire product life cycle. Industrie 4.0 is a key enabler for the circular economy as well as environmental and climate protection. The DPP4.0 concept can be used as an information system to enable connectivity in a federated digital ecosystem and to facilitate data exchange to promote sustainability. To this end, the standardization of sector-specific data and data formats will become increasingly relevant. Furthermore, it must be clarified which standards and norms are necessary to enable a federated system.
- **Analyze and Evaluate Use Cases for Application and Industry Relevance:** The various use case activities will be continued in the various working groups and committees of the standardization organizations and consortia.
- **Systemic Implementation of Industrie 4.0:** The overarching challenge remains to systematically bring together the different levels of abstraction of a business perspective and application perspective with the often very detailed technical considerations and implement them in practice.
- **Uniform Standards for Greater Interoperability:** Standardized mechanisms and procedures for the specification of new properties are increasingly being synchronized between ISO, ECLASS and IEC. The consistent use and standardization of the AAS is necessary to make it the central "integration connector" for digital ecosystems.
- **Industrial Communication:** With referencing in other technical standards (e.g. OPC UA, 5G-ACIA), the importance of the IEC/IEEE 60802 profile will increase. Supplemented by sections on a security model, the profile follows a security-by-design approach. Another activity in IEEE 802 is the attempt to transfer cut-through forwarding technology (CTF) into an IEE-E standard. CTF is already being used in various forms and reduces latencies in networks, especially in a linear topology.
- **People and Work in Industrie 4.0:** The trend towards more home offices and mobile working, as well as the advancing digitalization of production, are changing the way we work in the long term. Employees are increasingly able to work together remotely in groups, control machines and systems remotely and drive forward further developments. The targeted use of new technologies also offers the opportunity to actively shape and drive forward the sustainability transition.
- **Agile Standardization Using Open Source:** The great importance of Open Source and the development of open-source reference implementations to accelerate the spread of Industrie 4.0 have already been highlighted. There needs to be further discussion as to whether the topics of agile standardization (as a method) and Open Source (as a tool) need to be considered separately to prevent the two terms from being mixed up and to work out the potential of both topics.
- **Industrial Security:** Industrial security must be seen as an important enabler for further digitalization, especially in the context of industrial production. In the future, it will be important to describe the necessary use cases from a data-driven context. This still requires the integration of security-by-design approaches to guarantee the trustworthiness of a digital ecosystem for the stakeholders involved.
- **Specification of The Concepts for Functional Safety in Industrie 4.0:** The specification of the concepts is the prerequisite for the transfer of these concepts into standards with corresponding normative specifications and requirements. The initiation of corresponding research projects can be a suitable measure for accelerating this development. In Europe in particular, special attention must be paid to whether and to what extent a European AI regulation (EU-AI Act) will set requirements for the use of AI systems in safety-critical industrial environments.

Close coordination between the various disciplines is required to be able to set norms and standards from Germany. As already noted in the previous edition of the standards roadmap, topics such as semantic aspects of interoperability or collaborative Industrial Dataspaces have yet to take shape. The creation of national and international structures and the formulation of coordinated data models remain a challenge and will increase with the advancing digitalization and networking of systems.

Against this background, the various editions of the Standardization Roadmap Industrie 4.0, the corresponding progress reports and the supporting position papers have and will address the existing and upcoming challenges in future editions based on new findings and classify them in the respective normative context. It will update the standardization and stakeholder landscape, identify existing or potential gaps and make appropriate recommendations for action. Ensuring and internationally coordinating the consistency of an open and global Industrie 4.0 ecosystem should continue to be the declared goal.

With this in mind, we would like to invite all interested parties to actively participate in the process of creating the new Standardization Roadmap Industrie 4.0 and the position papers.

LIST OF ABBREVIATIONS

AA	Arbeitsausschuss - Working Committee
AAS	Asset Administration Shell
AI	Artificial Intelligence
AK	Arbeitskreis - Working group
CDD	Common data dictionary
CEN	Comité Européen de Normalisation - European Committee for Standardization
CLC	Comité Européen de Normalisation Électrotechnique - European Committee for Electrotechnical Standardization
CEN-CLC	CEN and CENELEC
COMDO	Common Data Repository for Smart Manufacturing
DIN	Deutsches Institut für Normung - German Institute for Standardization
DKE	Deutsche Kommission Elektrotechnik Elektronik Informationstechnik - German Commission for Electrical, Electronic & Information Technologies
DTR	Draft technical report
ED	Edition
ETSI	European Telecommunications Standards Institute
EU CRA	European Cyber Resilience Act
GA	Gemeinschaftsausschuss - Community Committee
GG	Gemeinschaftsgremium - Community body
HE	Handlungsempfehlung - Recommendation for action
IACS	Industrial Automation and Control Systems
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IS	International Standard
ISO	International Organization for Standardization
IT	Information Technology
JTC	Joint Technical Committee
KI	Künstliche Intelligenz - Artificial intelligence
NA	Normungsausschuss - Standardization committee
NIST	National Institute of Standards and Technology
NRM I4.0	Normungsroadmap Industrie 4.0 - Standardization Roadmap Industrie 4.0
OT	Operational Technology
PAS	Publicly Available Specification
PKI	Public-Key-Infrastruktur - Public key infrastructure
PNW	New work item proposal
SM2TF	Smart Manufacturing Standards Map Task Force
SC	Sub Committee
TC	Technical Committee

TR	Technical Report
TS	Technical Specification
TSN	Time Sensitive Network
WG	Working Group
W3C	World Wide Web Consortium

LIST OF LISTED STANDARDIZATION BODIES

National	
DIN NA 023 BR-03 SO	Ergonomics of work and product design for networked and intelligent digitalization
DIN NA 023–00-08 GA	Exoskeleton
DIN NA 043-01-41 AA	Internet of Things
DIN/DKE NA 043-01-42 GA	DIN/DKE Joint Working Committee on Artificial Intelligence
DKE/AK 914.0.11	Functional safety and artificial intelligence
DKE/K 931	System aspects of automation
DKE/AK 931.0.14	Smart Manufacturing und Industrie 4.0
DKE/AK 931.0.16	Asset Administration Shell for Industrial Applications
GG DPP	DIN/DKE Gemeinschaftsgremium „Digitaler Produktpass“ – DIN/DKE joint committee "Digital Product Passport"

Europe	
CEN/CLC/JTC 13	Joint Technical Committee Cybersecurity and Data Protection
CEN/CLC/JTC 21	Joint Technical Committee Artificial Intelligence
CEN/CLC/JTC 24	Joint Technical Committee Digital Product Passport
CEN/CLC/JTC 25	Joint Technical Committee, Data management, Dataspaces, Cloud and Edge
ETSI	European Telecommunications Standards Institute

International	
IEC/SMB	Standardization Management Board
IEC/SMB/SG 12	Standardization Management Board / Digital Transformation
IEC/TC 1	Terminology
IEC/SC 3D	Classes, Properties and Identification of products – Common Data Dictionary (CDD)
IEC/TC 65	Industrial process measurement, control and automation
IEC/TC 65/AG 4	Coordination of properties and CDD
IEC/TC 65/SC 65A	System aspects
IEC/TC 65/SC 65C/WG 18	Time-sensitive networking for industrial automation
IEC/TC 65/SC 65E	Devices and integration in enterprise systems
IEC/TC 65/WG 10	Security for industrial process measurement and control – Network and system security
IEC/TC 65/WG 23	Smart Manufacturing Framework and Concepts for industrial-process measurement, control and automation
IEC/TC 65/WG 24	Asset Administration Shell for Industrial Applications
IEC/SyC SM	IEC System Committee Smart Manufacturing
ISO/TMBG/SMCC	Technical Management Board/ISO Smart Manufacturing Coordinating Committee (SMCC)
ISO/TC 184	Automation systems and integration
ISO/TC 184/SC 4	Industrial data

ISO/TC 292	Security and resilience
ISO/TMB	Technical Management Board
ISO/IEC/JWG 21	Joint Working Group Smart Manufacturing Reference Model(s)
ISO/IEC/JWG 21/ TF 8	Task Force Digital Twin and Asset Administration Shell
ISO/IEC SM2TF	Smart Manufacturing standards map Task Force
ISO/IEC/JTC 1/AG 8	Meta Reference Architecture and Reference Architecture for Systems Integration
ISO/IEC/JTC 1/WG 13	Trustworthiness
ISO/IEC/JTC 1/SC 27/WG 5	Identity management and privacy technologies
ISO/IEC JTC 1/SC 38	Cloud computing and distributed platforms
ISO/IEC/JTC 1/SC 41	Internet of things and digital twin
ISO/IEC/JTC 1/SC 41/AG 20	Sectorial Liaison Group (SLG 1) on Industrial sector
ISO/IEC/JTC 1/SC 41/WG 3	IoT Foundational Standards – Development of IoT foundational standards, including IoT and Digital Twin vocabulary
ISO/IEC/JTC 1/SC 41/WG 6	Digital twin
ISO/IEC/JTC1/SC41/WG27	Digital Twin – Strategy
ISO/IEC/JTC 1/SC 42	Künstliche Intelligenz
ISO/IEC/JTC 1/SC 42/WG 1	Foundational standards
ISO/IEC/JTC 1/SC 42/WG 3	Artificial Intelligence – Trustworthiness
ISO/IEC/JTC 1/SC 42/WG 4	Use cases and applications

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