

DIN/DKE – ROADMAP

GERMAN STANDARDIZATION
ROADMAP

Industrie 4.0

Version 3



DIN

DKE

VDE

Published by

DIN e. V.

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Issue date: March 2018

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Cover photo: Fraunhofer IPA

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FOREWORD

Dear Reader,

The significance of standards is now greater than ever – they allow us to enjoy progress and experience security, to promote global trade and influence the economic growth of many countries. It is clear that digitalization requires some effort – we should not rest upon our strong start. Numerous challenges await us on the path to Industrie 4.0, such as ensuring a fast Internet, data protection or IT security. This is why German politicians and established standards bodies must make an even more intense effort to agree on aspects of Industrie 4.0 in order to support current activities carried out in the industrial, political and research sectors as effectively as possible. The support of actors in research and industry is needed once again to bring all current developments into the standardization process at an early stage and to effectively take them into consideration.

It is precisely this objective which motivated the German industrial associations BITKOM, VDMA and ZVEI, together with the standards organizations DIN and DKE, to set up the Standardization Council Industrie 4.0 (SCI 4.0) over two years ago. The SCI 4.0 is responsible for orchestrating standardization activities and, in this role, acts as a point of contact in connection with all matters relating to standardization in the context of Industrie 4.0. It brings German stakeholders together and represents their interests in international bodies and consortia.

With the help of this “orchestra” of stakeholders, we now present a strategic and technically oriented document in the form of this Standardization Roadmap, which describes current results of work and discussions relating to Industrie 4.0, and lays out effective measures for their successful implementation. The Roadmap has been prepared under the leadership of the SCI 4.0 Working Group “Standardization Roadmap Industrie 4.0” within which experts from industry, research, science and politics have participated. In addition to presenting the current status of standardization, the Roadmap primarily consists of recommendations, sketches what is needed and required of standardization, and provides an overview of standards and specifications relevant to Industrie 4.0.

As a key communication medium that plays a crucial role at national level but is equally important in the context of internationalization, the Standardization Roadmap is intended to generate discussion among national and international standards bodies, research institutions and the relevant political ministries, and presents a basis for ongoing standardization work.



The Roadmap will also be regularly updated to reflect new findings, for example as gained in research projects or work within standards bodies. We therefore look forward to your comments on this third version of the Roadmap and above all encourage you to get involved in the updating process. In fact, we have already set our eye on a 4th version of the Standardization Roadmap Industrie 4.0.

I hope you enjoy reading Version 3 of the Standardization Roadmap Industrie 4.0.



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1 EXECUTIVE SUMMARY

“The Standardization Roadmap Industrie 4.0 is a ‘living’ communication document by DIN and DKE. Updated regularly, each edition of this document provides an overview of the activities currently underway in the field of standardization. It also identifies areas in which standardization is needed and makes recommendations to international standards organizations from the viewpoint of the relevant German actors.”

(Dr. Günter Hörcher, Chairman of the working group “Standardization Roadmap” of the Standardization Council Industrie 4.0 and Head of Research Strategy at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA)



When the second version of the Standardization Roadmap Industrie 4.0 was published in 2015, the “Standardization Roadmap” Working Group that forms part of the Standardization Council Industrie 4.0 was assigned the task of revising and further developing this document. The Standardization Roadmap is a key medium for communication among standardization committees, industry entities, associations, research institutions and politics. It is a guide showing the way for individuals and organizations active in various sectors of technology, thus enhancing the market acceptance of new technologies and processes from the research and development stage onwards.

Since the previous version of the Roadmap was published, numerous advances have been made in connection with standardization work on Industrie 4.0. Since the standardized Reference Architecture Model Industrie 4.0 (RAMI 4.0), first issued in Germany as DIN SPEC 91345, was published at international level as IEC PAS 63088 in spring 2017, the focus of discussions lays upon the cooperating administration shells of physical assets (Industrie 4.0 components).

In the area of standardization, ISO/IEC Joint Working Group 21 (ISO/IEC JWG 21) was set up in July 2017 with the aim of harmonizing existing reference models and overseeing the development of an underlying architecture with regard to smart manufacturing components as a substantial aspect of the virtual representation of objects, thereby following the key recommendations from the second Standardization Roadmap.

In the field of semantics, the Semantic Alliance (SemAnz40¹), a project funded by BMWi, was set up to implement recommendations made in the second Roadmap. These involved drafting standards for descriptions based on properties (especially eCI@ss, IEC 61987) and the structuring of information (notably AutomationML, IEC 62714) and, in conjunction with additional standards and specifications, the creation of a semantic baseline for the exchange of information relating to Industrie 4.0 use cases.

1 www.semanz40.de

Section 3 of the present version of the Roadmap depicts in detail the challenges that semantic and ontological linkage with the administration shell and Industrie 4.0 components will bring in the future.

Within Industrie 4.0 itself, work is also in progress to develop appropriate modules that will enable life cycle data management. Section 3 on semantics shows the form this association is to have and what approaches are still needed for developing holistic solutions. At the same time, it is apparent that a digital, multiple-manufacturer description of an object that makes use of the administration shell will only be effective if this software is designed as an open source project and remains pre-competitive. In addition to unified structures, the administration shell must also provide for areas that are manufacturer-specific. To that end, the need for appropriate framework conditions for open source projecting must be addressed, for purposes such as ensuring the “Plug & Produce” use case scenario (i.e. the automatic connection and interaction of field devices).

If we take a look at the ongoing debate among experts, it becomes clear that within the context of Industrie 4.0 smart production locations will by no means be devoid of humans. The role of humans within the socio-technical work system therefore requires special consideration. Whether as an actor in the production process, as an operator of machines, or as a maintenance operative, production planner or programmer – humans will continue to play a key role within the production process. In order to design a work system that not only is efficient and flexible, but which will also prove successful in the long term, it is important that humans with all their abilities, skills, capabilities and limitations are included in the design process. Against that particular background, Section 4 of this document takes a detailed look at the role of humans and makes a number of recommendations.

The fourth industrial revolution and its impact, such as new forms of contracting, the networking and exchange of data, and a changing working environment, also merit examination from a legal perspective. After all, not only does the law dictate the framework within which standards and specifications are to be used, but the standards and specifications themselves also have a recursive effect upon the law itself. Special account must therefore be taken of this interaction whenever standards are being developed. An overview of this legal perspective is given in Section 5, the final section of this version of the Standardization Roadmap.

2 INTRODUCTION

2.1 Objectives of the Standardization Roadmap Industrie 4.0

The Standardization Roadmap is a strategic, technologically oriented document that presents the current results of work and discussions within the Industrie 4.0 domain and provides inspiration with a view to its successful implementation. The Standardization Roadmap is drafted by experts from industry, research, academia and politics. In addition to presenting the current status of standardization, it chiefly contains recommendations, sketches what is required and needed of standardization, and provides an overview of standards and specifications of relevance to Industrie 4.0 topics.

As a key communication medium that plays a crucial role on a national level, but that is equally important in the context of internationalization, the Standardization Roadmap is intended to generate discussion with national and international standardization bodies, companies, research institutions and the relevant political ministries, and functions as a basis for ongoing standardization work.

The Standardization Roadmap makes a conscious decision not to set priorities. The bodies with responsibility for implementation are requested to include the recommendations in their work programmes.

The Standardization Roadmap is to be regularly revised and amended on the basis of new findings – for example from research projects and the work in the standardization committees. Even after its publication, therefore, there is still an opportunity to take part in this process by submitting comments and working on standards.²

2.2 Actors and the context surrounding standardization

Germany as one of the world's leading industrial locations is competing to offer the best solutions for Industrie 4.0. Industrial production and production-related services in Germany account for over half of the country's entire economic output. Germany occupies a leading position in connection with a great many digital innovations in manufacturing technology, but competition from other countries continues to grow. To ensure Germany is equipped to succeed in the race to make the products and serve the markets of tomorrow, a holistic approach coupled with interdisciplinary collaboration is crucial. Standards and specifications are indispensable as a means of ensuring that Industrie 4.0 solutions are successfully marketed and implemented on a global scale. In Germany, a constellation made up of actors from the economic, scientific and political sectors has been established. These are presented below.

² Details of the persons to contact in connection with the Standardization Roadmap and all issues associated with standardization can be found at: www.din.de/go/industry-4-0 and <https://sci40.com/de/>

Plattform Industrie 4.0

Plattform Industrie 4.0³ was created in 2013 by the three industry associations BITKOM, VDMA and ZVEI and is currently lead-managed by the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Ministry of Education and Research (BMBF). Plattform Industrie 4.0 brings together representatives from the business sector, the scientific sector, trade unions, politics and consumer groups in a collaborative process to achieve a shared future for Germany as an industrial location. In addition to standardization, the focal areas especially include such areas of activity as research and innovation, the security of networked systems, the legal frameworks, and employment and (further) training. The German standards organizations DIN and DKE are involved in these working groups and support Plattform Industrie 4.0 in incorporating what they have developed in the standardization process, especially on an international level.

Standardization Council Industrie 4.0

DIN and DKE founded the Standardization Council Industrie 4.0 (SCI 4.0)⁴ in conjunction with the industry associations BITKOM, VDMA and ZVEI. SCI 4.0 is responsible for orchestrating standardization activities and, in this role, acts as a point of contact for all matters relating to standardization in the context of Industrie 4.0. In collaboration with the Plattform Industrie 4.0, SCI 4.0 brings together the interested parties in Germany and represents their interests in international bodies and consortia. SCI 4.0 also supports the concept of practical testing in test centres by initiating and implementing new informal standardization projects tailored to meet specific needs.

Labs Network Industrie 4.0

The Labs Network Industrie 4.0 (LNI 4.0)⁵ was set up by companies from the Plattform Industrie 4.0, together with BITKOM, VDMA and ZVEI. In the test centres, new technologies, business models and application scenarios (use cases) relevant to Industrie 4.0 can be tested and their technical and economic feasibility examined before they are launched on the market. LNI 4.0 therefore offers an ideal laboratory environment and environment for experimentation, especially for small and medium-sized businesses (SMEs). The close collaboration with SCI 4.0 makes it possible for new Industrie 4.0 solutions and the standards and specifications on which they are based to be tested, and the results are then incorporated directly into the further development of standards and specifications, both on a national and an international level.

3 www.plattform-i40.de/I40/Navigation/EN

4 www.sci40.com

5 <https://lni40.de/?lang=en>

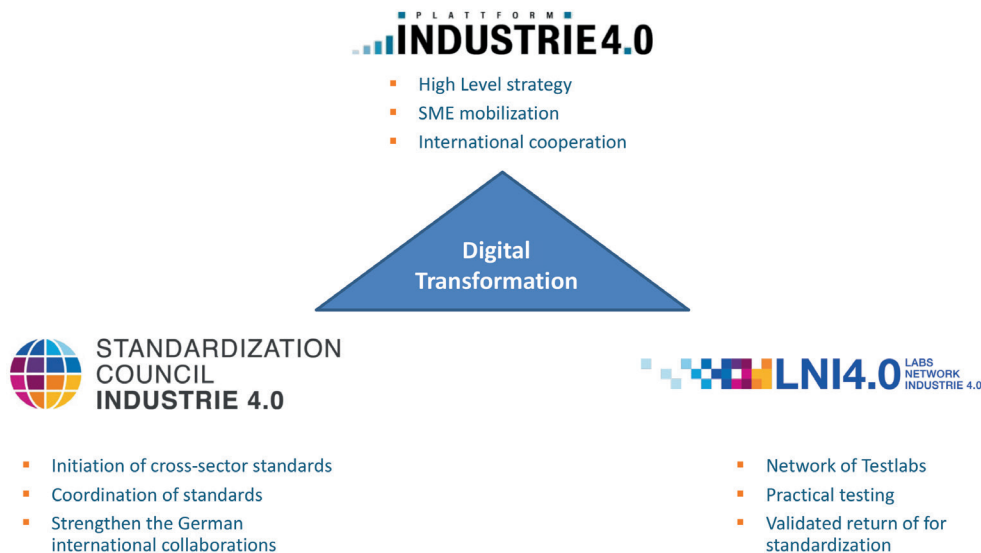


Figure 1:
Interaction of Plattform
Industrie 4.0, SCI 4.0 and
LNI 4.0

As clearly shown in Figure 1, the interaction between the three organizations is a highly responsive structure comprising strategy, conception, testing and standardization. The collaboration between the partners in the various test centres⁶ makes it possible to generate market-relevant requirements. Validated results are then incorporated directly into the standardization process via SCI 4.0. The findings and concepts defined by Plattform Industrie 4.0 are also taken into account and carried across into international standardization in a suitably focused manner via SCI 4.0. This serves to accelerate the development of marketable products, thereby ensuring that Germany remains in the lead when it comes to Industrie 4.0 concepts.

Within the constellation of actors that also includes the Plattform Industrie 4.0 and LNI 4.0, SCI 4.0 therefore has an important and unifying role, the aim of which is to enable the development of standardization processes that are more agile and responsive. To this end, the emphasis must now lie on updating and stabilizing the results and findings from the collaboration with the LNI 4.0 and Plattform Industrie 4.0. The necessary reference implementations are being introduced into the international standards organizations via SCI 4.0, while LNI 4.0 is providing use cases to help small and medium-sized enterprises introduce and implement Industrie 4.0 solutions⁷.

⁶ Map of the Industrie 4.0 test centres
<https://www.plattform-i40.de/I40/Navigation/EN/InPractice/Map/map.html>

⁷ Carrying the use cases forward, Aspects of the Research Roadmap in Application Scenarios
<https://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/aspects-of-the-research-roadmap.html>

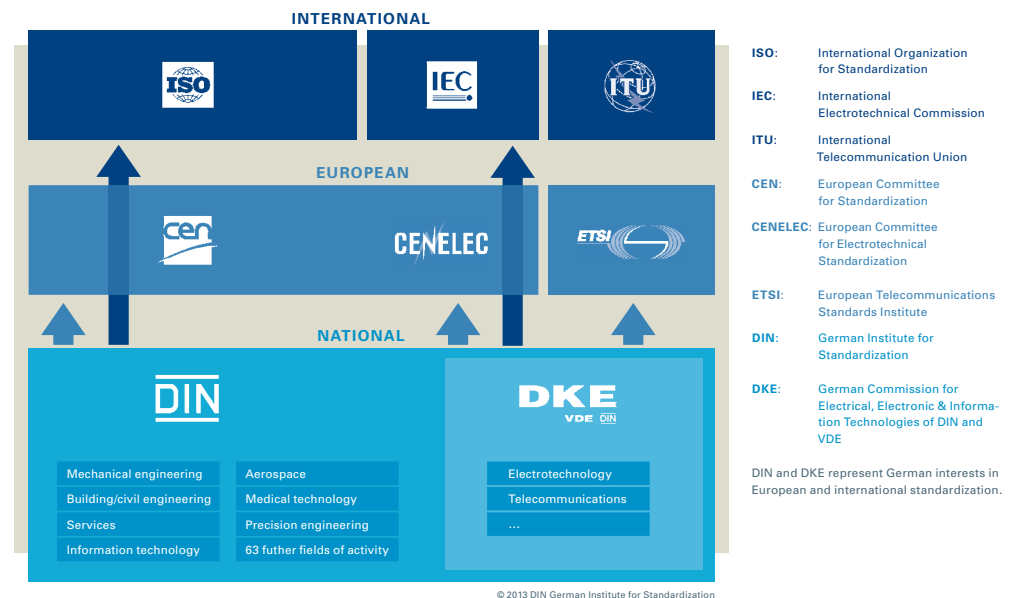
2.3 International standardization

2.3.1 Overview of the standardization landscape

In accordance with the German standardization strategy,⁸ formal standardization is understood to refer to the fully consensus-based development of rules, guidelines and properties for activities for general or recurring use by a recognized organization, whereas informal standardization is referred to in the German standardization strategy as the process of drawing up specifications. On a fundamental level, national and international consensus-based standardization is especially significant. Coordinated and comprehensively agreed standardization helps to ensure the breakthrough of the new concepts and technologies associated with Industrie 4.0.

The development of standards and specifications takes place on a variety of levels (national, European and international). A suitable overview, showing the way in which the development of standards and specifications is organized on a national, European and international level can be found in the illustration below, which depicts the standards organizations and their interaction (Figure 2).

Figure 2:
Presentation of the
international standards
organizations



8 The German Standardization Strategy www.din.de/go/german-standardization-strategy

In Germany, DIN, the German Institute for Standardization, is the responsible standards body representing German interests as a member of CEN (European Committee for Standardization) and ISO (International Organization for Standardization) on matters of European and international standardization.

DKE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE) represents the interests of the electrical engineering, electronics and information technology industries in the field of international and regional electrotechnical standardization work. It therefore represents German interests within both CENELEC (European Committee for Electrotechnical Standardization) and IEC (International Electrotechnical Commission).

Nowadays, almost 90% of standardization work is geared towards the European and international levels, with DIN and DKE organizing the entire process of standardization on the national level and ensuring German involvement in the European and international processes through the corresponding national committees (see Annex A). An outline of the most important international standardization bodies of relevance to Industrie 4.0 is provided below.

The international standards organizations ISO and IEC have recognized that it is not enough for work on the complex topic of Industrie 4.0 to be left to single technical committees (TC) working in isolation. For that reason, a strategic body was set up (ISO/SMCC and IEC/SyC), which consists of representatives from all relevant TCs and which coordinates the standardization work throughout the organizations.

ISO Smart Manufacturing Coordinating Committee (ISO/SMCC)

In September 2016, the ISO Strategy Group Industrie 4.0 successfully completed its work. In order to continue its international activities, the ISO/SMCC was set up as its successor body. In the first instance, it will remain in existence for two years and will comprise representatives from the relevant technical committees. Representatives were nominated from a total of 21 ISO committees, in addition to one representative each from the IEC and the ITU, to take part in the collaboration. Under German leadership, the ISO/SMCC has since been the driving force behind the work being carried out on an international level on Industrie 4.0. The aim is to ensure the overarching coordination in that area and to draw up implementation recommendations, especially with regard to a joint international approach. At the same time, a national mirror committee was set up as a means of offering interested parties a national platform that would enable them to take part in the shaping of the work being undertaken on an international level.

IEC System Committee Smart Manufacturing (IEC/SyC)

The IEC Standardization Evaluation Group Smart Manufacturing (IEC/SEG 7), the fundamental task of which is to develop a concept that will enable Smart Manufacturing to be addressed jointly in accordance with an overarching approach, concluded its work in 2017 and put together a proposal for the mandate of the IEC Systems Committee Smart Manufacturing (IEC/SyC) that

was being newly formed. The IEC/SyC is intended to be placed directly beneath the Standardization Management Board (SMB) of the IEC and is due to begin work in the second quarter of 2018. Besides coordinating standardization activities, the tasks of the IEC/SyC are to identify gaps and overlaps, especially relating to the collaboration between relevant standards organizations and standards developing organizations (SDOs).

ISO/IEC Smart Manufacturing Standards Map Joint Working Group (ISO/SMCC – IEC/SEG 7 Task Force)

This ISO/IEC group was set up by ISO/SMCC and IEC/SEG 7 as a joint working group. Its aim is to draw up, publish and update a body consisting of all Industrie 4.0 standards that is as complete, as dynamic and as simple to manage as possible.

ISO Technical Committee 184 (ISO/TC 184)

ISO/TC 184 is involved in standardization in connection with automation systems and their integration within the design, procurement, manufacturing, production and delivery, support, maintenance and disposal of products and within associated services. The standardization areas involved include information systems, automation and control systems, and integration technologies. A total of 44 countries are represented within ISO/TC 184, 20 of which are delegates from active Member States and 24 from Observer States.

IEC Technical Committee 65 (IEC/TC 65)

IEC/TC 65 develops International Standards for systems and elements used in continuous and discontinuous processes for the purpose of industrial process measurement and control. Its activities in the field of standardization are therefore geared towards equipment and systems incorporating electrical, pneumatic, hydraulic, mechanical or other measurement and control systems. Various subgroups have also been set up to deal with Smart Manufacturing. A total of 47 countries are represented within IEC/TC 65, 29 of which are delegates from active Member States and 18 from Observer States.

ISO/IEC Joint Working Group 21 (ISO/IEC JWG 21)

Due to the substantive overlaps that exist between the work of ISO/TC 184 and IEC/TC 65, the two bodies formed Joint Working Group 21 (JWG 21) “Smart Manufacturing Reference Model(s)” in July 2017, in which more than 70 experts from 13 countries participate. The Chair of JWG 21 is currently shared between Germany and Japan. The aim is to bring about the harmonization of existing reference models and to develop Smart Manufacturing reference models, especially with regard to various aspects such as life cycles and the technical and/or organizational hierarchies relating to assets. The development of a fundamental architecture for Smart Manufacturing components as an essential part of the virtual representation of assets (Industrie 4.0 components) is also planned. The contributions from the various countries are being consolidated, further developed and published in the form of consistent, unified models.

2.3.2 Aims and planned outcomes of international cooperation

Taking up the transnational opportunities and challenges posed by digitalization together forms the core principle behind standardization in the context of Industrie 4.0. To bring about a successful, international system of standardization equipping industry for digitalization, the aim is to achieve consensual and global harmonization of the concepts underlying Industrie 4.0. In this regard, the first harmonization work undertaken on reference architectural models for Smart Manufacturing is already clocking up its first successes and will continue to require comprehensive transnational cooperation in order to reach agreement on a binding model.

When discussing international cooperation, a distinction must be made between bilateral and multilateral transnational cooperation. Multilateral cooperations include political alliances such as the G20 and the European Union. A more detailed discussion of the activities and initiatives of the European Commission will take place separately below (see Section 2.3.4).

Within Europe there are also bilateral or trilateral agreements between EU Member States. These cooperations form the basis for the harmonization of the work to be undertaken in the future. The digitalization initiatives in Germany, France and Italy have agreed on a trilateral cooperation as a means of reinforcing and supporting the digitalization processes within the manufacturing sectors of each country. Its aim is also to encourage initiatives on a European level. To that end, the German Plattform Industrie 4.0, the French Alliance Industrie du Futur and the Italian initiative Piano Industria 4.0 have developed a joint action plan⁹, in which they have defined a number of measures and envisaged outcomes.

In general, the cooperating countries are actively represented within the international standards organizations, meaning that timely and consensual cooperation plays a significant part in achieving the desired goal. To that end, the parties involved have recourse to the cooperations that already exist between countries in order to synchronize these direct channels of communication with the work being undertaken within the relevant international standardization bodies. The cooperations involve the most important countries within the ISO/IEC bodies referred to above. As already stated, they require a high degree of cooperation and transparency from the countries in the elaboration of shared results.

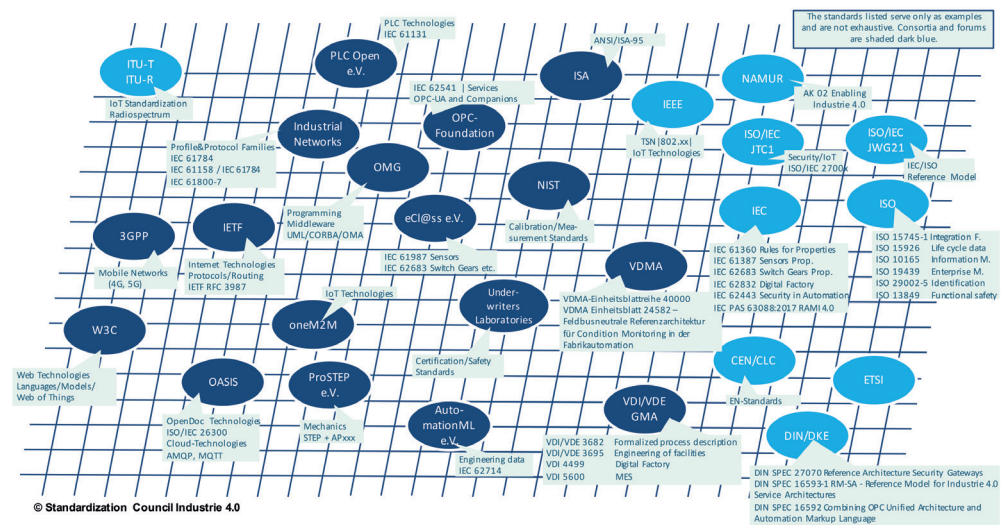
⁹ Trilateral Platform, DE-FR-IT Shared Action Plan, www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/shared-actionplan-fr-de-it.html

2.3.3 International cooperations

Alongside internationalization initiatives in the form of partnerships between countries, there exists a second important route towards internationalization. This involves collecting information about the range of bodies that exist around the globe, evaluating them, and networking them with experts from Germany.

On an international level, the range of actors currently involved in standardization relevant to Industrie 4.0 presents a very heterogeneous picture. Alongside the well-known, internationally recognized standards organizations such as ISO and IEC, for example, there are also a multitude of forums and consortia that draw up standards or recommendations (de facto standards¹⁰) and are designated as standards developing organizations¹¹ (SDOs) (Figure 3). In particular, the de facto standards emerging around the world in the context of the internet play an important role in the digital description of objects. To ensure adequate transparency, these must be included within the standardization network. This makes a holistic survey of standardization more complex, and the multitude of consortia and forums need to be taken into account in a systematic way.

Figure 3:
Bodies and consortia from around the world of relevance to Industrie 4.0



SCI 4.0 plays a leading and decisive role in the approach taken by Germany, which is to achieve cross-sectoral agreement and coordination between all actors. In addition to coordinating standardization activities, SCI 4.0 represents the interests of the German stakeholders in internal forums and consortia, incorporating these in turn into the Industrie 4.0 network. To achieve international networking of this type, it is necessary that all of the identified consortia, platforms and initiatives be systematically collated and evaluated in advance.

10 https://en.wikipedia.org/wiki/De_facto_standard

11 https://en.wikipedia.org/wiki/Standards_organization

2.3.4 Development phase standardization

The consecutive nature of scientific findings and their industrial application is now becoming more of a parallel process, as technology and service providers increasingly have to react to requirements from the practical environment even while development is in progress. In order to take account of this economic development, development phase standardization has been adopted at DIN and DKE.¹²

Standards and specifications represent an effective instrument for putting the results of research into practice in a rapid and user-friendly manner, and by doing so promoting rapid access to the market for innovations. They thus secure a broad acceptance for the implementation of new concepts and technologies in industrial practice, create confidence and trust among manufacturers and users, and provide the necessary security for investment.

Development phase standardization therefore makes a fundamental contribution to the utilization of research results. It plays a decisive part in making the traditional standardization process more dynamic, and comprises all activities which are aimed at detecting the standardization potential of strategic, fundamentally innovative products and services, systems and basic technologies, at as early a stage as possible.

In this way, innovative topics and research results can be publicized and made useful on a broad basis. The transfer of knowledge and technology, especially in fields with a high degree of innovation, is promoted and accelerated in this way.

When it comes to encouraging research on a national level, DIN¹³ and DKE are actively involved in a number of projects and tendering processes funded by the public sector, such as by the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for Economic Affairs and Energy (BMWi). In the context of Industrie 4.0, the following are particularly worthy of note:

Federal Ministry for Economic Affairs and Energy | PAiCE¹⁴

The funding and technology programme “PAiCE (Platforms, Additive Manufacturing, Imaging, Communication, Engineering) – Digital Technologies for the Commercial Sector” was set up by the Federal Ministry for Economic Affairs and Energy in 2016 and supports 17 research projects involving around 100 project partners from the commercial, scientific and research sectors in Industrie 4.0. The objective of this programme is to reinforce Germany’s position as a manufacturing location and as a provider of the most advanced manufacturing technology. The focal areas of the programme include product engineering, logistics, service robotics, industrial 3D

12 www.din.de/go/research-projects

13 www.din.de/go/industry-4-0

14 www.din.de/go/paice-english

applications and industrial communications. The technology programme is making an important contribution towards achieving the Federal Government's objective to turn Industrie 4.0 into reality.

In addition to the research projects, accompanying research was implemented in March 2017 in the form of an interdisciplinary project. As a partner involved in the accompanying research, DIN advises the project partners on all issues relating to standardization. DIN researches into standards and specifications of relevance to the subjects and projects concerned, analyses topics for their standardization potential, and initiates standards activities.

Federal Ministry for Economic Affairs and Energy | Industrie 4.0 testbeds

The objective and the motivation underlying this joint project is to expedite the establishment of a consensus and the implementation of standardization and guideline projects relating to Industrie 4.0. It is intended that implementing the project will provide evidence of the feasibility and the specific practical use of the outcomes. This approach will make it possible to identify additional hurdles and possible routes towards a solution. Within the consortium, the initial objective should be to define common baselines, such as terminology and architectures. Subsequently, actual Industrie 4.0 applications will be demonstrated based on four different use cases, in order to identify any need for standards or specifications. Ultimately, it is intended to initiate and actively encourage suitable standardization activities. The aim of the VDE|DKE subproject is to promote Industrie 4.0 standardization. In addition to advising project partners and carrying out standards research, the main task lies in the coordinated preparation of the necessary standards and specifications, the objective being their incorporation within the international processes at the earliest possible opportunity. The final task performed by the VDE|DKE is public relations work.

Federal Ministry for Economic Affairs and Energy | Secure digital identities¹⁵

Digitalization has given birth to a new reality that is growing at an unprecedented rate. Within that reality, the way in which the elements that form part of digitalization are perceived differs from the way in which these are perceived in the physical world. In the virtual world, it is a case of presenting and identifying an entity in the form of zeros and ones. When it comes to ensuring that the digital world in general and the projects of the future in Germany's economic sector in particular operate as intended, "secure digital identities" are essential. Digital interaction transcending company, system, sectoral or other "boundaries" is taking on a whole new dimension as a result of Industrie 4.0, Smart Cities, Smart Mobility and the Internet of Things. This in itself constitutes sufficient reason to establish the significance of and necessity for a shared understanding and approach.

Against this background, the DIN/DKE project entitled "Secure digital identities" is currently working to identify existing standards and specifications and ascertain the status quo with

¹⁵ www.din.de/go/sdi-english

regard to developments, solutions and the procedures common to the market in a variety of sectors. The project is being funded by the Federal Ministry for Economic Affairs and Energy, with the aim of setting in motion a process (comprising the Standardization Roadmap and political measures), which, as far as digital identities are concerned, will create the awareness, the content and the framework conditions for a shared baseline that will lead to the formation of an infrastructure that is not only interoperable, but also secure and efficient.

DIN Connect I Cloud federation¹⁶

Nowadays, mechanical engineering companies, but also manufacturers of components such as control components, sensors and actuators are increasingly offering cloud-based systems and services of their own. This however requires that the individual manufacturer enjoys suitable access to component or machine data in order to be able to provide the service. Operators of machinery and systems are increasingly being faced with a situation in which they supply data relating to their body of machinery (which is usually made up of machines from different manufacturers) to a multitude of third-party companies, in order to be able to receive the best possible service or functionality. It is assumed that cloud-based technologies are increasingly being deployed as IT systems by companies operating production systems and by component manufacturers or providers of remote services. On the one hand, the concept of a cloud federation encompasses communication from the field or edge components to the cloud of a system operator and vice versa. On the other hand, a cloud federation also involves company-wide communication between different cloud-based systems (technological) and/or communication between cloud-based systems controlled and/or operated by different companies (organizational).

The objective of the envisaged DIN SPEC 92222 "Reference Model for Industrial Cloud Federation" is to ensure interoperability and communication between the relevant IT subsystems and physical devices. It will look at communication from edge components into the cloud of the manufacturing company and, on a cross-company basis, into other cloud-based systems. The DIN SPEC will focus solely upon use cases from Industrie 4.0 (i.e. manufacturing, production and mechanical and system engineering). Based upon specific use cases, the DIN SPEC will define sample solutions for the industrial cloud federation. Sample solutions will include the types of technologies required for implementation, together with specific parameters.

Federal Ministry of Education and Research | ZDKI for Industrie 4.0¹⁷

In the future industrial world that is being discussed under the heading of "Industrie 4.0", wireless communication between distributed systems is indispensable. If closed loop control of complex processes is to be made possible, latency and jitter must be reduced to an absolute minimum. At the same time, it will be necessary to ensure a high degree of reliability in communications in

¹⁶ www.din.de/go/din-spec-92222-english

¹⁷ www.industrialradio.de/Menu/Home/ZDKI

conjunction with a simultaneously high device density. To ensure high data transfer rates with extremely low latency, it will only be possible to implement future applications such as the haptic human-machine interface or “augmented reality” by making use of a new type of wireless technology. The research project ZDKI (Reliable Wireless Communication in Industry), also known under the name of INDUSTRIALRADIO.DE,¹⁸ is addressing the present limits and will ensure real-time functionalities can be provided by means of innovative radio technologies. Eight independent research consortia from industry and academic institutions are dealing with this problem, drawing on various use cases from industrial practice. The eight projects are coordinated by the BZKI background research team in the aim of collating the findings from the projects for standardization purposes. Via the intermediary of the BZKI background research team, the first results have flowed back to 3GPP and the ITU-R in connection with the 5G standard.

Additional research projects funded by the Federal Ministry of Education and Research within the outsourcing series “Industrial Communications of the Future” focus on the various approaches to 5G technology in conjunction with Industrie 4.0. Results include TACNET 4.0 for communications within Tactile Industrie 4.0 and the accompanying IP45G research that includes several overall projects on 5G network management in association with Industrie 4.0.

European research funding

In the world of research and development, standardization is not only increasing in importance on the national level. Recognizing this, the European Commission is increasingly integrating requirements for standardization in its tendering documents. In consequence, DIN and DKE are also just as heavily involved in the diverse group of topics which make up Horizon 2020¹⁹, the European Union’s framework programme for promotion of research and innovation, as it was in the previous European research framework programmes.

Activities by the European Commission in relation to European Coordination

In April 2016, the European Commission published a package of measures for the digitalization of European industry (Digitising European Industry – DEI)²⁰. This package is intended to support and expand upon a variety of national initiatives, such as “Industrie 4.0”, “Smart Industry” and “Industrie du futur”. In this package, standards and specifications are identified as an integral part of the digitalization of European industry, as they have an influence in terms of competitiveness and are capable of supporting the performance of regulatory and legislative tasks. As part of the package, the European Commission has set out its priorities for ICT standardization.

18 www.industrialradio.de/Home/Index

19 <http://ec.europa.eu/programmes/horizon2020/>

20 <https://ec.europa.eu/digital-single-market/en/policies/digitising-european-industry>

In October 2017, the Directorates-General GROW, CONNECT and RTD established the extent of the need to support and coordinate standardization activities in order to achieve the digital transformation on a European level. Action identified as necessary includes:

- Orchestrating activities on a European level
- Identifying gaps in standardization
- Coordinating industry-led Public-Private Partnerships (PPPs)
- Providing strategic advice in connection with the implementation of pilot projects and platforms with a focus on standardization
- Identifying and using architectural reference models
- Providing advice and training for SMEs
- Tight integration with the “Rolling Plan for ICT Standardisation”

With regard to the recommendations for action, a clear separation of tasks was addressed between the industrial sector as the driver of standardization and the European Commission in its role as a supporter of the coordination of standardization activities and their linkage to pilot activities carried out by PPPs.

An additional group operating on a European level that focusses on standards for the digital transformation of industry is Action 14 of the Joint Initiative on Standardisation (JIS)²¹, which has been set up by the Directorate-General of GROW, in connection with the more detailed implementation of the Internal Market Strategy. From the present up to the end of 2019, Action 14 has set itself the objective of increasing knowledge of European Public Private Partnerships (PPPs) about international standardization activities.

In research projects, especially when these receive public funding, the focus lies upon the potential for effective commercial exploitation of the results. Research projects therefore have to be holistic in their approach. In order to provide optimum support to enable innovative results from research and development to be transferred to the market and disseminated, standardization activities should already be taken into account in the application phase of research projects.

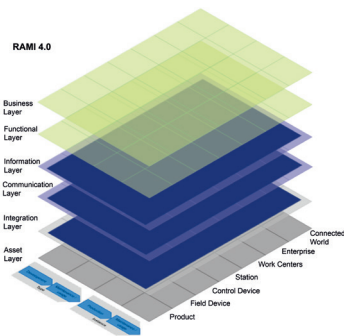
It is therefore recommended that funding bodies include standardization aspects in their tendering texts, and so provide an incentive to initiate standardization work in the research project phase.

DIN and DKE are able to be involved as project partners in national, European and international research projects. Thanks to the involvement of DIN and DKE in consortia, attention is paid at an early stage to standardization issues, thus ensuring that research results can be exploited²².

21 http://ec.europa.eu/growth/content/joint-initiative-standardisation-responding-changing-marketplace-0_en

22 www.din.de/en/innovation-and-research/research-projects

3 TOPICS AND STANDARDIZATION NEEDS



3.1 Semantics

3.1.1 Semantics, properties, ontologies

“Industrie 4.0” stands for the high-density networking of all objects over the whole life cycle of a product. In other words, from the time it is first conceived by engineers, via its production, right through to the end of the product life cycle, after which an object is disposed of or recycled. At all times during the product life cycle, information will need to be exchanged that can be understood by all partners in the same way. This requires the use of a set of uniform semantics. For example, those semantics will encompass standardized library directories (e.g. ecl@ss) incorporating standardized designations of properties, standardized engineering libraries (e.g. ProStep), the AutomationML exchange format and additional technological languages from the internet industry. This internationally binding consolidation and standardization forms a central component in the networking of things and requires the overarching coordination of a wide variety of SDOs with the partner countries involved in the consensus-based standardization.

The data to be exchanged must mean the same to all communication partners in the context of machine-to-machine communications and machine-to-human communications. This will be achieved, (1) if a common vocabulary is used, (2) if the context in which each item of vocabulary is used is known, (3) if agreed rules governing the formation of sentences to be used when exchanging messages are adhered to and, (4) if the subsequent step to be taken following the exchange of vocabulary or sentences is interpreted in the manner intended. In semiotics, these aspects of a language are known as syntax, semantics and pragmatics.

In the area of Industrie 4.0 all of the aforementioned aspects have to be unambiguously fulfilled. Somehow simplifying the term “interoperability” is often used to describe this. For this purpose, simple artificial languages are required that can be used digitally and universally. The central approach towards Industrie 4.0 in pursuit of objective (1) above is the properties model, which, as an integrated component of system and component models, fulfils the requirement (2) for assignment to the context [2]. In addition, rules are needed for the formation of notifications (3) between communication partners, the standardization of which has not yet been concluded. Furthermore, the interaction models (4) are still undergoing standardization [2].

Ontologies are description tools that formally cover the context of vocabularies ([1] and partly [2]). They are needed in order to recognize knowledge-based content within vocabularies and the relationships between them. Transformations of property-based vocabularies and the embedding of these within models are therefore required.

Ontologies connect information by means of logical relationships and are intended to explicitly specify formal terms, as a means of illustrating knowledge in its individual context. If these, mostly domain-specific, concepts are based on a common structure, data can also be interpreted across the boundaries of domains. Different consortia are working on cross-domain

concepts of this type. Uniform data structures facilitate conceptualization. A uniform and common understanding of data is essential, especially in the case of “big data” applications used to generate new business areas.

Use cases are extremely important in connection with the tasks described in the recommendations. They are being developed by LNI 4.0, by Working Group 3 of the Plattform Industrie 4.0, by DKE, as well as within ZVEI, Bitkom and VDMA, and will be available in a unified form.

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Recommendations

- 3.1-1** Property-based systems (1), as used in IEC Common Data Dictionaries (e.g. IEC 61987) and eCl@ss, need to be developed further in two directions [3, 4]. Firstly, the term used to denote a property must be expanded, both in terms of parameters and variables, as well as in terms of functions. This is due to the necessity to include in the vocabulary parameters, variables and function activations, such as those used during operational activities, in addition to the property master data of assets. It also includes the identification and annotation (time stamp, version statements) of instances of the properties, as the same property may exist several times within a single system. This will require additions and amendments to be made to IEC 61360/ISO 13584-42. Secondly, the available vocabulary must be considerably expanded, and its use by libraries and online accessibility facilitated and extended.
- 3.1-2** System models, such as AutomationML (IEC 62264), component models, such as the device description technologies (IEC 61804-3 to -6, IEC 62769, IEC 62453) and interface standards such as OPC UA (IEC 62541) must include properties as description tools. (2). That way, the context of the individual properties, parameters and functions can be identified in each case [1]. This step is the next one to be carried out.
- 3.1-3** The notification formats (3) must be capable of providing a high degree of flexibility. In contrast to the communication protocols in accordance with the OSI reference model, in which the structures of the protocol data units (often referred to as telegrams or datagrams) are fully pre-determined, it must also be possible for the structure to be formed on a generic basis, in order to provide the necessary flexibility and reflect the wide diversity that exists within the application scenarios. Standards still need to be developed in this area. Work has already begun by the Plattform [2] and VDI/VDE Gesellschaft für Mess- und Automatisierungstechnik [VDI/VDE Society Measurement and Automatic Control] (GMA) [GMA7.20].
- 3.1-4** The scope, variance and inclusion of errors and unwelcome system states when fulfilling the tasks that form part of a value-added chain mean that a variety of procedures need to be deployed. It is to be expected that patterns will emerge, each of which can be used for a particular category of tasks. Standards still need to be developed in this area. Work has already begun by the Plattform and the GMA [4]; an initial approach is given in IEC 62264-6, for example.

3.1-5 To achieve success, it is absolutely essential to increase the degree of formalization of standards and specifications. Provision must therefore be made for both formal and semi-formal means of specification to be used within an industrial software development process. Formal and semi-formal description tools (e.g. state machines, sequential diagrams) are particularly essential as a means of describing the mode of behaviour that occurs within interactions (4), as they form an integral part of semantics. Description tools such as UML generally form a good starting point.

3.1.2 Graph-theoretical approach for the formal description of the semantics of industrial systems (industrial automation and control systems – IACS)

On the basis of Section 3.1.1, we can infer that formal, standardized semantics are required that are as operational as possible. The reason for this is of a practical nature, in view of the fact that in the case of operational semantics, tools (such as graphical user interfaces (GUIs)²³, testers, simulators, model checkers, etc.) are available in the public domain. In order to represent and analyse the semantic properties of industrial automation and control systems (IAC), a graph-theoretical approach is therefore recommended, in which the semantic elements show the events in the form of the vertices or nodes of a graph. Events, in other words changes of state, are represented by the edges of a graph. In the majority of cases, a system state also contains an invariable, e.g. system stability, which applies for a certain period of time and can be checked from a graph-theoretical perspective using a tool.

In the context of an Industrie 4.0 system and when viewed from the perspective of a person involved in Industrie 4.0 (Section 4), the decision whether or not to act after observing a critical event should remain the exclusive domain of the human. On the other hand, the preparation leading up to that decision can be carried out by the machine, i.e. the machine or the tool involved is capable of reliably verifying which event rules have been triggered or will be triggered and may give rise to a critical change of state. This results in the establishment of a principle governing the use of technology, which sets out to support, and not replace, decision-making by a human being: the machine will verify the state of the system being scrutinized and the human can then respond by taking suitable actions or implementing appropriate measures. These actions can be represented in a graphic manipulation tool on the GUI and analysed. Separating human decision-making from the preparation by the machine in the run-up to the decision makes it possible to preserve the principles of human-friendly work.

²³ GUI, zooming user interfaces https://en.wikipedia.org/wiki/Zooming_user_interface

In situations where the consequences arising from the observed event appear compelling and without alternatives (taking into account legal and legislative aspects, and also the relevant ethical principles and any possible conflicts of values, objectives or interests), this component of human decision-making can be taken in advance by the system programming using an unambiguous “if then” operation that is based on rules, guidelines and standards that still partly remain to be developed and for which no binding description is as yet available. This may create the impression that the machine is making this decision on its own (“autonomation”).

If, however, these human decisions taken in advance during system development ultimately lead to a situation in which, in the context of “machine learning” and “artificial intelligence”, an increasing number of “machine-based decisions” are made that have not been checked and can no longer be checked by humans, and these have come to replace decisions taken by humans but prepared by machines, this will give rise to

- a) a crucial need for the axioms of “lawfulness/legality”, “ethical justification/embedding of values” and “transparency/traceability” to be closely observed (see also Section 3.5 and Section 5) and
- b) a risk that the principles of human-friendly work will be increasingly contravened in the sense that the scope within which humans can act and make decisions may become restricted and learning and development opportunities may be limited within the context of human-machine interaction (see Section 4). The standardization process under Industrie 4.0 should therefore continue to carefully monitor this potential area of conflict.

Use cases are especially significant for the formal description of system properties [ISI18], as a means of documenting a shared understanding between the various stakeholders. A use case description is usually undertaken using formal concepts from technical languages such as UML, AutomationML, JSON.

In the case of UML, geometrical UML graphics, (see [UML05]) are specified with the assistance of templates, stored in a data base and are able to undergo further processing as formal objects (see [UCM15]).

In order to represent a technical system in semantic terms, suitable semantic elements are needed, such as those taken from graph theory, set theory or modal logics, etc.

Thus, the principles of graph theory can be used as a basis for intended semantics, i.e. a common understanding resulting from changes to a so-called type graph that represents a system and its options [Mod05]. The effects and internal and external dependencies change the system state. For example, a user contravenes the access conditions of a cloud-based service, or there is a change in the weather that affects the current configuration of a smart grid. These changes in state can be presented very clearly as a graph in use-case format.

Taking, as an example, the specification language UML, there is, amongst other things, a GUI [Mod05] which can be used to represent use cases as standardized UML graphics. Basic

geometric figures such as lines, rectangles, ellipses, icons, etc., are assigned to semantic objects such as association, system, activity/use cases, stakeholders and so on.

Whilst use case specifications are represented in UML using geometric elements such as rectangles, ellipses, arrows, lines, etc., semantic concepts are generally a mathematical construct, such as vertices and edges in graph theory [Mod05]. The vertices represent system components, services or stakeholders; and edges that set a pair of vertices in relation to each other, for example, constitute a UML association between stakeholders, services, system components, etc.

Furthermore, it is recommended that a uniform vocabulary for modelling and for system description be created in use-case format, amongst other things [UCMeth15]. For example, in [ETSI06] there is a formal linguistic concept based on graph theory. Graphs can be used to represent use cases, system configurations and interconnections effectively when large quantities of data are involved. The terminology includes basic concepts such as stakeholder, role description, services, interfaces, attributes, associations, asset classes, abstract data typing, etc. These are required in order to bring about a common understanding and to ensure that representations are mutually comparable.

Industrie 4.0 modelling based on graph theory is supported by freely available tools and platforms, such as [AGG17], [GrGen10] etc., which mostly offer a GUI for the simplified representation of the semantics of use cases. GUIs of the supporting tools, Industrie 4.0 vocabulary and a standardized language are important prerequisites for achieving a uniform methodology for the analysis and synthesis of complex Industrie 4.0 systems, as outlined in [SemN18].

Recommendations

- 3.1-6** Alongside the elements intended to ensure IT security, standards on semantics with the resulting increase in the quality of IACS security should be included in every “Industrie 4.0 toolbox”. It is evident that there is a difference between IT security, which is generally based upon individual measures and usually sets out, as a minimum, to improve the CIA properties, as in Confidentiality, Integrity, Authenticity, etc., and IACS security, which is based on semantic standards.
- 3.1-7** Due to the high degree of complexity of the systems examined, it is recommended that a continuous, model-based approach be adopted and that semantic validation and verification tools be used, so that security decisions regarding IACS states can be taken in a reliable and traceable manner.
- 3.1-8** Furthermore, it is recommended that a uniform vocabulary for modelling and for system description be created in use-case format.

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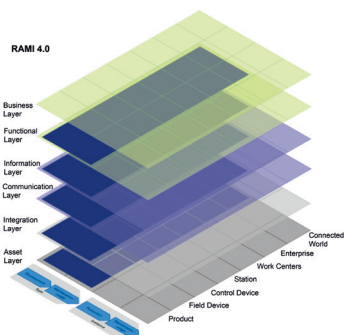
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3.2 Standardizing terminology

From the beginning, it was clear that as a result of the new models and methods, Industrie 4.0 needed new terms and designations. For this reason, a subgroup on terminology was set up in VDI/VDE GMA 7.21.

The glossary produced by the “Terms” working group was published by VDI²⁴ in April 2017 in bilingual form (German/English) under the title “Industrie 4.0 Begriffe/Terms” and is accessible to the public.

²⁴ https://m.vdi.de/fileadmin/vdi_de/redakteur_dateien/gma_dateien/7153_PUB_GMA_-_Industrie_4.0_Begriffe-Terms_-_VDI-Statusreport_Internet.pdf

The progress of the work can be viewed at the Fraunhofer IOSB²⁵ and the current status at any time is available on the homepage of Plattform Industrie 4.0²⁶.

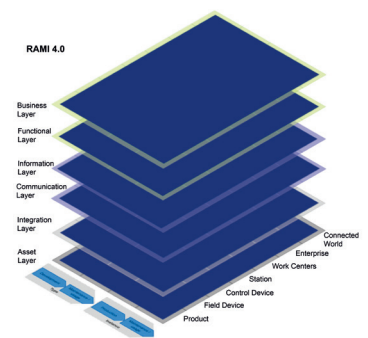
At IEC level (IEC/TC 65) too, a list of terms is being created, into which the “Plattform” has incorporated the terms relating to Industrie 4.0.

3.3 Reference models

A reference model is a model that provides a definitive description of an aspect that plays an important role within the systems belonging to a particular area of application. Reference models take account of organizational and technological conditions and view the system to be modelled from a specific perspective. This means that they are not without alternatives, but, in the opinion of experts, describe the circumstance in an accurate manner. Different groups of experts may however arrive at different reference models. This is not intended, but in some cases is unavoidable. Reference models are meta models and form the basis of a shared understanding in specialist circles. In addition, they describe the structure of the models in the use case and form the starting point for the tools that are based on them.

For Industrie 4.0, the availability of standardized reference models in all areas is crucial. The fact that they look beyond the confines of a single domain means that the ability of a reference model to represent circumstances in a clear, explicit and unmistakable manner is even more significant. To this end, the existing specialist models need to be supplemented, expanded and harmonized. A further challenge lies in the fact that reference models are frequently not explicit or clearly demarcated, but are described in a piecemeal manner across section standards. This leads to a multiple, ambiguous, inconsistent and non-referenceable description that can create difficulties when incorporating components into an overall system.

The primary aim of a reference model is to provide a clear and unambiguous description of a circumstance by means of a model. A reference model that fulfils these criteria is one that is suitable for standardization. Depending on one’s viewpoint or background and/or for reasons connected with technology or corporate policy, multiple competing reference models may emerge for the same circumstance, and in turn these will also lead to different solutions. In this undesirable situation, it may be better to approve multiple parallel standards within a consensus-based framework than to encourage the creation of consortium-based standards. In such cases, it is worth endeavouring to achieve at least a reference model that covers an entire domain.



25 <http://i40.iosb.fraunhofer.de/>

26 www.plattform-i40.de/I40/Navigation/EN/Service/Glossary/glossary.html

Service-oriented architectures (SOA) are used and required in the relevant Industrie 4.0 documents (such as in [1]). For that reason, it is vital that it is clearly agreed and specified what exactly is understood by the term and technical concept of “service”. This applies to the work that is currently underway in the Plattform Industrie 4.0, as well as for the subordinated working groups and bodies of the relevant associations. In DIN SPEC 16593-1, the idea was taken up in the form of a reference model for Industrie 4.0 service architectures (RM-SA), with the aim of creating a conceptual baseline for interactions

- between Industrie 4.0 components,
- and, using that as a starting point, of clarifying what constitutes a “service” in Industrie 4.0, thereby
- laying a foundation stone that will result in interoperability within Industrie 4.0.

Service orientation and service-oriented architectures (SOA) are technological requirements, not only in [1] and [2]; however no attempt is made to justify or refine them in conceptual terms. RM-SA is crucial if the standardization work for Industrie 4.0 that is currently in progress is to be more effectively coordinated and if the various initiatives are to be implemented in a complementary manner. Consensus about RM-SA will ultimately play a decisive role in determining whether

- service-oriented Industrie 4.0 reference architectures, service architectures, specifications,
- interaction protocols and suitable testing procedures

can be drawn up.

This will ensure the IT interoperability of Industrie 4.0 components and software applications. This is necessary so that Industrie 4.0 can be implemented on an international level under conditions of fair competition and so that small and medium-sized enterprises (SMEs) are also in a position to contribute solutions of their own.

The outcome of the workshop is DIN SPEC 16593-1, published in English in spring 2018 (with the title “Basic concepts of an interaction-based architecture”). It is the first part of a projected series of DIN SPEC documents entitled “RM-SA – Referenzmodell für Industrie 4.0 Service-architekturen” or “RM-SA – Reference Model for Industrie 4.0 Service Architectures”.

The interaction-based architecture (IBA) defined in DIN SPEC 16593-1 sets out, on the one hand, to facilitate the flexibility demanded of it in interaction and communication between Industrie 4.0 components by means of differing styles of architectures and on the other hand, to support widely used and currently recommended communication systems such as OPC UA.

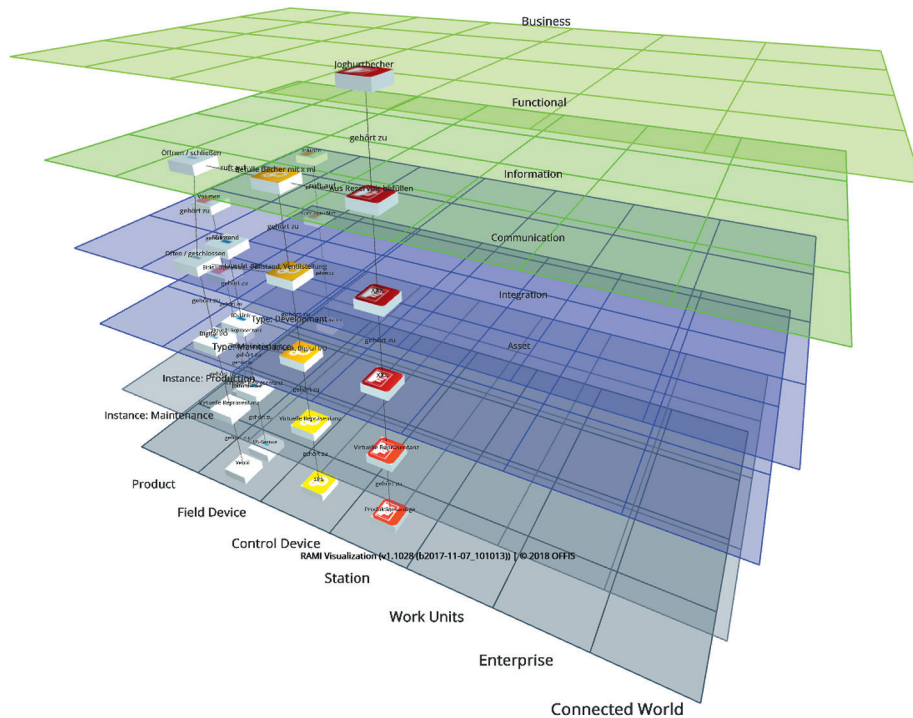


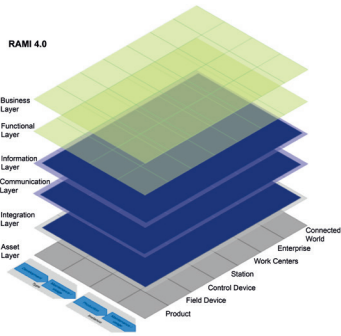
Figure 4:
Reference models using
the example of a filling plant
(IKIMUNI project)

Figure 4 situates an example of Industrie 4.0 in the RAMI 4.0 reference model. Based on the RAMI model of a filling plant for a made-to-order yoghurt with a batch size of 1, the example was transferred into a representation in the context of RAMI 4.0. This makes it possible to subdivide an actual production facility into various Industrie 4.0-compliant views, so that it can be analysed and evaluated in a more effective way. In contrast to the customary, mostly PowerPoint-based presentations, the tool developed in the IKIMUNI project²⁷ makes it possible to carry out interactive manipulations of the view by filtering, zooming, exporting in the form of a graphic, and transecting the cube. This prompts an interactive discussion and analysis of an Industrie 4.0 solution.

Bibliography

- [1] DIN SPEC 91345, Referenzarchitekturmodell Industrie 4.0 (RAMI 4.0); Reference Architecture Model Industrie 4.0 (RAMI 4.0); Modèle de référence de l'architecture de l'Industrie 4.0 (RAMI 4.0)
- [2] IEC PAS 63088 Ed. 1, Smart Manufacturing – Reference Architecture Model Industrie 4.0 (RAMI 4.0)

²⁷ www.ikimuni.de/en



3.4 Architectures and data models

3.4.1 Digital models

Satisfactorily representing the physical world in the information world is an aspect that is of crucial significance in the case of Industrie 4.0. The ZVEI “Models and Standards” working group has devoted its efforts to this particular issue since work on the topic of Industrie 4.0 got underway.

3.4.2 Reference architecture model

According to [1] and other sources, a reference architecture in information technology is a reference model for a class of architectures. We can look upon the reference architecture as a sample model, in other words, an ideal model that is typical of the class of architectures to be modelled. With the reference architecture model for Industrie 4.0, Industrie 4.0 does not provide a specification of “the” architecture as such, but solely a framework consisting of the minimum requirements. These include the establishment of concepts and a methodology containing rules for the description of the physical world for the purpose of reflection within the information world:

- The reflection of relevant parameters from the physical world within the information world
- Representation/format of the physical world in the information world
- Identification of components
- Orchestration of components
- Choreography of components
- Network structure and data format for the exchange of information between components
- Minimum requirements for implementation
- and many more.

According to model theory, a model must always have a purpose and a relationship to an original, and forms an abstract representation of specific properties of the original.

According to SemAnz [2], digital models and/or prospective models in Industrie 4.0 take the form of:

- An information model with its sub-models
- A property model for describing the properties of objects
- A system model used to describe the significance of objects
- A description of the connections between objects and sub-models
- A behavioural model used to describe the processes and variables
- A structural model with elements that actually exist
- A basic system for describing a system from a functional perspective

In information technology, the conventional type of modelling that makes use of equations is of no further assistance. This is why discrete models are used in Industrie 4.0.

Whilst the system architecture is customarily created purely on the basis of IT rules, such as ISO/IEC/IEEE 42010:2011, the objective in Industrie 4.0 is to create a methodology in advance for the coordinated transfer of all relevant information from the physical world into the information world in order to enable continuous, computer-supported automation. In Industrie 4.0, this is described using the term “reflection”. Reflection describes the procedure for creating, in the information world, a digital representation or image of the physical world in the form of data. These data are structured in accordance with the uniform rules of the Reference Architecture Model Industrie 4.0 [3], in order to guarantee that the description is a homogeneous one. RAMI 4.0 characterizes any given object, without needing its inner structure to be known. A uniform information model has therefore been specified for the information world of Industrie 4.0, in which the properties of an object play a prominent role for the purposes of reflection. In that regard, it is assumed that the physical world is made up of the sum of a number of individual objects. These may be the components of a plant; however an object can also be an idea or an entire plant. A plant can be taken to be the interaction of a large number of individual objects. In that regard, the description of any components of an object will be defined as (sub-)objects or the description of an entire object as a(n) (whole) object and will, wherever possible, include a description of the interaction that takes place between those objects. The method of object description based on RAMI 4.0 must be followed in every solution (application), so that these will collectively behave in a manner that is “Industrie 4.0 compliant”. Using this method, it is possible to ensure the transferability of information about objects and their interoperability.

3.4.3 Properties²⁸

A basic requirement for the reflection of an object in the information world is a description of its properties. Those properties can be trivial, such as “height”, “length” or “width”, or they may be properties that can only be characterized after performing complex calculations. What is needed is an unambiguous designation (terminology) denoting the properties of an object in the physical world, so that these can be reflected in the information world. The methodology employed in order to reflect the properties has been developed in accordance with the twin standards IEC 61360 and ISO 13584-42.

The information in binary format obtained as a result of the reflection process characterizes the object from the physical world as a list of properties in the information world. In view of the fact that in Industrie 4.0, no random objects are used, but only “objects that are of value to an organization” (= Industrie 4.0), these objects are known as “assets”.

eCl@ss e.V.²⁹ has already defined properties covering over 30 sectors. If the properties to describe a project are not in eCl@ss, these can be directly requested in the case of automation-

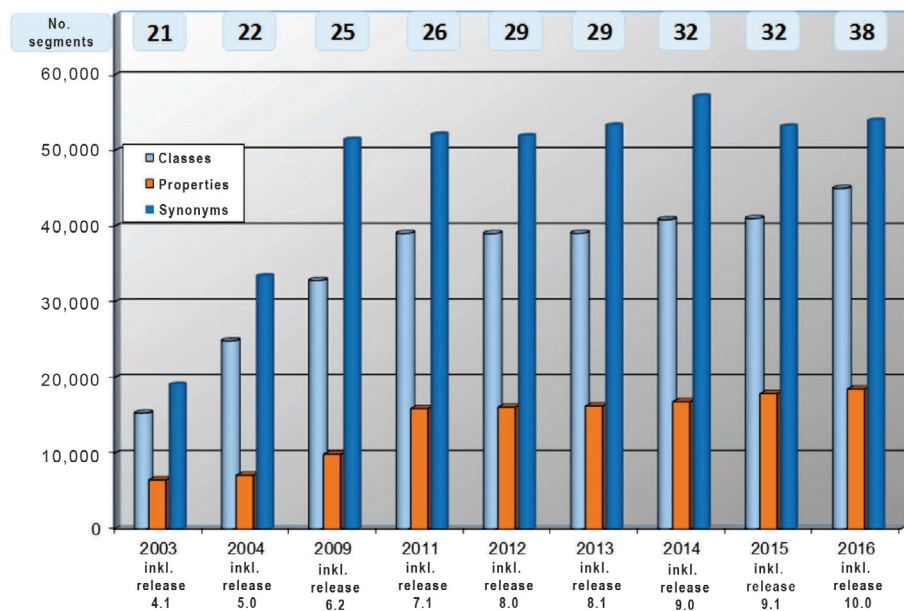
28 IEC 61360 and ISO 13584-42; for further details, see [1]

29 www.eclass.eu/en.html

related products, the healthcare sector or other sectors, either in an eCI@ss working group, in consortia of relevance to Industrie 4.0 or via the eCI@ss portal. eCI@ss works in close collaboration with the national, European and international standardization bodies. Some of the eCI@ss properties have already been standardized by IEC. In addition, a working group is currently creating a route that will enable properties standardized in IEC to be transferred across into eCI@ss and properties specified by eCI@ss to be transferred to IEC. Industrie 4.0 will therefore be able to have access to standardized properties by means of the eCI@ss standard and the assets reflected in the information world within IEC. The number of these is increasing all the time. At present, approximately 18,000 properties are available in the eCI@ss database (Figure 5).

Figure 5:
Selected eCI@ss segments
with properties in specific
years (source: eCI@ss)

~ 18,000 product properties



3.4.4 Reference Architecture Model RAMI 4.0

Describing an asset in the form of properties only is not enough. Every asset has specific technical functions and special properties that are described in the layers of RAMI 4.0 and identify the actual purpose for which it used. The life cycle axis of RAMI 4.0 characterizes the asset with specific states at a specific location at a specific time during its entire “life”. This makes it possible to maintain a type of “life cycle record” for each asset (see Section 3.5 Life cycle record for Industrie 4.0 components), which will remain with it for its entire life and will, as a minimum, include the parameters “time”, “location” and “state” and the minimum states “type” and “instance”. Finally, an asset is always assigned to someone or something, as can be seen on the hierarchy axis (Figure 6).

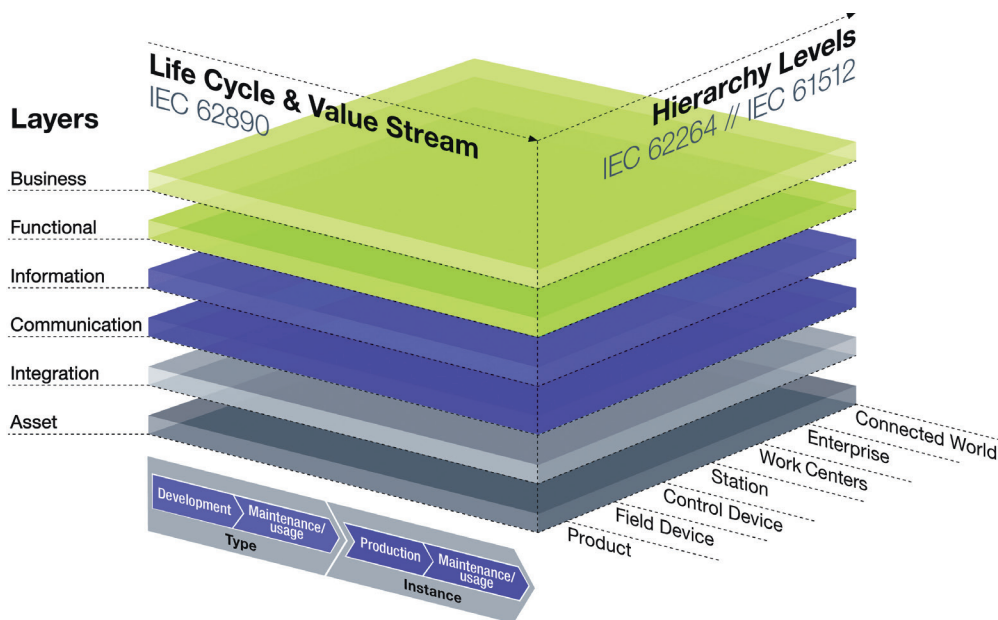


Figure 6:
The reference
architecture model
Industrie 4.0 (RAMI 4.0),
source: IEC PAS 63088

The methodology that makes use of RAMI 4.0 to describe all assets of an Industrie 4.0 solution makes it possible to describe an asset with sufficient precision to enable the production of an “informatic mirror image” of the asset that can be used in the information world.

3.4.5 The administration shell and Industrie 4.0 component

The finished “mirror image” of an asset must now cooperate for operational purposes with one or more other assets in the physical world or with their virtual mirror image in the information world.

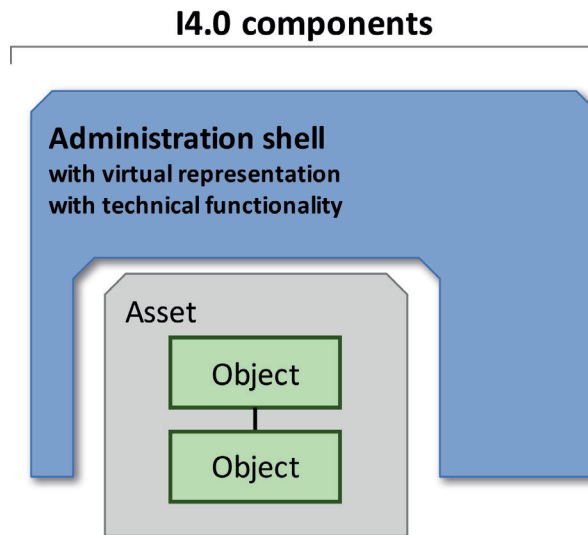
That is the purpose for which the Industrie 4.0 component is used (Figure 7). It consists of the asset in the physical world and its informatics mirror image in the information world, through the agency of the administration shell. This means that in order to be used in the information world, the properties characterizing an asset in the physical world are stored in the administration shells of Industrie 4.0 components, along with the relevant identifiers (IDs).

Exchange of information (information layer)

The administration shell makes its information available via an Industrie 4.0-compliant API³⁰. This consists of the Industrie 4.0-compliant communication, and, based on this, as well as offering services, OPC UA also provides security mechanisms.

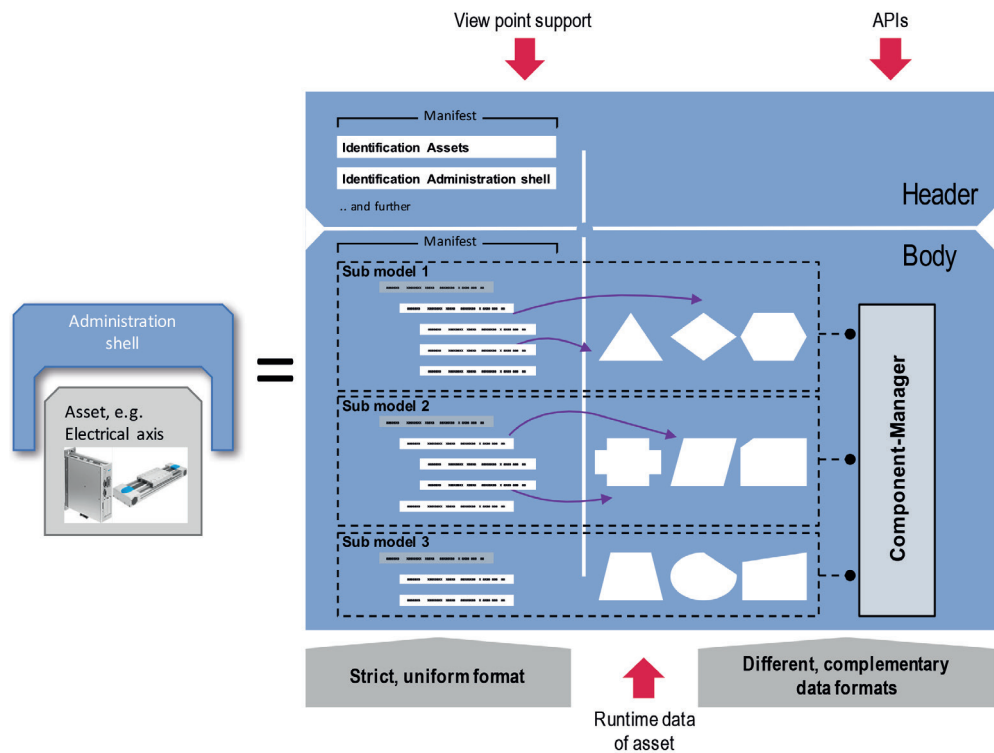
³⁰ Application Programming Interface

Figure 7:
Industrie 4.0 component
in accordance with
IEC PAS 63088
(DIN SPEC 91345)



An administration shell is fundamentally made up of two parts (Figure 8). The body characterizes the asset along with its properties, whilst the header contains all of the data of an asset that relates to its use. As a minimum, the header will contain the “life cycle record”.

Figure 8:
The basic structure
of the administration shell
in accordance with
IEC PAS 63088
(DIN SPEC 91345)



Description of the relationships within a solution

In line with the outcomes of SemAnz [2], the Automation Markup Language, or AutomationML for short, is a suitable means of achieving a complete description of a system and its internal relationships.

Technical functionality of assets (functional layer)

An asset possesses a technical functionality that enables it to fulfil its role within an Industrie 4.0 system. For that purpose, a formal, machine-processable description of that functionality must be available. The formal description can be created using a suitable “language”, or by using an executable code that is available within a library. The testing included within the “PLCopen Motion Control” methodology that is used in PLCopen is suitable for this purpose.

Recommendations

- 3.4-1** Use of the twin standards ISO 13584-42 and IEC 61360 for the specification of properties
- 3.4-2** Expansion of the model set out in the twin standards ISO 13584-42 and IEC 61360 with the addition of properties with variable manifestations and of variable property manifestations
- 3.4-3** Extended assignment to hierarchies in accordance with IEC 62264 (Expansion of the MES standard)
- 3.4-4** Observance of IEC PAS 63088 (RAMI 4.0 and Industrie 4.0 components, DIN SPEC 91345) in IEC/ISO JWG 21
- 3.4-5** Observance of the IEC 62832 series of standards (Digital factory framework with sub-specification for the interconnection of assets)
- 3.4-6** Observance of DIN SPEC 16593-1 (Basic concepts of an interaction-based architecture) to describe fundamental concepts for the interaction between I4.0 components and services developing from these that use different styles of architecture (see also Section 3.3 Reference models)
- 3.4-7** Compilation of the life cycle record in accordance with IEC 62890 and DIN 77005-1 (“Life cycle Management” and “Life cycle record of technical objects” respectively)
- 3.4-8** Utilization of the function model in accordance with VDI 3682. (Product, energy, information, function/process, technical resource for the formal description of processes)

- 3.4-9** Formulation of a structural model based upon ISO 62264, VDI 2206 and IEC 61512 (batch control, systems (equipment hierarchy), functional units, technical functionalities of assets)
- 3.4-10** Inclusion of detailed outcomes of SemAnz40 [SemAnz] regarding the description of processes
- 3.4-11** Behavioural model in accordance with IEC 61131-3 (program organization units, variables)
- 3.4-12** Utilization of OPC UA for the sharing of information IEC 62541 (OPC UA)
- 3.4-13** Observance of DIN SPEC 16592 (Mapping AutomationML and OPC UA)
- 3.4-14** Utilization of DIN SPEC 16593-1 for the definition of services
- 3.4-15** Utilization of the device model in accordance with IEC 61804-2 (relevant to integration and functional layer)
- 3.4-16** Examination of “PLCopen Motion Control” for its general suitability for the description of technical functionality

Bibliography

- [1] *Basiswissen Industrie 4.0, Referenzarchitekturmodell und Industrie 4.0-Komponente* [Basic Knowledge of Industrie 4.0, Reference Architecture Model and Industrie 4.0 components]; Heidel, Hoffmeister, Hankel Döbrich; Beuth Innovation July 2017
- [2] [SemAnz40] *Semantische Allianz für Industrie 4.0, Verbundvorhaben mit Mitteln des BMWi/AIF* [Semantic Alliance for Industrie 4.0; joint project funded by BMWi/AIF], www.semanz40.de
- [3] *IEC PAS 63088 Ed1, Smart Manufacturing – Reference Architecture Model Industry 4.0 (RAMI 4.0)*

3.4.6 Product criteria

The use of terms such as “IoT ready”, “RAMI 4.0 compliant” or “Industrie 4.0 Siegel” [Industrie 4.0 hallmark] continues to increase. Moreover, consultancy companies are offering to test products and entire companies for Industrie 4.0 compliance. In all too many cases, the various services on offer are actually based on a completely different definition of Industrie 4.0 and are causing confusion rather than clarity. ZVEI is currently drawing up general, manufacturer-independent criteria for Industrie 4.0 products, which will be described in the ZVEI criteria catalogue.

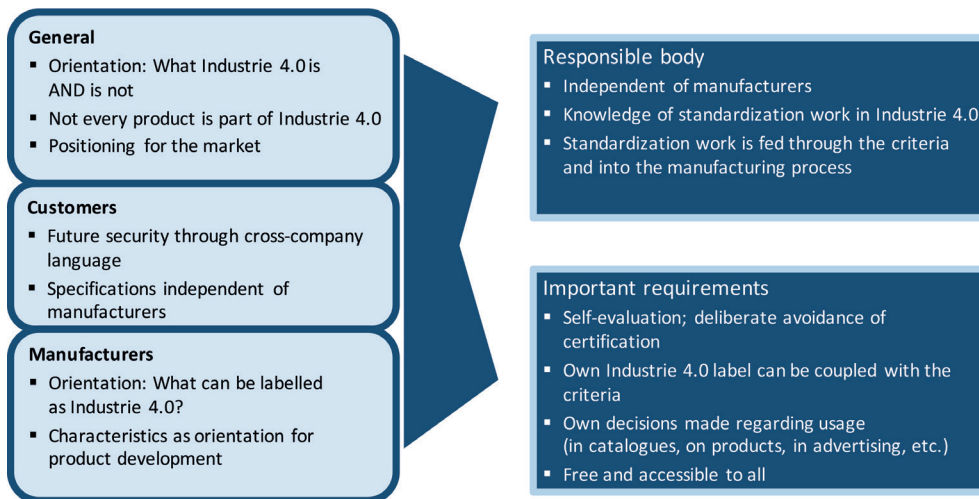


Figure 9:
Product criteria give customers and manufacturers an initial, manufacturer-independent orientation

The criteria will help market providers to decide what products can already be deemed to be Industrie 4.0 compatible. At the same time, companies can use those criteria as a guide in product development. For customers, the ZVEI definition offers clarity with regard to services and features that Industrie 4.0 products should possess. Overall, this will ensure greater market transparency and certainty. As an indirect consequence, it will also become clear which objects are not Industrie 4.0 compliant. Figure 9 shows the benefits for market players, whilst Figure 10 shows how the criteria have been derived.

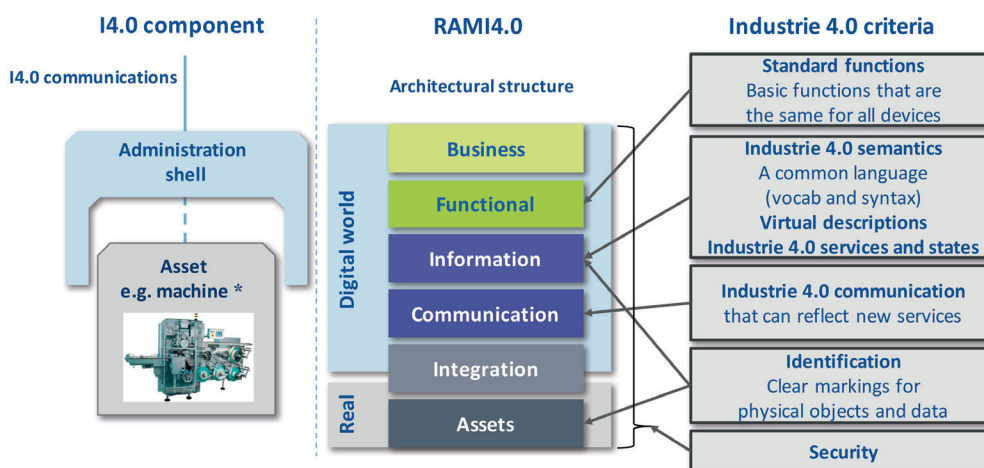


Figure 10:
Derivation of product criteria

The guidelines refer to criteria for products, whereby products may be devices, systems, machines or software in the sense of an Industrie 4.0 component. Criteria for comprehensive Industrie 4.0 solutions (hardware, software, services, applications, etc. as a full-service package) are not described. As a minimum, a comprehensive Industrie 4.0 solution should therefore

include an Industrie 4.0 product that fulfils the relevant criteria for Industrie 4.0 products and thus also has the minimum product properties.

Recommendation

3.4-17 The product criteria catalogue should be adapted at regular intervals in line with the working results obtained and findings made.

3.4.7 International Geometric Product Specification (GPS concept)

The international Geometric Product Specification (abbreviated to ISO GPS) has come to play a decisive role on the road towards the digitalization of processes and the associated transparency and traceability of data during the entire added value process. ISO GPS is used to lay down the geometrical requirements for workpieces in the form of technical specifications and establish what requirements will apply for their verification. The underlying International Standard, DIN EN ISO 14638:2015-12, describes the concept of ISO GPS and sets out details of a reference system that indicates how current and future ISO GPS standards will respond to the requirements to which the ISO GPS system will be subjected.

Note: The ISO GPS, which describes the properties of workpieces, is not to be confused with the satellite-supported Global Positioning System!

The ISO GPS concept

ISO GPS is a system which is used to describe certain workpiece characteristics through some of the different stages of its life cycle (design, manufacture, inspection, etc.). The properties addressed are geometrical properties, such as size, location, orientation, form and surface texture.

Nine geometrical properties are identified in the ISO GPS system:

- Size
- Distance
- Form
- Orientation
- Location
- Run-out
- Surface texture: profile
- Surface texture: areal
- Surface imperfections

The ISO GPS standards relating to each of these geometrical properties are subdivided into a series of nine categories of standards. Each category can be further subdivided into a number of specific elements and each of those specific elements identifies a chain of standards.

In order to describe each of these in an unambiguous way, each geometrical property must be specified, so that the properties can be checked and be compared with the verification by means of the requirements included in the specification. This conformance and non-conformance is described in chain link D.

The GPS standards relating to these requirements are specified in each chain of standards in links E to G. Chain link E describes the requirements for measuring feature properties and lays down the conditions under which this can be done. Chain link F describes the requirements governing the equipment used for measurement. Chain link G, in turn, specifies how this measuring equipment is to be calibrated.

Supplementary GPS standards referring to specific processes or specific machine elements can similarly be assigned to chain links.

Standards, properties and requirements can therefore be depicted in a matrix so that it is possible to indicate the scope of application of each standard and the relationships between individual standards.

Matrix

The ISO GPS standards can be subdivided into

- fundamental ISO GPS standards (these specify rules, principles, concepts and precepts that apply to all categories (whether these be geometrical property categories or other categories) and to one or more chain links within the ISO GPS matrix)
- global ISO GPS standards (these specify rules that apply in all cases, e.g. ISO 1, unless they are invalidated by specific information stated on the drawing or within the model)
- general ISO GPS standards (these apply to one or more geometrical property categories, and to one or more chain links, but are not fundamental ISO GPS standards)
- complementary ISO GPS standards (these refer to specific manufacturing processes or to specific machine elements).

They can be arranged in a matrix of rows and columns. Each row in the matrix consists of one of the nine geometrical property categories, which may be further subdivided into chains of standards, and each column is described as a “chain link”. The scope of each ISO GPS standard can be illustrated on the ISO GPS matrix by showing which chain links (columns) in which geometrical property categories (rows) the standard applies to.

Recommendations

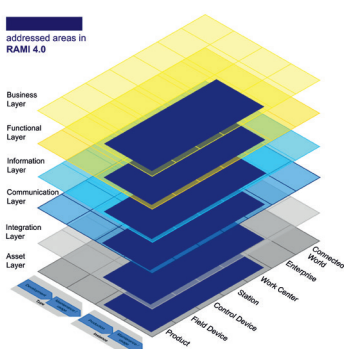
- 3.4-18** The Geometric Product Specification with all its special features and continual adaptations on the road towards “Industrie 4.0” as part of the digitalization process is dealt with by standards working group NA 152-03-02 AA. DIN EN ISO 14638:2015-12 is the basis for GPS. The responsible standards committee wishes to point out that in future standards-based discussions of the transparency and traceability of processes and products within the entire added value-adding process, it is important to ensure that there is a specification for each geometrical property.
- 3.4-19** The property must be measurable and it must ultimately be possible for the measurement of the property to be compared to the specification. The interaction between specification and verification and their mutual dependency must be achievable and/or guaranteed.

Bibliography

ISO 1: Geometrical product specifications (GPS) – Standard reference temperature for the specification of geometrical and dimensional properties

ISO 8015: Geometrical product specifications (GPS) – Fundamentals – Concepts, principles and rules

DIN EN ISO 14638: Geometrical product specifications (GPS) – Matrix model (ISO 14638:2015)



3.5 Life cycle record for Industrie 4.0 components

3.5.1 Modules and requirements for an electronic life cycle record

Over the life cycle of a product, a large amount of information is accumulated: during the design and development process, in production planning and when producing a series, batch or the instance (entity) itself, at the suppliers' premises or when extracting raw materials, during operation (operational data), during the course of maintenance and repair, during alterations and changes of use or ownership, right through to re-use (in full or in part) or recycling. Today, these data can generally only be obtained from the party responsible during each individual phase, if at all, and it is usually impossible to match them to a specific individual product without considerable effort. Much of these data are generated during development and production and, in the case of more complex products, can be accessed along with the operational data for mainte-

nance or repair, though they are mostly only available in paper form. In the case of food products and medicines, traceability is required by law. Closing the life cycle is not possible for the majority of products due to the fact that parties such as re-users only have very little, or insufficient, information about the product.

Within Industrie 4.0 itself, work is underway in many places to develop modules that will enable life cycle data management. This section provides an overview of these activities, and highlights the type of holistic approach that is still required. To relate the data to its context, see the Semantics section.

An Industrie 4.0 component consists of an asset (hardware, software or even an employee) and the administration shell (see Section 3.4.5 The administration shell and Industrie 4.0 component), in which all relevant information is collected and can be made available subject to a suitable means of secured access. The unique properties in accordance with eCI@ss mean that product properties are available electronically and have a unified form and semantics. DIN 77005-1 sets out the details of a life cycle record for technical systems. The ISO 20140 series currently under development describes the recording, agglomeration and evaluation of environmental and energy-efficiency data in production. These can be shown either for a variety of tasks related to production or for specific products.

If we view these modules together, we can see how data is captured during the course of the product life cycle, how it is collected in the administration shell in relation to components and products, and how it can be aggregated whenever components are assembled. This information can additionally be assigned to the life cycle of the product type (see also DIN EN 62890).

To ensure the management of information relating to life cycles, a combination of dependable information structures and possibilities to expand those structures is required. Here, it must be taken into account that the requirements relating to data and/or information management may change, depending on the point of the life cycle that has been reached.

The data in the administration shells can be of any level of complexity. They form a structure. Administration shells also need to reflect this structure, or take it into account. Administration shells must also reflect areas of responsibility for individual items of information. The full documentation of the primary asset is therefore made up of the sum of all subordinated administration shells.

The information in the administration shell should be labelled with details of its purpose. This focus upon purpose is required in the case of needs-based information logistics for business processes, technological assignments or data protection.

3.5.2 Life cycle record in accordance with DIN 77005-1

The term “life cycle record” is understood to refer to the mass of information that is accumulated throughout the entire life cycle of an asset. This information is structured in a uniform manner in accordance with an information model, in order, say, to guarantee the chronological traceability of the information concerned. General management rules and a method of application have been put in place to ensure consistent management of life cycle records.

Draft standard DIN 77005-1 specifies requirements for life cycle records and refers to systems used in processing, energy and production technology (see also Section 3.6 Life cycle of production systems). It describes the elements of a life cycle record in a neutral way without elaborating on specific technical implementations. The specifications of the standard can also be made to apply to Industrie 4.0 components.

The aim of the standard is to define a uniform approach towards the administration of asset-related information and to define both structural and dynamic specifications. The relevance of information derives from the legal and standard-based framework conditions that apply to the asset. Taking these as a basis, fundamental specifications are laid down with regard to management, in order to ensure that the administration of the life cycle takes place in a structured manner and is, ideally, of proven quality assurance. These specifications are also given in more detail in the form of a method for their application.

At the heart of this approach is what is known as “documented information” (see ISO 9001), which stands for all types of information (both documents and master data or transaction data). To be able to express how this information relates to systems and equipment, a systems structure has to be defined. This is obligatory for all documented information. An information model helps ensure that all information is presented in structured form. In view of the fact that a large quantity of information can accumulate during the lifetime or life cycle of an asset, it may be difficult to find the information required for a specific context. This is why a view concept was introduced as part of the information model. It enables the input of metadata for each item of documented information. The metadata are derived from the information needs of typical roles. To ensure that the life cycle records can be used as flexibly as possible, “specifications” have been introduced that describe the form each individual life cycle record should take.

Figure 11 below illustrates the life cycle record approach. It is based on the requirements from system-related processes and rules governing life cycle record management. Taking this as a basis, the information model describes the structure of the life cycle record, together with the information it is to contain.

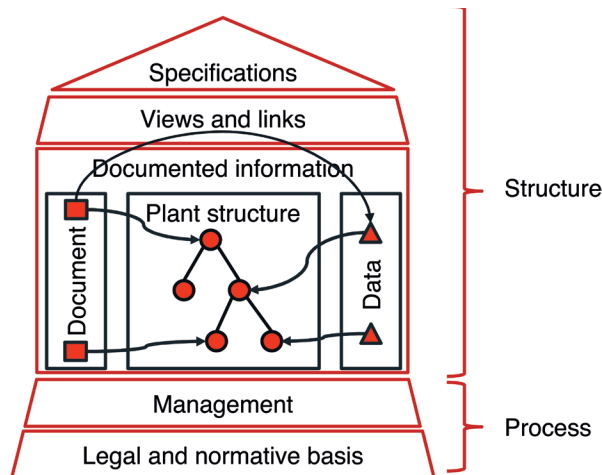


Figure 11:
Information model for the life cycle record in accordance with DIN 77005-1

The information model in the standard essentially describes four core entities and their properties (in the form of metadata): the life cycle record, the set of information, the view and the specifications.

A life cycle record always relates to an asset. That asset may take the form of a plant, a system, a product type or even a specific product. Depending on the nature of the asset, we can distinguish between three types of life cycle record. In order to be able to structure the information relating to complex assets, life cycle records can be subdivided into subordinate life cycle records, thereby forming a hierarchy.

All documented information must be enclosed by a set of information so as to group together information that belongs together and ensure its chronological traceability. Each item of information documented and the set of information itself possess an unambiguous reference to an asset.

The significance and evaluation of documented information may change during the life cycle of the asset or depending upon who uses the information (roles). A view is an aid that makes it possible to show the information needs of the various users. It is important to note that the various roles make use of different evaluations, and also different languages and classifications. This means that from a technical perspective, an item of documented information in the life cycle record may, for example, be regarded as critical, whilst from an economic perspective, that may not be the case. In addition, specific metadata are required for each user, so that the context and the meaning of the information actually documented can be exploited more effectively. For that reason, the DIN 77005-1-compliant life cycle record makes it possible for each item of information documented to be annotated from various views. The draft standard distinguishes between the economic, legal, material, technical and process technology views. It is however possible to define additional views. The ZVEI administration shell also contains a variety of views: business, design, performance, functional, local, security, network view, life cycle and human.

The specification “entity” is used to set out how the the life cycle record is to be structured, and also provides the user with flexibility when it comes to defining the metadata of each view. Thus, the information model is a meta model and the specifications represent a model of a life cycle record (see also DIN SPEC 40912). Within the specifications, it is possible to specify the structure of the metadata that is to be referred to in the views, and also values for those structures. The structures can then be assigned to the various views.

3.5.3 Transferability of the life cycle record to Industrie 4.0 components

Draft standard DIN 77005-1 contains a variety of concepts that are also of interest in connection with life cycle-oriented information management for administration shells. They describe a holistic approach that enables information to be structured in such a way that it can form complex systems and be evaluated using the views. Comprehensive information regarding complex objects can be subdivided into a hierarchy of life cycle records. By means of the specifications, it is possible to ensure that the various types of documented information are traceable. One example is the allocation of information to processes and another example relates to the legal requirements.

Overall, use of the life cycle record enables the context of the information to be recorded and evaluated in a systematic way. The method of application ensures that all parties involved make use of the life cycle record in the same way. The definitions of views in DIN 77005-1 are geared towards the processes and activities that take place in technical systems. These must be compared to the existing views that exist within the administration shell. The standard does not specify that the life cycle record should be in digital format. Instead, it takes the view that its provisions should be capable of being used for both paper-based and digital life cycle records.

The German standard DIN 77005-1 shows how a digital life cycle record can be designed for technical systems. Given the various purposes for which the life cycle record is to be used, the standard must incorporate different levels of detail. Whilst DIN 77005-1 places an emphasis on fundamental structural principles for life cycle records of technical systems, further standards are currently being developed to define the individual properties of systems and objects.

It is frequently observed that these standards and drafts are selecting different terms for key concepts, which, if examined more closely, can be regarded as synonyms. Different terms are also used when referring to the digital image of the physical object, such as the digital shadow, digital twin, digital life cycle record or administration shell. This inconsistent use of synonyms or terms with, at the very least, similar meanings frequently makes the transfer and re-use of these standards difficult in practice.

In the future, management of the life cycle data of an Industrie 4.0 component will focus on two key challenges:

- ensuring that data and properties are assigned to views in a methodical way that is tailored to specific needs
- ensuring the coordinated and structured management of data and information

Recommendations

3.5-1 Standardization of the terminology used to describe Industrie 4.0 components:

- Standardized descriptions of the properties of Industrie 4.0 components
- Based on the approaches and structures set out in DIN 77005-1, a generalized approach must be adopted for all types of Industrie 4.0 components
- As set out in DIN 77005-1 in connection with the life cycle record for technical systems, various user perspectives/views must be taken into account, so as to enable the data to be used for a specific purpose or application. Views currently existing should be expanded if necessary.
- There should be standards for using component data throughout a life cycle.
- The German standard on life cycle records should become established at international level.

3.5-2 The standardized use of the life cycle record has the potential to contribute towards increased integration between the various stakeholders and disciplines involved in Industrie 4.0:

- Standards must be defined for a variety of applications
- Account must be taken of the legal context, in order to ensure that all legal requirements are fulfilled (or in order to ensure user support)
 - e.g. indication of the location of the component, in order to determine the legal framework
 - the “legal framework” that applies in each case (including the standards context) should be recorded and linked in the life cycle record

3.5.4 The life cycle record in an environmental context

Based on the logic underlying the production and service networks that typify Industrie 4.0, it follows that essential information must be carried forward consistently, either with or on a product, throughout entire processes and value-added chains. In this way, process chains will become more transparent while the traceability of materials and process steps will increase. As digitalization increases, we will see an increasing amalgamation of the product life cycle phases, starting with the upstream chains (including raw material extraction) and continuing on through the usage

phase until such time as the product reaches the end of its life and is disposed of. The life cycle record referred to above could portray the complex data and networking structures on the one hand, and target and user-oriented output on the other.

Within an Industry 4.0 environment, the availability of data as a whole has significantly increased. The same applies to information and/or knowledge of processes, process chains, processing statuses, products, machinery, material flows, energy consumption, etc. From an environmental point of view, the smart aggregation, combination, structuring and evaluation of the available data open up completely new opportunities.

Conceivably, operational environmental management and environmental reporting also have optimization potential. Transfer errors could be avoided by using fully automatic, digital data capture and processing systems, and a largely automated reporting process would save both time and money. One of the prerequisites for all of the examples of applications referred to above is that the relevant data must always be digital and must have been recorded using standardized formats.

In an Industry 4.0 environment, all products and machines possess a full “digital image”, in which information is stored about the product or machine itself and about the way in which it was produced. This “digital image” could contain a variety of product parameters and production data, as well as information on transportation and environmental compliance, on raw materials, recyclability and methods of disposal. It could not only “speak” with the production machinery (M2M) during the production phase but could also communicate, say, with the user’s smartphone during the usage phase, or with the return and recycling systems (smart containers, dismantling robots, processing machinery, etc.) at the end of the usage phase. The life cycle record could contain significant parts of the digital image.

Industrie 4.0 offers a great deal of potential for development in the drive to achieve a circular economy and a fundamentally more efficient and sustainable use of all types of materials. During the transition of a product to the usage phase and the subsequent disposal phase, key information about the product is currently lost, although this is essential to ensure the product is used in a sustainable way and undergoes high-quality recycling at the end of its life. Introducing a life cycle record and the associated continuous carrying forward of product-specific information would mean that in the future, specific product information would be made available to the user throughout the life cycle of the product.

Industrie 4.0 offers scope for completely new business models and innovative ideas. For example, it would be possible to conceive of a web-based, automated secondary raw material trading platform, which, with the assistance of the life cycle record, would be able to offer its customers more, and more specific, product data and thereby offer, and guarantee, defined qualities of secondary raw materials. Recyclable materials could then remain in circulation for as long as possible, increasing efficiency and achieving the aim of a “circular economy”.

If, in the future, it is intended to achieve the interoperability and aggregation of data (for example, across entire process chains or material flows, beginning with the processing of raw materials right through to disposal, or product-related data), all the data formats currently in use must be harmonized, must conform to internationally agreed standards and must be stored in digital format in accordance with clearly established rules, such as in the form of a life cycle record. For example, this would apply to data from operational environmental management, emissions reporting, hazardous substance management, recycling or disposal.

It also needs to be pointed out that greater data availability is only useful or appealing if the data can be extracted, prepared and made available to the user in a simple, cost-effective way using universally available technology. Thanks to the global proliferation of smartphones and tablets, such technology is largely already available. However, if we are to obtain maximum utility from the potential of digitalization, there is still significant need for standardization in a number of areas: the data themselves, the definition of the interfaces (e.g. between users and disposal companies) and data transfer formats (e.g. for extracting the “memory” of a product).

Recommendations

- 3.5-3** The data formats stored in the “digital image” (life cycle record, etc.) of products, machines and other objects, must, in terms of their size, compatibility, etc. be standardized on an international level, with international consensus-based standards needing to be developed in the long term.
- 3.5-4** Digital interfaces or “transitions” to upstream or downstream chains that form part of the production chain or relate to a product must be defined and standardized. This applies in particular if the product data cannot continually be displayed throughout the entire value-added chain by means of one single joint model, such as the life cycle record.
- 3.5-5** Standards and specifications should also be developed on the user-related digital image of products, namely the “product memory”. Work must be undertaken in this area to ensure that harmonization on an international level is achieved in the long term.
- 3.5-6** Information transfer (wireless, QR-code, barcode, etc.) from, say, a product (product memory) to the user level (smartphone, tablet, etc.) also needs to be standardized if it is to be used efficiently and on an international level.

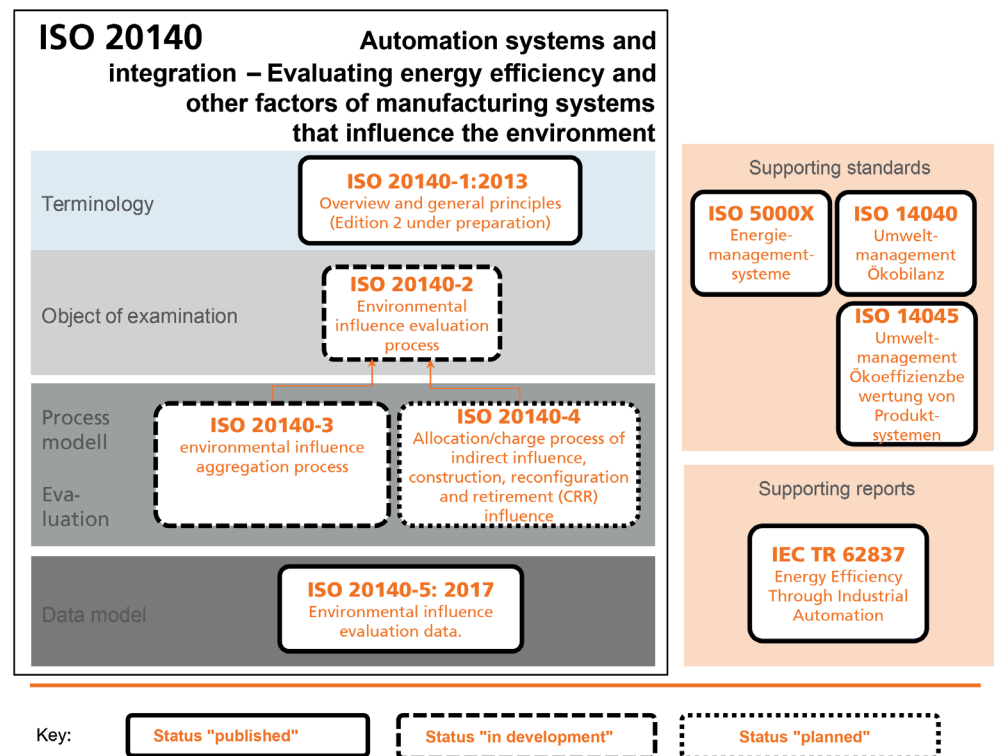
3.5.5 The recording of environment-related data during production

ISO 20140

An example of how International Standards in the field of data and sustainability management in production are developed is ISO 20140. The standard is based on the concept of the life cycle of production systems and products, and allows companies to measure and evaluate the sustainability of their production processes and to manage them with regard to their consumption of energy and resources, emissions and other environmentally relevant data.

The evaluation can be scaled across all levels of production systems: from an individual process to the production line and the factory, through to the entire value-added system. The evaluation can also be related to products, starting with the raw material and individual components through to the saleable product itself, the production batches and even entire product classes.

Figure 12:
Overview of ISO 20140



This series of standards is currently under development. It will consist of five parts – see Figure 12. Part 1, which is a general overview, has already been published, but is currently being revised in connection with the development of Part 2 (Evaluation process) and Part 3 (Data aggregation process). Part 5 (Data specification, extraction of data from automation

systems) has already been published in its first edition, but will need to be adapted in the light of the new parts.

The provisions and models contained within the ISO 20140 series are intended as part of the specifications in the life cycle record. The various model elements must also be assigned to the views, in order to ensure that the information is provided and can be evaluated in a manner that reflects the needs of the user. By associating the information from other views, optimum support for sustainability management systems can be given.

Recommendations

- 3.5-7** All the data aggregated in accordance with ISO 20140 during the manufacturing process, together with all the data of relevance to re-manufacturing, recycling or disposal, should be made available in the life cycle record until the product reaches the end of its service life.
- 3.5-8** A system for the management of data relating to hazardous substances must additionally be incorporated or be given a similar structure. This data will especially be required at the end of the product's service life so that it can either be re-used and/or recycled.
- 3.5-9** It must be examined whether the specifications laid down in this series of standards can be presented as reusable requirements on the lines of DIN 77005-1.

3.5.6 Use of the life cycle record in the context of occupational health and safety

There is a wealth of data and of information generated during the life cycle of a “smart factory” as a socio-technical system, including information generated in connection with the associated upstream, parallel and downstream performance, value-adding and support processes. This includes large quantities of data and information relating to work processes, work systems and employment relationships in a dynamic, closely interlinked “system of work systems”, largely via digital media. A considerable portion of that data and information consists of data directly relating to individuals, or that can be traced back to individuals (such as in the context of quality management, product liability or traceability required for other reasons). At the same time, large quantities of data and information for the protection of employees and the environment are collected (such as in connection with human-robot collaboration or in work using digital assistance systems), which once again, can be directly or indirectly attributable to individuals.

As a result, multiple problems and areas for action have remained concealed and received too little attention from standardization with regard to life cycle data management, Industrie 4.0 production systems as a whole, and individual Industrie 4.0 components:

- It is important that factors such as legislation, collective labour agreements and labour/management contracts, standards, directives, and technical regulations governing corporate co-determination, occupational health and safety and employee data protection are taken into account, from both a proactive and a preventative perspective, early in the planning stage, and also during requirements engineering and the socio-technical implementation of Industrie 4.0 production systems. However, it should not be assumed that these laws, agreements, rules and standards are automatically an inherent part of the knowledge base of many of the specialists that play a significant role in the technical and socio-technical planning and design/implementation of Industrie 4.0 production systems and individual Industrie 4.0 components, nor do these specialists always regard possession of this knowledge as a necessary element of their professional profile. At the same time, these laws, agreements, rules and standards are currently not available in a form that is appropriate or suitably prepared for the socio-technical design process of Industrie 4.0 as a “system of work processes and work systems”. This situation is hindering the consistent observance and proactive and preventative application of those laws, agreements, rules and standards from the very beginning and throughout the entire life cycle.
- The generally acknowledged characteristics of Industrie 4.0 production systems include their realization in the form of dynamic, global, cross-company value-adding processes and performance networks in the “Internet of Everything” (through to the ad hoc value-added network). From the employees’ point of view, this factor alone gives rise to a considerable lack of transparency and considerable uncertainty with regard to the laws, agreements, rules, standards and other standard baselines that apply in their areas of employment and the job they are to perform. In the global business process, which frequently transcends the boundaries of individual companies, contradictions and inconsistencies may occur, which can quickly lead to a lack of transparency and traceability.
- As mentioned above in connection with the lack of transparency and barriers to information in respect of worker and employment protection and standards, there is an abundance of laws, collective labour agreements, rules and standards that need to be taken into consideration within the planning and realization process of Industrie 4.0 production systems and their associated components. At the present time, we lack uniform, accessible tools for recording and documenting efforts in that area over life cycles. There is also a lack of standards aimed at providing more detailed specifications and facilitating implementation, both in relation to the design of the work system in the context of Industrie 4.0 production systems, and the new individual fields of design (part of which have undergone considerable change as a result of Industrie 4.0) that relate to the creation of task structures that promote innovation, skills development and health, and product and process ergonomics aimed at enhancing the suitability-for-purpose of work information and equipment.
- With regard to the large quantities of personal data and data traceable to individuals that arise during the operation of Industrie 4.0 production systems (some of which occurs as a

result of the processes and some of which is collected in a targeted way), it is necessary to ensure that the laws, agreements, rules and standards whose purpose it is to protect employees are consistently incorporated as a core set of shared values on which all actions are based (following the tenets of Corporate Social Responsibility). They must be incorporated as a system of corporate targets, both in the system design and in the everyday practice of the Industrie 4.0 production system and in the planning and socio-technical realization of the individual Industrie 4.0 components. This specifically applies to

- the right to informational self-determination as a fundamental right derived, in its census judgment, by the Federal Constitutional Court from the personal rights enjoyed by an individual (Article 2, paragraph 1 of the Grundgesetz [Federal Basic Law], in conjunction with Article 1, paragraph 1 of the Federal Basic Law)
- the fundamental right guaranteeing the confidentiality and integrity of information stored within IT-based systems (fundamental right to digital privacy)
- the secrecy of telecommunications (Article 10, paragraph 1 of the Federal Basic Law)
- the fundamental principles of data protection law in accordance with the European General Data Protection Regulation and the Bundesdatenschutzgesetz [German Federal Data Protection Act], namely the principle of the legality of data processing, the principle of data minimization, the principle that data may only be used for the purpose for which it was collected and the principle of guaranteeing the security of data
- the tenet, derived from those principles and fundamental rights, that the employer is only entitled to process the personal data of employees if this is necessary and appropriate (proportionate) for the purposes required under the employment relationship
- the fact that the continuous monitoring of the performance and/or behaviour of an employee is fundamentally prohibited
- the tenet that the purpose of any handling of the employee's personal data must be clearly defined in advance and that the transparency of the checks must be ensured.

When comparing these fundamental rights and principles with actual everyday practice in the handling of data and information within existing Industrie 4.0 production systems and Industrie 4.0 components currently available on the market, many observers believe that an implementation loophole exists within companies and within society itself. The actual magnitude of this loophole is not yet able to be determined due to a lack of adequate resources and methods laying the groundwork for transparency and traceability.

Recommendations

- 3.5-10** The socio-technical aspects of design and the related design process must be appropriately reflected in the digital life cycle record of Industrie 4.0 components and Industrie 4.0 production systems as a whole.

- 3.5-11** Checks should be carried out to determine whether and in what way the digital life cycle record of Industrie 4.0 components and Industrie 4.0 production systems could be used as a suitable means of reminding stakeholders, in a pragmatic and effective way, of the rules, laws and standards governing the design of work and employment in the design process and operation of Industrie 4.0 components and production systems.
- 3.5-12** Supplementary and more detailed standards should be developed that increase the normative pressure to take account of the aforementioned socio-technical aspects. These pragmatic and simple forms of documentation would be used to provide proof that planning and requirements engineering have taken account of these design aspects, from planning and requirements engineering to realization, system operation, reconfiguration and winding down/disassembly.

References

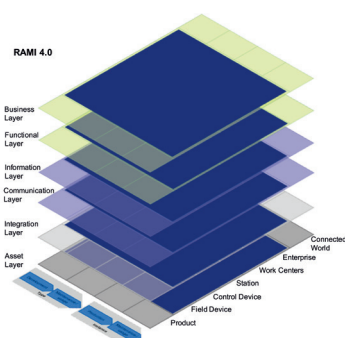
ZVEI: Struktur der Verwaltungsschale – Fortentwicklung des Referenzmodells für die Industrie 4.0-Komponente [Structure of the administration shell – Further development of the reference model for the Industrie 4.0 component]

DIN EN 62890 (VDE 0810-890): Life-cycle management for systems and products used in industrial-process measurement, control and automation (IEC 65/617/CDV:2016)

DIN 77005-1: Life cycle record of technical objects – Part 1: Terms and structure

DIN SPEC 40912: Core models – Specification and Examples

DIN EN 62507-1: Identification systems enabling unambiguous information interchange – Requirements; Part 1: Principles and methods (IEC 62507-1:2010)



3.6 Life cycle of production systems

3.6.1 Initial situation

A highly diverse range of components and systems are developed in the environment of Industry 4.0. The extent to which development processes and indicators can be standardized (and the extent to which this would be useful at all) is not currently foreseeable.

The digital factory is an important topic within Industry 4.0. In that context, development, engineering and construction are especially worthy of mention as difficult synthesis processes

which require a multitude of auxiliary and ancillary processes (artificial intelligence, simulation, verification, etc.). The resulting requirements for system architecture have to be taken into account in the Industry 4.0 concepts.

3.6.2 Areas of application

- Development of products
- Development of functional elements (functional, software-based, mechatronic)
- Modelling and simulation in the course of development
- Consistency of development in product families and variant management
- Verification and quality assurance for the components developed
- Service engineering
- Product development and system planning in the digital factory
- Simulation in advance of physical implementation, and virtual commissioning
- Simulation during operation for optimization planning and adaptability
- Consistency of development and engineering throughout the life cycle (of both the products and the production systems and factories)
- Construction and commissioning
- Maintenance
- Re-use or recycling

3.6.3 Development

The increasing complexity of software applications in the context of Industrie 4.0 leads developers to make use of supporting tools. At the present time, developers are mostly making use of conventional software development tools, such as Git³¹ (a version-management and source-code management system), Codebeamer³², Jira³³ (a project management tool), Jenkins³⁴ (a build-management tool), SonarQube³⁵ (code-quality analyses), or Docker³⁶ (a virtualization operating system in containers). Nevertheless, the list of conventional software development tools must be expanded to include additional, specific tools for the development of Industrie 4.0 technologies, such as embedded systems, IIoT and smart distributed applications. What is more, developers should be provided with suitable standards that lay down the specific require-

31 <https://git-scm.com/>

32 <https://codebeamer.com>

33 www.atlassian.com/software/jira

34 <https://jenkins.io/>

35 www.sonarqube.org

36 www.docker.com

ments for the development of software and hardware, such as firmware updates to a CPS via a cloud-based platform.

One of the central ideas of Industrie 4.0 is integrated product and process development. Terms such as “digital factory”, “reverse engineering”, “model-based development”, “concurrent engineering” and “automated synthesis” show that this issue has already been discussed in the past. If we examine them in detail, however, the various tasks and functions exhibit crucial differences. The development of a mechatronic component, for example, is fundamentally different from the development of a new vaccine or new type of plant. Nevertheless, product descriptions, descriptions of requirements and descriptions of the process steps and process dynamics (for simulation and production automation, etc.) play an important role in all cases. There are already working groups dealing with standardization on this topic in professional associations and standards organizations. These groups must be supported by providing fundamental data structures and architectures, within which the various requirements of the different industries can be mapped as uniformly as possible.

Recommendations

- 3.6-1** Create a transparent and seamless database and development tools for the product life cycle as a whole
- 3.6-2** Ensure qualified IT developments are given timely support in the form of standards and specifications in the field of automation
- 3.6-3** Carry out research and development projects to prepare and support the fundamental development of system standards for cooperating systems, that specify, for example, the development of procedures and, more specifically, their chronological progression.

In the field of technology and solutions, there are a great many well-proven standards and specifications serving to ensure the future-proof and interoperable interaction of components in heterogeneous networks. Given this situation, there is no urgent need to make any changes to established procedures. Generally speaking, the approach is a conservative one. The standards are only defined on the basis of the technology that already exists and is generally available. In the future, it should be verified individually whether or not it would make sense for identifiable IT developments to be incorporated into consensus-based standards more quickly. One of the prerequisites for this is to carry out a critical analysis to establish the extent to which a new IT development has the potential to be successful on a broad scale in the field of industrial automation.

3.6.4 Maintenance

(see also Section 3.7.6 Maintainability)

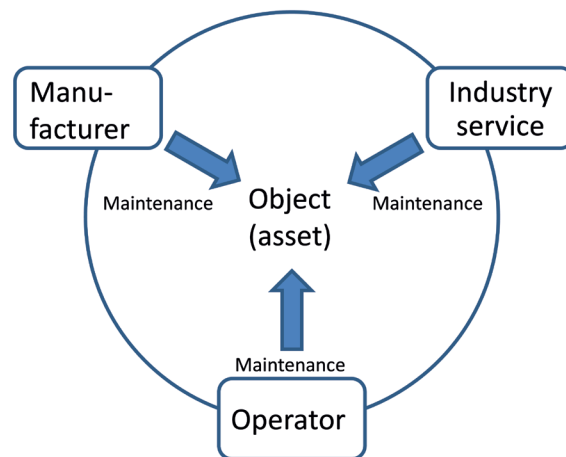
Increasing automation and the catenation of production are also giving rise to an increase in requirements in terms of reliability and availability. As a result, maintenance continues to gain in importance, and its function as a guarantor of the availability and reliability of machinery and plants means that it will come to play a key role. At the same time, maintenance must ensure that its own strategy, organization and management adapt to this transition. Standards and specifications are an essential tool in this transition process. Amongst other things, they help by regulating the cooperation between the various actors involved in maintenance. The existence and application of such standards have become indispensable for maintenance, especially in production environments operating in accordance with the principles of Industrie 4.0.

In addition to technological standards, the vision for “smart maintenance” in Industrie 4.0 will also need to include standards for plant management. Smart maintenance defines itself as the “enabler” of Industrie 4.0, in that it is responsible for ensuring that the cyber-physical systems (CPS), which are characterized by an enhanced degree of networking, digitalization, decentralization and autonomy, are kept efficient and readily available.

In the context of smart maintenance, reactive and periodic preventative maintenance strategies are increasingly being replaced by predictive ones. In the future, smart, interconnected plants will identify a large proportion of their faults before they occur. Their ability to do this will be provided by condition monitoring technologies, in which a wide range of data relating to a plant will be captured using special sensors. The condition management system will also need to be notified of any manual interventions that alter the behaviour of the plant. To that end, it will be necessary to ensure that the user interface between the specialist personnel carrying out the maintenance and the plant is made compatible, and likewise the data interface via which this maintenance information can be submitted. VDI/VDE-GMA FA 7.26 is currently drawing up a standard for an interface that will enable current maintenance information to be entered into the condition monitoring system.

Condition monitoring and predictive maintenance will only enable the acquisition of new knowledge on maintenance if the plant data that are usually captured automatically are linked to the experience of the maintenance personnel. To this end, algorithms will need to be developed that will also take into account the activities and experiences that form part of maintenance. In addition, the condition monitoring and predictive maintenance systems must be configured in a manner that provides sufficient scope for manufacturers, but also plant operators and authorized service providers, to be able to evaluate the data in the context of predictive maintenance.

Figure 13:
Interaction in the context of
smart maintenance



Smart maintenance will also be characterized by the intensive interaction of various service providers (manufacturers, operators, industrial services) for the maintenance of individual plants (Figure 13).

Manufacturers of Industrie 4.0 plants regard plant maintenance as an after-sales service that is additional to their product business and makes a substantial contribution to the turnover and profit of their businesses. Furthermore, this after-sales service reinforces customer loyalty and provides manufacturers with an opportunity to differentiate themselves from their competitors, something that is becoming increasingly difficult to do in the context of product business in the conventional sense. And finally, the close customer contact that constitutes part of plant maintenance services, not to mention the operational data and the experience of service personnel in carrying out maintenance work, can be utilized as a means of improving subsequent generations of the same product.

Plant operators are users of an Industrie 4.0 plant and rely upon the interchangeability of system components. To that end, the availability of general descriptions of Industrie 4.0 components is urgently required. The maintenance managers must maintain control of the interface management between the various service providers involved and must take on the role of system integrators. This will require the availability of standardized role profiles, competence descriptions or qualification modules.

The industrial services sector sees itself as a provider of know-how and as an innovation partner for production companies. By providing specialist and multidisciplinary services, industrial service companies make a substantial contribution towards the successful introduction of Industrie 4.0 within the processes of their clients. On the one hand, this can be achieved by providing specialist advice and support in the form of project resources, and on the other hand, by providing technology in addition to processes that the service provider has developed itself. For industrial services in particular, uniform rules governing the delegation and documentation of tasks, standardized lists of services and specifications of work, data exchange standards for

certification and qualification purposes, and reference processes are important for the success of their business models.

For all three types of service provider, (manufacturers, operators and industrial services), an important part of smart maintenance will involve the capture and the processing of all data relating to the objects to be maintained and to the maintenance processes themselves. In this document, these are collectively referred to as maintenance data (Figure 14).

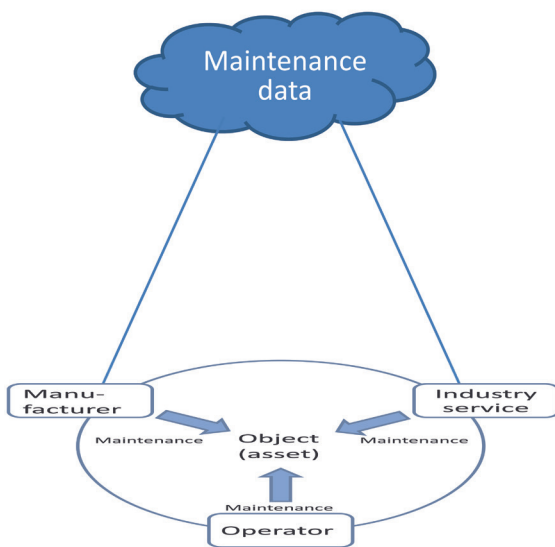


Figure 14:
Shared maintenance data
in the context of
smart maintenance

In order to enable the shared use of maintenance data, and to place such shared use on a legal footing, the technical details regarding communication within a CPS (human to human, human to machine and machine to machine) and the exchange of information, data and knowledge across company boundaries must be unified and the arrangements formalized. A digital life cycle record, as required by DIN 77005-1 (to be published in 2018), should provide a baseline for the standardized, structured storage of data and information across company boundaries.

In addition to standards governing the sharing of data, it will also be necessary to have a common “language” that can be used in the interactions between the stakeholders within the maintenance process. A shared “language” of that type will be based, amongst other things, on a uniform understanding of the concepts involved, as well as upon a set of mutually agreed maintenance processes. Non asset-specific basic standards for maintenance will form the foundation for specialist or sector-specific standards governing aspects specific to maintenance. For example, uniform definitions of the concepts underlying all types of maintenance and maintenance management have already been formulated in DIN EN 13306:2018-02, irrespective of the objects or maintenance stakeholders involved. A detailed specification of the essential processes that form part of an overarching maintenance organization and the associated reciprocal relationships can be found in DIN EN 17007:2018, thereby ensuring that all involved in maintenance share the same understanding of the process.

Maintenance plays a key role within the life cycle of a plant, due to the fact that it has a significant effect on the service life of the plant itself. Maintenance can only fully do justice to this role if the relevant requirements are taken into account in the early stages of the plant's life cycle. Precisely how this can be achieved can be seen in DIN EN 16646:2015-03, which deals with maintenance within physical asset management.

From a maintenance point of view, the provision of spare parts throughout the entire life cycle of a plant is also extremely important. Obsolescence management is becoming increasingly important, due to the fact that in the event that replacement parts are not available, current strategies, such as producing replicas or retrieving parts, are only possible to a limited degree where Industrie 4.0 plants are concerned. Many of today's "smart" components incorporate electronic elements and include software, making replication impossible. DIN EN 62402:2017-09 sets out requirements governing obsolescence management of assets and deals with all types of assets, the availability of which may come to an end during the life cycle of the product. Obsolescence management should therefore be taken into account when Industrie 4.0 plants are first being conceived and developed.

In the context of smart maintenance, the integration of humans into their new work environment also plays a significant role. Given the requirement profile of maintenance, (with its one-off activities, creativity and flexibility in finding solutions, etc.), the full-scale automation of maintenance activities is not an option. As a result, personnel need to be suitably prepared for the changing working requirements by providing them with targeted and individual instruction and training. In addition, with the development of suitable assistance systems, maintenance personnel must be trained to understand complex relationships, to select and prepare data, to interact and communicate with machines and plants, and to make the correct decisions. With this in mind, the "Smart Maintenance for Smart Factories"³⁷ initiative sets out recommendations for politicians, the business sector and society that support these ideas and underline the importance of maintenance in the context of Industrie 4.0.

Recommendations

- 3.6-4** Maintenance aspects must be taken into account from the viewpoint of manufacturers and operators alike, including and especially in relation to standards governing predictive maintenance
- 3.6-5** The interfaces for the entry of current maintenance information (repair, servicing, conversion) in condition monitoring and predictive maintenance systems must be standardized

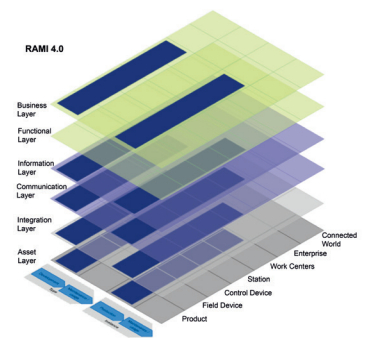
³⁷ www.acatech.de/uk/home-uk/work-and-results/projects/smart-maintenance-for-smart-factories.html

- 3.6-6** Uniform maintenance terminology compliant with DIN EN 13306:2018-02 should be used in all standards in which maintenance aspects are included
- 3.6-7** Coordinated process interfaces compliant with DIN EN 17007:2018 should be taken into account in all standards setting out maintenance processes
- 3.6-8** All stipulations governing Industrie 4.0 solutions should be evaluated in terms of the controllability of possible risks of obsolescence on the lines of DIN EN 62402:2017-09

3.7 Non-functional properties³⁸

3.7.1 Initial situation

The target systems of Industry 4.0 are industrial manufacturing systems. In addition to their actual function, these have to possess a series of non-functional properties to fulfil the operational requirements for efficient, safe and robust production. Non-functional properties are typically cross-cutting properties. Both the individual elements and the nature of their interaction in the interconnected system as a whole contribute to their fulfilment. The non-functional properties are already an important area for standardization. This involves defining and demarcating the property itself, and specifying quantitative limits for uniform classification and methods to ensure that those limits are actually maintained. It is a necessity and an objective for the systemic and systematic consideration of the non-functional properties also to be applied to the new concepts of Industry 4.0. The integral involvement of the worldwide information network, the cross-domain consideration of production chains and the inclusion of the business process level in that consideration result in a new system architecture, which has to be aligned with the concepts of the non-functional properties. This is an essential condition for implementation in operational practice.



3.7.2 Defining terminology for the non-functional properties

The concept of non-functional properties is increasingly gaining in importance even beyond the field of automation technology. Non-functional properties are to be designated explicitly in standards and defined as characteristics. The term “non-functional property” is defined in association with functional properties as follows: Functional properties refer, as the term indicates, to the function of a system. The function describes the relationship between the input and output variables of a system in general, i.e. what the user of a system expects from it. Functional prop-

³⁸ Each functional unit not only has the capability of performing its primary useful function (functional properties), but also other administrative and workflow-related properties. In automation technology, these are termed non-functional properties.

erties then refer to the input and output variables, such as available values or value range, and to properties of the function, such as the steadiness or opportunities for continuous or discrete change of the variables. These functions are implemented by real physical systems, i.e. devices and components. These also have properties which influence the way in which the functions are performed. These properties of the devices and components, which often entail restrictions in the provision and execution of the functions, are termed non-functional properties. This applies both to hardware and to software.

3.7.3 Functional safety

The objective of functional safety is to protect humans and the environment and to protect valuable goods from serious damage. Functional safety does not incorporate a risk model of its own. Risk models are always provided by a different domain, such as machine safety or process technology. A key concept within functional safety is the safety function, namely the task that must be fulfilled in order to keep the system under review in a safe condition or return it to a safe condition. Not only do IEC 61508³⁹, IEC 61511⁴⁰ and ISO 13849⁴¹ provide models for the analysis and evaluation of risks, but they also contain detailed models outlining approaches to identify the necessary precautions, how these are to be applied, and the types of equipment required. The standards include methods and key performance indicators that enable the risks and the reduction of risks to be determined in quantitative terms. The standards have proven their worth hitherto, and must also be stringently applied to future systems. There should be no attempt to reduce the requirements of the relevant functional safety standards in the aim of enabling IT systems designed to fulfil general purposes to be designated as safety-oriented systems.

Examples of issues that require examination include the following:

- Is it possible to prepare the risk assessment for components to such an extent that the risk assessment of an entire system, of which those components come to form part, can be carried out without human involvement?
- Is it possible to conclude that an entire system possesses certain risk-reducing properties, simply due to the fact that the components of which it is made up themselves possess such properties?
- Must configuration parameters for safety functions be securely handled within the administration shell?

39 See the DIN EN 61508 (VDE 0803) standards series "Functional safety of electrical/electronic/programmable electronic safety-related systems (E, E, PES) for the protection of people and the environment".

40 See the DIN EN 61511 (VDE 0810) standards series "Functional safety – Safety instrumented systems for the process industry sector".

41 See the DIN EN ISO 13849 standards series "Safety of machinery – Safety-related parts of control systems".

In the past, a number of standards committees have drawn up their own provisions to deal with functional safety that deviate from those laid down in the basic safety standard IEC 61508. Though these are not fundamentally different and do not make for unsafe products, they do give rise to differences in the terminology and metrics that form part of the stepped requirements. The merging together of systems specified in accordance with differing functional safety standards will mean increased complexity and higher costs. There is a justifiable fear that such systems may no longer be controllable if this trend continues.

In some places, overlaps have occurred between the non-functional properties referred to here. Standards setters and system architects are therefore called upon not only to fulfil a specialist role in respect of one of these properties, but also to study the approaches adopted in neighbouring areas. Any contradictions or duplication of effort should be reported back to the relevant standards committees. When developing standards in new areas, such contradictions or duplications of effort cannot be ruled out, but they should be kept to a minimum.

New areas of application will serve to define additional requirements applicable to safe systems and the relevant methods with which functional safety can be evaluated. They should therefore be examined to determine whether they may be of relevance to the objectives of Industrie 4.0.

3.7.4 Security

Security describes the protection of a system from impermissible external influences. The concepts are general and can, for example, serve as basic standards for concrete solutions or as a basis for product standards (e.g. “security by design”⁴²).

Security as a concept applies both to physical influences, e.g. entry into a room by unauthorized persons, and to impermissible influencing of an IT system via its communications interfaces. With the intensive use of the internet for control functions in automation systems, with virtualization and cloud computing, and also with the self-x technologies (self-configuration, self-healing and self-optimization) and the networking of smart functions as agents, IT security is of special importance in Industry 4.0. IT security is an essential condition for information security, and is closely connected to it.

The German Standardization Roadmap on IT Security deals with the standardization of security aspects. It provides an overview of the focal areas of IT security standardization which are currently at the forefront of discussions, and presents prospects and recommendations for action on the basis of the present discussions.

⁴² See also the implementation recommendations [Umsetzungsempfehlungen] by the “Industrie 4.0” working committee, page 50, item 1 „Security by Design”.
www.bmbf.de/files/Umsetzungsempfehlungen_Industrie4_0.pdf

The standardization roadmap IT Security is compiled and regularly updated by the IT Security Coordination Office at DIN in cooperation with DKE. The current version (in German) can be downloaded at www.din.de/go/kits.

3.7.5 Reliability and robustness

The objective of production safety is to ensure the robustness and reliability of the production systems. Irrespective of the question of serious damage to the plant or the environment or injury to human beings, failure of a production system is rarely tolerated today. Failures significantly reduce the performance of a system and impair competitiveness. Modern production systems take account of this aspect and are correspondingly designed to be robust and reliable. In the CPPS field, new concepts have to be developed to ensure failure safety even in a virtualized IT environment without significant additional costs.

However, in CPPS/Internet of Things systems, which are in some cases highly dynamically networked, system robustness is of special importance. It must not only take account of the properties of individual components, but must rather define a functionality docked onto the system as a whole.

3.7.6 Maintainability

(see also Section 3.6.4 Maintenance)

In this connection, maintainability is also of significance. This is the ability of a production system to be maintained rapidly and easily. The resulting requirements such as the opportunity for fault diagnosis, replaceability, modularity, preventive maintenance, etc., are already to be taken into account during the planning and conceptual design of a CPPS. After all, the maintainability of a system has a significant influence on the future workflow and cost of maintenance, and thus on the costs and cost-effectiveness of the system. The acceptance by customers of new Industry 4.0 solutions will therefore be influenced to a great extent by the maintainability of those solutions.

Fundamental aspects of maintainability are already described in DIN EN 60300-3-10:2015-01. The specific features of Industry 4.0 solutions, which result in particular from the vertical and horizontal integration of the systems, nevertheless require these aspects to be accompanied by further requirements on maintainability which are inherent in Industry 4.0: With the vertical integration of the business processes and systems, the various IT systems also have to be integrated for maintenance purposes in such a way that information on the current condition of the system is made available simply and rapidly to all relevant levels of the enterprise.

Standards on integrated solutions must however at the same time take account of aspects of modularity and interchangeability, so that they, as open systems, continue to enable the operators to procure the necessary services such as repairs, maintenance or condition monitoring independently from a variety of suppliers. In this context, particular attention is to be paid to the free exchangeability of condition data for condition monitoring. On the basis of VDMA Standard Sheet 24582, DKE Working Group 931.0.13 has compiled and submitted to IEC/SC 65E a standards proposal on condition monitoring functions for uniform treatment of condition monitoring data.

Furthermore, account has to be taken in standards on integrated systems of the usually different life cycles of parts of those systems. The obsolescence of one part of the system is not permitted to lead to obsolescence of the integrated system as a whole. Standards for integrated Industry 4.0 solutions are consequently to be drafted with attention to this aspect.

3.7.7 Addressing non-functional properties in standards

The description of non-functional properties, their objectives and the ensuing requirements in respect of regulation, the device manufacturers, the integrators, operators and users is an ambitious task and should be formulated in a comprehensive and unambiguous way. It should be the endeavour to define each non-functional property in the form of standards. The basic safety standards specifying functional safety are a very effective approach, as they view the aspect of functional safety from any context, which means that in principle, they can be used in all areas.

Recommendations

- 3.7-1** Taking use cases as a basis, safety functions should be classified in order to establish whether all classes can be specified in sufficient detail using the existing standards.
- 3.7-2** New standards for functional safety should be based on IEC 61508.
- 3.7-3** Deviations are only permissible if the models on which IEC 61508 is based are incapable of specifying the new situation sufficiently (due to a different life cycle, different failure models).
- 3.7-4** The existing, non-compliant standards that are required for an Industrie 4.0 environment, must be aligned with the terminology and key performance indicators in IEC 61508.

- 3.7-5 Specifications laid down in sector-specific standards, but which are of general significance for Industrie 4.0, should be transferred to the basic standard IEC 61508.
- 3.7-6 The solutions in connection with reliability and robustness must be classified, and key performance indicators must be defined that will enable their characteristic properties to be described in unambiguous terms. Forecasting a quantitative estimation of “reliability” as a property is very difficult in practice, however.
- 3.7-7 The maintainability of plant and machinery should be taken into account in all standards of relevance to Industrie 4.0 in conformity with DIN EN 60300-3-10:2015-01.
- 3.7-8 Duplication of work and non-functional properties in a variety of areas should be identified and reported to the relevant standards committees.
- 3.7-9 Efforts should be made to specify each non-functional property in standards.

3.8 Communication technologies

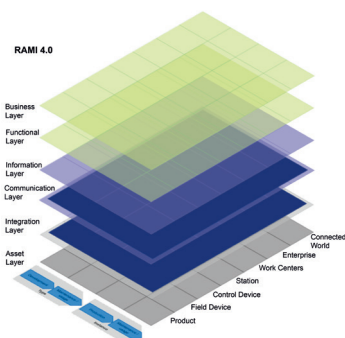
3.8.1 Initial situation

Communication requirements within Industrie 4.0

A significant aspect of the implementation of Industrie 4.0 is the networking of all instances involved in value creation. With regard to communication, this will involve the following changes compared to the current situation:

- The amount of communication within and between the hierarchy levels of the factory (RAMI 4.0 hierarchy levels) will increase considerably.
- Wireless communication between spatially and organizationally distributed instances will be necessary, whether for reasons of flexibility or because of the mobility of the instances themselves.
- Communication requirements do not continue to apply in the same manner throughout the entire life cycle of a production plant (known under RAMI 4.0 as the “life cycle value stream”), but will change in line with flexibility in production.
- The volatility of Industrie 4.0 processes also requires communication between the application process and the communication process.

The communication systems in use at the present time will be supplemented or replaced by new developments. Examples include Time Sensitive Networking (TSN) or developments in connection with 5th Generation mobile networking (5G). The existing standards and/or those under development must be examined to determine whether they are applicable. If necessary,



profiles must be specified to enable a conformity test to be carried out in order to ascertain the interoperability of products from different manufacturers.

The communications standards of IEEE or 3GPP specify the bit transfer layer (physical layer) for utility data traffic and the medium access (medium access control sub-layer). If no higher layers of the internet, such as IP, TCP or HTTP can be, or should be, used, additional specifications will need to be provided.

The communication requirements in the context of Industrie 4.0 will vary considerably. This means that a considerable variety of cable-based and wireless communication systems will be used. An open interface standard is gradually becoming established in the form of UPC UA, which masks the diverse nature of industrial communication systems in use. This interface standard complements existing communications solutions. It is based on concepts that are fundamentally new, such as a service-oriented architecture (SOA) and information models for the specification of devices and their capabilities. An SOA makes it possible for components, machinery and plants to act more flexibly if they are not designed and programmed to carry out a specific production task but instead provide basic capabilities as services. These include the ability not only to transport device data (measurement values, settings and parameter values), but also to describe them semantically in machine-readable form.

Initial situation of line-based communication

Industrial communication systems, also known as fieldbuses, already provide established solutions for line-bound communication which meets stringent requirements, on the basis of IEEE 802.3 (Ethernet). With Industry 4.0 networks which cover not only the shop floor but also the office floor, however, the previous requirements are joined by further requirements concerning modularization and the flexible addition, removal and rearrangement of modules. In addition to the non-hierarchical networking of the components, the increasing number of sensors and actuators and extended network connections for equipment, for instance for diagnosis purposes, result not only in increasing data traffic but also in changing needs with regard to the topology of the networks.

With regard to topology, we have two different worlds at present. On the one hand, the active, linear topology which is standard in industrial automation, in which every station has a switch which connects both incoming and outgoing lines and the internal link to the device. On the other hand, structured building cabling involves a star topology with the three hierarchical stages of campus, building and floor. Investigations should be performed to ascertain what an ideal network structure for Industry 4.0 looks like, and radio-based communication should also be included in those considerations. This covers communication within I4.0 components and networking between the various, in some cases mobile, I4.0 components, communication with the higher level automation devices and links with the commercial data processing systems, up to the cloud for data storage and cloud-based services. The solutions found are to be standardized.

In order to implement diagnosis and monitoring functions in an Industry 4.0 network, the infrastructure components of the line-based communications systems, both active (routers, switches, repeaters, etc.) and passive (cables and plugs), require virtual representation. The characteristics (data describing products and data related to their application) and the condition information of the infrastructure components are to be standardized in order to facilitate a uniform view.

Initial situation of radio-based communication

Communication resources cannot be expanded to the extent that would be required to fulfil the rapidly growth in communications requirements. The radio spectrum, in particular, is very restricted. Currently, radio communication makes use of radio spectra which are generally not exclusively used for a single purpose. Today, priority can only be given to particular radio-based applications if the regulatory authorities allocate a specific frequency or frequencies for that purpose. The flexibility of the production processes and the mobility of the instances also make it possible, however, to adapt the communication relations to the degree required. For example, IEC 62657 specifies a system of co-existence management that can be implemented either manually or automatically and is not frequency-dependent.

Flexible communication systems (such as mobile telephony systems) offer management and control services that enable the communication system used within a company to be adapted to the communication requirements that apply in each individual case. To make use of these services within the application process, it would make sense to regard communications devices as Industrie 4.0 components and to take account of the aspects laid down in the architecture layer of RAMI 4.0 during their development.

New communications technologies, together with the adaptivity of communication systems described above, also give rise to new requirements in terms of security. In addition, mobility and the determinism of the applications mean that communication systems must also provide radiolocation and chronological synchronization services.

Against this particular backdrop, the following standardization activities are recommended in connection with communications for Industrie 4.0.

3.8.2 Work to achieve exclusive frequency ranges for industrial automation

The flexible networking which characterizes Industry 4.0 scenarios will require more frequency bands than are currently available. Especially for applications with high demands for real time capability, determinism and availability, a frequency range for industrial systems which is avail-

able worldwide will be required. Amongst other topics, the ITU-R study period that is currently underway in the run-up to the World Radiocommunication Conference in 2019 is discussing issue 9.1.8 under agenda item 9.1, namely the technical and operational aspects of radio networks and systems, as well as the spectrum needed, including any possible harmonized use of the spectrum to support the implementation of machine-type communication structures.

Under that agenda item, the 5G-ACIA (5G Alliance for Connected Industry and Automation) newly set up within ZVEI (the Central Association for the Electrical and Electronics Industry) in Germany is drawing up proposals which it will submit to the ITU-R bodies for IMT-2020 bands (5G technology) and non-IMT bands (5.8 GHz ISM band), via the German Federal Network Agency. It looks as though it will be possible to have a spectrum assigned for exclusive use for industrial automation purposes within the 5G bands, based on orderly cooperation between all co-users.

User industries will have to step up their activities to contribute towards drawing up requirements, especially with regard to:

- Private, industrial network operations within bands designated for mobile telephony
- Cooperative network operations with a public network operator, making use of optimum spectrum resources, open interfaces for purposes such as network management functions and security requirements
- Procedures for 5G frequencies to be used on a regional basis for industrial automation purposes

Recommendation

- 3.8-1** Efforts to obtain a worldwide allocation of frequency spectra for industrial automation applications must be actively assisted by experts in measurement and automation technology. As the frequency spectrum is managed by the government authorities that hold sovereignty in each jurisdiction, it will be necessary to maintain close contact with the relevant administrations.

3.8.3 Network management

Complex communication networks for Industrie 4.0 will require automated management. The communication networks cannot be designed to meet the continual increase in demand for communication. The provision of communication services should instead be spread out to suit the changing requirements of the production process and the priorities these necessitate.

For network management purposes, a distinction is made between configuration services (management plane) and control services (control plane). Technologies such as Software Defined Networking (SDN) or Self Optimizing Networks (SON) are currently under development. It is a case of examining to what extent it will be possible to use these technologies for industrial communications networks based on Ethernet, Time-Sensitive Networking (TSN) or wireless communication technologies. Looking at standardization, the following aspects must be taken into account:

- Wired and wireless networks must be viewed together
- There must be access to the network diagnosis information needed for the automation applications
- It must be possible for the networks to be controlled in accordance with the requirements of the industrial applications prevalent at any given time
- The future will see a growing division of responsibilities for networks, communication components and/or automation devices (CPS), and distributed automation applications, and this must be taken into account

Services and protocols provided by communication components within industrial automation devices and infrastructural devices must be specified.

IEC 62657 specifies a frequency-independent co-existence management system for industrial radio communication applications that can be implemented both manually and automatically. These specifications must be taken into account when drawing up network management standards in the future.

Recommendation

- 3.8-2** Uniform specifications governing services and interfaces for the management of the various communications networks should be drawn up in a manner that reflects the applications to which they relate. Account must be taken of the need to distinguish between the provision of networks (management services) and the provision of communications services (control services).

3.8.4 Local industrial networks

Some of the radio technologies developed for home and office communications also satisfy the requirements of industrial automation applications. There are however some which are not suitable for these IT solutions. Special stipulations have therefore been made for automation technology in the standards IEC 61784-2, IEC 62591 (WirelessHART) and IEC 62601 (WIA-PA). For developments such as Near Field Communication (NFC) or reconfigurable systems such

as Software Defined and Cognitive Radio (SDR/CR), and also for new mobile telephony standards, it will have to be ascertained whether and for which applications they can be used without changes, or whether, for example, profiles have to be established for their application in the industrial field. Aspects of industrial applications are being dealt with by 3GPP and ETSI. Cooperation should be sought with these consortia and standardization organizations.

In the course of the implementation of Industry 4.0, a special radio standard will also become necessary for communication in the manufacturing cell or in the vicinity of the manufacturing machine. Sensors, for example, will play an increasingly important role in the identification of workpieces, in the control of machines and manufacturing cells, and in the documentation of the manufacturing process. They are the source of a process image which is exact as possible. On the other side, more and more actuators are involved in the production process. The wiring between the growing numbers of sensors and actuators in mechanical engineering is complex, and in some cases technically difficult to implement. Wireless incorporation of sensors and actuators will therefore gain in importance. The variety of suppliers of sensors and actuators, in some cases highly specialized, requires standardization of radio communications. The properties of simple sensors (endpoint devices) with regard to overall size, performance and price⁴³, are to be taken into account. Different approaches, where present, are to be harmonized, as diversity is not commercially viable in this field.

Recommendations

- 3.8-3** New standards for global mobile network technologies should be drafted or existing standards expanded in a form enabling such technologies to be used as local industrial networks.
- 3.8-4** New standards for global mobile network technologies should be drafted or existing standards expanded in a form enabling a seamless transition between (private) local industrial networks and industrial long-distance networks.

3.8.5 Integration of communications

The requirements for (uniform) management of communications systems with a wide range of technologies within the life cycle of manufacturing systems also have an effect on the role of those communications systems. They are not merely a means to an end (i.e. communication), but also an integral part of the production system. In contrast to office communications, the changing requirements on industrial communications are the result of using automation and a direct consequence of the increasing flexibility of the production process. As such, communica-

⁴³ A suitable candidate for standardization is available in the form of the IO Link Wireless specification.

tion assets should also be developed as Industry 4.0 components as defined within the reference architecture model for Industry 4.0. First it must be ascertained which assets would best benefit from the definition of a digital representation. It is a circumstance for discussion as to whether, in addition to assets such as modems, switches, base stations, etc., passive assets such as cables, plugs or antenna systems should be specified using administration shells.

Corresponding actions are to be taken for integration of the communications and management systems in the world of industrial automation. This applies to wired and wireless communication technologies in equal measure.

3.8.6 Industrial location management

Industrial location management is the systematic detection, management and representation of the geographical position of distributed and networked components of an automation system. There are highly diverse approaches to the performance of this function. Uniform standards on the following aspects are however lacking:

- Formats for location data
- Agreements on data storage (centralized/decentralized)
- Services and protocols for data transmission

As, with wireless networking in particular, the implied reference to a particular location is lost, work on this field is considered advisable.

The standards of ISO/IEC JTC 1/SC 31/WG 5 shall be the primary basis. It is recommended that those standards that are not yet part of the standards harmonization process for Industrie 4.0 should be incorporated, and if necessary further expanded.

In the past, ISO/IEC JTC 1/SC 31/WG 5 developed the standards for real-time location systems (RTLS). Numerous potential applications for such systems are emerging, especially in the context of Industrie 4.0, and these will require a more extensive harmonization of standards. This particularly applies with regard to ensuring their interoperability and their co-existence.

Potential applications are:

- Primary object-tracking (mobile/quasi-stationary devices, (semi-)transportable systems, (semi-)mobile manufacturing cells, semi-finished goods, tools, mobile edge devices, etc.)
- People-detection (movement, location, geo-fencing, etc.)
- Applications in production automation, inter- and intra-logistics, indoor localization in support of visualization and/or AR/VR applications in the context of digital twins

Alongside their elementary purpose, i.e. for object detection and tracking within a flexible automation solution, RTLS can also be used to enhance safety.

Examples include territorial and area protection, sharing of devices inside a building or on a company site, localization options (e.g. security function) for devices or individuals, or for fencing.

More far-reaching national and international standardization should focus on the interoperability and co-existence of the various systems-based implementations listed below (frequency band, technology).

RTLS functions primarily serve the purpose of

- a) establishing the actual location of an object
- and also, in some cases
- b) communicating between the RTLS transponder and the RTLS base station/reader.

At the present time, a variety of technologies using different bandwidths are employed for this purpose:

The majority of the applications that have implemented so far operate in the 2.4 GHz industrial, scientific and medical (ISM) band.

More recently, applications have become established that operate in the range between 6 GHz and 8.5 GHz using Ultra Wide Band (UWB) technology.

Alongside the 2.4 GHz frequency range, each of these frequency ranges has proven useful, as sufficient bandwidth is available (83 MHz and > 500 MHz respectively) to achieve the necessary – and requested – spatial resolution.

The most important standards that apply in this area:

ISO/IEC 24730-1 (RTLS API) defines an Application Programming Interface.

ISO/IEC 24730-1 makes use of SOAP (Simple Object Access Protocol) and is flexible and expandable.

ISO/IEC 24730-2 (2.4 GHz DSSS) defines an air interface that utilizes the 2.4–2.483-GHz range, which is known as “Direct Sequence Spread Spectrum”.

ISO/IEC 24730-5 (2.4 GHz CSS) utilizes the “Chirp Spread Spectrum” in the 2.4–2.483-GHz band.

ISO/IEC 24730-6 (UWB) is made up of two parts.

Recommendation

3.8-5 For the purpose of industrial location management, uniform standards are required in connection with the following aspects:

- Technologies to establish location data
- Formats for location data
- Agreements on data storage (centralized/decentralized)
- Protocols for data transmission
- Applications and visualization tools

3.8.7 Industrial long-distance networks

One of the most important concepts in the course of development of 5G technology is what is known as “network-slicing”. This essentially involves an approach in which the physical 5G network infrastructure (base stations, transmission and core network) can be configured in a flexible way so as to create logically separated subnetworks that are specially tailored to the needs of industrial users and the services they require. The technological basis is being put in place in the form of the new, more flexible air interface design (5G new radio), the software-defined network approach (SDN), network function virtualization (NFV) technology and real-time distributed edge-cloud computing architectures.

Recommendation

3.8-6 The network-slicing concept makes it possible for “private” industrial 5G subnetworks to be virtualized within (public) 5G networks, so that applications and services with Industrie 4.0 communication requirements can be served. To ensure the seamless merging of (heterogeneous) industrial networks with 5G networks, it will be necessary to provide and define open interfaces for both types of infrastructure.

3.8.8 Evaluating the reliability of communication

The leaning towards mass-market communication technologies and the growing complexity of communication networks as a result of Industrie 4.0 is giving rise to a more pronounced separation between the providers and users of communications services. This is also resulting in the need to formulate, establish and verify the requirements for the provision of communications services in a clear and accountable manner, especially when communications services are provided for a fee. The following specifications should be drawn up:

- application-oriented, quantifiable service-quality parameters
- a reference interface to which the values of the service-quality parameters relate
- influencing variables to be taken into account
- requirements for establishing the values of the service-quality parameters
- methods of establishing the values of the service-quality parameters

These specifications should take into account the fact that more than one party is responsible for the fulfilment of service quality. These parties are:

- manufacturers of radio modules
- integrators incorporating radio modules into automation devices (CPS)
- application programmers
- network equipment providers
- network operators
- production plant operators

With this in mind, requirements must be formulated that are to be observed by these stakeholders.

3.8.9 Validation and testing

The high demands industrial communication places on the functionality and reliability of devices and systems necessitates a distinct testing strategy. Account must be taken of the fact that functionalities that are not obligatory can result in incompatibilities. The possibility of different stack architectures whose components are specified by different standards setting organizations must also be kept in mind. Provisions must be specified stating how the compliance and interoperability of the communication implementations are to be verified. Given the many potential manufacturers of industrial communication devices, a certification strategy is recommended.

3.8.10 Real-time capability

Real time is an essential characteristic of CPS systems. As it is predicted there will be discussions on the topic of real time in long-distance, flexible, adaptive and autonomous network systems, work on a standard that gathers together and unifies the concepts and properties relevant to industrial real-time systems should be given urgent priority.

3.8.11 Interoperability between systems

Components and cross-system communication and interaction schemes play a crucial role within Industrie 4.0. The systems involved must be designed with interoperability in mind and must be interoperable in operation.

Interoperability refers to the ability of devices and components to fulfil a common task based on interactions and information exchange. Interoperability encompasses both functional and non-functional properties, and it must be established whether these are compatible for the purpose of the collaboration.

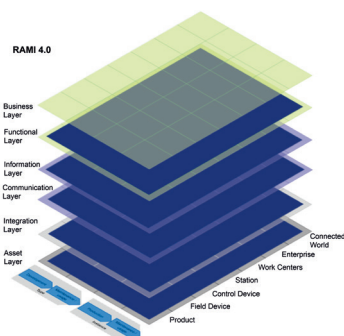
Recommendations

- 3.8-7** Selected communication devices must be modelled as Industrie 4.0 components, and appropriate properties and services must be specified.
- 3.8-8** Standards must be drawn up for evaluating the reliability of communications networks and communications services, so as to enable a transparent, quantitative and contractually secure evaluation at the cross-over between the provider and the user.
- 3.8-9** Communications standards for Industrie 4.0 must provide test specifications that can be used to verify the compatibility and interoperability of products.
- 3.8-10** The security standardization process must be notified of additional requirements in terms of information security that arise as a result of new properties in association with communication technologies (e.g. adaptability of connections).
- 3.8-11** A standard must be developed to provide a unified overview of concepts and properties relating to industrial real-time systems.

3.9 Security and IT security

3.9.1 Cybersecurity for Industrie 4.0

The subject of information security is crucial when it comes to ensuring the reliable functioning of industrial applications. The high-density networking and the dynamic interaction of components require internationally agreed standards for the specification of uniform requirements and solutions. Industrie 4.0 necessitates an internationally agreed approach to security and safety.



Today's production plants are increasingly automated, with networked computer systems, measurement systems and control systems. This means that in the relevant industrial plants, not only the existing office IT packages, but also the production process itself is increasingly becoming a safety-critical IT complex at all levels of the automation pyramid.

Areas of technology that were previously self-contained and acted independently of each other are increasingly working in cooperation. To ensure cybersecurity within production, special conditions apply, such as the long-term fitness for purpose of security solutions, the stringent requirements that apply in terms of availability and real-time operation of plants, and the integration of security in established operating and maintenance processes. Thus, the security mechanisms with which we are familiar from the office domain cannot simply be transferred to the production domain, even if the automation technology is increasingly reliant on standard hardware and software (COTS) and open standards such as TCP/IP are coming to the fore as the communication basis. Requirements that are typical for Industrie 4.0, namely flexible manufacturing and customized production, are also major factors.

Owing to the increasing number of interfaces and processes between humans, machines and organizational processes, and the increase in process-based communications beyond the boundaries of individual domains, the complexity of the interacting systems is significantly gaining in magnitude. The result is a considerable increase in exposure to attack. In addition, every legally relevant communication between the partners in the value-added network must be secured in an appropriate manner.

As far as Industrie 4.0 is concerned, it is therefore a case of establishing the typical security risks and the resulting security requirements and systematically addressing them one by one. Here, standards and specifications will play a decisive role when it comes to achieving security architectures that are globally compatible and consistent.

The integration of new subject areas in Industrie 4.0 means that special priority must be given to ensuring a system-oriented approach is adopted. Concepts that cut across levels and domains must be developed and standardized. Establishing an overarching security level is not enough to achieve this. What is required is a holistic approach using specifications and standards to support developments efficiently.

A list of current standardization committees and documents is given in Annex A1.

3.9.2 Functional safety – IT security

A key aspect of IT security in Industrie 4.0 will be the interaction between “functional safety” and “IT security” when networking automation and production systems.

At the present time, many different groups are working intensively to establish IT security for safety-relevant systems in a purposeful form within the various industrial sectors. To a certain extent, this is resulting in the emergence of idiosyncratic viewpoints and nomenclatures. To counteract this trend, a comprehensive sharing of information is needed so as to enable the development of uniform, standardized solutions.

On an international level, IEC/TC 65/WG 20 is in the process of drafting Technical Report IEC 63069, which will specify the interaction between functional safety, as set out in IEC 61508, and IT security, as specified in IEC 62443. Within the DKE, this series of topics has been taken up by Working Group DKE 931.3 and also by a cross-sectoral working group (the TBINK ad hoc working group on IT security), which includes members from multiple sectors. As a result of the input of expertise from a variety of standardization bodies, results will be quickly incorporated in the standardization activities that are already taking place.

Current standardization landscape

Protection of information as a valuable asset from loss and misuse, ensuring its timely provision to entitled users, and maintenance of its integrity and confidentiality are an indispensable basis of every IT system. With the virtualization, flexibilization and coupling of internal corporate management, production and field networks with the worldwide web, a multitude of new challenges for information security arise. Statements, requirements, stipulations and recommendations on information security are currently being produced in many places. The contacts for these are the regional data protection officers, BSI, and national and international standardization organizations (e.g. IEC, ISO, DKE and DIN) with active assistance from the relevant associations (VDMA, BITKOM, VDE, VDI and GMA).

To ensure that the requirements that exist in the context of industrial production are met, it is essential that a map be drawn up showing, in a structured form, the areas of information security that exist in respect of industrial production, together with the requirements needing to be met and any solutions already on offer.

Recommendations

3.9-1 Security for agile systems

Define standards for the technical negotiation of (capability-based and property-based) security profiles for Industrie 4.0 communication and/or cooperation of entities within a variety of security domains. This includes:

- Technical support for the classification of information, and requirements for the handling of suitably classified data
- Identification and authentication requirements
- A method of evaluating the trustworthiness of cooperation partners

3.9-2 Trustworthiness of the value-added network

Define process standards for the security of the cooperation within the value-added network. This includes:

- A method of evaluating the trustworthiness of cooperation partners. Typical mechanisms include manufacturers' declarations, certificates, auditing
- Rules for the sharing of classified data and information
- Minimum requirements regarding security for B2B

3.9-3 Standardized concept of roles and permissions for parties involved in Industrie 4.0

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

3.9-4 Security infrastructure for safe inter-domain communication

Secure communication requires secure identities (identifying factors and attributes) and trust anchors. Generating and administering secure identities and securing their trustworthiness requires a secure infrastructure. The requirements for this include factors such as scalability, resilience, cost-effectiveness, long-term fitness for purpose, and (user-defined) trustworthiness beyond, and independent of, local jurisdictions.

3.9-5 Standardization of a security engineering process for integrators and operators

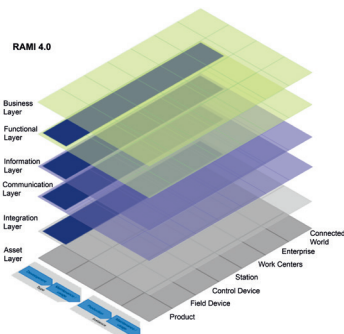
IEC 62443-4-1 defines a security engineering process for component suppliers; this must be expanded to take into account the other parties that form part of the value-added network (such as operators and integrators), to enable implementation of comprehensive and consistent security architectures.

3.9-6 Model for the security level of assembled products, based on the security level of the components contained or interacting within the product

The security properties of a system are dependent on the relevant properties of the components (software and hardware) and their configuration, this dependency being complex and chiefly non-linear. More detailed research is required into this issue and should be made more accessible once standardization work has reached a suitable level of maturity.

3.9-7 Data protection/privacy

The fitness for purpose of existing standards that relate to Industrie 4.0 scenarios must be clarified. In the case of automated communication across domain boundaries (such as the boundaries between jurisdictions), the relevant data protection requirements and associated security requirements derived from these must be harmonized.



3.10 Open source

Open source is gaining in significance in association with standardization. In a way similar to standards and specifications, open source takes the form of open technologies that are developed in collaborative processes and that are provided for use by all market players. This subject has therefore been included as an objective within the new German Standardization Strategy (DNS): “DIN and DKE are establishing partnerships and are seeking ways to cooperate effectively with open source projects and take advantage of open source technologies and methods in standardization.”

Nevertheless, open source must not be regarded as equivalent to, or be confused with, standardization. In open source projects, collaborative source code is compiled and software developed which is then made available to the market in the form of open source software – subject to certain licensing conditions that the market has established over the years and that are tailored to the specific conditions and requirements applicable to open source projects⁴⁴.

Open source projects complement standardization in a variety of ways.

- The standard is implemented in open source software: Open source is increasingly becoming a method of rapidly positioning technologies on the market – together with the associated standards and specifications, each of which has been implemented in open source format.

⁴⁴ The Open Source Initiative provides a comprehensive overview of Open Source, including the different types of licences and licensing models. For information, please visit <https://opensource.org/>

- The specification is developed in the context of an open source project: As far as interoperability interfaces and similar interoperability technologies are concerned, developments take place in open source. As explained above, these are made available to the market directly in open source format or flow back into the standardization process.
- A consensus-based standard is jointly developed with its open source implementation: Besides the dissemination of technologies in open source format, information on functionalities and especially on functional loopholes flows back into the standardization process, thereby enabling standardization bodies to respond very rapidly and in a targeted way to rectify the situation that has been identified. An example of this type of procedure is the “Agile standardization” approach presented in Figure 15.

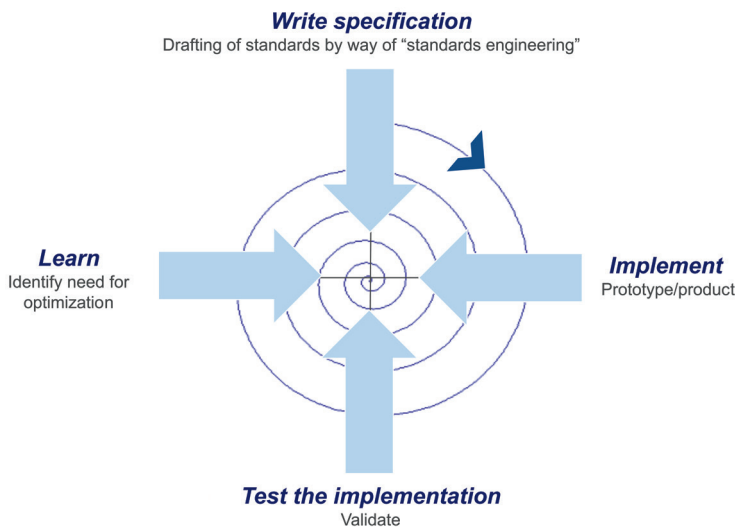


Figure 15:
“Agile standardization”

- With these mechanisms, the significance of open source for Industrie 4.0 is also growing. One aspect is that open source technologies may be, or may become, relevant to Industrie 4.0 applications. Another aspect is the potential of open source for use as a way of realizing implementing scenarios collaboratively – including the implementation of the associated standards and specifications. And ultimately, there is, of course, also the possibility that open source software will directly yield technologies that will function as standards. Examples are APIs, which set interoperability standards.

Open source – sample projects of relevance to Industrie 4.0

There exists a series of open source technologies and projects of direct relevance to Industrie 4.0 that are closely related to standardization.

OpenAAS (open Asset Administration Shell)

Open AAS is all about displaying and trying out an Industrie 4.0-compliant administration shell. This implementation of an Industrie 4.0 component in open source is capable of making a considerable contribution towards the spread of the technology on the market, thereby significantly encouraging the acceptance and take-up of RAMI 4.0.

A GitHub repository was set up for the execution of the project: “This repository shows the current development state of the administration shell and contains models, specifications and prototypes. The specifications are based on previous achievements of ZVEI working groups. For prototype development, we use the model based runtime environment ACPLT/RTE as well as open source OPC UA stack open62541. There are several base models that are used to describe the constituent parts of an AAS and the AAS itself⁴⁵.

The relevant GitHub Development Repository⁴⁶ also provides a detailed overview of the objectives of the project and offers an entry portal for those wishing to take part in open source development.

Eclipse IoT

In the context of Eclipse IoT, a series of technologies are under development that will be of significance in terms of Industrie 4.0 and IoT. These include the following:

- **Eclipse Paho Project:**

This project provides open source client implementations of standard messaging protocols (MQTT) within the machine-to-machine domain for numerous programming languages.

- **Eclipse OM2M project:**

This is an open source implementation of the oneM2M and SmartM2M standards and enables devices to communicate with each other horizontally, regardless of the underlying network.

- **Eclipse Milo project:**

This project offers all tools that are required for the implementation of the OPC Unified Architecture (UA) client and/or server functionality.

Distributed ledger technologies (DLT)/Blockchain

Distributed ledger, commonly known under the term blockchain, is a database technology that is increasingly gaining in importance and is no longer associated in people's minds with merely payment transactions and bitcoins. Its strength primary lies in areas in which many partners share data and all actions need to be recorded securely.

45 <https://github.com/acplt/openAAS>

46 <https://acplt.github.io/openAAS>

A blockchain is a type of decentralized database, in which transactions are verified, validated and aggregated into “blocks”. The blocks are then linked together in “chains”. This results in a structure of blocks linked together in a chain that increases in size in a linear direction. The data contained within the blockchain cannot be changed and can no longer be manipulated or deleted. Each participant in a blockchain stores the entire blockchain on his/her computer. If new data are added, the blockchain will be updated everywhere. This ensures that data are kept safe from fraud and makes the sharing of data more secure overall. In conjunction with Industrie 4.0, blockchain is ideally suitable for the secure and global sharing of sensitive information, such as design and production parameters.

One function of a blockchain that is of significance for industry is that of “smart contracts”. These are internet-based contracts the contractual obligations of which are permanently programmed and have been saved within the blockchain. They are executed once certain conditions are fulfilled. In the context of Industrie 4.0 services, blockchain technology can therefore be used as a platform, for example for the generation, autonomous negotiation and automated closure of dynamic value-added chains.

Blockchain technology is developed in open source projects and is made available as open technology. A prominent example is Hyperledger, a project conducted by the Linux Foundation, which counts more than 100 well-known companies from around the world as its members. Hyperledger coordinates and encourages the development of frameworks and tools for blockchain technology in a number of subordinated projects, such as:

- **Hyperledger Fabric:**
A framework with which a variety of blockchain applications and solutions can be compiled. Thanks to its modular architecture, various components (a consensus mechanism, access permissions, etc.) can easily be added.
- **Hyperledger Composer:**
A collection of collaboration tools for the construction of blockchain business networks, enabling business owners and developers to create smart contracts and blockchain applications to solve business-related problems.
- **Hyperledger Cello:**
A toolkit intended to support a “blockchain-as-a-service” solution, in order to reduce the cost of creating, managing and terminating blockchains.

Blockchain-related standardization projects have been launched to complement the open source development work that is underway in the field of distributed ledger technologies/ blockchain. In April 2017, Technical Committee ISO/TC 307 “Blockchain and Distributed Ledger Technologies” was set up at international level, and a corresponding German national counterpart mirroring it was created within DIN Standards Committee “Information Technology and Applications” (NIA). A variety of working groups are examining the topics of terminology, reference architectures, identities, use cases, security and smart contracts. The ITU-T has also launched activities in blockchain standardization. What is more, the European Commission has given

CEN an assignment to carry out a landscape analysis of blockchain standardization; a number of concomitant workshops have already been held.

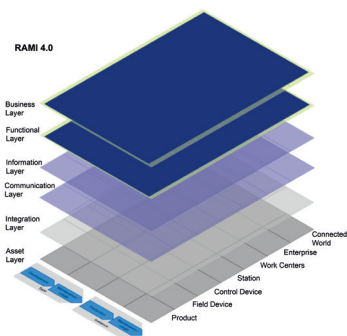
Looking ahead

Further open source projects are expected in connection with Industrie 4.0. Test environments and test beds are particularly suitable for collaborative development, as are (reference) implementations and the development of new technologies. DIN and DKE are well positioned in regard of these new developments, and they are working to secure partnerships with open source organizations so as to continue the successful collaboration between standardization and open source development.

Standardization and open source are not two contradictory concepts, but actually complement each another. On occasion, borderline situations may occur, in which a development in open source could be regarded as standardization – the example involving APIs and interoperability solutions is one such borderline case. But in situations such as this, a well-organized collaboration of standardization and open source can provide routes that will enable the open source development to be included within the consensus-based standardization mechanisms and made available to the market in the form of standards and specifications.

Recommendation

3.10-1 It is recommended that the proposals on the collaboration of standardizers and standards-setters with open source be evaluated in suitable pilot projects and be made available as appropriate services. To this end, it is recommended that the requirements (in terms of formal and informal standards) and the specification (relating to implementation in open source) be dealt with separately.



3.11 Use cases

3.11.1 Use cases: benefits and motivation

The term “use case” as used nowadays has a diverse range of meanings. Given this fact, it is important to use the term consistently in the context of the Standardization Roadmap. The term is mainly used as follows:

- A “use case” in the sense of a business scenario, in which, in accordance with a business model logic (e.g. business canvas), business relationships within a value-added network are

described. One example of a “use case” in this particular sense are the application scenarios⁴⁷ employed by Working Group 2 of the Plattform Industrie 4.0⁴⁸.

- “Use cases” in the sense of general understanding as to how a technical system is viewed in the context of its application. It is used to describe the interaction of a technical system with actors (such as technical systems or humans). An example of a “use case” in this sense of the word is the working paper entitled “Industrie 4.0 Plug-and-Produce for Adaptable Factories”, published by Working Group 1 of Plattform Industrie 4.0⁴⁹.
- “Use cases” in the sense of specific projects. Examples are the application examples on the map produced by the Plattform Industrie 4.0⁵⁰ or the test projects of Labs Network Industrie 4.0 (LNI 4.0).

All of these approaches have their justification and are worth pursuing further, however it appears necessary for the purpose of the Roadmap to differentiate more precisely between these approaches, as their underlying concepts differ.

It is generally agreed that “use cases” help us to develop, in a systematic way, the challenges and consequences, but also possible solutions, with regard to digitalization within the manufacturing industry:

- In particular, the business scenarios are helpful to users as a means of generating ideas for their own future business.
- The purpose of the use cases is to serve as a means from which to derive the requirements relating to the functions, architecture and interoperability of (future) technical systems. In this way, they form the foundation for work on a standard or specification.
- On the one hand, the specific projects provide information on which seem to be the areas of greatest need from a market perspective. In addition, the research projects in particular serve to identify the potential and the risks of new technologies and methods.

47 The individual application scenarios have developed over time. As a means of describing the business relationships within a value-added network, some are more specific than others.

48 Plattform Industrie 4.0: “Aspects of the Research Roadmap in Application Scenarios in Industrie 4.0”, October 2016

49 Plattform Industrie 4.0: “Industrie 4.0 Plug-and-Produce for Adaptable Factories: Example Use Case Definition, Models, and Implementation”, June 2017

50 Map of Industrie 4.0 use cases www.plattform-i40.de/140/Navigation/EN/InPractice/Map/map.html

3.11.2 Evaluating the status quo and relating this to other activities

Evaluating the status quo

Plattform Industrie 4.0 has published a total of 9 application scenarios. In addition to the summaries published by Plattform Industrie 4.0, the long versions of the application scenarios (the length of which ranges from 5 to 10 pages) are also available on request. These definitions share a common structure. Working Group 2 of the Plattform Industrie 4.0 makes no claim that the application scenarios are exhaustive, and additional application scenarios are welcome. To this end, it has defined the following procedure to enable the incorporation of additional application scenarios (including those not formulated by Working Group 2):

- A proposal is drawn up for a new application scenarios in the form of a brief description on a slide
 - Presentation at a meeting of WG 2
 - Nomination of the motivator and team
 - Approval by Working Group 2 to begin work
- The main points of the application scenarios are set out relating to the following:
 - Motivation
 - Stakeholders involved and underlying value-added network
 - Disruptive potential and driving forces
 - Benefits and challenges
 - Effects arising from value-added chains
 - Relationships to individual working groups of Plattform Industrie 4.0
- The application scenarios is discussed in WG 2
 - Instructions for revision and/or an assignment to draft a long version (approximately 5 to 10 pages)
- The long version is drafted by the team and reviewed by WG 2
- A short version, slide, etc. are produced by the Plattform Industrie 4.0 administrative office
- The application scenario is communicated (by inclusion in relevant documents, publications, etc.)

Nevertheless, the feeling is that the essential business scenarios have already been described – or put in more straightforward terms: the number of application scenarios is unlikely to amount to more than 15.

A variety of use case descriptions are in existence. Until now, these have neither been registered in a centralized way (some even take the form of internal company documents) nor do these descriptions have a uniform structure, nor do these depictions seem to be sufficiently complete. What is more, the descriptions differ markedly in terms of the level of detail they contain.

There is a considerable diversity of concrete projects, and the descriptions of the projects do not adhere to any common structure. There are currently 350 projects on the map issued by

Plattform Industrie 4.0 alone, and other countries (such as France and Japan) have issued similar maps containing several hundred projects. A project carried out by the Scientific Committee analysed (based on the 2016 version of the map) in what way these examples could be assigned to the application scenarios described by Working Group 2 of Plattform Industrie 4.0. In China too, there are more than 200 standardization-related projects on “intelligent manufacturing”. At the present time, there are more than 30 test projects being carried out by the Labs Network Industrie 4.0; in this case, there is a defined process by which the findings from those projects are transposed into standardization (Figure 16). It is important to note that it is the initiator of the project who establishes the extent to which the outcomes of a test project are published and are made available for a process of standardization. Standardization activities initiated to that end will then take place outside the test project itself.



Figure 16:
Standardization process of the
Labs Network Industrie 4.0 and
the Standardization Council
Industrie 4.0.

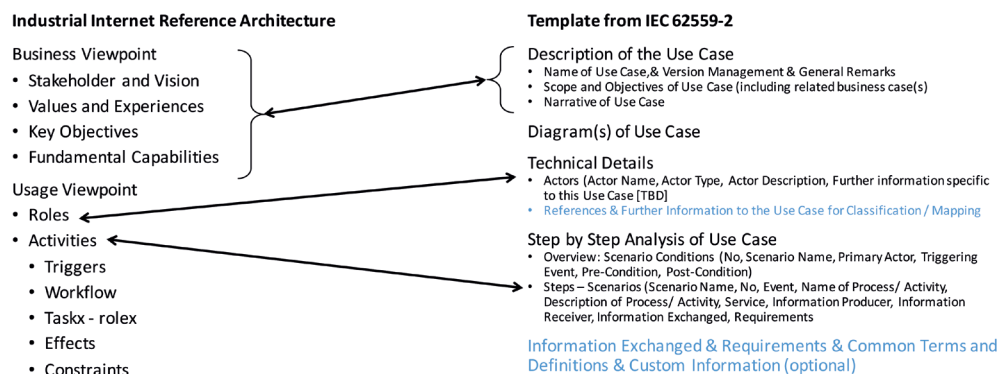
Relationship to other activities

The reference architecture model RAMI 4.0 was developed in the context of the Plattform Industrie 4.0, and the Industry Internet Consortium (IIC) developed what is known as the Industrial Internet of Things Reference Architecture (IIRA). Joint Working Groups 1 and 2 carried out a comparison of the reference architecture models of the Plattform Industrie 4.0 and the IIC⁵¹ (Figure 17). It was established that the application scenarios of the Plattform Industrie 4.0 are more concrete forms of the business viewpoints of the IIRA. Use cases are concrete forms of the usage viewpoints of the IIRA. This was described in more detail in a publication by Working Group 2 of the Plattform Industrie 4.0, which was approved by the IIC⁵². The use case description in the context of the usage viewpoint of the IIRA is not as detailed as the description of a use case in accordance with IEC 62559-2. Plattform Industrie 4.0 is not currently involved in any activities that are systematically devoted to the subject of use cases.

51 Architecture Alignment and Interoperability: An Industrial Internet Consortium and Plattform Industrie 4.0 Joint Whitepaper, December 2017

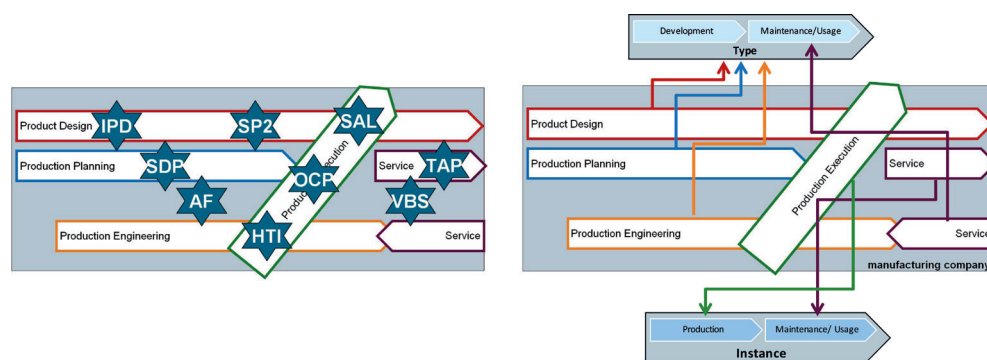
52 Exemplification of the Application Scenario Value-Based Service following IIRA Structure, April 2017

Figure 17:
The structure of IIRA
versus the structure of the
IEC 62559-2 template



The application scenarios were anchored within the value-added chains of manufacturing companies (Figure 18). As the basis, the value-added chains were selected as described by Working Group GMA 7.21⁵³. The RAMI 4.0 life cycle und value stream axis is an abstraction of those value-added chains.

Figure 18:
Connection between the
application scenarios and the
RAMI 4.0 life cycle and value
stream axis



As part of the subject of “smart grid”, use cases are being collected and described in accordance with the IEC 62559-2 template. Experience has shown that in order to complete this template in full, around 50+ pages will be required (see the working paper referred to above entitled “Industrie 4.0 Plug-and-Produce for Adaptable Factories”). The value-added processes and business models relating to production are more complex than those relating to the “smart grid”, however. That is the reason why, at the present time, it appears expedient to also specify use cases in accordance with the more lightweight usage viewpoint of the IIRA. This procedure is currently being followed both in the German-Japanese collaboration in IEC/TC 65 “Smart Manufacturing” and also in the German-Chinese Standardization Cooperation Commission. In view of the fact that the usage viewpoint is an abstraction of the IEC template, including further details in the specification at a later date in accordance with the IEC template will not be a problem.

⁵³ VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik: Industrie 4.0 Statusbericht Wertschöpfungsketten [Industrie 4.0 – Status report of value added chains], April 2014

3.11.3 Proposal for an overarching structure

The predicted continued growth and the broad diversity of use cases means that structuring and categorizing the use cases will be crucial. Only that way will it be possible to maintain an overview of the use cases, to assign related use cases correctly and to identify any gaps in the use case landscape that already exist or that result from new insights. To that end a total of 3 levels have been introduced:

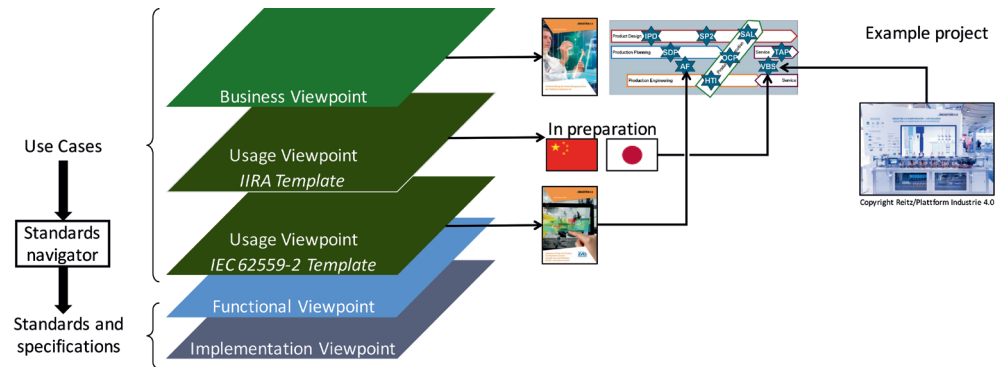
- **Level 1:** Application scenarios in the sense of business scenarios. These are structured in a tried-and-tested manner, based on the value-added chain according to GMA 7.21.
- **Level 2:** High-level use cases that are defined in accordance with the usage viewpoint of the IIRA. Examples are currently being developed with top-down approaches as part of the German-Japanese collaboration in IEC TC/65 “Smart Manufacturing” and within the German-Chinese Standardization Cooperation Commission.
- **Level 3:** On the lines of the standardization work undertaken in connection with the “smart grid”, these use cases are being described using the IEC 62559-2 template. An example that already exists is the aforementioned working paper “Industrie 4.0 Plug-and-Produce for Adaptable Factories”. These use cases do not necessarily need to be derived top-down from application scenarios or high-level use cases, they can also be developed bottom-up as a result of specific requirements or projects.

The extent to which structuring levels ought to be introduced will depend on the progress of the work on the development of use cases.

No particular structure is currently being proposed for the many specific projects. However, where a specific project addresses an application scenario and/or a high-level use case and/or a use case or aspects thereof, the project should refer to the application scenario and/or high-level use case and/or use case (or several of these) as shown in Figure 19.

However, these greatly diverse use cases need to be linked to the standards and specifications landscape. Many of the standards and specifications address the functional viewpoint (e.g. IEC 62264/ISA-95) or the implementation viewpoint (such as OPC UA) in accordance with IIRA. On a conceptual level, a standards navigator will be required to link the usage and/or business viewpoint and the functional and/or implementation viewpoint.

Figure 19:
Proposed structure
for use cases



Recommendations

- 3.11-1** Definitions and descriptions of use cases with a precise degree of abstraction are required, so as to allow identification of the standards available for implementing the use cases and also to enable the identification of any existing standards that need editing. For this reason, the project “FitFor4.0” for describing use cases and assigning standards for SMEs by means of a standards navigator should be implemented.
- 3.11-2** The use cases developed by LNI 4.0 in Germany should – provided the initiator gives permission – be incorporated within the proposed structure and subsequently included in international discussions. A key starting point in all efforts to achieve standardization will involve a uniform understanding of use cases on an international level.
- 3.11-3** Where new application scenarios are formulated, the Plattform Industrie 4.0 should be informed accordingly and should issue a recommendation on the extent to which the description corresponds to the quality criteria proposed by Working Group 2. The descriptions should be collated at a single location.
- 3.11-4** Besides the activities in connection with German-Japanese collaboration in IEC/TC 65 “Smart Manufacturing” and in the German-Chinese Standardization Cooperation Commission, it is recommended that additional high-level use cases be formulated. The descriptions should be collated at a single location.
- 3.11-5** On the lines of the standardization work being undertaken in connection with the “smart grid”, it is recommended that additional use cases be described using the IEC 62559-2 template. The descriptions should be collated at a single location.
- 3.11-6** It is recommended not to use a template when describing projects. Nevertheless, project descriptions should make use of terminology already established by the Plattform Industrie 4.0 (such as RAMI 4.0), and should not unnecessarily superimpose additional terminology.

3.11-7 If, from within a particular project, a specific need for standardization is expressed, that project should link to application scenarios, high-level use cases and/or use cases. If that is not possible, the project should at least formulate a relevant high-level use case, so that the need for standardization can be formulated in a non project-specific way.

3.12 Service robotics

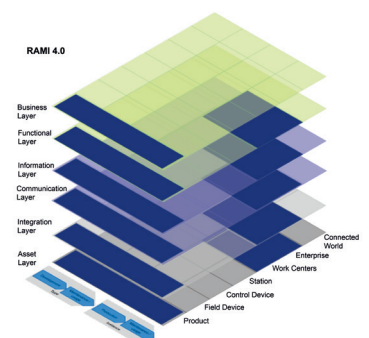
The development of service robotics is especially significant, given the fact that Industrie 4.0 takes the form of collaborative platforms with cooperating (Industrie 4.0) components.

Compared with conventional industrial robotics, the term “service robotics” is neither unambiguous nor self-explanatory. It is something that has emerged over time. Under the term “service robots”, ISO 8373⁵⁴ lists all systems of robots that are not used in a fully automated context. As a result of this negative definition, service robots are understood to include robots within a private or individual context and also robots used in a professional context as long as they are not being used in fully automated production lines. Correspondingly, ISO 8373 and studies such as World Robotics⁵⁵ distinguish between “personal service robots” and “professional service robots”:

1. When robots are used for non-commercial purposes, no specialist knowledge is required to operate the robot. In many cases, the robot can even be operated by laymen (personal service robots).
2. To use robots for commercial purposes, suitably trained staff will generally be required in order to operate and deploy the robot (professional service robots).

The most concerted efforts in service robotics standardization are currently being undertaken by ISO Technical Committee (TC) 299 “Robotics”, which was set up as recently as 2016 from within ISO Technical Committee ISO/TC 184 (the work carried out by TC 299 is being mirrored on a national level by Working Group NA 060-38-01 AA). Until 2016, the issues addressed by TC 299 were still the responsibility of Subcommittee (SC) 2 of TC 184 “Automation systems and integration”. TC 299 is receiving active support from the “Standardization” topic group set up in 2014 within the non-profit association euRobotics aisbl. It is intended that all current research proposals are mirrored directly in the form of standardization projects.

The corresponding structure and organization of ISO/TC 299 and the six working groups that are currently active, along with their objectives and activities and the most relevant standards, are illustrated in Annex A2.



54 www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=55890

55 www.worldrobotics.org

At the centre of current developments in the field of service robotics, ever greater emphasis is being placed on the creation of platforms for service robotics solutions in applications that fulfil a market need. The thinking behind these efforts relates to the fact that in order to take advantage of a mass market, a significant reduction in acquisition and integration costs will be needed. The (smart) capabilities offered by these solutions must also be more closely aligned to users' specific needs⁵⁶. Making it simpler to re-use software components offers the most potential for achieving cost savings, especially in system integration, which nowadays accounts for the largest proportion of investment in service robotics solutions for professional purposes. Service robotics platforms that enable service robots to be developed in a more collaborative way have the potential to enable innovative ideas to be achieved more quickly and at a reduced cost if they are based on existing, reusable solutions, available standard components and available service offerings.

On a European level, two key projects are currently in progress: ROSIN and RobMoSys. The objective of RobMoSys, which was launched on 1 January 2017,⁵⁷ is to guarantee the integration of the various robotics components and to improve tools that have already been developed so these can be put to additional use. It aims to achieve this by utilizing model-driven methods and tools and by applying these to existing technologies. To that end, the consortium is relying upon the open source framework SmartSoft, a project under the leadership of Ulm University of Applied Sciences⁵⁸. The ROSIN project, which also began in early 2017,⁵⁹ aims to improve the availability and quality of software components for robotics. The project is focusing on the further development of the existing Robot Operating System (ROS) and its offshoot, ROS-Industrial, which specializes in factory automation⁶⁰.

Similarly layered approaches are being pursued on a national level, especially within the technology programme PAiCE⁶¹ (Platforms | Additive Manufacturing | Imaging | Communication | Engineering) The "platform for service robotics" section includes at least three relevant projects: RoboPORT, RoboTOP and SeRoNet.

Within the RoboPORT project,⁶² a platform is being developed allowing various actors to work together to develop and produce components for service robotics applications. The community approach, which is already extremely widespread within the software development sector, also has the potential to reform the development of robotics hardware. The platform provides a

56 www.digitale-technologien.de/DT/Redaktion/DE/Downloads/Publikation/paice-broschuere.pdf?__blob=publicationFile&v=2

57 <http://robmosys.eu>

58 www.servicerobotik-ulm.de/drupal/?q=node/19

59 <http://rosin-project.eu/>

60 <https://rosindustrial.org>

61 www.digitale-technologien.de/DT/Navigation/DE/Foerderprogramme/PAiCE/paice.html

62 www.roboport.eu

large number of collaborative developer tools, an open source robotics library, and a range of knowledge and project management tools.

In the ROBOTOP project⁶³, an open platform is being developed that will enable exploitation of the mass market for robots in service, logistical and production applications. The platform makes it possible for smart standardized and reusable hardware and peripheral components to be combined to create tailor-made service robotics solutions. Before they are actually installed, the solutions can be examined using 3D simulation to ensure that they fit. This way, the number of changes to the offer, the engineering and the cost of the planning and design of robotics solutions can be significantly reduced.

Within the SeRoNet project,⁶⁴ an open IT platform is being developed for users, system service providers and robotics and component manufacturers from the service robotics sector. The platform enables software and hardware producers, service providers and customers to collaborate to develop service robotics solutions. Each party has a different role, depending on individual requirements. The objective is to achieve a significant reduction in the cost of software development within the professional service robotics sector by means of a development approach that is modular, collaborative and composition-oriented and in which solutions are created by putting together prefabricated modules. System integrators will be able to exploit new markets, especially SMEs, as the development cycles will take place more rapidly. At the same time, end users will be able to make use of the platform as a means of offering software services of their own to other companies. From a technical perspective, the modularity of systems is ensured by OPC UA using model-driven tools.

A key factor when it comes to creating an efficient and easily accessible service robotics ecosystem is that agreement should be reached between the various initiatives, in order to achieve a set of standardized modules. This especially applies in the case of machine-interpretable descriptions of functional and non-functional properties of hardware and software components, the interoperability of the various components and the integration of a variety of interfaces and communication protocols. Only in that way will it be possible to develop new modules and to re-use existing ones in an efficient way.

These issues are being addressed by Working Group 6 of ISO/TC 299, amongst others. However, the development of service robotics platforms is proceeding at a very rapid pace and there is a realistic danger that within the various platforms and ecosystems this will result in a landscape of interfaces and standards that is just as heterogeneous as the one that came about in the SmartHome sector. For this reason, it is strongly recommended that, as part of the process preceding standardization, steps be rapidly taken to harmonize the essential interoperability

63 <https://robotop-konfigurator.de>

64 www.seronet-projekt.de

aspects of key development projects. Within the context of PAiCE (see Section 2.3.4) these efforts are being actively expedited at the present time.

4 HUMANS AND WORK

4.1 Human-friendly design of work

4.1.1 Initial situation

In the context of Industrie 4.0, the role of humans within socio-technical work systems is especially worthy of attention. Whether as an actor in the production process, as an operator of machines, or as a maintenance operative, production planner or programmer – human beings will continue to occupy key roles within the production process. To design a work system that is ergonomic, efficient and flexible but that is also successful in the long term, it is important that humans, with their abilities, skills, capabilities and limitations, are included in the design process.

To that end, the widely accepted criteria for human-friendly work (see Figure 20) can be employed. These should govern all actions of the standardization process that are related to ergonomics.

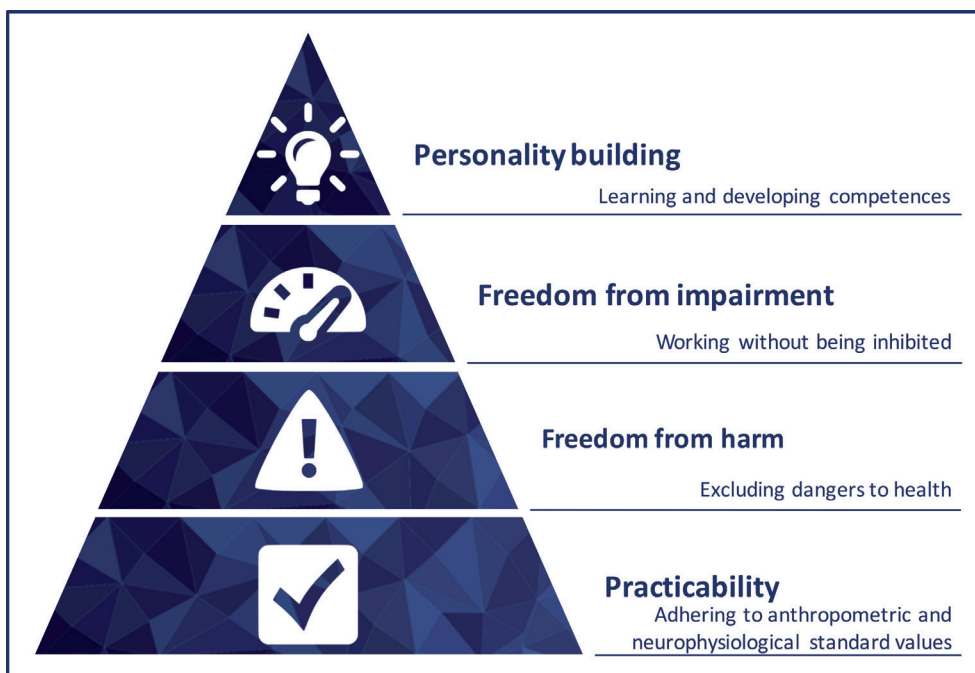


Figure 20:
The criteria for human-friendly work, according to Hacker (2005)

The fundamental criterion underlying the structuring of work is the practicability of activities within the context of the physical and mental performance capacity of the individual. Furthermore, work is not permitted to cause harm to the individual. Accidents and damage to health must therefore be avoided by designing the work appropriately. Today it is already the case, and tomorrow even more so, that numerous assistance systems and automation solutions are taking over or provide support in tasks that would otherwise be impossible to perform or that would be harmful to health if performed by a human. Adaptive technologies enable this support to be tailored to the individual employee involved. What is more, work ought not to cause any impair-

ment of the individual, i.e. it should be designed to exert an optimum amount of stress and so avoid the employee being physically or mentally overworked – or underworked.

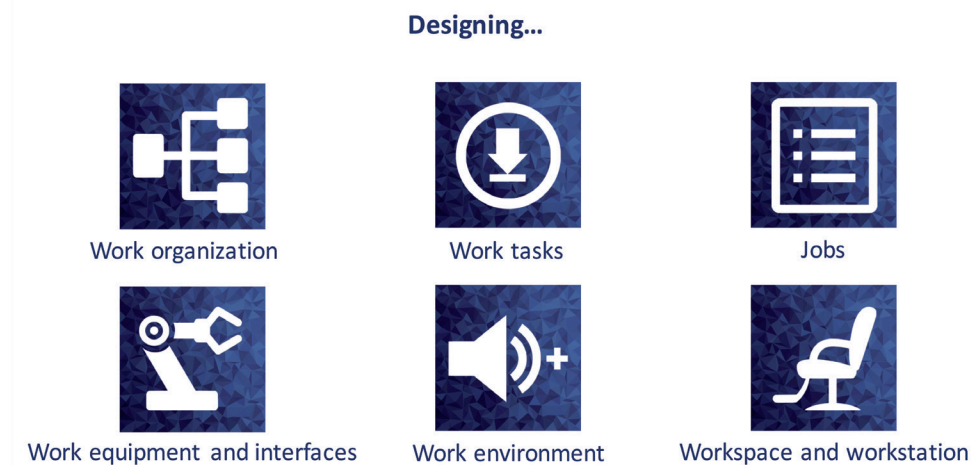
The developments within Industrie 4.0, such as dynamic cyber-physical systems, high information availability and complex human-technology interaction can have a load-reducing effect. If inappropriately designed, however, they may have the opposite effect. In contrast, if the individual becomes the servant of technology and is left to carry out residual activities of a uniform, non-complex nature, this can give rise to monotony. As far as an individual's workload is concerned, the two extremes – overwork and underwork – must be avoided. At the highest level, it is a case of designing work in such a way that it promotes the development of the individual by enabling him/her to learn and develop new competences. By ensuring the continuous and individualized qualification of employees and by transferring responsibility for part of the work system to them, learning can be promoted and deskilling avoided.

4.1.2 Ergonomic principles for the design of work systems

The current (2016) version of the standard DIN EN ISO 6385:2016-12 is the internationally accepted standard for work systems, and is the basis for the ergonomic design of the interaction of workers and equipment within a workspace, at a workstation or in a work environment. The contents of the standard apply to a wide range of work systems, such as those used in production, in the provision of services or in knowledge-based work or logistics.

The standard sets out to embed fundamental concepts underlying human-centred design and the suitability for purpose of a work system. It also defines key concepts in ergonomics and identifies the essential components of a work system that will need to be designed (see Figure 21).

Figure 21:
Elements of a work system
that can be designed in
accordance with
DIN EN ISO 6385:2016-12



The structure of the chapter is based on these elements. Essential, however, are not just the individual design elements of the work system, but, especially in times of interconnected, dynamic and complex production systems, especially the interactions between the elements.

4.1.3 An increasing requirement: working with information

In Industrie 4.0, information plays a significant role in the design of work. This applies both to supporting of work by providing information (e.g., in assembly operations, by providing working plans specific to the order and situation), as well as to work with information (e.g. analysing large quantities of data or process planning).

According to Schlick et al. (2010), work can be subdivided into various types, depending on the proportion of energetic or information-related aspects it encompasses (see Table 1). The implementation of both aspects and thus any permutation of these can be supported by providing information relating to the tasks and to the situation involved. In addition, human-robot interaction, exoskeletons and the like can provide the mechanical or motoric parts of jobs with powered support. In contrast, we have creative, combinatory jobs, where information is processed whenever it is a case of understanding complex procedures and intervening in them. Examples could be planning the workflow for the production of an object, or programming a robot for a specific purpose. As automation and smart systems will take over a large proportion of the less information-intensive routine jobs, and in view of the fact that we will witness the advent of effective opportunities to reduce incorrect workloads and to optimize the physical demands made of workers, humans will in future increasingly either perform tasks that are accompanied by information-related or powered support, or perform tasks that require an adequate response in emergencies and where problem-solving and creative thinking play a decisive role. Problem-solving tasks of that type can be identified by cognitive and/or physical components. These may differ depending on the situation, and the cognitive requirements, especially when diagnosing problems, are high and require the individual to develop knowledge that can be used to guide his or her actions. To enable people to perform these tasks and be capable of acting in non-routine cases, the promotion of learning and individual professional development play an especially important role. This is why the final section of this section will be specifically devoted to the facilitation of learning within Industrie 4.0.

Type of work	Energetic work				Informational work
	Mechanical	Motoric	Responsive	Combinatory	Creative
What is required from a person in order to perform the task?	Exerting forces "Mechanical work" in the physical sense	Performing movements Precise movement while exerting little force	Responding and acting Absorbing and responding to information	Combining information Associating information with the contents of one's memory	Generating information Associating information with "new" information
What organs or functions are used?	Muscles, tendons, skeleton, respiratory function	Sensory organs, muscles, tendons, circulation	Sensory organs, responsiveness and retentiveness, and muscles	Ability to think, retentiveness and muscles	Ability to think, retentiveness and ability to draw conclusions
Example	Carrying	Assembling	Driving a car	Constructing	Inventing

Table 1: Types of work and their composition as a combination of basic types (Schlick et al. 2010 modified from and based on Rohmert 1983)

4.1.4 Connections to areas not relevant to standardization

Health and safety rules and regulations

For the design of work systems, it is not enough just to draft standards and take them and the findings emerging from scientific research into account. Requirements in terms of workstations and work equipment are regulated by national and European legislation. It is important to distinguish between statutory requirements which relate to the design and marketing of products and equipment on the one hand and to occupational health and safety on the other.

In the case of products and equipment, the European Machinery Directive (2006/42/EC, 2009/127/EC) is of particular importance. In Germany, this has been transposed on a national level into the Produktsicherheitsgesetz [Product Safety Act – ProdSG] and the Maschinenverordnung [Machinery Ordinance – 9. ProdSV] which is based on the Act. The harmonized standards mandated by the European Commission are of considerable relevance to the safety of machinery. Where they are applied, it can be presumed that the machine has been designed in accordance with the statutory requirements. Matters not governed by harmonized standards must be evaluated by a risk assessment (a demand that becoming ever more prevalent) and taking appropriate measures, where necessary.

Besides the Machinery Directive, there are a number of other European Directives, including the transpositions of these into national legislation, which must be taken into account when designing Industrie 4.0 technologies. Examples are the Directive relating to electromagnetic compatibility (2014/30/EU), or the Low Voltage Directive(2014/35/EU).

In Germany, occupational health and safety is governed by the Arbeitsschutzgesetz [Occupational Health and Safety Act], which transposes the essential elements of European occupational health and safety legislation into national law. A central tool of the Occupational Health and Safety Act is risk assessment, which examines the working conditions and the corresponding risks to employee health. In the case of the complex technologies and human-machine systems characteristic of Industrie 4.0 technologies there must be a check for risk factors that are difficult to discover, such as those resulting from operating concepts. This applies both during the risk assessment by the manufacturer of the equipment and during the risk assessment that is carried out in an operational context.

The Occupational Health and Safety Act is enacted in more specific terms in the form of ordinances that constitute legally binding regulations. The Betriebssicherheitsverordnung [Operational Safety Ordinance] and the Arbeitsstättenverordnung [Workplaces Ordinance] are of crucial significance in connection with the design and implementation of Industrie 4.0 work systems. Observing this legislation helps to ensure that equipment is used in the workplace in a safe and healthy manner and that the work environment is designed with health and safety in mind. The Ordinance is also enacted in more specific terms by state Technische Regeln [Technical Regulations], which contain highly precise design criteria. Observance of the regulations of the Deutsche Gesetzliche Unfallversicherung [German Public Accident Insurance – DGUV], supplemented by more detailed rules and information, is also required.

The above has only provided an outline of the rules and regulations applicable in Germany to occupational health and safety and thus also to the design of work in the realm of Industrie 4.0. Any projects that are planned or to be realized will require specific scrutiny of the regulations by an expert. It is worth doing this before any investment or implementation decisions are taken.

Data protection aspects

Industry 4.0 technologies are typically characterized by their extensive use of sensors, actuators and powerful control software. This may give rise to interactions between data protection requirements and employees' rights to privacy, for example: When a human and a robot work together and, in the most complex situation, when a human works on a workpiece together with a smart robot, information on the individual behaviour of the human, and in some cases, about his/her physical characteristics such as body size, are processed by the software of the work system. This is necessary for a number of reasons, such as the need to adapt the working speed to the person or situation, or to ensure the work system is more ergonomically designed. At the same time, there is a possibility that information may automatically be generated on break times, errors and productivity. The continuous, systematic monitoring of employees by means

of smart sensors is, however, of legal relevance, in view of the fact that it constitutes a restriction of the right of the employees to privacy (e.g. their right to informational self-determination) and it would be possible to draw conclusions with regard to an employee's specific way of working, without the employee being aware of this. Furthermore, the availability of personal data may create a situation in which the employer owes duties of care to its employees.

The fundamental principles of data protection, such as

- establishing the purpose of the data or using the data for the purpose for which they were obtained
- the necessity of the data
- the transparency of the data
- data avoidance and data minimization

require careful consideration when designing the work system. Since data protection legislation does not provide any conclusive arrangements governing data collected in the context of an employment relationship, labour-management contracts and service agreements may prove a sensible option.

4.1.5 IT security: The role of humans

The security of a company's IT infrastructure also depends on the human factor. By virtue of their status as users of corporate IT systems, employees have access to such systems. This can give cause to unintentional human error, negligence or intentional misconduct, on the one hand. On the other hand, criminal influence could result in significant damage and also a risk to the security of personal data. Typical human behaviour such as curiosity or a lack of attention are exploited by criminal agents as a means of attacking IT systems.

Typical weak points include

- insufficient security due to the use of passwords that are too simple
- phishing scams, i.e. counterfeited email messages or falsified websites that make it possible to obtain unauthorized access to a system or to obtain data, or
- social engineering, i.e. obtaining confidential data by illicit means, by making personal contact with employees and pretending to be a different person or pretending to hold a particular position.

It is especially difficult to estimate the consequences of criminally motivated attacks. Companies are therefore faced with the task of formulating rules and codes of conduct governing the use of the company's IT system and the handling of confidential data.

First and foremost, software systems must be designed to help users perceive risks and determine how to adequately respond to them. This requires information and instruction sessions to

teach employees to recognize risks and attacks at an early stage and to behave in a manner that upholds security. Furthermore, to raise awareness of these issues, there should be a comprehensive campaign involving all employees that have IT access.

4.1.6 Use cases

Complex human-machine interfaces

The transition to Industry 4.0 is restricted neither to specific sectors, nor to individual areas of a company. This means that all types of work will – to differing degrees and in a variety of ways – be subject to change and can be supported by assistance systems based on the specific needs that exist. The use case described below is intended to help to ensure that the implications of a human-centred design of innovative work systems is more easily understood. In the subsequent sections, reference will be made to this use case whenever appropriate.

Digitalization offers comprehensive technical possibilities to use assistance systems to support types of work involving energy or information (see also Table 1): On the one hand, assistance systems such as exoskeletons or human-robot interaction are available when performing subtasks that require energy to be exerted⁶⁵, whilst on the other hand, informational assistance systems, such as those used in order to prepare and depict empirically based task descriptions, are also available. Data glasses are a typical example of this.

The means of supporting a specific job can be ascertained on the basis of need and are selected from the facilities to provide support to the two basic types of work. The following notional use cases are by way of example, and incorporate aspects of these functions.

Use case “assistance system”

Description

The job at hand is the final assembly of the interior by an assembly technician as part of the automobile production process. The following types of technology are used:

- a type of exoskeleton/orthosis in the form of a dynamic seat support to make it easier to sit and to perform the necessary movements (work of a mechanical/motoric nature)
- a collaborative robot to support the handling and installation of large components of the vehicle interior (e.g. the rear seat, dashboard) (work of a mechanical/motoric nature)
- a pair of data glasses for use in specific situations to provide assembly and quality assurance information relating to variants, whilst at the same time making use of camera technology to document the process and, in specific situations, to make recordings (including

⁶⁵ An exoskeleton (a term derived from the Ancient Greek “exo”, meaning outer, and “skeletós”, meaning a dried-out corpse) provides a supporting structure for an organism, forming a stable shell around the organism itself.

verbal recordings) of suggestions for improvement or of similar information provided by assembly personnel. Such glasses would also make it possible to incorporate facilities that would enable communication with line managers, specialists, etc. (reactive, combinatory and creative work)

Actors involved

The actors involved are: assembly personnel, assembly managers, work system planners, work process planners, assembly control, mechanical and electrical maintenance personnel, maintenance personnel for the software and hardware for the assistance systems and functions.

Initiator

The assembly process is initiated as the production plan progresses.

Invariables

To avoid the production line coming to a standstill following the failure of a technical aid, it must still be possible for the assembly process to be carried out without robotic or assistance systems.

Outcome

The interior component (e.g. rear seat, dashboard) has been fitted.

Standard process

- The vehicle and interior component are available on the production line
- With powered support from the systems, a person with an orthosis seat and a handling robot guides the component into the vehicle
- Rough/fine positioning of the component by means of human/robot collaboration
- Fixing
 - Optional: Variant-specific information can be requested via the data glasses
 - Documentation of the work step using the camera system on the data glasses
 - Optional: Capturing of suggestions for improvements (visually or verbally) via the data glasses

Alternative process steps

If the support provided by the orthosis or the collaborative robot were to fail, the assembly procedure can be performed with the help of a second assembly technician.

4.2 Design of the work system

Thanks to Industrie 4.0, companies now have access to innovative solutions with the potential to help them design their work and value added processes in a more flexible way. This potential for flexibility can be fully utilized by appropriate design of the work system, i.e. by

designing (or developing) the individual elements of the work system in accordance with DIN EN ISO 6385:2016-12, or by combining them. The planning, introduction and operation of Industrie 4.0 solutions demands a systematic and strategic procedure since the complexity of the work system's design and the close networking of Industrie 4.0 solutions with the value-added process as a whole mean that sustainable solutions cannot be achieved by means of intuitive or one-off actions.

What is more, Industrie 4.0 can only be successful and sustainable in a work system once it has achieved a certain level of maturity⁶⁶. This is something that has been confirmed in a variety of current studies: According to the study into the development of competences in the context of Industrie 4.0 that was carried out by acatech⁶⁷, the most important competences required by companies are as follows: data evaluation and analysis (60.6% of companies), followed by process management (53.7%). These appeared ahead of IT-specific competences in the list. The outcome of the study entitled "Industrie 4.0 im Mittelstand" (Industrie 4.0 in small and medium-sized enterprises) carried out by Deloitte⁶⁸ in relation to specific Industrie 4.0 projects in small and medium-sized enterprises during the past 12 months was that 86% of those questioned were in the course of optimizing their processes. Against this particular backdrop, the design of the work system must always be carried out in parallel to the technical planning of an Industrie 4.0 solution.

The standard DIN EN ISO 6385:2016-12 defines the design of work systems as an iterative and structured process that encompasses a number of design phases, which results in a new design or a redesign. The work system design process should include all phases throughout the life cycle of the work system from conception through development, realization and implementation, utilization, maintenance and support to decommissioning. DIN EN ISO 6385:2016-12 recommends that the process be carried out by a multidisciplinary design team and also points out the importance of using suitable processes and technologies when designing a new work system.

In addition to DIN EN ISO 6385:2016-12, a variety of other standards contain isolated normative information of relevance to the process of designing a work system: For example, DIN EN ISO 27500:2017-07, DIN ISO 45001:2017-06 and DIN EN ISO 9000 ff. contain conditions underpinning the design of work systems, whilst DIN EN 16710-2:2016-10, for instance, presents a methodology for work analysis when designing work systems.

Due to the complexity of the topic, none of the standards include any specific information on operational implementation; as a consequence these must be determined on the basis of the situation that applies within each company.

66 see [Stowasser (2015)], page 8

67 [acatech (2016)], page 13

68 [Deloitte (2016)], page 9

Recommendations

The available standards are worded in a general way and do not specifically deal with implementing solutions under Industrie 4.0. Against this background the following steps should be taken:

- 4.2-1** The standards governing the design of technological processes as an element of work system design need to be checked, and revised where required.
- 4.2-2** It is important to check whether minimum standards need to be formulated with regard to consider socio-technical aspects. This may lead to additions, and in some cases, amendments, being made to existing standards.

As referred to above, the relevant statements regarding the design of work systems are currently scattered across various standards. This means that operational planners find it more difficult to find them and to take sufficient account of them when planning Industrie 4.0 solutions. This especially applies if the planners or the planning team have a technical background and have not had any previous involvement in the design of work systems. To cater for this, the following is recommended:

- 4.2-3** Operational planners should be provided with a document containing a summary of all process-relevant statements regarding Industrie 4.0. In the first instance, this should take the form of a guide on the design of work systems relating to Industrie 4.0 solutions. This will provide companies with timely assistance, whilst enabling account to be taken of the fact that Industrie 4.0 technologies are, in many cases, still under development.
- 4.2-4** A set of guidelines giving orientation could be modified by iterative means so as to remain in line with current developments. These could be transformed into a standard once the technological developments associated with Industrie 4.0 have stabilized.

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4.3 Designing the work organization

The organization of work can be subdivided into the operational and the organizational structure. The operational structure involves processes within the company being organized in such a way as to ensure that products are manufactured or services are provided. Organizational structures must be designed to enable and support the operational structure.

Standards address the topic of work organization either from a human-centred perspective (ISO 27500:2016, EN ISO 27500:2017), or against the backdrop of specific issues, such as quality management (DIN EN ISO 9001:2015), project management (ISO 21500:2012, DIN ISO 21500:2016), or the development of business models (DIN SPEC 91300). These documents mainly describe requirements that an organization is expected to fulfil within its own individual context and keeping in mind the specific features of the organization.

One of the benefits of digitalization is that the handling of information and information flows can be supported by technology and can be changed so that information can increasingly be integrated both horizontally and vertically as well as inside and outside a company. On this basis, organizational tasks (such as staff deployment planning) can be partly or fully assigned to technical support systems. At the same time, subtasks that impose a considerable physical load on the person performing them can be assigned to technical systems – either partially (such as in the form of a human-robot collaboration) or fully (such as in the case of driverless transport systems). Human-robot collaboration must be organized in such a way that the specific strengths of the human (such as creativity or manual dexterity) and of the robot (such as precision and power) can be utilized in a targeted way. This will generate scope, not only to make sure that the work-related tasks taking place during the work process or value-added process are more holistic, but also to enable them to be used for continual improvement (such as the further development of the organization). This second type of activity can be supported by means of statistical evaluations of large quantities of data (big data).

Approaches such as predictive and preventative maintenance are based on this premise. Their objective is to avoid faults and to schedule any work that is needed at suitable times, enabling the capacity that must be kept available for fault rectification to be reduced. The resulting ability to plan work volumes means companies can act in a proactive and strategic way (rather than “only” reacting). This also enables new or greater flexibility with regard to working hours and

locations. For this flexibility to succeed, modifications will need to be made in leadership, co-determination and collaboration processes covering the entire spectrum, from presence within the company and presence in virtual spaces to limited contactability and the informational richness of the communication methods or communications media used in each case. In some cases, these processes may need to be decentralized. Based on the above, the operational structure can be reconfigured by agile methods, depending on the order situation, and even greater account can be taken of ergonomic aspects, such as age-appropriate working structures, so that the work performance and the efficiency of the workforce will improve through their entire working lives. In the same way, learning content and qualifications can be planned to suit the workload and can be integrated within the job.

Given the speed at which digitalization is progressing and the equally dynamic market environment, the design of the organization or operational structure should enable flexibility and short decision-making lines. Decentralized approaches that focus on functions are ideal in this regard and will provide support for collaborative, project-related working methods. One example of this is the breaking down of a “silo mentality”. The organizational structure in companies that have successfully implemented digital transformation processes will be characterized by cross-departmental working groups and/or teams.

Referring back to the use case described in the introduction, these developments mean that more criteria can be taken into account in staff deployment planning than was previously possible. In addition to presence and qualifications, factors such as ergonomic aspects can be systematically taken into account, e.g. by planners as a means of varying the work strain; the same applies in the case of experience and learning situations and levels of practice, which, depending on the workload at any given time, can be scheduled in a targeted way, or can be maintained or increased. In this way, it is possible to maintain or increase the efficiency of the assembly workforce and incorporate learning or practice into their work processes, whilst at the same time reducing the load upon those individuals tasked with planning duties. The assembly tasks overall thus become more holistic, for example by adding further (sub)tasks and, more especially, by enhancing processes through continuous improvement. This can be achieved by linking overarching data, such as quality management data (frequently occurring faults) to specific (sub-)tasks (screw fastening too loose or too tight) or component properties (material is too thin/too brittle) and by devising the necessary approaches and action in a targeted way. In contrast to assembly work, planning work (such as the designing of a typical assembly work system) can frequently be performed at any location, neither does it need to be carried out at a particular time. In order to turn the concept into reality, organizational structures will be required that enable and ensure that agreement and collaboration are achieved between the individuals involved in design and development (from departments such as production planning, work planning, IT, personnel development and quality assurance). The communication and agreement of assembly targets between management and specialists will ensure that the work is in line with the strategic policy of the company. Decentralizing decision-making on that basis will increase the agility of planning and development processes and will help reduce the amount of time

required for developments or for planning changes to the assembly work system (for example when changing models).

Recommendations

The developments outlined, some of which are highly dynamic, and developments currently underway, provide standardization with a variety of approaches.

- 4.3-1** Procedures for deciding on how the work is to be divided up in the context of human-robot collaboration
- 4.3-2** Procedures governing the situation-specific integration of human-robot collaboration within existing work processes – such as in situations involving high capacity utilization
- 4.3-3** Procedures for the transformation of organizational structures in accordance with the qualification structures within the company (polarized organization versus swarm organization – advantages and disadvantages – configuration of mixed forms – effects with regard to the designing of work and working conditions, employee development, etc.)
- 4.3-4** Specification of human-centred aspects of leadership – the tasks of a Chief Digital Officer (CDO)
- 4.3-5** Further development and/or configuration of change management for digitalization processes
- 4.3-6** Normative formalization and strategic planning of digitalization measures within the company
- 4.3-7** Key performance indicators that can be used to specify the quality of digitally supported processes
- 4.3-8** The design of digital approval procedures
- 4.3-9** Process development by integrating cloud technologies
- 4.3-10** Procedures for the linking and targeted evaluation of big data (from data handling to statistical analysis, if needed)
- 4.3-11** (Examples) use cases for all items referred to

4.4 Design of tasks and jobs

The standards DIN EN 614-2, DIN EN ISO 9241-112 and DIN EN 894-1 count among those providing terminology definitions and requirements regarding tasks and jobs, and what form they are to take.

DIN EN 614-2 describes the requirements for the design of jobs relating to machinery. It focusses on the interaction between the design of a machine and the work tasks of the operator. DIN EN ISO 9241-112 contains six principles relating to the display of information, as well as numerous recommendations for its use. These are to be applied in conjunction with the principles relating to user–system interaction, and the relevant recommendations given in ISO 9241-110, such as that regarding suitability for a given task. DIN EN 894-1 lays out the requirements for the ergonomic design of displays and manual controls. Requirements are given for various different operating situations and conditions, and aim to optimize the interaction between the operator and the machine for a given task.

When designing future work tasks within Industrie 4.0, the functions of humans and machines will remain separated but decisions regarding the assignment of these functions will have to become more flexible and dynamic. Technical systems will, in future, be able to fully or partially adopt the tasks of humans (and vice versa), thus the employee will be supported by an assistance system in parts of their work. This will allow the interaction between human and machine to be highly varied. As a result of this, different levels of activity will emerge, from the autonomous functionality of the machine to the separation of each activity and decision, right up to the independent decision-making of the human.

Digitalization offers us vast technological possibilities for supporting information-related and energetic work with assistance systems (see Section 4.1.3 An increasing requirement: working with information). Firstly, digitalization makes it possible to create assistance systems for energetic system parts such as exoskeletons or human-robot collaborations. ISO/TS 15066 and DIN EN ISO 10218-2 are two standards that lay out the requirements for robotic systems. Secondly, it provides us with informative assistance systems, such as those that prepare task descriptions based on experience; and display them in smart glasses. Aside from these, other work systems are involved, such as those with monitoring tasks at the control centre (see DIN EN ISO 11064-1).

With regards to the collaboration of humans and robots, many different variations are possible and this must be considered when designing the specific task in question. In principle, all options fall under one of the following five descriptions:

1. The robot carries out the entire task and the human monitors the process.
2. The robot and the human each assume half of the task (50:50 solution).
3. The human assumes the whole task and uses the robot as and when needed.
4. The human directs/leads the robot with a digital tool.
5. The human programs the robot, sets it up and puts it into operation. This is followed by case 1, where the robot takes over.

Cases 1 to 3 can be dynamically varied. Implementation of the human-robot collaboration requires the division of labour between the robot and the human to be re-imagined. The tasks should be assigned to each party with a certain logic. For example, the robot takes over the monotonous and/or difficult stages so that the human is left to concentrate on the tasks in which it has the upper hand, such as complex joining processes or steps that are flexible. Tasks that may physically or psychologically impair the human are also assumed by the robot. The strengths of the human (intuition, flexibility, perception, thinking, deciding and acting) are combined with the strengths of the robot (speed; and movements that are strong, long-lasting, reproducible and precise).

Recommendations

It can be assumed that in future the tasks of humans will involve more monitoring, checking and control processes. These tasks will, in turn, place new requirements on the employee. He or she will be required to have in-depth knowledge of IT, for example, with a particular focus on the collaboration with robots and the use of digital aids such as smart glasses, apps and smart phones. The involvement of collaborative robots increases the scope of activities and this triggers the need for new tasks and qualifications. Many factors will have to be carefully considered when designing a task or job, such as how information is used and processed, content flexibility, life-long learning, the dynamics of change, indirect, technology-aided communication and an increased need for coordination across parties. Digital integration is also going to lead to a need for employees to better understand the relationships between different systems and processes.

As a result of this, certain standards need adapting as detailed here:

- 4.4-1** DIN EN 894-1 does not currently make any reference to the structure and content of a task, and it is not clear how the design of the task impacts on the design on the information display, and to what extent the display design is limited (in cases where specific tasks require it). DIN EN 894-1 therefore requires updating with specific regard to new forms of interaction between humans and machines, as well as with regard to different types of operation (maintenance, error resolution and servicing). The information required for the task, (ergonomic) displays and the preparation of information are to be designed with the above issues in mind.
- 4.4-2** In DIN EN 614-2, working at or with other machines is not explicitly dealt with. In future, the dynamic assignment of functions that this interaction requires is to be sufficiently covered.

- 4.4-3** Technology is to be designed in future so that it supports communication structures and processes that aid work, i.e. those between different people within process monitoring systems, for mobile work and with other departments. This affects the standards DIN EN 894-1 ff and the ISO 9241 series of standards.
- 4.4-4** The change from autonomous robotic operations to collaborative robotic operations involves a change in the task of the employee. The ergonomic requirements this places on the design of the task are currently not described (see DIN EN ISO 10218-2).
- 4.4-5** In future, it must be ensured that machines recognize human characteristics and adapt themselves accordingly. DIN EN ISO 6385:2016-12 will need to be adapted/ supplemented.

4.5 Design of products, equipment and interfaces

Smart devices, i.e. devices connected to services, are part of everyday life today – for school pupils and employees of all types, from manual labourers through to managers. And that is the case even if the working day is analogue, not digital; reaching for your smartphone, playing an online game or using a streaming service are common daily activities. Digitalization is being transferred from the average working person into industry. The boundaries between products, systems and services are becoming blurred. And we are still facing the continually dynamic development of new work-related technologies that, in turn, bring with them new and unknown interactions between humans and machines. So when it comes to the ergonomics of interaction between humans and systems, it does not matter whether we are dealing with a product, system or service; the desired characteristics of efficacy, efficiency and the satisfaction of the user are the same for everyone. The consequence is that all equipment and the products related to it need to be subjected to the same ergonomic requirements and thus the interfaces between humans and systems are not only to be seen as functional or technical. Topics such as “bring-your-own-device” or “user experience” are taking a more prominent position in the digitalization discussion and in standards (see the definition of “user experience” in ISO 9241-210:2010). They prove that the successful and economically viable application of systems is largely decided by the quality of the user’s experience.

When it comes to redefining products, equipment and interfaces within the context of Industrie 4.0, new technologies such as smart devices, virtual, mixed or augmented reality, or intelligent assistants are not merely an end unto themselves. It is rather the case that this equipment requires the new conceptualization of interfaces and thus new usage models. Businesses that are (or plan to be) active within the scope of Industrie 4.0 will encounter a process of change as a result of the new user experiences. This change will affect how all aspects of systems are defined. This, in turn, requires the comprehensive harmonization of the different domains, i.e.

it requires the fundamental concepts of ergonomics relating to human-machine interaction to be transferred to the products and equipment that are becoming more prevalent in the world of production today. This will affect products such as 3D glasses, gesture control, system control with speech and voice recognition, or new forms of data visualization. In reality, a high-quality automated tool such as a robot is no different to any other interactive system and so the criteria of ergonomic system design can also be applied to it.

Achieving this involves incorporating design concepts that are centred around human beings into existing planning and development processes. By concentrating on the usage of a system by humans and by applying knowledge and technologies stemming from workplace science/ergonomics and usability (according to ISO 9241-210:2010), this approach aims to ensure that all elements of the job are fit for purpose.

The DIN EN ISO 9241 series of standards provides a comprehensive basis for the issues surrounding the design of products, equipment and interfaces. Having said that, the definitions of terms and basic concepts are not to be neglected, especially those that play a large part in the highly heterogeneous field of “solution spaces”. The standard DIN EN ISO 9241-210 describes the activities in cases where the interaction of humans and systems is characterized by a human-centric design. It supports the use of iterative, agile procedures that regularly include the user and collect their feedback. This standard also expressly states that a certain degree of creativity is required to ensure that a workspace or process is usable. It makes clear that modern technologies and their applications should no longer be seen as purely functional. Furthermore, this standard calls for the use of an interdisciplinary team for designing tasks. It also defines “user experience” and describes how this concept can be understood.

DIN EN ISO 9241-112, on the other hand, states principles for the presentation of information, the generally validity of which extends to their application in virtual or augmented interfaces. DIN EN ISO 9241-110 covers the dialogue principles of human-system interaction, such as suitability for the task, or controllability. In other parts of the ISO 9241 series, specific equipment items are dealt with, such as keyboards or screens, or even specific parts of the interaction such as visual interface elements or dialogue-related technologies.

Recommendations

Standards today are not able to deliver recommendations or requirements with regards to the design of products, equipment and interfaces in Industrie 4.0, as the content matter falls short.

- 4.5-1** The model of a computer-based work station where information and interactions are displayed statically can often not be applied to the challenges of new, dynamic systems. System design in Industrie 4.0 deals with systems that may no longer be solely reliant on a single screen but instead extend to complex models that involve a number of different displays.
- 4.5-2** The use of gesture and/or voice control of products, interaction in virtual spaces and the display of dynamic data (no matter where and when the the data is required by the user) require a re-evaluation of the information currently contained in the ISO 9241 series of standards. It is to be taken into consideration that firm evidence in this area is still emerging.
- 4.5-3** The same is true for the implementation and display of information in virtual environments and augmented systems.

4.6 Design of work environments, workspaces and workstations

DIN EN ISO 6385:2016-12, which is also mentioned in the introductory section, contains terms and definitions and also requirements for the design of people-oriented work environments, workspaces and workstations. It gives special consideration to the interaction with other elements of the work system (e.g. equipment). According to this standard, the **work environment** includes the physical, chemical, biological, organizational, social and cultural factors that surround the employee. Among other things, it places the following requirements on the work environment:

- The negative effects on health, safety and the well-being of the employee are to be minimized.
- Confirmation of the employee's ability and willingness to carry out the tasks is to be obtained.
- Objective and subjective evaluations are to be considered.
- The recognized limits with regards to health, safety and well-being are to be adhered to.
- Options for providing positive support are to be considered.
- The employee's ability to influence the work situation is to be enabled.

The **workspace** is the area assigned to one or more people within the work system in which they carry out their tasks. The **workstation** describes the combination and spatial organization of the equipment within the work environment, under the conditions required by the tasks. The standard specifies, among other things, the following requirements for the design of the workspace and workstation.

- Working with both static posture and the ability to move around must be possible.
- A safe and secure must shall be provided, from which bodily strength can be applied.
- Body shape, posture, muscular strength and body movements must be considered.

Specific aspects of the work environment are covered in existing standards (e.g. lighting in the workplace: see DIN EN 12464-1:2011-08). Furthermore, some VDI Guidelines also exist (e.g. VDI 2058 Part 3 “Assessment of noise in the working area with regard to specific operations”). The essential requirements are covered in the Technischen Regeln für Arbeitsstätten (ASR) (Technical Rules for Workplaces). These solidify the requirements of the Arbeitsstättenverordnung (Workplace Ordinance).

When designing a work space or station, the body shape and strength of the employee are to be taken into consideration. The committees ISO/TC 159/SC 3 “Anthropometry and biomechanics” and NA 023-00-03 Joint working committee “Anthropometry and biomechanics” are currently discussing and developing the following topics:

- updating data on body shapes
- the use of new technologies (e.g. 3D body scanning, digital ergonomics) to extract data; and requirements for the technologies as a prerequisite for generating risk assessments

Adaptive equipment shall therefore enable the work station to be individually adapted to each employee.

Even the lighting for a work station will be influenced by technological developments. Artificial, biologically effective lighting, for example, creates a pleasant and productive work environment. FNL 27, a Subcommittee of DIN-Normenausschuss Lichttechnik [DIN Standards Committee Lighting Technology] has published a specialist report on this topic: DIN SPEC 67600:2013-04 Biologisch wirksame Beleuchtung – Planungsempfehlungen [Biologically effective illumination – Design guidelines]. The KAN position paper on artificial, biologically effective lighting in standards⁶⁹ deals with this topic from the perspective of safety at work. One of the things the paper indicates is that lighting does indeed have an impact on occupational health and safety. Further research needs to be conducted in this area. Standards, for example, can be used to describe the product requirements for components of lighting installations.

69 www.kan.de/fileadmin/Redaktion/Dokumente/Basisdokumente/en/Deu/2015-08-26_KAN-Position_Lighting-en.pdf

Recommendations

When designing workspaces and workstations, the potential deployment of new technologies such as exoskeletons and orthotics should be considered (see Section 4.1.6 Use cases). These are able to support the employee in various situations, such as where particular bodily strength is required.

- 4.6-1** It is to be checked whether existing data relating to muscular strength needs to be supplemented in order to address this sort of support.
- 4.6-2** The possibility that mobile, collaborative robots, exoskeletons/orthotics or smart glasses could lead to an entirely new set of risks should also be examined. Requirements for elements such as escape routes or the permissible ceiling in the real work environment will have to be defined.
- 4.6-3** Requirements for the safety of these technologies and their interaction with the work space will also have to be defined.
- 4.6-4** Mobile computer technologies are often talked about in relation to Industrie 4.0; these would allow the work to be carried out from any location. Designing work so that it is mobile is a particular challenge because the designer often has little influence on the equipment used.
- 4.6-5** The work environment also incorporates the social and cultural factors that surround the employee. It is therefore important to check whether the use of new technologies has an effect on these aspects and whether particular cultural tendencies may lead to an employee dealing with the technologies in a different manner. These findings are also to be reflected in the design.

4.7 Designing work so that it promotes learning and the development of competences

Work-related tasks that are not only practicable, harmless and free from impairment, but that provide opportunities for personal development and the achievement of one's potential, meet the essential criteria for the design of people-friendly work (see Section 4.1.1 Initial situation). By promoting health and learning they are deemed to be motivating and productive⁷⁰.

In standards, the promotion of learning is mostly mentioned in the context of ergonomic design. Engaging with the requirements of a work-related task and the mental stress and mental

⁷⁰ [Schlick et al. 2010, Hacker 1994, Luczak & Schmidt 2009, Patterson et al. 2004]

strain associated with this can initiate a learning process. In this way, learning can be facilitated (DIN EN ISO 10075-1:2018-01). In addition, existing standards provide information relating to the design of software in such a way that it encourages dialogue between humans and the technical system in a manner that promotes learning (DIN EN 29241-ff./ISO 9241-ff.).

Taking the use case outlined in Section 4.1.6 Use cases, this means that performing the assembly task and the associated mental interaction with the task constitute a learning process. In this way, the person is able to learn how to perform the task, will be able to continually improve his/her command of the movements required, and will be able to increase his/her understanding of the system and how the various components are interrelated. Likewise the person will gain more knowledge of the reasons why errors and faults occur.

The high pace of development in the field of digitalization is creating a situation in which work tasks and, in some cases, organizational structures are changing more rapidly than ever before. As a result, the requirements humans need to fulfil (in terms of qualifications, competences and skills, etc.) are also changing at a more dynamic rate. The importance of competences that enable individuals to adapt to new or changed working situations is therefore growing, as is the significance of continuous knowledge development (lifelong learning) for all concerned – whether managers or employees. At the same time, digitalization provides a significantly broader range of opportunities to design work in a way that facilitates learning and that integrates workplace-based learning by incorporating appropriate learning situations in the work process. These include experience-based task descriptions and also the regular assignment of specific tasks so that the individual can gain a high degree of practice or is able to learn how to carry out incremental changes to the work task. This is deemed the way forward to align the efficiency and innovation targets that companies are endeavouring to achieve by means of digitalization with employee-related targets that are intended to ensure that work is designed in a manner that promotes competences and “on-the-job learning”. In this regard, it is necessary to have a corporate culture that regards learning as an opportunity and something to be closely interwoven with continual professional development. Learning and participatory processes involving tasks and processes can make a substantial contribution towards enabling companies to align their product and process innovations with workforce development, so that the expertise they need can be – at least partially – generated from within the company’s own workforce.

As far as the use case itself is concerned, this means, for example, that work descriptions can be displayed on the data glasses and the amount of information given can be adapted to match the experience of the particular individuals carrying out the work. Less experienced workers would be given detailed descriptions, so that they are able to understand the task and can learn how to perform it (avoiding them becoming overburdened due to the absence of certain information), whilst more experienced workers will only receive key information, such as the latest changes or special versions (avoiding them becoming underworked by providing them with information they already know).

Recommendations

The developments outlined, which, in part, are highly dynamic, and the developments that are currently in progress provide a variety of approaches which standardization is recommended to take.

- 4.7-1** When constructing and designing the technical systems, and in particular when designing human-machine interfaces, aspects of the design that will facilitate learning must be taken into account. It is a case of looking ahead and taking account of the operational processes (control and information processes, and communication and feedback processes).
- 4.7-2** Procedures that will enable the establishment of lifelong learning should be defined as part of the continual improvement process (and/or existing specialist knowledge should be updated by means of incremental learning).
- 4.7-3** Procedures should be defined that will reinforce problem-solving skills – e.g. when handling new/changing work situations.
- 4.7-4** A method should be described that will enable identification of the knowledge to be imparted, in addition to the didactic concepts that will respond to the need.
- 4.7-5** Approaches for the targeted integration of aspects facilitating learning within work processes and systems must be developed and be underpinned by application examples.

4.8 Conclusions

The achievement of Industrie 4.0 work systems in research and practice provide evidence of the importance of the need to take a focused look at the role played by humans. Failure to pay due regard to any one of the individual factors required to design human-friendly work may have considerable negative effects in terms of functionality, reliability and productivity and, first and foremost, in terms of the health and the safety of the workforce itself. The complex operational reality that exists within a company involves the interaction of a constantly increasing number of parameters, so much so that it is necessary for the interactions between humans and technology to be charted and analysed. The established criteria governing what constitutes human-friendly work are suitable for use as an evaluation standard in this regard, and tried-and-tested standards are available that can be used to systematically examine the various aspects. Some aspects of Industrie 4.0 work systems, such as innovative interfaces and interactions, technical flexibility and complexity will, however, require specific updating and expansion of the standards dealing with ergonomics.

5 LEGAL CHALLENGES⁶⁷

Industrie 4.0 is creating new challenges for jurisprudence and its practical application. This ongoing industrial revolution is fundamentally based on the networking, collaboration and automation of systems. From a legal perspective, new types of contracts, the networking and sharing of data, errors specific to the collaborative production process, a different work environment and changes in the way that works come about all play a key role in this new development. This is of relevance to standardization, not least because it is not only legislation that dictates the framework within which standards and specifications operate; standards and specifications have a retroactive effect on legislation. Those effects on the law should therefore be taken into account. For example, the criterion as to what constitutes negligence in the context of civil and also criminal law is considerably influenced by provisions that are not anchored in law.

Both the subject of contracts and the terms and conditions in the contracts themselves change. Products are manufactured on a collaborative basis, services are offered and/or sought via platforms, and information is stored in clouds, etc. A considerable degree of contractual freedom is required to amend contracts in line with developments. At the same time, B2B contracts in Germany are afforded a high degree of protection by arrangements that limit the applicability of general terms and conditions, and this is given particular backing by jurisprudence. This would appear to be a problem in view of the latest developments, and will require legislative and practical changes to be made. What is more, contracts are no longer always concluded by physical persons or legal entities only; in some cases electronic agents are used for this purpose. This can be catered for under the law as it stands today, however it is important to consider the fact that these agents act too independently to be regarded as mere tools of the parties themselves. In part, it is assumed in such cases that when independent electronic agents are used, this takes the form of a type of “blanket declaration”.

Not even in Industrie 4.0 are all products made to be fault or error-free, and not all contracts will be fully satisfied or meet obligations completely. In other words, there will continue to be liability cases, and these will include cases of civil and criminal liability. As a result of collaboration, networking and automation, it will however be more difficult to prove the cause of a fault and therefore to determine who is responsible. Thus, it will be hard to determine the party against which liability claims can be brought. This will be to the disadvantage of the aggrieved party, which is why discussions are currently in progress to reach new solutions. These range from insurance companies discussing guaranteed payment for all cases of damage by the relevant industrial sectors through to the concept of an “electronic entity”, which, in the same way as the “legal entity” that already exists, could be able to act as the addressee representing the parties involved. However, this will not change the issue of criminal liability, which by its very nature can only be applied to an individual. New problems also need to be discussed with regard to the

71 For detailed information regarding the individual aspects, please see the publication by the Legal Frameworks (Plattform Industrie 4.0) working group. www.plattform-i40.de/I40/Navigation/EN/ThePlatform/PlatformWorkingGroups/platform-working-groups.html and www.plattform-i40.de/SiteGlobals/I40/Forms/Suche/EN/Servicesuche_Formular.html?resourceId=185566&input_=185518&pageLocale=en&templateQueryString=Enter+search+term&sortOrder=score+desc&submit=Anfrage+senden

definition of negligence. This is relevant to civil and criminal law, such as in the necessity for the damage to be foreseeable or in relation to the extent of risk that is permitted. In that regard, non-governmental standards play a key role in providing initial guidance.

The concept of networking also poses challenges in terms of IT security. In this context too, it is essential to protect humans from IT systems, but also to protect systems and products from unauthorized access. It is also necessary to guarantee the functionality of IT systems, to exclude the possibility of manipulation, to restrict access, and to ensure that a source is genuine. This is difficult to achieve due to the fact that under Industrie 4.0, an extremely large quantity of data is exchanged, sent, stored at various locations, processed, etc. That data presumably also includes information about production processes, employees, customers, end-users, etc. Some of this will be sensitive information, the publication of which could give rise to competition issues. In many commercial sectors, protecting know-how is of primary importance as a means of ensuring the competitiveness of companies. In that sense there is call for action primarily on the part of the companies themselves, as this is in their own self-interest.

Some of the data may also take the form of personal data, such as data relating to employees or customers, and these may be subject to the rules governing data protection, including the European General Data Protection Regulation (GDPR), which is due to enter into force in May 2018. These rules are also insufficient to cover the latest changes in the handling of information and data in the context of Industrie 4.0, so that here too changes will need to be made to legislation in the long term. The subject of “who data actually belongs to”, for instance, is continually being discussed, however no satisfactory answers have yet been found.

But especially with regard to collaboration during the manufacturing of products, it is not only a matter of protecting information – on a very general level, there is a need to clarify who is actually entitled to the rights to the products. The discussion could include the question as to who, for the purpose of copyright, is to be regarded as the creator of a product manufactured in collaboration or of a development that takes place on a platform. Another aspect for discussion relates to who is able to register a patent on any innovations and/or what types of innovation should be protected under patent law (cf. the discussion regarding software patents). This will mean existing law will need to be amended. Conceivable would be a precise definition distinguishing different types of origination or a splitting up of the patent. On a general level, it will be necessary to consider whether patents in their conventional form, directed at personification, are still in keeping with the times or whether patent law itself should be fundamentally updated.

Another area of law that will face a number of challenges as a result of Industrie 4.0 is labour law. This will mean reforms of the contractual relationship and revisions to contractual agreements, statutory regulations and collective bargaining agreements being ultimately required. For example, working hours will change and as a result of more widespread digitalization in certain areas of work, it may appear desirable to reduce working hours or redesign the work world. How these changes should look is not something that can be dictated by law, however – legislation would

have to respond to any such needs that arise. Due to the use of platforms and other forms of interaction, there will probably be a decline in the prevalence of conventional employer-employee relationships. In the long term, there will be a need to bolster pseudo-self-employed persons, freelance workers, and also the genuinely self-employed. The concept of an “employee” will need to be redefined. What is more, increasing collaboration and networking, including between companies, will be accompanied by changes in accountability structures. Finally, personal data relating to those involved will also need to be granted special protection.

ANTITRUST LAW AND LEGAL NOTICE

As previously shown, the development of “Industrie 4.0” poses a number of challenges from a legal perspective. What is more, those challenges are not confined to a single area of law. In order to address them effectively, it is therefore necessary for academic lawyers and experts from a variety of fields to work together.

A large number of conventional areas of law, such as the drafting of contracts, liability, relationship superiority and data protection, can be effectively addressed on the basis of individual actions, clear attribution and unambiguous ownerships.

Networking and collaboration are, however, increasingly undermining those legal concepts.

These challenges can be met as long as the law remains flexible and can undergo adaptation through appropriate interpretation, and as long as new legislative initiatives are set in motion.

6 FURTHER INFORMATION

Standardization Council Industrie 4.0

www.sci40.de

Plattform Industrie 4.0

www.plattform-i40.de/I40/Navigation/EN/Home/home.html

Labs Network Industrie 4.0

<https://lni40.de/?lang=en>

Standards organizations

- DIN on Industrie 4.0
www.din.de/en/innovation-and-research/industry-4-0
- DKE on Industrie 4.0
www.dke.de/de/themen/industrie-4-0
- ISO
www.iso.org
- IEC
www.iec.org
- CEN-CENELEC
www.cencenelec.eu

Industry associations

- Bitkom on Industrie 4.0
www.bitkom.org/industrie40
- VDE on Industrie 4.0
www.vde.com/topics-de/industry
- VDI-GMA
www.vdi.de/industrie40
- VDMA on Industrie 4.0
www.industrie40.vdma.org
- ZVEI on Industrie 4.0
www.zvei.org/en/subjects/industry-4-0/

Politics

- BMWi – Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
www.bmwi.de/Redaktion/EN/Dossier/industrie-40.html
- BMBF – Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
www.bmbf.de/de/zukunftsprojekt-industrie-4-0-848.html
- European Commission
<https://ec.europa.eu/digital-single-market/en/policies/digitising-european-industry>
- G20
www.g20-insights.org

7 RELEVANT STANDARDS AND SPECIFICATIONS

The topic of Industry 4.0 touches upon a large number of professional disciplines. Fields of major relevance to Industry 4.0 include mechanical engineering, automation, information and communications technology, ergonomics, security, services, maintenance and logistics. In order to provide an overview of existing standards and specifications that cuts across committees and organizations, experts from various disciplines have identified around 700 standards that are recognized as having priority status. These priority standards are intended to aid SMEs in the difficult process of identifying and correctly applying relevant standards and specifications.

Overview of Industrie 4.0 standards and specifications

www.din.de/go/industry-4-0

www.dke.de/Normen-Industrie40

8 ABBREVIATIONS

3GPP	3rd Generation Partnership Project
AAL	Ambient Assisted Living
acatech	Deutsche Akademie der Technikwissenschaften (German National Academy of Science and Engineering)
AK_STD	Arbeitskreis Standardisierung (Working Group Standardization)
B2B	Business-to-Business
BITKOM	Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V. (Federal Association for Information Technology, Telecommunications and New Media)
BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
BMWi	Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Technology)
BSI	Bundesamt für Sicherheit in der Informationstechnik (Federal Office for Information Security)
BZKI	Begleitforschung für zuverlässige Kommunikation in der Industrie (Accompanying Research – Reliable wireless communication in industry)
CDD	Common Data Dictionary
CEN	Comité Européen de Normalisation/European Committee for Standardization
CENELEC	Comité Européen de Normalisation Électrotechnique/European Committee for Electrotechnical Standardization
COTS	components-off-the-shelf
CPPS	Cyber Physical Production System
CPS	Cyber Physical System
DEI	Digitising European Industry
DG CONNECT	Directorate General CONNECT
DG GROW	Directorate General GROW
DG RTD	Directorate General Research and Innovation

DIN	Deutsches Institut für Normung e. V. (German Institute for Standardization)
DIN SPEC	DIN Specification
DKE	Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE (German Commission for Electrical, Electronic & Information Technologies of DIN and VDE)
DNS	Deutsche Normungsstrategie (German Standardization Strategy)
EBN	R & D phase standardization
EDDL	Electronic Device Description Language
EN	Europäische Norm (European Standard)
ERP	Enterprise Resource Planning
ETSI	European Telecommunications Standards Institute
EU	European Union
GL	Grundlagen (Fundamentals)
GMA	VDI/VDE Gesellschaft Mess- und Automatisierungstechnik (VDI/VDE Society for Measurement and Automatic Control)
GUI	Graphic User Interface
HTTP	Hypertext Transfer Protocol
IACS	Industrial Automation and Control System
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ICT	Information and communications technology
IML	Fraunhofer Institute for Material Flow and Logistics
IOSB	Fraunhofer Institute of Optronics, System Technologies and Image Exploitation
IPA	Fraunhofer Institute for Manufacturing Engineering and Automation
IP45G	Information platform for 5G – Industrial Internet
ISA	International Sociological Association

ISO	International Organization for Standardization
IT	Information Technology
ITA	Industry Technical Agreement
ITG	Informationstechnische Gesellschaft im VDE (VDE Information Technology Society)
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union, Radiocommunication Sector
JIS	Joint Initiative on Standardization
JTC	Joint Technical Committee der IEC und ISO
JWG	Joint Working Group
KMU	Klein- und Mittelständische Unternehmen (Small- and mid-sized enterprises, SMEs)
LNI 4.0	Labs Network Industrie 4.0
M2M	Machine-2-machine
MOM	Manufacturing operations management
MRK	Mensch-Roboter-Kollaboration (human-robot collaboration)
NAMUR	User Association for Automation in Process Industries
DNS	Deutsche Normungsstrategie (German Standardization Strategy)
OMG	Object Management Group
OPC UA	Open Platform Communications – Unified Architecture
OpenAAS	Open Asset Administration Shell
PAiCE	Platforms, Additive Manufacturing, Imaging, Communication, Engineering
PAS	Publicly Available Specification
PPP	Public Private Partnership
RAMI 4.0	Referenzarchitekturmodell Industrie 4.0 (Reference architecture model Industrie 4.0)

RoboPORT	Crowd-Engineering-Plattform für Robotik (Crowd-Engineering platform for robotics)
RM-SA	Referenzmodell-Systemarchitektur (Reference model for system architecture)
ROSIN	Qualitätsgesicherte ROS-Industrial-Softwarekomponenten (Quality-assured ROS industrial software components)
SCI 4.0	Standardization Council Industrie 4.0
SDO	Standards Developing Organization
SemAnz40	Semantische Allianz 4.0 (Semantic Alliance 4.0)
SEG 7	Standardization Evaluation Group 7
SeRoNet	Service Roboter Netzwerk (Service Robot Network)
SG	Strategiegruppe (Strategy Group)
SMCC	Smart Manufacturing Coordinating Committee
SMB	Standardization Management Board (IEC)
SOA	Service-orientierte Architektur (Service-oriented architecture)
SyC	System Committee
TACNET 4.0	Taktiler Internet – Konsortium (Tactile Internet – Consortium)
TC	Technical Committee
TCP	Transmission Control Protocol
TR	Technical Report
TS	Technical Specification
UK	Unterkomitee (Subcommittee)
UML	Unified Modelling Language
VDE	Verband der Elektrotechnik Elektronik Informationstechnik e. V. (Association for Electrical, Electronic & Information Technologies)
VDI	Verein Deutscher Ingenieure e. V. (Association of German Engineers)

VDI/VDE GMA	VDI/VDE Gesellschaft Mess- und Automatisierungstechnik (VDI/VDE Society for Measurement and Automatic Control)
VDMA	Verband Deutscher Maschinen- und Anlagenbau e. V. (German Engineering Federation)
W3C	World Wide Web Consortium
WG	Working Group
XML	Extensible Markup Language
ZDKI	Zuverlässige drahtlose Kommunikation (reliable wireless communication)
ZVEI	ZVEI Zentralverband Elektrotechnik- und Elektronikindustrie e. V. (Central Association of the Electrical and Electronics Industry)

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A1 Industrie 4.0: Relevant committees and consortia worldwide

National committees and consortia	Standards and specifications	
DIN/DKE	DIN SPEC 27070 Reference architecture of a security gateway for the exchange of industry data and services DIN SPEC 16593-1 RM-SA – Reference Model for Industrie 4.0 Service architectures – Basic concepts of an interaction-based architecture DIN SPEC 91345 Reference Architecture Model Industrie 4.0 (RAMI4.0) DIN SPEC 16592 Combining OPC Unified Architecture and Automation Markup Language	
VDI/VDE GMA	VDI/VDE 3682 Formalized process description VDI/VDE 3695 Engineering of facilities VDI 4499 Digital Factory VDI 5600 MES	
Automation ML e. V.	Engineering data IEC 62714	
eCl@ss e. V.	IEC 61987 Sensors IEC 62683 Switch Gears	
ProSTEP e. V.	Mechanics STEP + APxxx	
PLC Open e. V.	PLC Technologies IEC 61131	
IEC	IEC 61360 Rules for Properties IEC 61387 Sensors Prop. IEC 62683 Switch Gears Prop. IEC 62832 Digital Factory IEC 62443 Security in Automation	

International committees and consortia Standards and specifications

ISO	ISO 15745-1	Integration Framework
	ISO 15926	Life cycle data
	ISO 10165	Management information
	ISO 19439	Enterprise modelling
	ISO 29002-5	Identification
	ISO 13849	Functional safety
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ISO/IEC JTC 1	Security/IoT	
	ISO/IEC 2700x	
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IEC/ISO JWG 21	IEC/ISO Reference Model	
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CEN/CLC	EN Standards	
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IEEE	TSN 802.xx	
	IoT Technologies	
<hr/>		
ITU-T	IoT Standardization Radio spectrum	
ITU-R		
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ETSI	EN-Standards	
	SDR VNF/Radio/	
	4G, 5G/Security/M2	
<hr/>		
Industrial Networks	Profile & Protocol Families	
	IEC 61784	
	IEC 61158/IEC 61784	
	IEC 61800-7	
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OASIS	OpenDoc Technologies	
	ISO/IEC 263007	
	Cloud-Technologies AMQP, MQTT	
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Object Management Group (OMG)	Programming	
	Middleware	
	UML/CORBA/OMA	
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3GPP	Mobile Networks (4G, 5G)	
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oneM2M	IoT technologies	
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OPC Foundation	IEC 62541 Services	
	OPC UA and Companions	

IETF	Internet Technologies Protocols/Routing IETF RFC 3987
NIST	Calibration/Measurement Standards
Underwriters Laboratories	Certification/Safety Standards
W3C	Certification/Safety Standards

A2 Standards activities: Cyber security

A2.1 Active standards committees

The development of consensus-based standards is being driven forward by the relevant committees. They all aim for a situation of longevity and sustainability. In Germany, DIN and DKE are the main bodies involved; in Europe CEN, CENELEC and ETSI are involved; and ISO and IEC act on an international level. In addition to these officially mandated bodies, other groups are drawing up standards and guidelines for standardizing Industry 4.0. The table below gives an overview of some bodies active in Industry 4.0 standardization:

Organization	Committee designation	Title of committee	Field of activity
DIN	NA 043-01-27 AA	"IT Security Techniques"	Mirror committee to ISO/IEC JTC 1/SC 27 "IT Security techniques"
DIN	NA 043-01-17 AA	"Cards and security devices for personal identification"	Mirror committee to ISO/IEC JTC 1/SC 17 "Cards and security devices for personal identification"
DIN	NA 043-01-37 AA	"Biometrics"	Mirror committee to ISO/IEC JTC 1/SC 37 "Biometrics"
DIN	NA 043-02-01 AA	Working Committee "Measures against counterfeiting"	Mirror committee to ISO/TC 292
DKE	DKE/GK 914	Functional safety of electric, electronic and programmable electronic systems (E, E, PES) for protection of persons and the environment	Mirror committee to IEC/TC 65/SC 65A/WG 14 "Energy Efficiency in Industrial Automation" (EEIA)

DKE	UK 931.1	IT security for industrial automation systems	Mirror committee to IEC/TC 65/WG 10 "Security for industrial process measurement and control – Network and system security"
DKE	AK 952.0.15	DKE-ETG-ITG Informationssicherheit in der Netz- und Stationsleittechnik	Mirror committee to IEC/TC 57/WG 15 "Data and communication security"
DKE	AK 353.0.11	Backendkommunikation für Ladeinfrastruktur (Backend communication for charging infrastructure)	Mirror committee to IEC/TC 69/JWG 11 "Management of Electric Vehicles charging and discharging infrastructures" and mirror committee to IEC/TC 69/WG 9 "Electric vehicle charging roaming service"
DKE	TBINK AK	IT-Security and Security by Design	Platform for the coordination of various standardization activities surrounding "IT security and functional safety"
DKE	UK 967.1	Elektro- und Leittechnik für kerntechnische Anlagen	Mirror committee to IEC/SC 45A "Instrumentation, control and electrical power systems of nuclear facilities"
ISO/IEC	JTC 1/SC 27	IT Security Techniques	Generic IT/information security management systems
ISO/IEC	JTC 1/SC 17	Cards and security devices for personal identification	<ul style="list-style-type: none"> ■ Identification and related documents, ■ Cards, ■ Security devices and tokens <p>and interface associated with their use in inter-industry applications and international interchange</p>
ISO/IEC	JTC 1/SC 37	Biometrics	Standardization of generic biometric technologies pertaining to human beings to support interoperability and data interchange among applications and systems
IEC	TC 65 WG 10	Industrial-process measurement, control and automation	Industrial communication networks – Security for industrial and control systems
ETSI	TC Cyber	Technical Committee (TC) Cyber Security ETSI	Develop and maintain the standards, specifications and other deliverables to support the development and implementation of cyber security standardization within ETSI

ISA	ISA 99	Industrial Automation and Control Systems Security	IT security of industrial automation systems Preliminary work for IEC/TC 65/WG 10
ISO	TC 39/SC 10	Safety	Safety wrt = with regard to machine tools
ISO	TC 292/WG 4	Authenticity, Integrity and Trust for Products and Documents	Processes and procedures against counterfeiting
ISO	ISO TMBG SMCC	Smart Manufacturing Coordination Committee	Coordination of standardization activities about smart manufacturing

Table: The current landscape of standardization (as regards IT security)

A2.2 Current documents

ISO/IEC 2700x

The standard ISO/IEC 27001 describes the basic requirements for the information security management systems (ISMS) in an organization. Further standards from the ISO/IEC 2700x series are the supplements found in ISO/IEC 27001. In ISO/IEC 27006, for example, requirements are described for jobs that certify or audit ISMS. This sort of certification is suitable for a company to prove, on a global scale, that they comply with IT security. The target group of this family of standards is the company IT department. This series of standards is continually being updated and expanded upon.

IEC 62443 Industrial communication networks – Security for industrial and control systems

The European series of standards EN 62443 and the German series of standards DIN EN 62443 (VDE 0802) have been available since 2015. The IEC 62443 series of standards plays an important role in the standardization landscape. However, the extent to which these standards cover all necessary areas must still be investigated in detail.

Key documents are described in more detail below.

The IEC 62443 series of standards, “Security for Industrial Automation and Control Systems”, will take on a pivotal role for IT security within Industrie 4.0. This series is being developed by IEC/TC 65, working closely with the US organization “International Society of Automation (ISA)”, and will deal with IT security in automation technology on a procedural and functional level. The European standards organization CENELEC has decided to adopt the IEC 62443 series on IT security in industrial automation systems.

The series is divided into four Parts:

Part 1 describes introductory and general aspects of IT security in automation technology.

- **IEC 62443-1-1** (published in 2009 as a Technical Specification): Part 1-1 introduces terminology, general security concepts, foundational security requirements and security levels.
- IEC 62443-1-2 (in preparation): Part 1-2 gives a list of abbreviations and a glossary.
- IEC 62443-1-3 (draft rejected): Part 1-3 describes the steps for defining and applying the metrics used to define conformity to security requirements.
- IEC 62443-1-5 (in preparation): Part 1-5 describes the usage of the IEC documents for evaluating the protection (through specified protection levels) of operational equipment.

Part 2 describes the security requirements placed on the organization, and the processes of the operator.

- IEC 62443-2-1 (published in 2010 as an International Standard): Part 2-1 describes the requirements for establishing a framework for IT security management. These elements include guidelines, procedures, practical implementation and human resources. This standard includes guidelines on the development of these elements.
- IEC 62443-2-2 (planned): Part 2-2 is intended to give guidelines for the implementation of a framework for IT security management.
- IEC 62443-2-3 (published in 2015 as a Technical Report): Part 2-3 describes requirements for patch management – for manufacturers as well as for users of industrial components and systems – including exchange systems.
- **IEC 62443-2-4** (published in 2015 and 2017 as an International Standard): Part 2-4 describes requirements for processes and organizations for integrators and service providers of industrial automation and control systems.

Part 3 describes requirements for the establishment of a secure industrial automation and control system (IACS).

- **IEC 62443-3-1** (published in 2009 as a Technical Report): Part 3-1 describes and evaluates existing security measures, technologies and tools within the context of IACS. These serve processes such as authentication and authorization, filtering, blocking, access control, encryption, data validation, auditing and monitoring; and also include operating systems and physical measures.
- IEC 62443-3-2 (in preparation): Part 3-2 describes requirements for the implementation of a cell protection concept on the basis of risk analysis.
- **IEC 62443-3-3** (published in 2013 as an International Standard): Part 3-3 describes the security requirements for a system on the basis of the seven foundational requirements and in relation to the four defined security levels.

Part 4 describes security requirements for industrial components that are used in a secure industrial automation and control system.

- **IEC 62443-4-1** (published in 2017 as a final Draft International Standard): Part 4-1 describes the requirements for a secure development process for industrial components. Requirements and guidelines are described for the collection of security requirements, a secure design, secure implementation (and secure validation of the implementation), patch management and phase out.
- IEC 62443-4-2 (in preparation): Part 4-2 describes the security requirements for industrial components on the basis of the seven foundational requirements and in relation to the four defined security levels.

VDI/VDE Guideline 2182

This guideline describes how the manufacturers of automation solutions, machine vendors, system integrators and the operators of manufacturing and processing installations depend on each other. Within the context of Industrie 4.0, these actors are part of an added value network that is to be considered from the point of view of IT security. The guideline follows a risk-based approach that identifies the automation solution as the initial issue for consideration. As such, it is in the spotlight as regards the application of the model procedure in VDI/VDE 2182. The automation solution goes through various different life cycle phases (manufacture, integration, operation). It must be considered that the life cycle phases are not necessarily limited to a single organization. It is therefore generally known that the manufacturer of the automation solution not only develops the product; they also manufacture it. That is why the manufacturer often slips into the role of the operator. These life cycle phases can be represented by a number of different organisations that are connected within added value networks.

The methodology defined in Part 1 of the guideline may be applied to existing automation solutions or those being prepared. The model procedure described therein is based on a process-oriented and cyclical approach. The model itself is comprised of several process steps.

The entire process must itself be tested at set times (controlled by a schedule and/or by occurrences) in order to ensure that the security of the information in the automation solution is being maintained. This encompasses the entire product and equipment life cycle.

The automation solution is central to the risk analysis as the environment in which it is typically or specifically used must be defined within the scope of a structural analysis. The structural analysis then forms the basis for working out the individual steps. A further basis is the definition of which specific occurrences or periods of time trigger the start of the process. This makes clear the fact that the process is based on a cyclical, iterative model. One more essential factor is the definition of the roles, i.e. of the people that will actively participate in each step, for which they shall assume certain tasks – responsibility being one.

The results and decision-making process of each individual step in the process shall/must be documented. At the end, documentation about the process will exist that ensures traceability and ultimately provides the basis for an audit.

The process described here supports the person applying the method to define and validate an appropriate and economically viable security solution for a concrete automation solution.

The guideline is supervised by VDI/VDE-GMA Committee 5.22.

BSI IT-Grundschutz (basic IT protection)

The Bundesamt für Sicherheit in der Informationstechnik (BSI – German Federal Office on Information Security) provides IT protection documentation in the form of a comprehensive library of standards on information security management. It also includes supporting documents that draw on practical experience. These have been available for twenty years and are intermittently updated. In order to modernize it, the collection was overhauled in autumn 2017. This involved refining its existing contents and scope, and adding new topics. The documents are directed at companies of all sizes and are, in particular, intended to provide support to SMEs with implementing new processes, especially those involving information security management.

The protection gives meaning into the very generally worded requirements of the 2700x series of ISO standards and helps users to put the tips, background information and examples into practice. Furthermore, the protection is compatible with the ISO 2700x series so that certification based on the latter is possible. A further benefit of the BSI IT protection documentation is its public availability on the internet. All documents are available in German.

Below is an overview of the BSI Standards on information security.

■ **200-1: Information Security Management Systems (ISMS)**

This BSI Standard describes the basic requirements for an ISMS. It also depicts the different components of an ISMS and the tasks involved.

■ **200-2: Implementing the basic IT protection**

This BSI Standard describes the procedure for implementing the IT protection. This includes the known methods of standard data backup, as well as backup for basic and core business processes. The basic backup is an initial security measure that covers the company in detail, while the core backup protects particularly sensitive data and systems.

■ **200-3: Risk analysis based on IT protection**

This BSI Standard describes the procedure for risk analysis in IT protection, and the risk management that accompanies this.

■ **200-4: Emergency management**

This standard on emergency management describes a systematic way to construct, monitor and develop an emergency management system. The basic concepts laid out are intended

to increase the resilience of a business and ensure the continuity of the core business processes and tasks in the event of a crisis or emergency (see BSI (editor) (2008d)).

The previous IT protection catalogues have been fed into the IT Basic protection compendium, where the central elements of IT protection are summarized. The central elements describe the dangers and also the safety requirements for a given topic and provide concrete recommendations for implementing protection. For the area of industrial automation, specific elements are discussed that deal with the peculiarities of this area.

NAMUR Worksheet NA 115 – “IT-Security for Industrial Automation Systems: Constraints for measures applied in process industries”

NAMUR, the “User Association of Automation Technology in Process Industries” published its worksheet NA 115 in 2006. This document includes reports of experience gained by and working documents for the chemical and pharmaceutical industries. It is not a standard or guideline, but rather describes state-of-the-art technological developments. The protection targets in IT security for the process industry are listed in order of priority: 1. Availability, 2. Integrity, followed by authenticity, confidentiality, non-repudiation and controllability. Over the past few years IT security has become increasingly important for industrial automation. Reasons for this include expanded system functionality in comparison with earlier systems, along with a greater integration of these systems in the IT landscape of companies, and the transition from proprietary systems to systems based on standard hardware and operating systems.

The greater integration of systems not only increases the possibility of attacks; using standard IT components as the basis for systems also means that these attacks have a higher chance of success. In fact, modern automation technology is just as vulnerable as are classical IT systems. The purpose of this NAMUR worksheet is to illustrate the framework conditions associated with IT security products in automation engineering from the point of view of the user. It is intended for manufacturers and system integrators, and provides them with information on framework conditions specific to the process industry as regards the implementation of security measures and/or design of new systems. It also addresses users, giving them relevant criteria to consider when making a purchasing decision. This NAMUR worksheet addresses measures that are indispensable for current systems, as well as for the development of future industrial automation systems from the point of view of IT security.

Industrial Control System Security Compendium

In 2013 the BSI published a “compendium” on the IT security of industrial control systems (ICS). This document serves as a basis for discussions between IT and cyber security experts and industry specialists. It includes a best practice guide for operators, an audit methodology for ICS installations, an overview of R&D that still needs to be carried out, and the standardization landscape. The aim is to synchronize the sector-specific know-how in the international standards

bodies with the work of the BSI to keep national and international activities from going in different directions.

In 2014 the BSI also published an “ICS Security Compendium” addressed to manufacturers of components. It provides guidance on establishing a “security-by-design” approach to component development, using IT security tests and employing measures for avoiding weaknesses.

A3 Standards activities regarding service robotics

WG 1 – Vocabulary and coordinate systems

The goal of WG 1 is to collate fundamental terms and definitions regarding robotics and autonomous systems. ISO 8373 is being continually updated in order to incorporate new areas such as robotics in medicine. As part of this, terms for mobile robotics (e.g. for navigation and perception) are being developed.

Relevant standards:

- ISO 8373 – Robots and robotic devices – Vocabulary (2012)
 - ISO 9787 – Robots and robotic devices – Coordinate systems and motion nomenclatures (2013)
 - ISO/CD 19649 – Robots and robotic devices – Vocabulary for mobile robots (2016)
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WG 2 – Personal care robot safety

ISO 13482 offers basic safety standards for personal care robots. To aid this process, guidelines are being developed to help manufacturers to comply with standards and to verify their products.

Relevant standards:

- ISO 13482 – Robots and robotic devices – Safety requirements for personal care robots (2014)
 - ISO/CD TR 23482-1 – Technical report: Validation criteria for personal care robots (committee draft)
 - ISO/CD TR 23482-2 – Application guide for ISO 13482 to be published as a technical report (committee draft)
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WG 3 – Industrial safety

The development of ISO/TS 15066, which defines the upper limits for any contact forces and pressures for a potential collision during the human-robot collaboration, is an integral part of industrial safety. Additionally, specific safety stipulations are to be developed for loading and unloading involving the interaction of humans and robots, as well as for automatic machines that are similar to robots.

Relevant standards:

- ISO 10218-1 – Robots and robotic devices – Safety requirements – Part 1: Robots (published in 2011, periodic review started)
 - ISO 10218-2 – Robots and robotic devices – Safety requirements – Part 2: Robot systems and integration (published in 2011, periodic review started)
 - ISO TS 15066 – Robots and robotic devices – Safety requirements for industrial robots – Collaborative operation (published in 2015)
 - ISO/NP TR 20218-1 – Robots and robotic devices – Safety requirements for industrial robots – Part 1: Industrial robot system end of arm tooling (end-effector) (in preparation)
 - ISO/DTR 20218-2 – Robots and robotic devices – Safety requirements for industrial robots – Part 2: Industrial robot system manual load stations (committee draft)
-

WG 4 – Service robots

This working group coordinates, first and foremost, the standardization efforts of the other working groups and works closely with the IEC⁷⁰. Their work involves closely monitoring the market in order to analyse the need for new standards and rules within the area of service robotics. Furthermore, standards on test methods for measuring the performance of service robots (e.g. on forward motion or object recognition) have been, and will continue to be, developed.

Relevant standards:

- ISO 18646-1 – Robots and robotic devices – Performance criteria and related test methods for service robot – Part 1: Locomotion for wheeled robot (2016)
 - ISO/CD 18646-2 – Robots and robotic devices – Performance criteria and related test methods for service robot – Part 2: Navigation (committee draft)
 - ISO/NP 18646-3 – Robots and robotic devices – Performance criteria and related test methods for service robot – Part 3: Manipulation (new work item)
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⁷⁰ The IEC published the current standards for vacuum cleaner and lawn mower robots, among others, under IEC 60335-2-2 and IEC 60335-2-107.

JWG 5 – Medical robot safety

The joint ISO/IEC working group is developing safety and performance standards for surgery and medical robots for the genre of rehabilitation.

Relevant standards:

- IEC/TR 60601-4-1 – Medical electrical equipment – Part 4.1: Guidance and interpretation – Medical electrical equipment and medical electrical systems employing a degree of autonomy (2017)
 - IEC/CD 80601-2-77 – Medical Electrical Equipment – Part 2-77: Particular requirements for the basic safety and essential performance of medical robots for surgery (committee draft)
 - IEC/CD 80601-2-78 – Medical Electrical Equipment – Part 2-78: Particular requirements for the basic safety and essential performance of medical robots for rehabilitation, compensation or alleviation of disease, injury or disability (committee draft)
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WG 6 – Modularity

This working group was only formed in 2014 and works on standards that focus on increasing the reusability of hard and software, as well as the interoperability of components.

Relevant standards:

- ISO/AWI 22166-1 – Robotics – Part 1: Modularity for service robots – Part 1: General requirements
-

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