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Status Report

Reference Architecture Model
Industrie 4.0 (RAMI4.0)

July 2015

Foreword

The main discussion on future trends in manufacturing is very much focused on the use of Internet IT-technologies. This global trend, which is often named as Internet-of-Things (IoT), is driven in Germany by the so called platform “Industrie 4.0” a joint activity of the industrial associations ZVEI, VDMA and BITKOM supported very actively by researchers and the VDI. Several working groups (WG) were initiated to define a consensual base for later product developments.

A first very important step was the definition of a reference architecture for “Industrie 4.0”. Under the common umbrella of this national platform the

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WG2, the Technical Committee 7.21, the focus group “Industrie 4.0” of the VDI/VDE Society Measurement and Automatic Control (GMA) and the mirror Working Panel SG2 of ZVEI worked in close cooperation. The result of that work is documented in chapter 6 of the Implementation Strategy for Industrie 4.0 issued by the three industrial associations. This chapter is published here in English translation to open the ideas to all interested engineers worldwide. This also emphasizes broad consensus in the various sectors of industry and the academic world. To that extent, it can be assumed to constitute a foundation which may be built upon for the next steps.



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1 Summary

The physical and virtual worlds are increasingly converging. More and more physical objects can draw on smart sensor and actor technology, and are becoming networked in the evolutionary development of the Internet of Things. The availability of all relevant information in real time by networking of all the instances involved in adding value, and the ability to use those data to establish the optimum value stream at any particular time are triggering a further industrial revolution (known as Industrie 4.0) in business processes, and facilitating new business models. In that connection, the focus is on optimization of the following core industrial processes: research and development, production, logistics and service.

With a view to securing the future of Germany as a business location and of its industry, the implementation strategy for Industrie 4.0 has been established by Plattform Industrie 4.0 in cooperation with the associations BITKOM, VDMA and ZVEI, and various German industrial enterprises. Chapter 6 of the implementation strategy for Industrie 4.0 [1] was planned in advance in such a way that it could be extracted and published as a GMA Status Report. The result is this paper.

This GMA Status Report presents a reference architecture model (RAMI4.0) for semantic technologies and their benefits for automation and its associated technologies. The structures and functions of what

are termed Industrie 4.0 components (referred to below as I4.0 components) are also described. Where appropriate, parts of the reference architecture model and the I4.0 components draw upon existing and relevant standards, so as to gain acceptance more rapidly. Where necessary, the implementation strategy identifies and describes additional standardization requirements.

As a result of the increasing networking and controllability of physical objects and the simultaneous rise in the threat level posed by hackers, secret services, espionage and so on, special security requirements are necessary. These are outlined in chapter 7 of the implementation strategy for Industrie 4.0.

The Status Report is addressed to readers from German industry, the relevant technology-oriented sectors, research and government. In particular, it is intended for managers, experts and consultants, and all parties interested in the future of Industrie 4.0 in Germany or wish to assist in shaping it.

Note

English translation of the german Status Report “Referenzarchitekturmodell Industrie 4.0 (RAMI4.0)” which was published in April 2015 by VDI/VDE Society Measurement and Automatic Control (GMA).

2 Reference architecture

2.1 Consensus among the associations

The reference architecture for Industrie 4.0 described here is the result of cooperation between several institutions. In particular, experts from Technical Committees 7.21, “Industrie 4.0”, and 7.20, “Cyber-Physical Systems” of the VDI/VDE Society for Measurement and Automatic Control (GMA) have made a major contribution to the results. This work follows on from that described in the three status reports [2-4] published to date, which, together with this paper are available for download at no charge from www.vdi.de/industrie40. This present status report was created in cooperation with the ZVEI mirror committee SG2, which also contributed to the development of the model described here. The German Commission for Electrical Engineering (DKE) was also involved in all the work.

The role of coordinating the activities in the numerous subcommittees and ensuring consistency therefore fell primarily to WG2 of Plattform Industrie 4.0, enabling the platform to perform its intended task of ensuring concerted action by a broad range of different organizations and associations. The broadly based results presented below are therefore an important step towards preserving the competitiveness of German industry.

2.2 Introduction

One of the fundamental ideas on the reference architecture of Industrie 4.0 is the grouping of highly diverse aspects in a common model. Vertical integration within the factory describes the networking of means of production, e. g. automation devices or services. As a new aspect in Industrie 4.0, the product or workpiece is also involved. The corresponding model must reflect this aspect. But Industrie 4.0 goes considerably further. End-to-end engineering throughout the value stream means that the technical, administrative and commercial data created in the ambit of a means of production or of the workpiece are kept consistent within the entire value stream and can be accessed via the network at all times. A third aspect in Industrie 4.0 is horizontal integration via added value networks, extending beyond individual factory locations and facilitating the dynamic creation of such added value networks.

The task to be performed was to represent these aspects in a model. It should, after all, be possible to represent

closed loop control circuits with polling rates in milliseconds, controlling dynamic cooperation between several factories, within a common added value network and with additional commercial issues, in a model. In this connection, the perspectives of different application domains had to be understood, and their fundamentals identified and united in a common model.

Before work proper could commence on the reference architecture model RAMI4.0, then, it was necessary to establish an overview of the existing approaches and methods. It rapidly became clear that there was already a series of existing and usable approaches, which however as a rule only addressed partial aspects of the holistic view of Industrie 4.0 outlined above. The following individual aspects were considered in greater detail:

- Approach for implementation of a Communication Layer
 - OPC UA: Basis IEC 62541
- Approach for implementation of an Information Layer
 - IEC Common Data Dictionary (IEC 61360 Series/ISO13584-42)
 - Characteristics, classification and tools to eCl@ss
 - Electronic Device Description (EDD)
 - Field Device Tool (FDT)
- Approach for implementation of a Functional and Information Layer
 - Field Device Integration (FDI) as integration technology
- Approach for end-to-end engineering
 - AutomationML
 - ProSTEP iViP
 - eCl@ss (characteristics)

The first step was a fundamental examination of whether these approaches match the reference architecture model presented in section 2.3. It was found in principle that they do, although the concepts and methods considered still require more detailed examination.

2.3 Reference architecture model for Industrie 4.0 (RAMI4.0)

Highly divergent interests meet in the discussion concerning Industrie 4.0: industries from process to factory automation with totally different standards, information and communication technologies and automatic control,

the associations Bitkom, VDMA, ZVEI and VDI and the standardization organizations IEC and ISO with their national mirror committees in DKE and DIN.

In order to achieve a common understanding of what standards, use cases, etc. are necessary for Industrie 4.0, it became necessary to develop a uniform architecture model as a reference, serving as a basis for the discussion of its interrelationships and details.

The result is the reference architecture model for Industrie 4.0 (RAMI4.0). See figure 1.

It contains the fundamental aspects of Industrie 4.0, and expands the hierarchy levels of IEC 62264 by adding the “Product” or workpiece level at the bottom, and the “Connected World” going beyond the boundaries of the individual factory at the top. The left horizontal axis is used to represent the life cycle of systems or products, also establishing the distinction between “Type” and “Instance”. Finally, the six layers define the structure of the IT representation of an I4.0 component.

The special characteristics of the reference architecture model are therefore its combination of life cycle and value stream with a hierarchically structured approach for the definition of I4.0 components. Maximum flexibility for the description of an I4.0 environment is provided in this way. The approach also permits encapsulation of functionalities where appropriate.

By means of the reference architecture model, the conditions have thus been created for the description and implementation of highly flexible concepts. In that context, the model permits step by step migration from the world of today to that of I4.0, and the definition of application domains with special stipulations and requirements.

The reference architecture model RAMI4.0 has been put forward for standardization as DIN SPEC 91345.

2.3.1 Requirements and objectives

Objectives

Industrie 4.0 is a specialization within the “Internet of Things and Services”. Around 15 industries have to be involved in the deliberations. Using the reference architecture model, tasks and workflows can be broken down into manageable parts. In this way, the subject matter is to be made so accessible that a productive discussion, for instance on standardization issues, becomes possible. The existing standards which come

into question are, then, to be identified, consequently revealing where there may be a need for additions or amendments, or where standards are missing. Overlaps will then also become visible and open to discussion. If consideration of the model reveals that there are several standards for the same or similar matters, a preferred standard can be discussed within the scope of the reference architecture model.

The aim is to cover the issues with as few standards as possible.

Compliance with standards

The concepts and methods described in the selected standards are to be reviewed to ascertain the extent to which they are suitable for applications in the Industrie 4.0 environment. Implementation of part of a standard may be sufficient for an initial I4.0 application. This would accelerate the implementation and introduction of non-proprietary solutions which are essential for Industrie 4.0, and would also enable smaller companies to adapt to Industrie 4.0 and master its challenges more rapidly.

Use Cases

The reference architecture model also provides an opportunity to locate I4.0 use cases, so as for example to identify the standards required for the relevant use case.

Identification of relationships

Various topics can be represented as subspaces of the reference architecture model. Industrie 4.0 essentially depends upon the ability to detect and process relationships, e. g. those between these subspaces, electronically.

Definition of higher level rules

The reference architecture model permits the derivation of rules for the implementation of I4.0 applications on a higher level.

The objectives at a glance

- Simple and manageable architecture model as the reference
- Identification of existing standards
- Identification and closure of gaps and loopholes in standards
- Identification of overlaps and stipulation of preferred solutions

- Minimization of the number of standards involved
- Identification of subsections of standards for rapid implementation of parts thereof in Industrie 4.0 (“I4.0 ready”)
- Identification of use case contents
- Identification of relationships
- Definition of higher level rules

2.3.2 Brief description of the reference architecture model

A three-dimensional model is best suited to represent the I4.0 space. The basic features of the model reflect those of the Smart Grid Architecture Model (SGAM – Note: CEN/CENELEC/ETSI SG-CG, Overview of SG-CG Methodologies, Version 3.0, Annex SGAM User Manual, 2014), which was defined by the European Smart Grid Coordination Group (SG-CG) and is accepted worldwide. It was adapted and extended to meet the I4.0 requirements.

Layers are used in the vertical axis to represent the various perspectives, such as data maps, functional descriptions, communications behaviour, hardware/assets or business processes. This corresponds to IT thinking where complex projects are split up into clusters of manageable parts.

A further important criterion is the product life cycle with the value streams it contains. This is displayed along the left-hand horizontal axis (figure 1). Dependencies, e. g. constant data acquisition throughout the life cycle, can therefore also be represented well in the reference architecture model.

The third important criterion, represented in the third (right-hand horizontal) axis, is the location of functionalities and responsibilities within the factories/plants. This represents a functional hierarchy, and not the equipment classes or hierarchical levels of the classical automation pyramid.

2.3.3 Layers of the reference architecture model

The Smart Grid Architecture Model (SGAM) is a good initial approach for representation of the circumstances to be described. It deals with the electricity grid, from generation through transmission and distribution to the consumer. Industrie 4.0 focuses on product development and production scenarios. Consequently, it is necessary to describe how development processes, production lines, manufacturing machinery, field devices and the products themselves are configured and how they function.

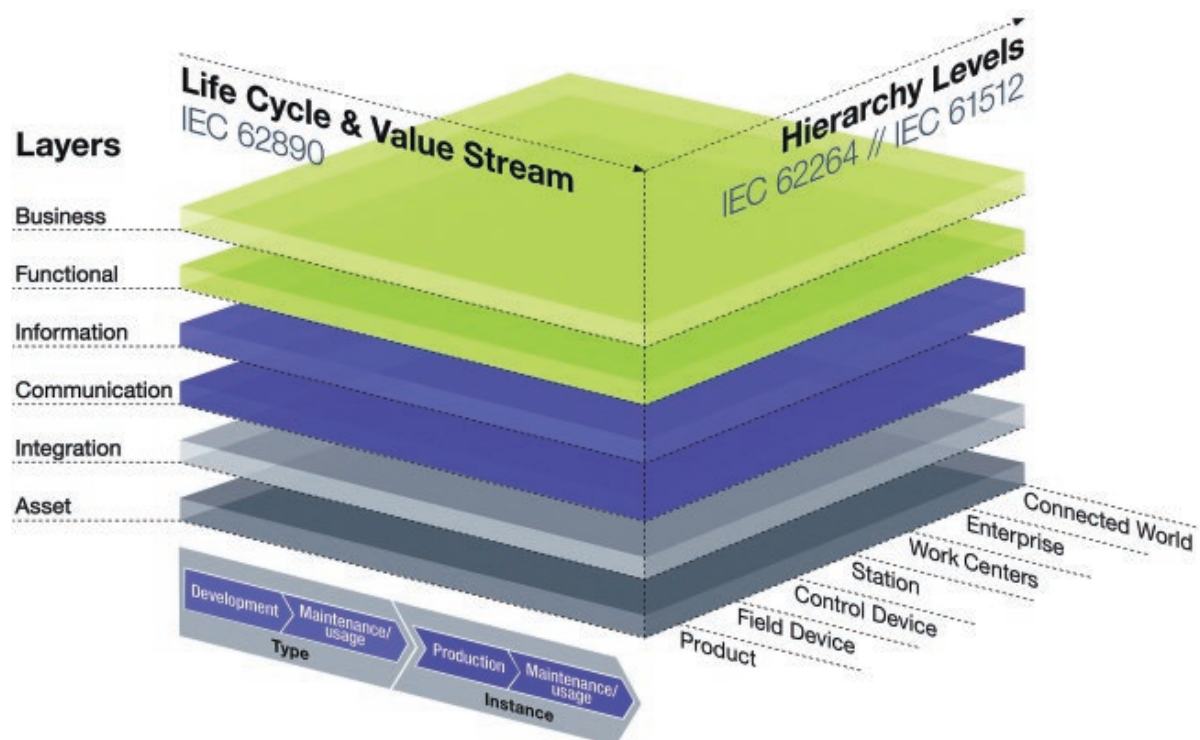


Figure 1. Reference architecture model for Industrie 4.0 (RAMI4.0)
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For all components, no matter whether they are a machine or a product, it is not only the information and communication functionality which is of interest. In the simulation of a system, e. g. a complete machine, its cables, linear drive and also its mechanical structure are also considered. They are part of the reality, without any active communication ability. Their information has to be available as a “virtual representation”. For that purpose they are, for example, connected to a database entry via a 2D code.

For better description of machines, components and factories in comparison with SGAM, the component layer has been replaced by an Asset Layer at the bottom of the model with the newly inserted Integration Layer above. This facilitates digitization of the assets for virtual representation. The Communication Layer deals with protocols and the transmission of data and files, the Information Layer contains the relevant data, the Functional Layer all the necessary (formally defined) functions, and the Business Layer maps the relevant business processes.

Note: A high level of cohesion is to prevail within the layers, with loose connections between them. Events may only be exchanged between two adjacent layers and within each layer.

Several systems are grouped together to form larger overall systems. Both the individual systems and the overall system must follow the reference architecture model. The contents of the layers must be compatible with each other.

The individual layers and their interrelationships are described below.

Business Layer

- Ensuring the integrity of the functions in the value stream.
- Mapping the business models and the resulting overall process.
- Legal and regulatory framework conditions.
- Modelling of the rules which the system has to follow.
- Orchestration of services in the Functional Layer.
- Link between different business processes.
- Receiving events for advancing of the business processes.

The Business Layer does not concern concrete systems, such as an ERP system. ERP functions in the process context are typically located in the Functional Layer.

Functional Layer

- Formal description of functions.
- Platform for horizontal integration of the various functions.
- Run time and modelling environment for services which support business processes.
- Run time environment for applications and technical functionality.

Rules and decision-making logic are generated inside the Functional Layer. Depending on the use case, these can also be executed in the lower layers (Information Layer or Integration Layer).

Remote access and horizontal integration only take place within the Functional Layer. This ensures the integrity of the information and conditions in the process and the integration of the technical level. The Asset Layer and Integration Layer may also be accessed temporarily for maintenance purposes.

Such access is in particular used to call up information and processes which are only relevant to subordinate layers. Examples include flashing of sensors/actuators or the reading of diagnosis data. This maintenance-related temporary remote access is not relevant to permanent functional or horizontal integration.

Information Layer

- Run time environment for (pre-) processing of events.
- Execution of event-related rules.
- Formal description of rules.
- Context: event pre-processing.

In that context, rules are applied to one or more events to generate one or more further events, which then initiate processing in the Functional Layer.

- Persistence of the data which represent the models.
- Ensuring data integrity.
- Consistent integration of different data.
- Obtaining new, higher quality data (data, information, knowledge).
- Provision of structured data via service interfaces.
- Receiving of events and their transformation to match the data which are available for the Functional Layer.

Communication Layer

- Standardization of communication, using a uniform data format, in the direction of the Information Layer.

- Provision of services for control of the Integration Layer.

Integration Layer

- Provision of information on the assets (physical components/hardware/documents/software, etc.) in a form which can be processed by computer.
- Computer-aided control of the technical process.
- Generation of events from the assets.
- Contains the elements connected with IT, such as RFID readers, sensors, HMI, etc.

Interaction with humans also takes place on this level, for instance via the Human Machine Interface (HMI).

Note: Each important event in the real world points to an event in the virtual world, i. e. in the Integration Layer. If the reality changes, the event is reported to the Integration Layer by suitable mechanisms. Relevant events can trigger events signalled to the Information Layer via the Communication Layer.

Asset Layer

- Represents reality, e. g. physical components such as linear axes, metal parts, documents, circuit diagrams, ideas and archives.
- Human beings are also part of the Asset Layer, and are connected to the virtual world via the Integration Layer.
- Passive connection of the assets to the Integration Layer, for instance by means of QR codes.

2.3.4 Life Cycle & Value Stream

Life Cycle

Industrie 4.0 offers great potential for improvement throughout the life cycle of products, machines, factories, etc. In order to visualize and standardize relationships and links, the second axis of the reference architecture model represents the life cycle and the associated value streams.

The draft of IEC 62890 is a good guideline for consideration of the life cycle. The fundamental distinction between type and instance is of central importance in those considerations.

Type

A type is always created with the initial idea, i. e. as a product comes into being in the development phase.

This covers the placing of design orders, development and testing up to the first sample and prototype production. The type of the product, machine, etc. is thus created in this phase. On conclusion of all tests and validation, the type is released for series production.

Instance

Products are manufactured industrially on the basis of the general type. Each manufactured product then represents an instance of that type, and, for example, has a unique serial number. The instances are sold and delivered to customers. For the customer, the products are initially once again only types. They become instances when they are installed in a particular system. The change from type to instance may be repeated several times.

Improvements reported back to the manufacturer of a product from the sales phase can lead to an amendment of the type documents. The newly created type can then be used to manufacture new instances. Similarly to each individual instance, then, the type is also subject to use and updating.

Example

The development of a new hydraulic valve represents the creation of a new type. The valve is developed, initial samples are set up and tested, and finally a first prototype series is manufactured and validated. On successful completion of validation, the hydraulic valve type is released for sale (material number and/or product designation in sales catalogue). At that point, series production also starts. In series production, each hydraulic valve manufactured is, for example, provided with its unique identification (serial number) and is an instance of the previously developed hydraulic valve.

Feedback on the hydraulic valves sold in the field (instances) may for example lead to minor adjustments to the mechanical design and the relevant drawing, or to corrections in the firmware for the valve. These modifications are modifications to the type, i. e. they are applied as amendments to the type documentation, are once again released, and new instances of the modified type are then created in production.

Value Streams

Digitization and linking of the value streams in Industrie 4.0 provides huge potential for improvement. Links spanning various functions are of decisive importance in this connection.

Logistics data can be used in assembly, and intralogistics organize themselves on the basis of the order backlog. Purchasing sees inventories in real time, and knows where parts from suppliers are at any point in time. The customer sees the completion status of the product ordered during production, and so on. The linking of purchasing, order planning, assembly, logistics, maintenance, the customer and suppliers, etc., provides great improvement potential. The life cycle therefore has to be viewed together with the value-adding processes it contains, and not in an isolated fashion with a view to a single factory, but rather in the collective of all the factories and all the parties involved, from engineering through component suppliers to the customer.

With regard to the value streams, we would also draw attention to the publication on value streams by the GMA Technical Committee 7.21 [2].

2.3.5 Hierarchy Levels

The third axis of the reference architecture model describes the functional classification of various circumstances within Industrie 4.0. The issue here is not implementation, but solely functional assignment.

For classification within a factory, this axis of the reference architecture follows the IEC 62264 and IEC 61512 standards (see figure 2). For a uniform consideration covering as many sectors as possible from process industry to factory automation, the terms “Enterprise”, “Work Unit”, “Station” and “Control Device” were selected from the options listed there and used.

For Industrie 4.0, not only the control device (e. g. head controller) is decisive, but also considerations within a machine or system. Consequently, the “Field

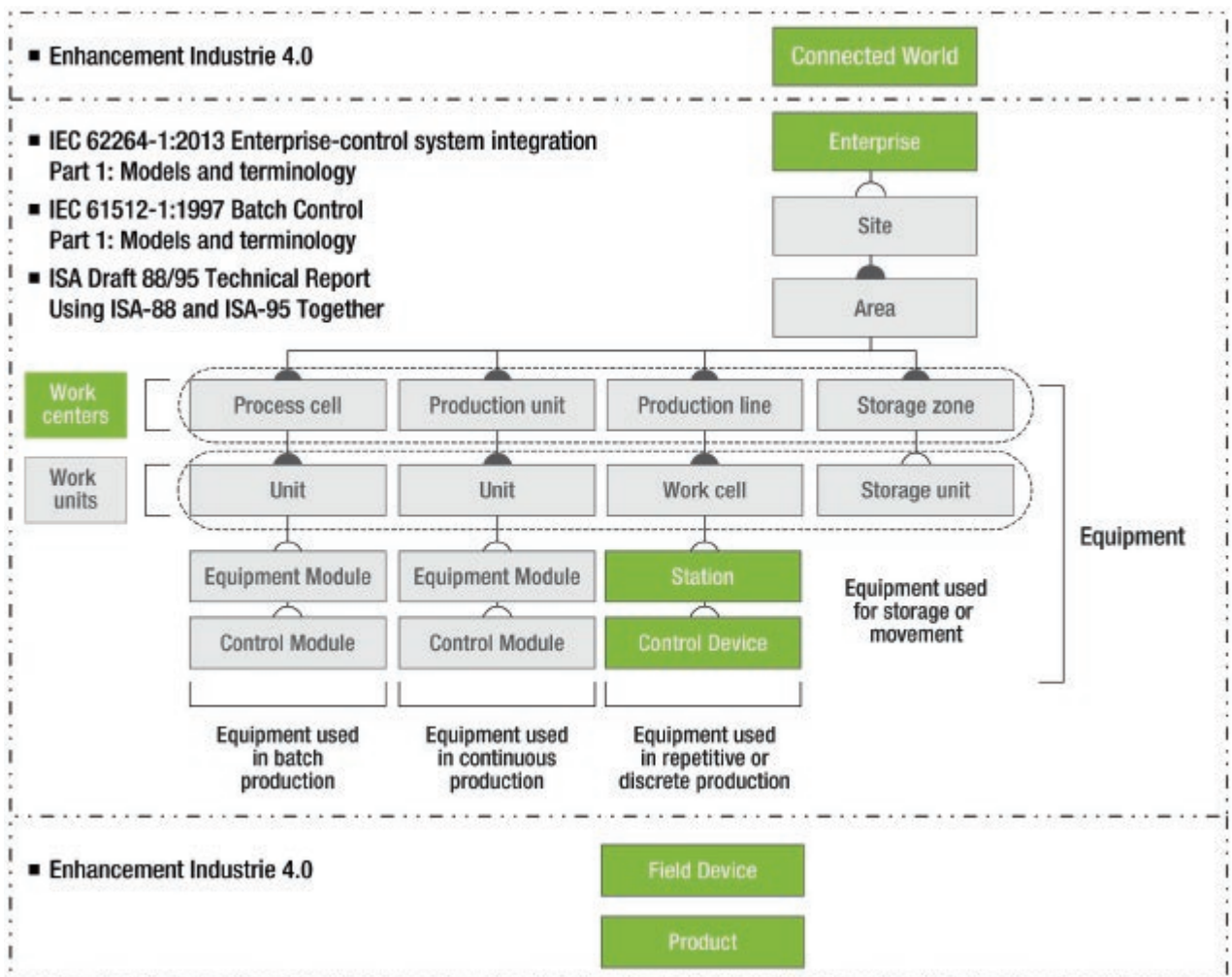


Figure 2. Derivation of the hierarchy levels of RAMI4.0
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Device” has been added below the Control Device. This represents the functional level of an intelligent field device, e. g. a smart sensor.

Furthermore, not only the plant and machinery for the manufacture of products is important in Industrie 4.0, but also the product to be manufactured itself. It has therefore been added as “Product” as the bottom level. As a result, the reference architecture model permits homogeneous consideration of the product to be manufactured and the production facility, with their interdependencies.

An addition has also been made at the upper end of the hierarchy levels. The two IEC standards mentioned only represent the levels within a factory. Industrie 4.0, however, goes a step further and also describes the group of factories, and the collaboration with external engineering firms, component suppliers and customers, etc. For observations above and beyond the Enterprise level, the “Connected World” has therefore been added.

2.4 Reference model for the I4.0 components

Version 1.0 of the “reference model for I4.0 components” described below is intended to be the first of several elaborations to be published at intervals of less than one year.

In a further step, therefore, sections with more precise definitions are to follow, and formalization with UML is planned.

Care is taken in the text to identify precisely where texts/quotations from other sources are adopted in the I4.0 environment. In the final version, the terms used and their definitions are to be identical with those in the glossary agreed and published by the GMA Technical Committee 7.21 (see section 2.5). Examples are also explicitly identified in order to avoid exclusions which are not explicitly named in the example.

2.4.1 Integration in the discussion on Industrie 4.0

The discussion on Industrie 4.0 can be roughly understood as the interaction between four aspects, as illustrated in figure 3 drawn from the final report of the Industrie 4.0 Working Group [5]:

According to figure 3, these four aspects are as follows:

- **I4.0 Aspect (1)** Horizontal integration through value networks

- **I4.0 Aspect (2)** Vertical integration,
 - e. g. within a factory or production shop
- **I4.0 Aspect (3)** Life cycle management, and end-to-end engineering
- **I4.0 Aspect (4)** Human beings orchestrating the value stream

The I4.0 component described in this text provides a flexible framework with which data and functions that facilitate and promote the I4.0 aspects listed above can be defined and provided. The concepts described in this text currently address above all Aspect (2), and take account of some requirements from Aspect (3).

2.4.2 Contents from further relevant publications

Objects, entities and components

Attention is drawn here to the VDI Status Report “Industrie 4.0: Gegenstände, Entitäten, Komponenten” (Industrie 4.0: Objects, entities and components) from GMA Technical Committee 7.21 [4]. Definitions from that report are reflected in those presented in previous sections of this status report.

Types and instances

Here too, attention is drawn to the VDI Status Report “Industrie 4.0: Gegenstände, Entitäten, Komponenten” (Industrie 4.0: Objects, entities and components) from GMA Technical Committee 7.21 [4]. The state of the art in distinctions between types and instances in Industrie 4.0 is examined there.

Life cycles

According to Dr. Carmen Constantinescu and Prof. Thomas Bauernhansl of Fraunhofer IPA, life cycles in various dimensions are of relevance to the operation of a factory in Industrie 4.0.

- **Product:** A factory produces several products. Each product has its own life cycle.
- **Order:** Each order for manufacturing runs through a life cycle and its specifics necessarily have an impact on the production facility during performance of the order.
- **Factory:** A factory also has a life cycle: It is financed, planned, constructed and recycled. A factory integrates production systems and machines from various manufacturers.
- **Machine:** A machine is ordered, designed, commissioned, operated, serviced, converted and recycled.

Horizontal integration



Vertical integration



End-to-end engineering



Humans orchestrate the value stream



Figure 3. Four important aspects of Industrie 4.0 (Sources: Siemens, Festo) Copyright „Umsetzungsstrategie Industrie 4.0 - Ergebnisbericht, Berlin, April 2015“

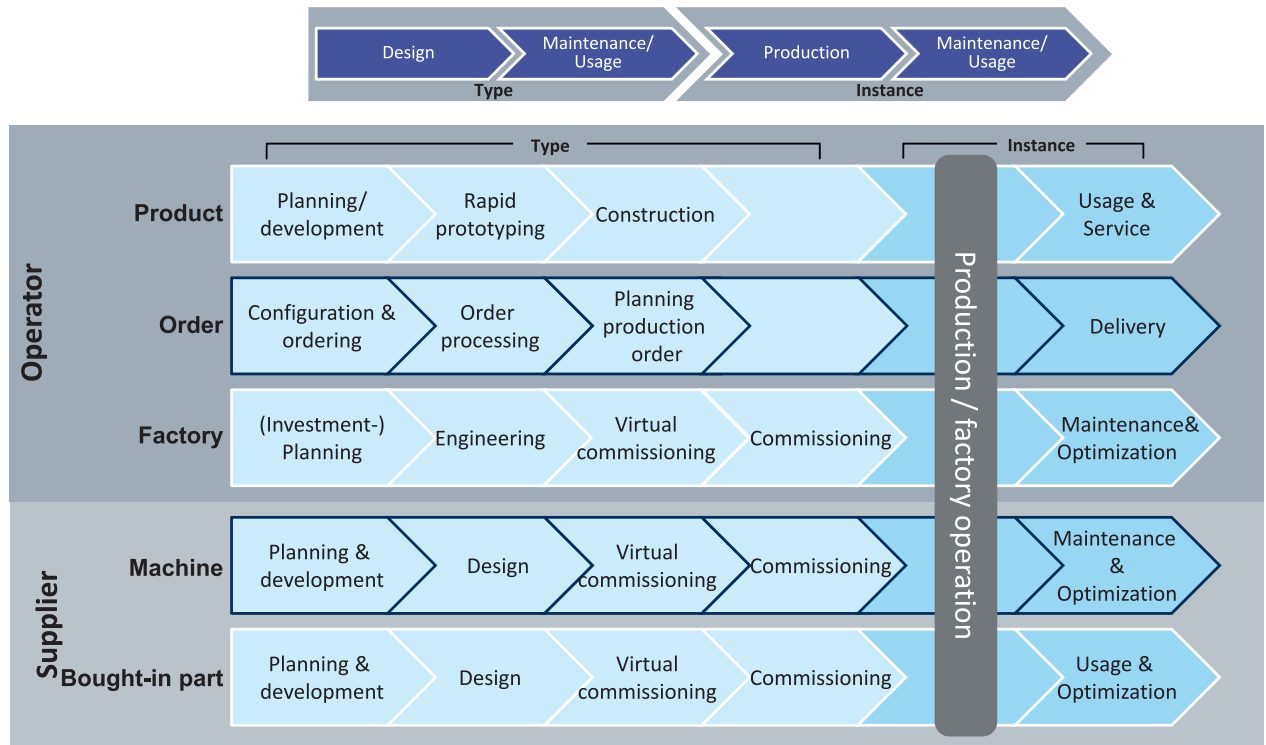


Figure 4. Relevant life cycles for 14.0 components; Source: M. Hankel, Bosch Rexroth. Based on Plattform Industrie 4.0 WG3. Based on Prof. Bauernhansl, Fraunhofer IPA Copyright „Umsetzungsstrategie Industrie 4.0 - Ergebnisbericht, Berlin, April 2015“

The manufacturer of a machine purchases individual parts, which are referred to in this paper as “objects”. The supplier (usually a component manufacturer) also puts these parts through a life cycle:

- **Component:** Planning and development, rapid prototyping, construction, production and use, up to servicing.

Figure 4 illustrates the assignment of types and instances to the life cycle.

Linking of life cycles

The reason why it is necessary to distinguish between types and instances is the interaction of various business partners and their individual life cycles with the

planning processes. During planning, various hypotheses and alternatives are considered. The planning proceeds on the basis of potential objects, and refers to them as “types”.

- **The component supplier** refers to them as “part types”. Only manufacture and the subsequent delivery to the customer (machine manufacturer) “creates” an instance, which the machine manufacturer uses as a bought-in component.
- **The machine manufacturer** discusses “machine types” with his customer, and designs them. Construction of a specific machine creates an instance which is then used by the factory operator.
- **The factory operator** also initially develops a product as a product type. Only receipt of an order initiates production and implements the manufacture of concrete product instances which are delivered.

It is remarkable in this context that during the design and planning of each type a large amount of data and information is generated, and can be drawn upon by the downstream business partner in the added value network during the use of the relevant instance. Further information is added during production of a particular instance (e. g. tracking data and quality data). The reference model for I4.0 components therefore deals with types and instances as being similar and equivalent.

Reference Architecture Model for Industrie 4.0 (RAMI4.0)

With regard to the definitions in the Reference Architecture Model for Industrie 4.0 (RAMI4.0), attention is drawn to the preceding sections. The I4.0 component presented in figure 5 is located within the layers of RAMI4.0. It can adopt various positions in the life cycle and value stream, and occupy various hierarchical levels: a final assignment is only possible in the case of an actual instance.

2.4.3 I4.0 component

An initial generally recognized definition of an I4.0 component is adduced in this section.

Allocation of the I4.0 component to “office floor” and “shop floor”

In order to achieve a clear assignment of responsibilities, companies usually distinguish between “office floor” and “shop floor”. In modern businesses, however, these areas are increasingly dovetailed. If the focus is on automation systems, the relevance of the office floor decreases, while more and more requirements of the shop floor become relevant. The same also applies in reverse. As a result of the

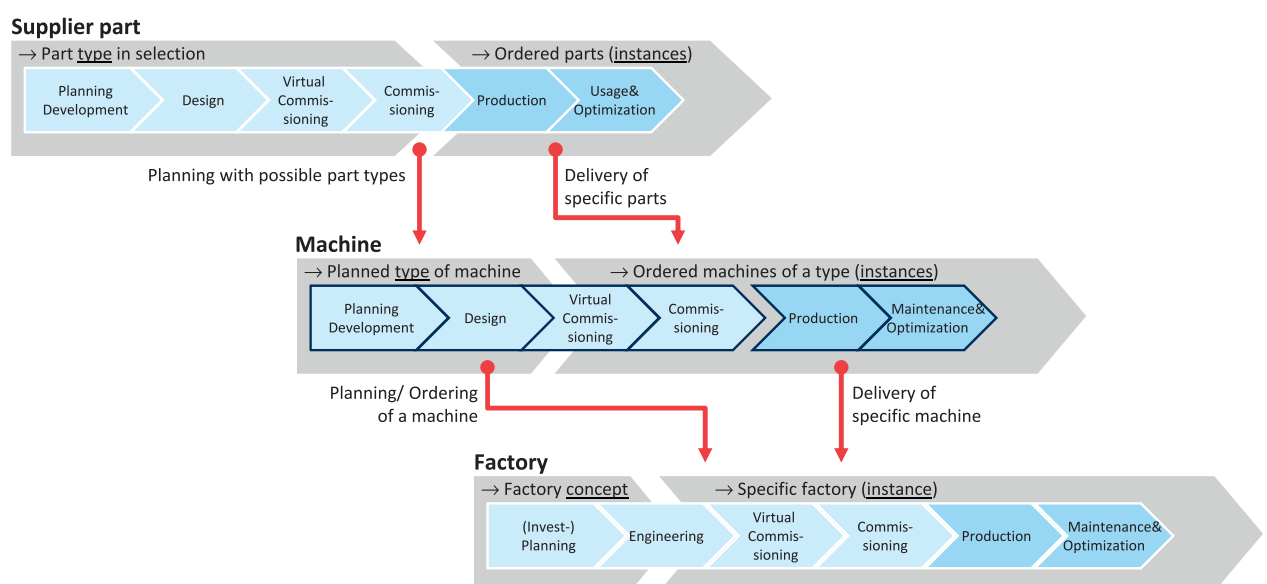


Figure 5. Types and instances in the life cycle
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requirements for connectivity to any end points and a common semantic model in figure 6, components must have certain common properties independently of the levels. They are specified in the form of the I4.0 components.

An I4.0 component can be a production system, an individual machine or station, or an assembly inside a machine. Each I4.0 component, however different they may be, therefore moves along the life cycle of the factory in the field of tension between the relevance of the office floor and shop floor, and in contact with such central and significant factory systems as the PLM (Product Lifecycle Management), ERP (Enterprise Resource Planning) and Industrial Control and Logistics systems.

Requirement: A network of I4.0 components must be structured in such a way that connections between any end points (I4.0 components) are possible. The I4.0 components and their contents are to follow a common semantic model.

Requirement: It must be possible to define the concept of an I4.0 component in such a way that it can meet requirements with different focal areas, i. e. "office floor" or "shop floor".

From the object to the I4.0 component

In the following section, the individual findings of the VDI/VDE Society for Measurement and Automatic

Control (GMA) are to be set in relation to each other, so as to arrive at a definition of an I4.0 component:

Classes of objects

GMA names four classes of objects:

- Unknown
- Anonymous
- Individually known
- Entity

In order to link data and functions to an object, it must take the form of an entity.

Software, which in the conventional sense can be delivered physically or non-physically, is also an object. Ideas, archives and concepts are also objects within the meaning of the word here.

Remark 1: As it is one of the objectives of an I4.0 component to provide data and functions within an information system, individually known objects as defined by GMA automatically undergo a transition to being an entity.

Remark 2: The term object is used below whenever an object/entity is referred to.

Type/Instance

Objects may be known in the form of a type or of an instance. An object in the planning phase, for example,

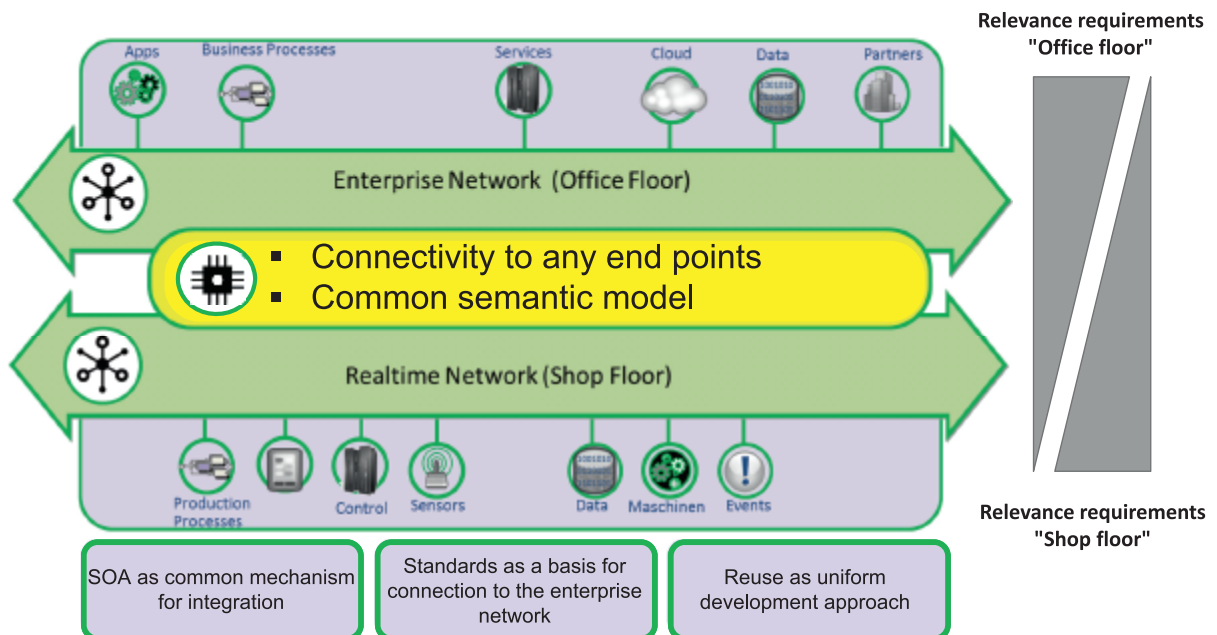


Figure 6. Demarcation between office floor and shop floor
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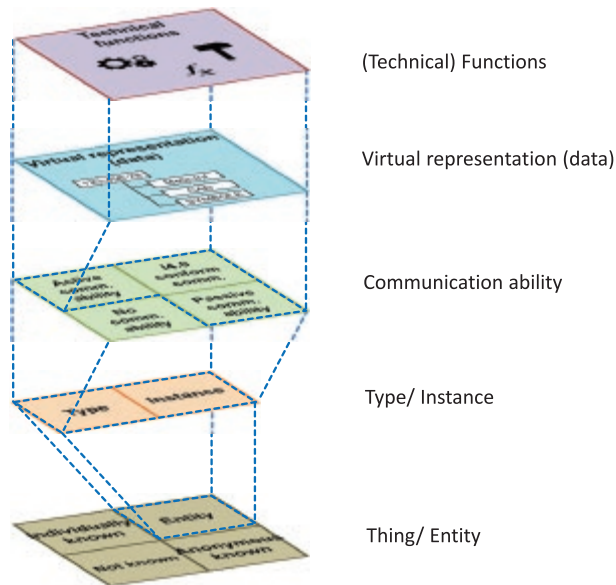


Figure 7. I4.0 component
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is known as a type, and if the order information for a planned object is known, it can be regarded as an individually known type. All the objects in an actually existing machine, for example, are to be regarded as instances. No separate account is currently taken of apparent instances, which arise from multiple instantiation of a type for purposes of countability (batches). In such cases, instantiation should be performed as a concrete process and a reference to the type established.

Communication ability

If the properties of an I4.0 component are to be made available, at least one information system must maintain a connection with the object. This therefore requires at least passive communication ability on the part of the object, which means that an object does not necessarily have to have the ability of I4.0 compliant communication as set out by GMA Technical Committee 7.21. In consequence existing objects can be “extended” to constitute I4.0 components. In this case, a higher level IT system takes on part of the I4.0 compliant communication by way of a service oriented architecture and a deputization principle.

An identifiable terminal strip, for example, or a Profi-Net device (identifiable by its I&M data) can become an I4.0 component in this way.

Virtual representation

The virtual representation contains data on the object. These data can either be kept on/in the I4.0

component itself and made available to the outside world by I4.0 compliant communication, or they can be stored in a (higher level) IT system which makes them available to the outside world by I4.0 compliant communication.

In the reference architecture model RAMI4.0, virtual representation takes place in the Information Layer. I4.0 compliant communication is thus of great importance.

Requirement: The I4.0 compliant communication must be performed in such a way that the data of a virtual representation of an I4.0 component can be kept either in the object itself or in a (higher level) IT system.

One important part of the virtual representation is the “manifest” [selected on account of the .JAR file, see Manifest at: http://docs.oracle.com/javase/7/docs/technotes/guides/jar/jar.html#JAR_Manifest], which can be regarded as a directory of the individual data contents of the virtual representation. It therefore contains what is termed meta-information. Furthermore it contains obligatory data on the I4.0 component, used among other purposes for connection with the object by providing for the corresponding identification.

Possible further data in the virtual representation include data which cover individual life cycle phases, such as CAD data, terminal diagrams or manuals.

Technical functionality

Apart from data, an I4.0 component can also possess a technical functionality. This functionality may, for example, comprise the following:

- Software for “local planning” in connection with the object. Examples: welding planning, software for marking of terminal strips, etc.
- Software for project planning, configuration, operator control and servicing.
- Value added to the object.
- Further technical functionalities which are relevant to the implementation of the business logic.

Technical functionality takes place in the Functional Layer of the reference architecture model RAMI4.0.

An “administration shell” turns an object into an I4.0 component

As the section above indicates, different objects with different communication abilities can be implemented

as I4.0 components. This section is intended to describe these various embodiments in greater detail on the basis of examples. The various embodiments are of equal value for the purposes of the “I4.0 component” concept.

Figure 8 shows that an object, no matter what kind it is, is not initially an I4.0 component. Only when that object, which must be an entity and at least have passive communication ability, is surrounded by an “administration shell”, can it be described as an I4.0 component.

Within the context of the section above, the administration shell covers both the virtual representation and the technical functionality of the object.

Figure 8 provides four examples of a possible object:

- 1 An entire machine can be implemented as an I4.0 component, above all as a result of its controller. This embodiment of the I4.0 component is, for example, implemented by the machine manufacturer.

- 2 A strategically important assembly from a supplier can also be regarded as an independent I4.0 component, so that it can, for example, be registered separately by asset management and maintenance systems. This embodiment of the I4.0 component is, for example, implemented by the component manufacturer.
- 3 It is also possible to regard individual composite parts in the machine (to avoid the term component) as I4.0 components. For a terminal block, for example, it is important to retain the wiring with individual signals and keep it up to date throughout the life cycle of the machine. This embodiment of the I4.0 component is, for example, implemented by the electrical design engineer and electrician.
- 4 Finally, the software supplied can represent an important asset in a production system, and thus be an I4.0 component. Such standard software could, for example, be an independent planning or engineering tool which is important now or in the future for operation of the manufacturing system. It

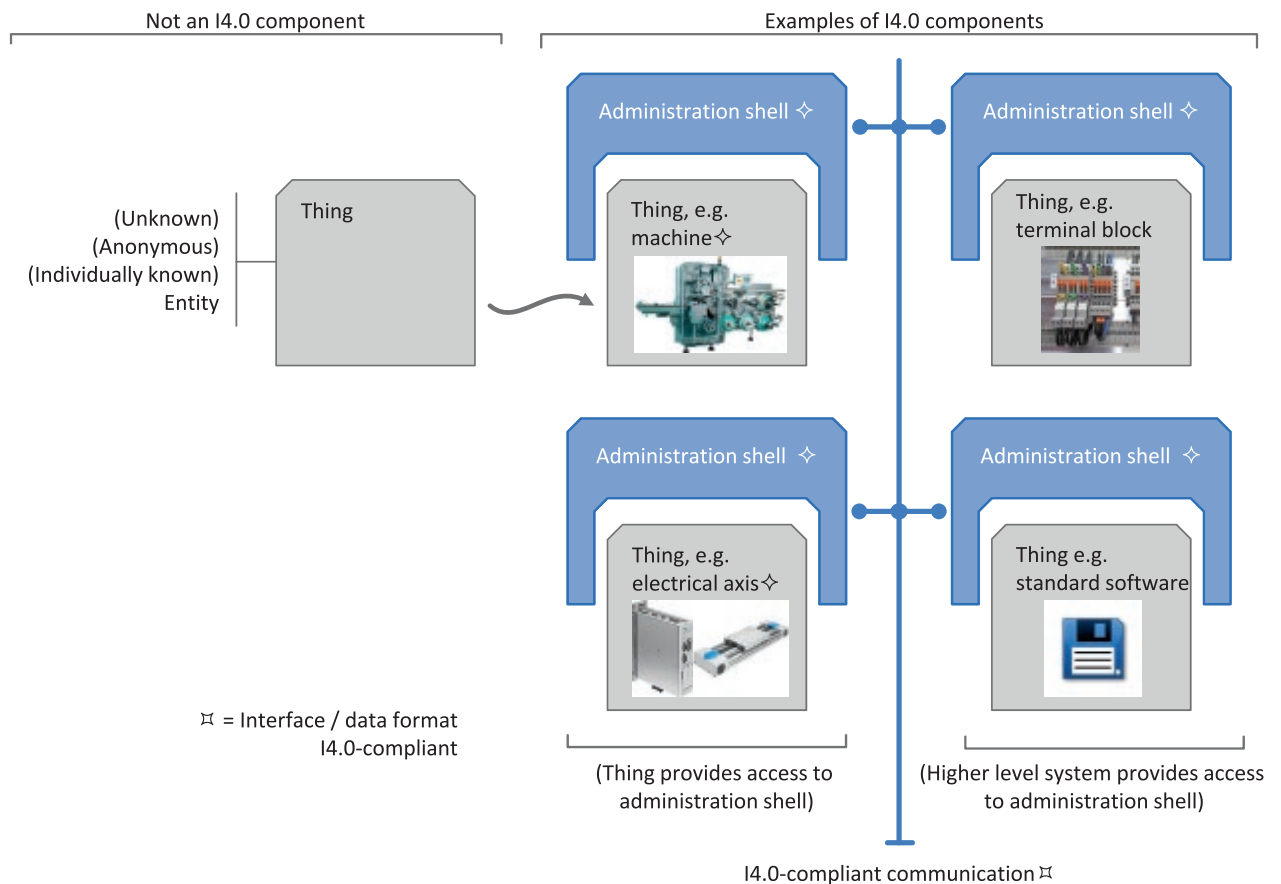


Figure 8. An object becomes an I4.0 component
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is also conceivable that a supplier may wish to sell a library which provides extended functions for his products as separate software. This embodiment of the I4.0 component would then, for example, be implemented by the software supplier; distribution among individual IEC 61131 controllers would be effected by the various I4.0 systems.

Figure 8 shows from the point of **view of logic** that an administration shell belongs to each object. From the point of **view of deployment**, the object and the administration shell may by all means be **decoupled**. With objects which possess passive communication ability, for instance, the administration shell may be hosted by a higher level IT system. The connection between the object and the administration shell is maintained with the aid of the object's passive communication ability and the I4.0 compliant communication regime of the higher level IT system. The same applies when the object has active, but not I4.0 compliant, communication ability. Only with I4.0 compliant communication ability can the administration shell be hosted "in" the object (it is for example stored in the controller of a machine and supplied via the network interface). For the purposes of the "I4.0 component" concept, these alternatives are to be regarded as equivalent.

One object may have several administration shells for different purposes.

Requirement: A suitable reference model must be established to describe how a higher level IT system can make the administration shell available in an I4.0 compliant manner (SOA approach, deputy principle).

Requirement: A description of how the administration shell can be "transported" from the originator (e. g. component manufacturer or electrical designer) to the higher level IT system (e. g. as an attachment to an email) is required.

Further disambiguation

Figure 9 provides a further disambiguation of the terms:

From a logical point of view, an I4.0 component comprises one or more objects and an administration shell which contains the data for virtual representation and the functions of the technical functionality. The manifest, as part of the virtual representation, details the necessary administrative details on the I4.0 component. The "resource manager", as defined by GMA Technical Committee 7.21, is also part of the administration shell.

With that resource manager, IT services have access to the data and functions of the administration shell and make them available to the outside.

The administration shell and its contents can be hosted within one of the objects of an embedded system (active, I4.0 compliant communication ability) or distributed among one or more higher level IT systems (deployment view).

Requirement: Depending on the nature of the higher level systems, it may be necessary for the administration objects to allow for deployment in more than one higher level IT system.

Cyber-Physical System

The I4.0 component constitutes a specific case of a cyber-physical system.

I4.0 components from the point of view of deployment

The section above makes it clear that from a logical point of view an administration shell belongs to each object for each I4.0 component. It is however also emphasized that situationally, from a deployment point of view, the administration shell can be relocated into a higher level system.

I4.0 component mapped in repository

For a better understanding, a representation of a repository conforming to the "digital factory" and in harmony with the concepts outlined can be shown (figure 10).

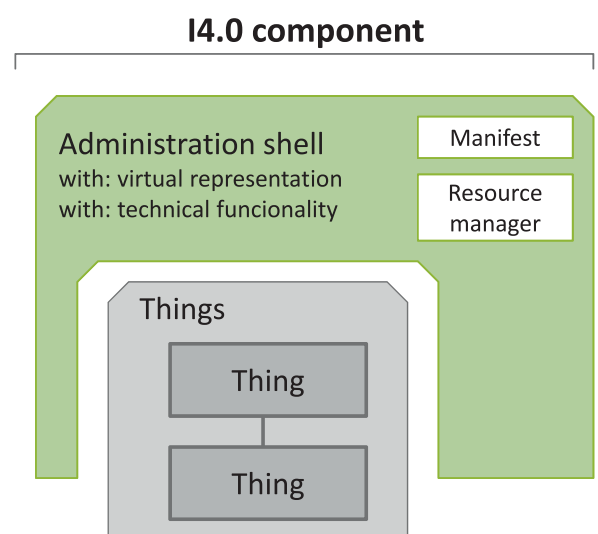


Figure 9. I4.0 component

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Life cycle of the factory

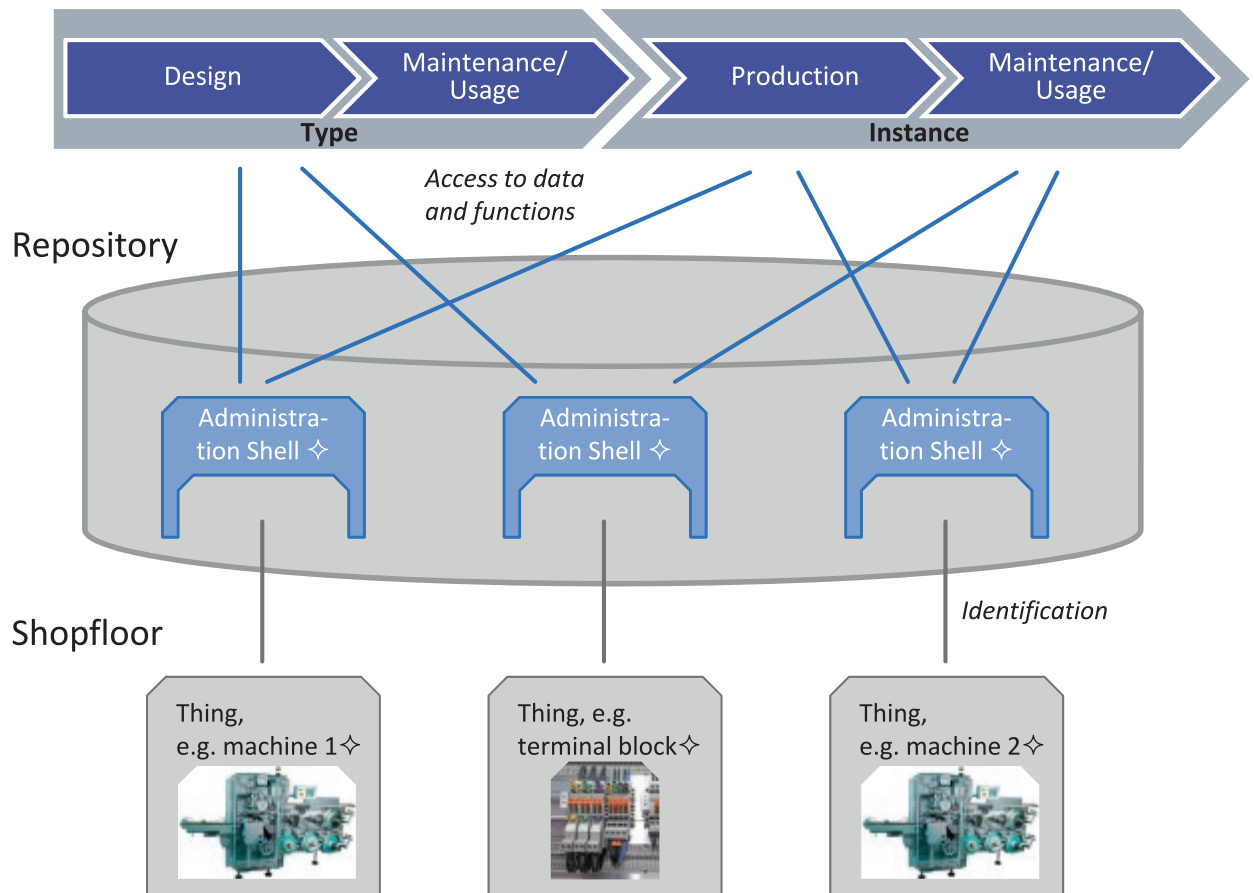


Figure 10. Repository
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I4.0 component mapped by object

If one of the objects in the I4.0 component has I4.0 compliant communication ability (CP34 or CP44 to [4]), it is appropriate to map the I4.0 component by the object (figure 11).

An I4.0 component is separable

The I4.0 component is to be consciously capable of entering into and initiating all possible cross-connections within the I4.0 factory (figure 12, no. 1). But this networking must not lead to a restriction of the core functionality (figure 12, no. 2). The ability to keep this core area free from faults, even when the “external” network is experiencing disturbances, is designated by SG2 (ZVEI Mirror Committee on Reference Architecture) and SG4 (ZVEI Mirror Committee on Security) as “separability”.

Requirement: The I4.0 component, and in particular the administration shell, its inherent functionality and the protocols concerned are to be “separable”.

The present concept fulfils this requirement in that the administration shell is implemented as an independent data/function object. Access to the data and functions it contains is to be provided for in accordance with the principle of “Separation of Concerns” (SoC), so that influencing of workflows critical for production can, at the state of the art, be excluded.

It follows from the application of this principle that I4.0 compliant communication does not necessarily have to completely replace the Ethernet-based field buses currently used in production (migration scenario).

However, I4.0 compliant communication and a possible deterministic or real-time form of communication should be brought into line with each other, and, for example, the same (physical) interfaces and infrastructures used wherever possible. Freedom from contradiction between the two communication channels must be ensured.

Life cycle of the factory

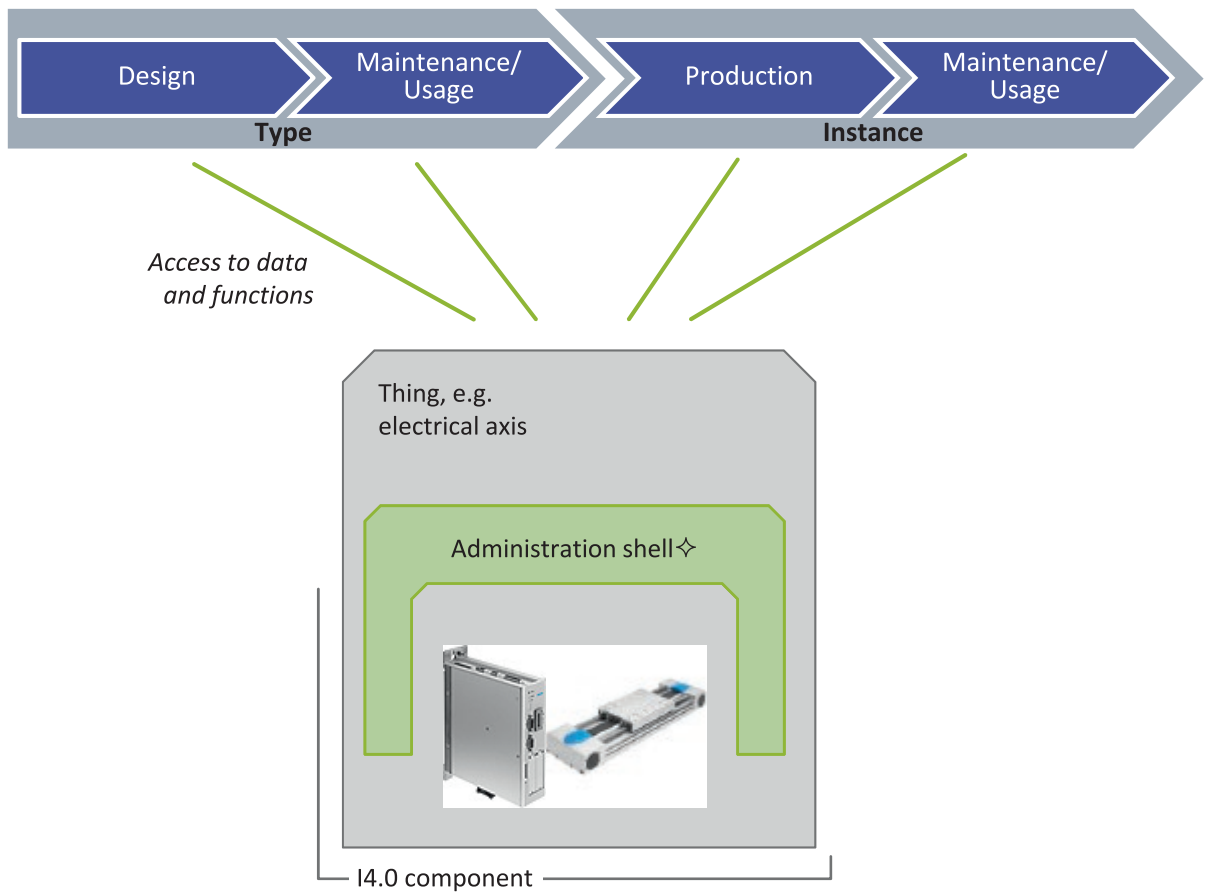


Figure 11. Life cycle of the factory
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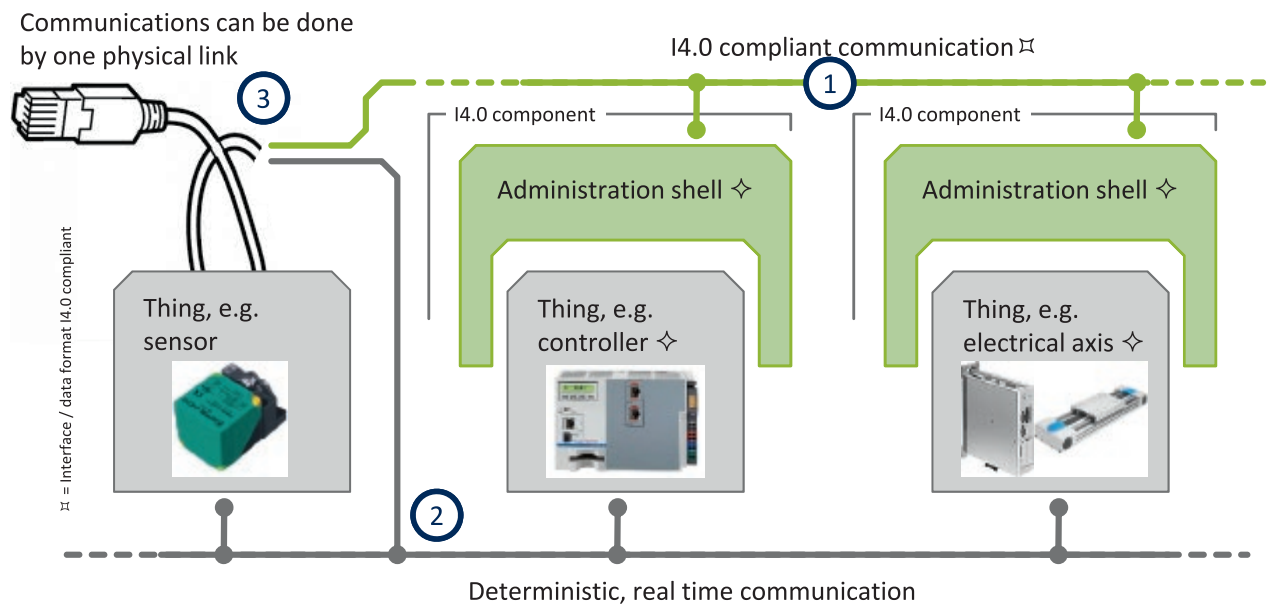


Figure 12. Separability and networking of an I4.0 component
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With regard to the reference model described in this paper, this argument means that I4.0 compliant communication does not have to implement all the properties of deterministic or real-time communication itself, but can delegate them to existing technologies.

The aim of the I4.0 component is to detect non-I4.0 compliant communication relationships leading to or from the object's administration shell and to make them accessible to end-to-end engineering.

The real-time Ethernet protocols which are standard today permit the expectation that it will be possible to effect both forms of communication via the same communications infrastructure (connectors, plugs and intermediate stations) (figure 12, no. 3). According to the principle of "Separation of Concern", however, both types of communication are to remain logically separated.

An I4.0 component can contain several objects

This section uses an example to show that an I4.0 component can contain not only one, but also several objects.

The objects shown in figure 13 together form an example of an electrical axis system. There is design software from a manufacturer which has led during the engineering phase to the individual partial systems being combined in a single system. There is configuration software from the manufacturer, with which the system as a whole can be put into operation. Traversing blocks, recorded wear data and



Figure 13. I4.0 component consisting of several objects
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condition monitoring have to set the individual parts of the system in relation to each other (e. g. with regard to the maximum traversing length).

From an I4.0 view, it is therefore appropriate to manage these individual objects as a system and map them as one I4.0 component. A breakdown into individual I4.0 components would necessitate the mapping of many different interrelationships by one or possibly even more higher level I4.0 systems, and unnecessarily complicate the process.

An I4.0 component can be logically nestable

Industrie 4.0 demands the modularization of production systems for order-related reconfiguration and re-use of (corporate) assets under the terms of I4.0 Aspect (2), "Vertical Integration". The concept therefore provides for an I4.0 component to encompass other components in logical terms, for them to act as a unit and to abstract logically for a higher level system.

In addition, I4.0 Aspect (3) requires "end-to-end engineering", with further-reaching data and engineering planning available online for as many objects in a production system as possible. The administration shell provides for data which can be unequivocally assigned to the objects in the I4.0 component also to be available in such a distributed manner. Such distributed data are advantageous for distributed engineering and for rapid reconfiguration.

The concept for an I4.0 component should therefore enable other I4.0 components to be logically assigned to a first I4.0 component (e. g. an entire machine), in such a way that there is (temporary) nesting.

From a technical point of view, this can be done in such a way that the higher level object (e. g. a machine) develops two I4.0 compliant communication interfaces, so that there is clear logical and physical separation between superordinate and subordinate I4.0 components (figure 14, no. 1). A further method would be to have the I4.0 compliant communication physically unified at the "top" and "bottom" but logically separated (figure 14, no. 2).

The administration shell can have a suitable "component management" system to manage such a logical assignment of "subordinate" I4.0 components. This can, for example, provide support in the reconfiguration of a machine, or provide a suitable map of the status of the machine to the higher level.

Requirement: It is to be possible to assign other I4.0 components to a first I4.0 component (e. g. an entire machine) in such a way that there is (temporary) nesting.

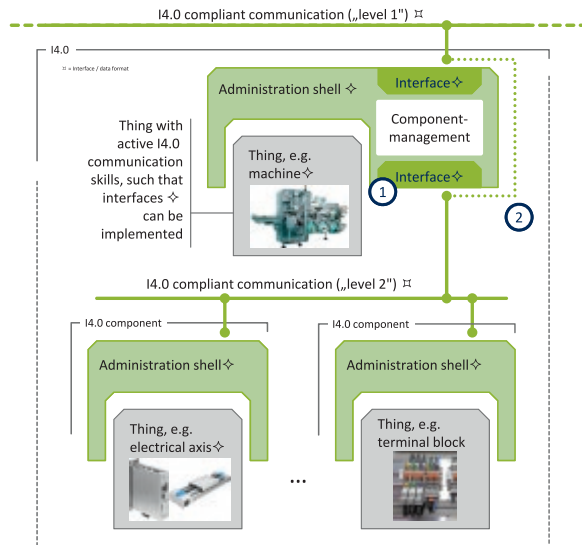


Figure 14. Nestability of I4.0 components
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Requirement: Higher level systems are to be able to access all I4.0 components in a purpose-driven and restrictable manner, even if these are (temporarily) logically assigned.

Component state model

The state of an I4.0 component can always be polled by other subscribers in I4.0 compliant communication. In this context, it follows a defined component state model.

As I4.0 components can be organized hierarchically, a suitable method of mapping substates in a state should be defined (“What happens to the machine when a part is not ready to operate?”).

In addition, the component state model should also be complemented with a larger number of state variables which permit a more detailed view of the states of virtual representation and technical functionality. This permits a consistent view of the state of an I4.0 component at time “t”, for instance for purposes of statistically correct data analysis.

General characteristics of the “I4.0 component”

VDI/VDE-GMA TC 7.21 defines the term “component” in the context of Industrie 4.0 as follows:

The term “component” is a general term. It designates an object in the physical world or the information world which plays a particular role in its system

environment or is intended for such a role. A component can be, for example, a tube, a PLC functional module, a lamp, a valve or an intelligent drive unit. The important things are that it is considered as a unit and that it has a relationship with the role (function) which it is to perform or already performs in a system. What we call an I4.0 component is a special type of component. I4.0 components are notable for fulfilling certain requirements with regard to the classification characteristics set out above. Even in an I4.0 system, there are many components which do not fulfil these requirements and are therefore not I4.0 components.

The concept presented here also permits objects which have passive or active communication ability which is however not I4.0 compliant. The following therefore applies to an I4.0 component within the meaning of this document:

- It is either a CP24, CP34 or a CP44 component in terms of CP classification.
- It has an administration shell which can be communicated in such a way that it becomes a fully fledged service system subscriber in the I4.0 network.

The following section is based on the GMA definition while presenting distinctions of the concepts in greater detail. In complete accord with the VDI Status Report “Gegenstände, Entitäten, Komponenten” (Objects, Entities, Components) [3], the following characteristics are first and foremost required of an I4.0 component as a service system subscriber in the I4.0 network:

Identifiability

It is unequivocally identifiable in the network and its physical objects are identified by means of a unique identifier (ID). If it is a CP34 or CP44 component, it can be reached via a communication address (e. g. IP address).

I4.0 compliant communication

The I4.0 components communicate with each other at least in accordance with the SOA principle (including common I4.0 compliant semantics).

I4.0 compliant services and states

It supports the service functions and states generally standardized (and subsequently loadable) for an I4.0 system.

Virtual description

It supplies its virtual description, including its dynamic behaviour. This description is established by the virtual representation and the manifest.

I4.0 compliant semantics

It supports the I4.0 compliant semantics standardized for an I4.0 system.

Security and safety

It provides sufficient protection (security) for its functionality and data in accordance with its function. In addition, applications may also require functional safety and machine safety measures.

Quality of Services

It possesses the Quality of Services (QoS) properties necessary for its function. With regard to applications in automation systems, these are characteristics such as real time capability, fail safety and clock synchronization. These characteristics may reflect the requirements of a profile.

State

It provides information on its state at all times.

Nestability

Every I4.0 component can consist of other I4.0 components.

I4.0 components in the context of this document stand for production systems, machines, stations and conceptually important parts or assemblies in machines.

Re characteristic (1): Identifiability

The objective of the I4.0 approach is to be able to access all the relevant data in real time. The I4.0 components represent an important part of an expansion in infrastructure relative to the present day. This applies throughout the life cycle of the production system. I4.0 components therefore play a central role in ensuring a consistent and uniform exchange of information in all I4.0 value streams [4] and all their value adding processes.

An active I4.0 component can perform I4.0 compliant communication itself; for a passive I4.0 component this is handled by the necessary infrastructure.

There is a need for communication which fulfils the requirements of industry. As production systems are increasingly working in networks, and in that context great distances sometimes have to be overcome, the connection of local area networks by wide area links is constantly gaining in importance.

Requirement: The wide area networks used in the connection of I4.0 components should behave in such a way that local area networks can communicate via the long distance link extensively without restrictions.

This concerns the availability of such connections, their security and their behaviour in terms of time.

Even if streaming technologies and other mechanisms could constitute a basis for appropriate solutions, fundamental work is still required in that field.

One level higher, connections have to ensure that stable and reliable communication is ensured for a long period. In this context, existing protocols are to be examined for usability in I4.0 applications. A distinction is to be made between the addressing of the I4.0 component and the addressing of its (application) objects. The latter are addressed by means of a unique, global and non-proprietary ID. As regards handling of IDs, attention is drawn to [6] and [7] and other standards.

Requirement: A distinction is to be made between the addressing of the I4.0 component and the addressing of its (application) objects.

Re characteristic (2): I4.0 compliant communication

The information on itself provided by an I4.0 component is implemented on the basis of a service-oriented architecture (SOA) with services in accordance with a service model (Resource Manager). A corresponding profile of the I4.0 component can regulate how those services can be implemented technologically (e. g. via OPC-UA basic services).

Re characteristic (3): I4.0 compliant services and states

As different applications have to be operated on the shop floor and on the office floor, there must be the option for I4.0 components to operate the various application levels with different protocols.

Requirement: Protocols and application functions should therefore be loadable as options.

Re characteristic (4): Virtual description

The information for description of the characteristics, including the relevant dynamic behaviour, of an I4.0 component is generated in an I4.0 data format from the virtual map of the real component. This map is termed a “virtual representation”; and one part of the virtual representation is the manifest, which must have unequivocal semantics. The specification of characteristics plays an important role.

The following, for example, are parts of the manifest:

- Characteristic features of the real components
- Information on relationships between the features
- Relationships between I4.0 components which are relevant to production and production processes

- Formal description of relevant functions of the machine and its workflows

The following, for example, are parts of the virtual representation:

- Commercial data
- Historical data, e. g. service history
- etc.

The **demarcation** between the manifest in particular and administration objects in general is that the manifest contains information which must be publicly known and have unequivocal semantics for the realization of an “I4.0 compliant network” in accordance with the I4.0 aspects. Administration objects can also contain such information, although here the manufacturer may decide independently what is to be revealed in what form.

Re characteristic (5): I4.0 compliant semantics

The exchange of information between two or more I4.0 components requires unequivocal semantics. These must be stipulated throughout I4.0 by means of the characteristics set out under (4). According to [6], it appears helpful to classify the characteristics according to the following fields:

- Mechanics
- Functionality
- Location
- Efficiency
- Social conditions

On dealing with of characteristics, attention is drawn to [6], [7] and [8].

Re characteristic (6): Security and safety

Every I4.0 component has a minimum infrastructure to ensure the security functions. As security is only ensured when the production processes concerned are directly involved in the security considerations, the security infrastructure of an I4.0 component provides necessary, but by no means sufficient functionality. If functional and machine safety have to be ensured, this has an impact on the characteristics of the individual I4.0 components. Additional characteristics have to be recorded, assessed and passed on to higher level systems in this context.

Requirement: The minimum infrastructure must satisfy the principles of Security by Design (SbD).

Re characteristic (7): Quality of Services

The use of an I4.0 component in a particular environment determines the requirements placed upon it.

The properties demanded in the relevant environment (QoS) must therefore already be taken into account in the selection of the components for a machine or system. Especially for automation environments, these are properties such as:

- Duration of real time for production communication, e. g. determinism with real time capability of D1ms
- Maximum fail-safety of the surrounding network infrastructure (robustness)
- Clock synchronization
- Interoperability
- Diagnosis and engineering on the basis of uniform rules
- Establishment of ad-hoc connections

Re characteristic (8): State

As every I4.0 component represents part of a conglomerate with certain functions, and these functions must be performed in processes in a coordinated manner, the state of every I4.0 component must be accessible to other subscribers in an I4.0 compliant communication network at any time. This information is used for local administration of other I4.0 components and global administration for coordination of the workflows.

Re characteristic (9): Nestability

I4.0 components may be grouped together in a single I4.0 component. In this way, for example, a machine can constitute an I4.0 component. It can itself consist of independent I4.0 components, e. g. as a modular machine. The individual machine modules may for their part also be structured from individual I4.0 components.

2.5 Industrie 4.0 glossary

In the context of Industrie 4.0, the languages of production and ICT (Information and Communication Technology) are growing together. There are however differences and ambiguities rooted in history surrounding important terms in Industrie 4.0. The Working Panel on “Terminology” in Technical Committee 7..21, “Industrie 4.0” of the VDI/VDE Society for Measurement and Automatic Control (GMA) under the leadership of Dr.-Ing. Miriam Schleipen of Fraunhofer IOSB is working to establish a common basis (terminology) for Industrie 4.0 in the form of linguistic and conceptual constructs. The work is also being performed in cooperation with the responsible committees (e. g. DKE/UK 921.1) of Division 9 of the DKE and is coordinated with WP2 “Reference Architecture” of Plattform Industrie 4.0.

The objective is a common understanding of the fundamental terminology, building upon existing standards from the fields of ICT and production.

In the environment of Industrie 4.0, terminology and concepts from various domains (for instance orchestration of services in a service-oriented environment from the ICT area) are drawn upon. Several terms, however, denote different things in the domains involved (for instance service in ICT and service as opposed to production). Other terms are even ambiguous or imprecise within a single domain. These linguistic and conceptual differences and imprecisions and the need for explanations of concepts outside the

subject area concerned are an obstacle in the development of comprehensive complex technical solutions for Industrie 4.0 and in standardization.

The glossary will therefore create a common basis for terminology in the context of Industrie 4.0, taking account of the different points of view and requirements. This is intended to facilitate cooperation across the boundaries of companies and industries, and is a necessary condition of standardization.

The current definitions can be found, among other locations, at the following website:
www.iosb.fraunhofer.de/?BegriffeI40

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