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PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD

colour inside

Smart manufacturing – Reference architecture model industry 4.0 (RAMI4.0)

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SMART MANUFACTURING – REFERENCE ARCHITECTURE MODEL INDUSTRY 4.0 (RAMI4.0)

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The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document
Draft PAS	**Report on voting**
65/645/PAS	65/655/RVDPAS

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INTRODUCTION

Background

Industry requires constant attention on optimization, cost efficiency, energy efficiency, environmental concerns, quality, security, safety, time-to-market, inventory reduction, simulation, ease of maintenance, etc. Customers also want to satisfy new requirements and address new use cases now reachable given the availability of new technologies. Addressing these challenges, several projects in different countries were issued with similar names and aims, e.g. in Germany "Industrie 4.0", in France "Industrie du Futur", in China "Intelligent Manufacturing", in Japan etc.

Manufacturers, customers, service providers are working in a more and more global market. The need of interoperability of products, open interfaces, etc. can only be achieved with International Standards. To cover these needs, IEC and ISO have activities related to Smart Manufacturing.

Objective

This specification defines a Reference Architecture Model to identify, structure, and illustrate the different areas where standards exist or standards are required. It allows setting standards in relation to different aspects, hierarchies and life cycles.

Life cycles are relevant to products, to assets in the factory or plant, to orders from planning to cash and to the supply chain covering the process from source to delivery.

In addition, this specification defines term and definitions generally for Smart Manufacturing. As Smart Manufacturing is covering different domains (batch, continuous, discrete, etc.), terms need to be harmonized and globally accepted.

The fundamental purpose of Industry 4.0 is to facilitate cooperation and collaboration between technical objects, which means they have to be virtually represented and connected. In this context, a technical object is an object that is of value to an organization, which therefore not only means physically tangible objects, but also intangible objects such as ideas, archives and software. The concept of Industry 4.0 is intended to create digital description rules for a technical object throughout its entire lifetime, and for the associated changes in value, in the form of the Reference Architecture Model for Industry 4.0 "RAMI4.0". The purpose of this model is to represent the technical object and all aspects relevant to it, from its development, production and use right through to its disposal. The Industry 4.0 component provides a digital description of the object, making it possible to represent that object virtually.

Technical objects are intentionally manufactured in order to fulfil a specific purpose. They possess common characteristics in terms of their lifetime and the associated changes in value. Technical objects for which a "change in value" or an "owner" are important aspects are also referred to as "technical assets". Because this is almost always the case, the terms "technical object" and "technical asset" can be regarded as synonymous. In this document, the term "technical asset", or simply "asset" is used.

This document describes two fundamental reference models for the Industry 4.0 concept:

– The reference architecture model RAMI4.0 is a reference model of Industry 4.0 reference architecture and gives a structured description of fundamental ideas. See Clause 5.
– The I4.0 component reference model provides digital access to this description. See Clause 6.

The central concept of Industry 4.0 is that assets can be combined in any way, and these assets are formally described in sufficient detail for use in the digital world. This methodology not only enables sufficient generic descriptions of a configuration, but through an increasing degree of detail also allows for very specific descriptions. This is a core concept regardless of the way in which the asset is used.

To virtually represent configurations of assets and the connections between them, the “principle of recursive description of assets” is used to characterize an asset as follows:

– the structural description is compliant with RAMI4.0;
– a configuration of two or more assets collectively forms a new asset, which is described using RAMI4.0;
– components of an asset can themselves represent separate assets that are described with RAMI4.0;
– the asset description is provided as structured information in the administration shell of the I4.0 component that acts as a virtual representation of an asset.

This means that any configuration can be digitally represented to any degree of granularity by describing structured assets, and combinations thereof, using RAMI4.0.

SMART MANUFACTURING – REFERENCE ARCHITECTURE MODEL INDUSTRY 4.0 (RAMI4.0)

1 Scope

This document, which is a PAS, describes a reference architecture model in the form of a cubic layer model, which shows technical objects (assets) in the form of layers, and allows them to be described, tracked over their entire lifetime (or "vita") and assigned to technical and/or organizational hierarchies.

It also describes the structure and function of Industry 4.0 components as essential parts of the virtual representation of assets.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61360-1, *Standard data element types with associated classification scheme for electric components – Part 1: Definitions – Principles and methods*

IEC 61360-2, *Standard data element types with associated classification scheme for electric components – Part 2: EXPRESS dictionary schema*

IEC TR 62794[1], *Industrial-process measurement, control and automation – Reference model for representation of production facilities (digital factory)*

IEC TS 62832-1, *Industrial-process measurement, control and automation – Digital factory framework – Part 1: General principles*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
administration shell
virtual digital and active representation of an I4.0 component in the I4.0 system

Note 1 to entry: An administration shell contains the manifest and the component manager.

[1] Withdrawn.

3.2
architecture
fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution

[SOURCE: ISO/IEC/IEEE 42010:2011, 3.2]

3.3
archive world
all the information in the digital world which is no longer valid or up-to-date and which therefore can no longer be changed

Note 1 to entry: Information which is no longer valid or up-to-date is transferred to the archive world.

Note 2 to entry: No statement is made on when the information is transferred from the model world or state world to the archive world.

3.4
asset
object which has a value for an organization

3.5
service
separate scope of functions offered by an entity or organization via interfaces

Note 1 to entry: This definition is not the same as the definition of services by the OASIS-RM ("Services are the mechanism by which needs and capabilities are brought together").

3.6
entity
uniquely identifiable object which is administered in the information world due to its importance

3.7
information world
digital world or cyber world
ideas, concepts, algorithms, models and entirety of representations of physical objects and people in the virtual environment

Note 1 to entry: The framework for considering each entirety needs to be defined.

Note 2 to entry: The elements of the information world can be semantically related to each other.

3.8
component manager
organizer of autonomous administration and access to resources of the relevant I4.0 component, such as the I4.0 component itself, object, technical functionality, virtual representation

Note 1 to entry: In many documents, the component manager is referred to as the resource manager, but this should be called the component manager in future.

3.9
manifest
externally accessible, defined set of meta-information on the functional and non-functional properties of the relevant I4.0 component

Note 1 to entry: The manifest can be regarded as similar to the manifest in information technology.

3.10
physical world
all actually existing objects and people

Note 1 to entry: The real world is the same as the physical world.

Note 2 to entry: Loaded or stored software is part of the physical world.

Note 3 to entry: The framework for considering each entirety needs to be defined.

3.11
reference architecture
model for an architecture description (for I4.0) which is generally used and recognized as being suitable (has reference character)

Note 1 to entry: A reference architecture can be defined on the basis of a reference model.

3.12
reference model
model that is generally used and recognized as being suitable (has recommendation character) for deriving specific models

3.13
value-added chain
sequence of processes that add value (linear or hierarchical, which formally means acyclically aligned)

Note 1 to entry: Company boundaries are not necessarily relevant for a value-added chain or value chain.

3.14
value-added system
network or system of value-added chains that can include connections and dependencies between them

3.15
value-added process
process during which a commodity can be created which is valuable for a customer

Note 1 to entry: The commodity does not have to be tangible (such as a raw material or manufactured product), but can also be intangible (such as knowledge, information or a service).

Note 2 to entry: The determination of the value or price is not considered here.

Note 3 to entry: Value-added processes are value activities according to Porter.

4 Assets in Industry 4.0

4.1 The object world

Figure 1 shows the structure of the object worlds. In the object world of Industry 4.0, assets from the information world and the physical world are considered. Besides these assets, people (the human world) also play an important part. The information world is divided into the model world, the state world and the archive world. The model world contains objects such as meta-documents, models, concepts, technical documentation, production plans and procedural descriptions. The state world describes the current state. The archive world contains the recorded state and life cycle information of processes that have taken place. These can be production processes, development processes, maintenance processes and so on.

The physical world includes all physical products, installations, resources, IT systems, loaded programs, etc. When classifying software, it should be noted that the algorithm itself belongs to the information world, but the executable program loaded to a system is part of the physical world. People are part of the physical world and participate in the information world. Because of their intelligence and freedom to make decisions, human beings have a special status.

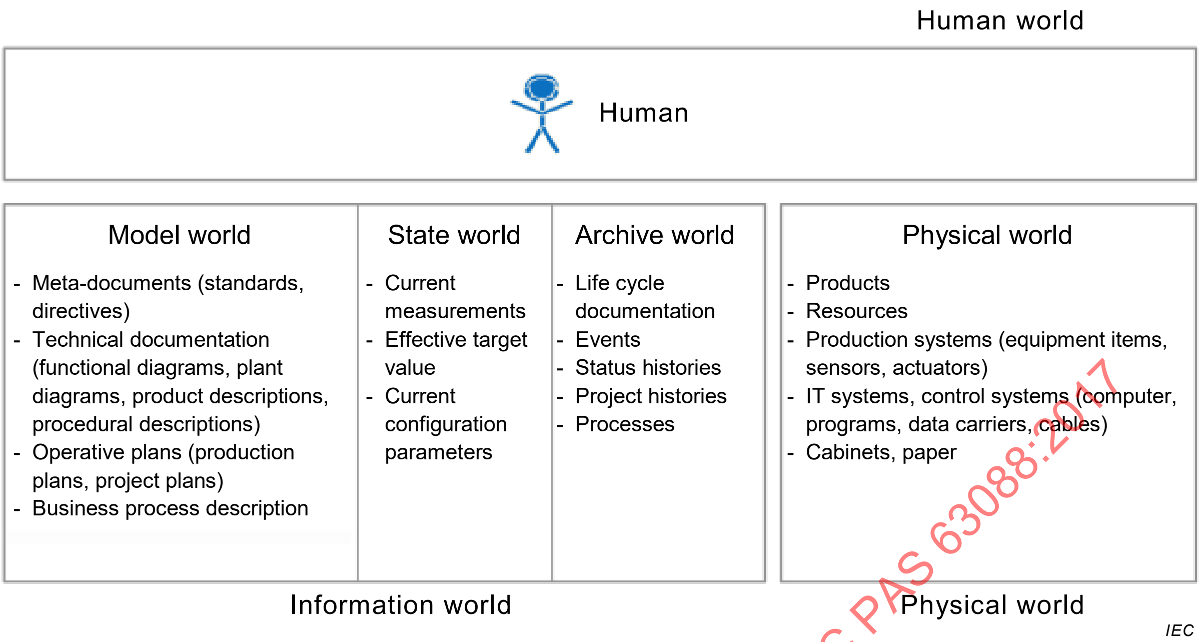

Figure 1 – Structure of the object worlds with examples

4.2 Information carriers

Figure 2 shows examples of various carriers of information. A plan, for example, can be stored as an xml or pdf file on a computer. It can also be inside somebody's head or printed out on a piece of paper. In each case, the information asset "plan" is the same. The character of the physical carrier does not alter the information asset. If the carrier is destroyed, so is all the information stored on it. To prevent information from being lost, copies of it can be made on multiple carriers. However, they are all still the same asset.

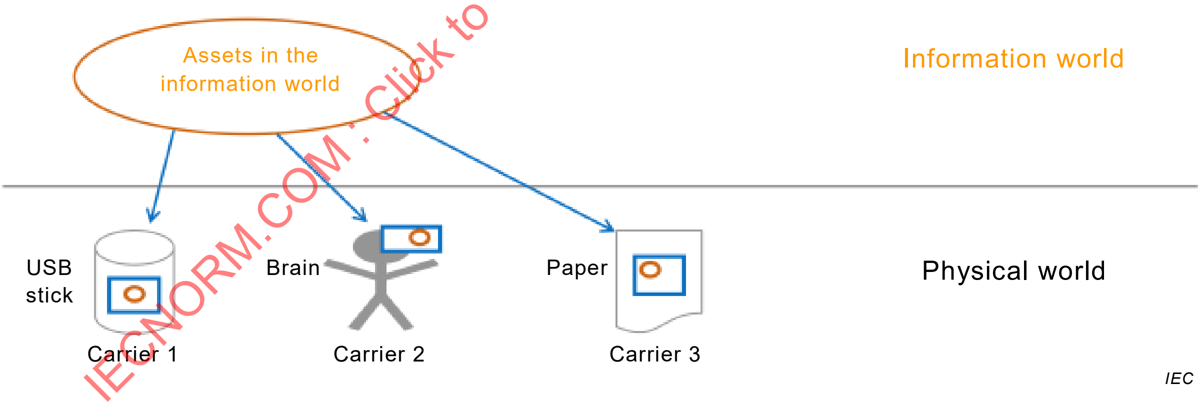

Figure 2 – Assets in the information world and their physical carriers

4.3 Assets and the information world

Every asset has a value for an organization. It represents an artefact that is specifically intended to perform a particular role in a particular system. Assets are intentionally manufactured in order to fulfil a specific purpose. They possess a common "vita", or lifetime, and the associated change in value. See Figure 3. Assets for which a "change in value" or an "owner" are important aspects are also referred to as "technical assets".

The key task in Industry 4.0 is to take technical assets from the physical world and virtually represent them in the information world. The physical world is to be understood to mean the entirety of all real assets and people.

The following applies to every asset.

– The asset is designed, created, used and disposed of.
– The asset can be an idea, a software program, an archive, a service or any physical item (in other words it does not have to exist in a physical form).
– The asset has a lifetime.
– The asset is clearly identifiable.
– The asset is represented in the virtual world by its administration shell.
– The asset can have multiple virtual representations specified according to the rules of Industry 4.0 for different purposes.
– Assets can be combined to create new assets with different properties.
– The asset is characterized in a process by means of time, location and state.
– Each piece of information has a carrier.
– The asset's characteristics are described using Industry 4.0 vocabulary that includes a collection of terms which describe properties.

EXAMPLE: Assets in the context of Industry 4.0 are whole installations or parts thereof, electronic modules, subsystems and systems, machinery, plants and networks, services, concepts and ideas, plans, archives and programs.

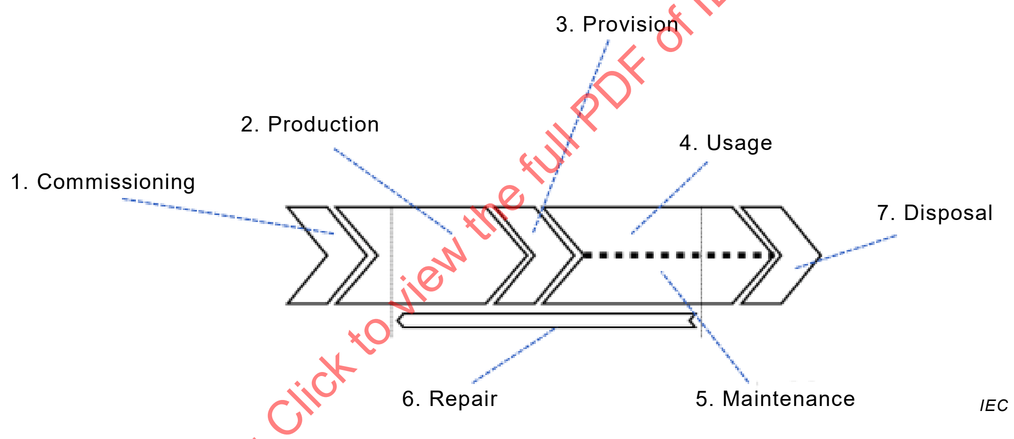

Figure 3 – Life ("vita") of an asset

4.4 Life ("vita") and characterization of an asset

Each asset has a specific lifetime, during which it serves the purpose for which it was specifically created (see Figure 3). The way it is created depends on the type of asset. Creation can mean development (of a type), engineering (of a plant), measurement (of a status), construction (of an installation) or production (of a product). In this context, these are all creation processes. Once an asset is created, it exists, but it is not yet ready to use. The provision phase includes all processes between the time the product is created and the time it is ready and working at the place of use. Provision processes include shipping, transport, warehousing, configuration and assembly, and for software assets, processes such as release, downloading and installation. After provision, the asset is installed and ready to use on site, in other words, it is ready to perform its intended role as a technical device. In the subsequent phase, two different uses of the asset shall be taken into account: usage and maintenance. When being used, the asset is part of the technical system for carrying out the desired technical (production or usage) processes. During maintenance, the asset is still a product whose functionality shall be maintained or restored. Maintenance can be carried out by the user, by an external workshop or by the manufacturer. The work can take place on site, by remote maintenance or (for example after it is removed) at a workshop. Certain maintenance procedures can be regarded as a loop, involving a renewed manufacturing phase and recommissioning, while others are simply a change of status of the asset in use.

As regards the information world, an asset can be characterized as shown in Figure 4. It:

– is presented, or made known, in a certain way (i.e. is known or not known to a certain degree);
– has a specific state within its life (at least a type or instance);
– has communication capability;
– is represented by means of information (data);
– has technical functionality.

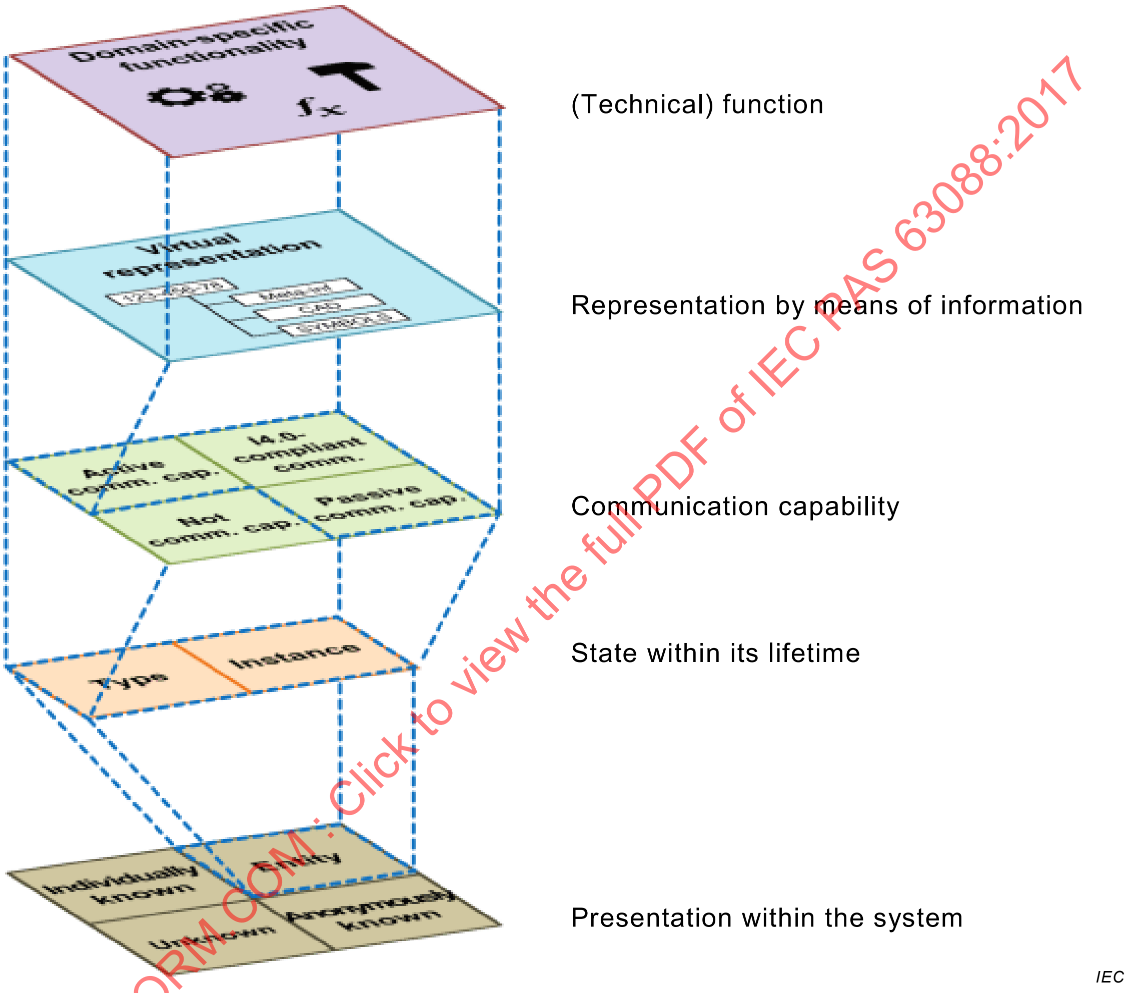

Figure 4 – Concepts of an asset

4.5 Means by which an asset is actively presented, or made known, in the information system

4.5.1 General

An asset exists in itself and has a specific lifetime. This is true for all types of asset. Initially, however, the existence of the physical asset, its identity, state and lifetime ("vita") are not known in the information system. One of the most important questions of system design is whether and to what extent this information is made known to the information system, and how much of that information is presented in the system.

An asset in the information world is at the very least known in its own information system. If information on physical assets is contained within the information system, then the administration objects that manage the asset need to be created and supplied with information. An asset can be classified as follows, depending on the amount of information available in the information system:

– unknown;
– anonymously known;
– individually known;
– administered as an entity.

4.5.2 Unknown assets

An unknown asset is one that is not known in the information world.

4.5.3 Anonymously known assets

An anonymously, not individually known asset is one which can only be recognized in the information world as an asset of a particular type at a particular place.

EXAMPLE: A screw is in a box with other screws. Even if the number of screws in the box is known, no individual properties can be assigned to any of the screws other than the general ones common to that type. If an asset that is not individually identifiable is included in a system, then it can be indirectly identified by means of its location. If a screw is installed in a plant, then it can be determined that precisely that screw installed at that particular location is rusty and has to be replaced. However, this is only true as long as the screw is installed. Once it is removed, it ends up in the scrap bucket and can no longer be identified. The same goes for products such as punched parts. During the punching process, it is possible to identify which punched part is in which section of the matrix. After it is discharged, the part is no longer individually identifiable, but the information system still knows that this punched part exists and is in the discharge container.

4.5.4 Individually known assets

An individually known asset is unambiguously identifiable. It has a unique name that is known in the information world. The system has an identification method with which the asset can be identified in the physical world and assigned to the name object.

NOTE Here it is irrelevant which technology is used for identification: it can be an ID code physically attached to the asset (nameplate with serial number, barcode, RFID, etc.), an analysis of characteristic physical properties (fingerprint etc.) or a deterministic and systematic tracking strategy in the system (coil, batch, etc.). In each case, the detected asset can be assigned unambiguously to the name object in the information world.

4.5.5 Assets administered as entities

An entity is an unambiguously identifiable asset which, due to its importance, is administered in the information world.

Entities are assets that possess objects of their own so that they can be administered and used, in other words they are represented by information.

Their representation by information means that data on the asset is kept. This data can be kept either on or in the relevant I4.0 component (as described in Cause 6) and can be made available to the outside world using I4.0-compliant communication. Alternatively, the data can be kept on a (higher-level) IT system that makes it available to the outside world by means of I4.0-compliant communication.

I4.0-compliant communication shall take place in such a way that it is possible to access the information of a representation of the relevant I4.0 component either in the asset itself or in a (higher-level) IT system.

The functionality thus available in the information system goes far beyond mere identification. It includes functions for purposes such as tracking assets, recording lifetime data, operational management of the company's own production process, and automated monitoring and quality assurance. If the administration functions are encapsulated in a functional unit and carry out their tasks proactively, the functional unit is known as a component manager (see Figure 5).

Whether or not an asset is regarded as an entity is a design decision in each individual case. As shown in Figure 5, entities cannot only be assets in the physical world, but also assets in the information world.

EXAMPLE: The lifetime of a radar probe is documented on the left of Figure 5. The radar probe is regarded as an entity and is given its own component manager. The example on the right documents the lifetime (creation, release and maintenance processes) of a diagram (P&ID). The P&ID becomes an entity and is also given its own component manager. In the model used here, the asset itself is conceptually separate from its administration.

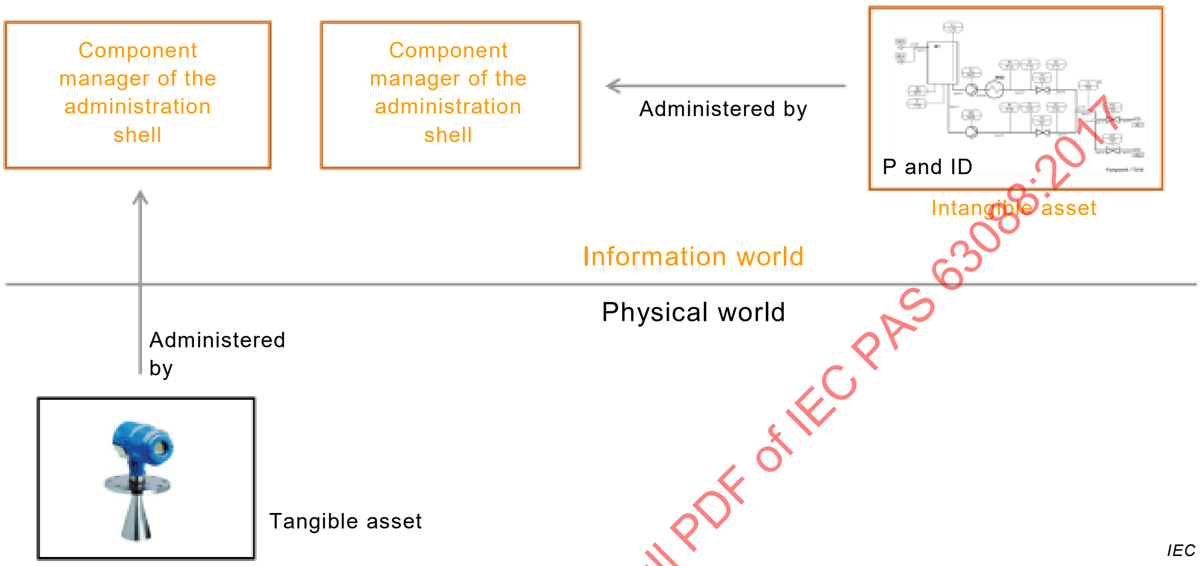

Figure 5 – Component manager for administering entities

4.6 State in an asset's lifetime ("vita")

4.6.1 General

Throughout its lifetime, an asset has a particular state at a particular time at a particular location. This state can be described more precisely using additional information. When observing an asset, a distinction is made between type and instance. Depending on how the asset is used in the value-added chain, the properties and state of its type or of its specific instance are relevant. Both types and individual instances are subject to usage and maintenance.

4.6.2 Type

The type of an asset defines the sum of the properties which are characteristic for all instances of that particular asset. The type of an asset is unambiguously identifiable and arises with the initial idea, in other words when it is created, e.g. during the development phase. This means, for example, ordering, development and testing, right up to the initial sample and prototype production. Once all tests required for validation are completed, the type is released for series production, which means that instances of that type can be produced.

4.6.3 Instance

An instance is a specific, unambiguously identifiable asset that is characterized by the properties of a type. An instance always has an unambiguously relationship to its type.

For a physical asset, concrete assets are created in production on the basis of the type. Each manufactured asset represents an instance of a type and can be utilized. The instances can be sold, delivered to customers, used by customers and maintained.

For an asset in the information world, instances are created on the basis of the type, for example by allocating and initialising data structures, which are used, modified and later released again.

4.7 Communication capability

4.7.1 Communication capability of assets in the physical world

4.7.1.1 General

Assets in the physical world can have a physical application (e.g. a pipe, or a cable), can function as information carriers (e.g. a server) or do both together (e.g. an "intelligent" field device). Because they carry information, assets in the physical world shall be integrated in the technological information network of a system for communication purposes. Communication capability always refers to the ability to communicate using digital communication systems (such as field bus or TCP/IP communication).

Assets can be placed in the following categories according to their communication capability:

- assets without communication capability;
- assets with passive communication capability;
- assets with active communication capability (basic component);
- assets with I4.0-compliant communication capability (I4.0 component).

4.7.1.2 Assets without communication capability

A physical asset has no communication capability if it either has no functionality as an information carrier at all (such as screw, cable or tank) or if it has information carrier functionality but no digital interface (such as a conventional washing machine or a 4-20 mA field device without HART).

4.7.1.3 Assets with passive communication capability

If an asset has an information carrier which can be read via interfaces, it has passive communication capability. The information carrier itself is passive, but allows its data to be read and the asset to be identified, for example (RFID, barcode, etc.).

4.7.1.4 Assets with active communication capability (basic components)

A physical asset that is capable of actively taking part in network communication is regarded as a basic component in terms of digital communication. It actively identifies itself on making contact with the network and logs in to participate in communication.

4.7.1.5 Assets with I4.0-compliant communication capability (I4.0 components)

An asset that has all the capabilities of an I4.0 service system user is known as an I4.0 component due to its special role in the I4.0 system. I4.0 components whose software and hardware form a unit are called autonomous I4.0 components.

For an I4.0 component to be able to provide information, it shall at least have a connection to the asset via an information system. This means that passive communication capability is a minimum prerequisite. To also be able to integrate an asset that is passively or actively capable of communication, but not I4.0-compliant, a higher-level IT system can be used as proxy for I4.0-compliant communication based on a service-oriented architecture (SOA).

EXAMPLE: In this way, an identifiable terminal block can become an I4.0 component.

4.7.2 Communication capability of assets in the information world

4.7.2.1 General

In addition to the physical components, assets from the information world can also be classified according to the same scheme.

4.7.2.2 Assets without communication capability

The data carrier is not capable of communication. All the data on it is not capable of communication.

EXAMPLE: Physical nameplate of a device, P&ID information as paper printout.

4.7.2.3 Assets with passive communication capability

The asset does not communicate actively. However, the data is stored on the carrier in a form that can be read (and possibly written) in the system.

4.7.2.4 Assets with active communication capability

The data is administered in an active software component. The software component is able to actively take part in system communication. The software component identifies itself when activated and logs in to participate in the exchange of information in the system.

4.7.2.5 Assets with I4.0-compliant communication capability (I4.0 components)

An I4.0 component which represents an asset has all the capabilities of an I4.0 service system user. Unlike an I4.0 component representing an asset from the physical world, this kind of I4.0 component represents an I4.0 software component.

NOTE Both 4.7.1.5 and 4.7.2.5 describe I4.0 components.

4.8 Classification of assets in terms of presentation and communication capability

The means by which an object is administered in the information system, and thus its presentation, or “publicity”, in that system, are independent of its communication capability. This means that an important unit in the system, for example an engine, can be administered as an entity, even if it is entirely incapable of communication. It shall then be tracked and its state recorded using external measurement and identification systems or by human beings in person.

NOTE 1 In order to administer an entity it is useful if the entity asset is at least capable of passive communication (for example using signal interfaces or RFID), but this is not a prerequisite.

Figure 6 illustrates the classification system. The administration class of each object – i.e. its presentation, or “publicity”, in the information system – can be freely chosen and is a design decision.

Communication capability is useful, but not essential, for administering the object. Conversely however, a particular communication capability requires that the object be sufficiently identifiable, in other words it has to be sufficiently known, in the information system.

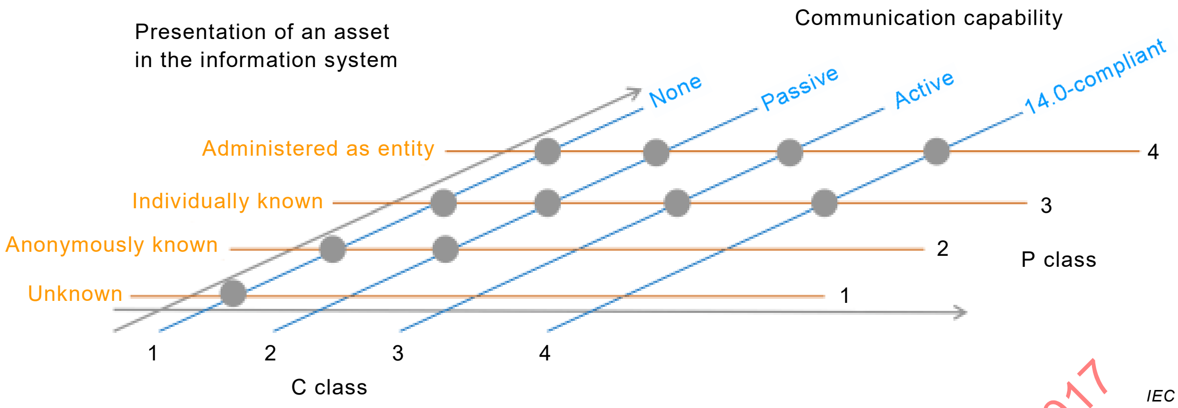

Figure 6 – Active presentation of an asset in the information system and its communication capability

Because of the importance of an object's communication capability and presentation, or "publicity", its assignment to a certain class can be expressed using "CP" and a number. CP stands for "Communication" and "Presentation". This type of notation is similar to such widely used notation systems as that for IP protection classes. Figure 7 illustrates the CP notation system.

EXAMPLE: CP33 denotes an individually known component capable of active communication, for example a classical field device with a field bus connection. The CP class for a security container which is monitored throughout its life but is not capable of any kind of communication would be CP14.

NOTE 2 According to the system shown in Figure 7, an I4.0 component is either a CP24, CP34 or CP44 component.

CP classification
CP XY

Communication capability (X number)	Presentation in the information system (Y number)
4 – Communication compliant with service system	4 – Administered as an entity
3 – Active communication capability	3 – Individually known
2 – Passive communication capability	2 – Anonymously known
1 – No communication capability	1 – Unknown

IEC

Figure 7 – CP notation system for classifying according to communication capability and presentation ("publicity")

In order to assign data and functions to an asset, it has to exist as an entity.

NOTE 3 Software, which in the conventional sense can be delivered both physically and non-physically, is also an asset. Ideas, archives and concepts are also assets in this sense.

NOTE 4 Because the purpose of an I4.0-compliant asset is to provide data and functions within an information system, individually known assets are entities by their very nature.

4.9 Representation by means of information and technical functionality

Representation by means of information encompasses all data and properties which characterize an associated asset or represent important information for other assets.

The functions of an asset represent its actual "technical" functionality.

5 Reference Architecture Model Industry 4.0 (RAMI4.0)

5.1 General

The reference architecture model Industry 4.0 (RAMI4.0) provides a structured view of the main elements of an asset using a level model consisting of three axes, as shown in Figure 8. Complex interrelationships can thus be broken down into smaller, more manageable sections by combining all three axes at each point in the asset's life to represent each relevant aspect.

The three axes are:

– the architecture axis ("Layers"), with six layers to represent the information that is relevant to the role of the asset;

– the "Life cycle & value stream" axis to represent the lifetime of an asset and the value-added process, based on IEC 62890;

– the "Hierarchy levels" axis for assigning functional models to specific levels, based on the IEC 62264-1 and IEC 61512-1 standards.

The aim of the reference architecture model Industry 4.0 (RAMI4.0) is to describe assets and combinations of assets with sufficient precision.

The description in RAMI4.0 is a purely logical one. The actual implementation can be different from the logical description. For example, an MES function for a machine is logically described on the hierarchical level "Work centres". However, when it is implemented, this function might be implemented in the hierarchical level "Station".

Security is an elementary aspect of RAMI4.0 and shall always be included in the description of each section of the three axes.

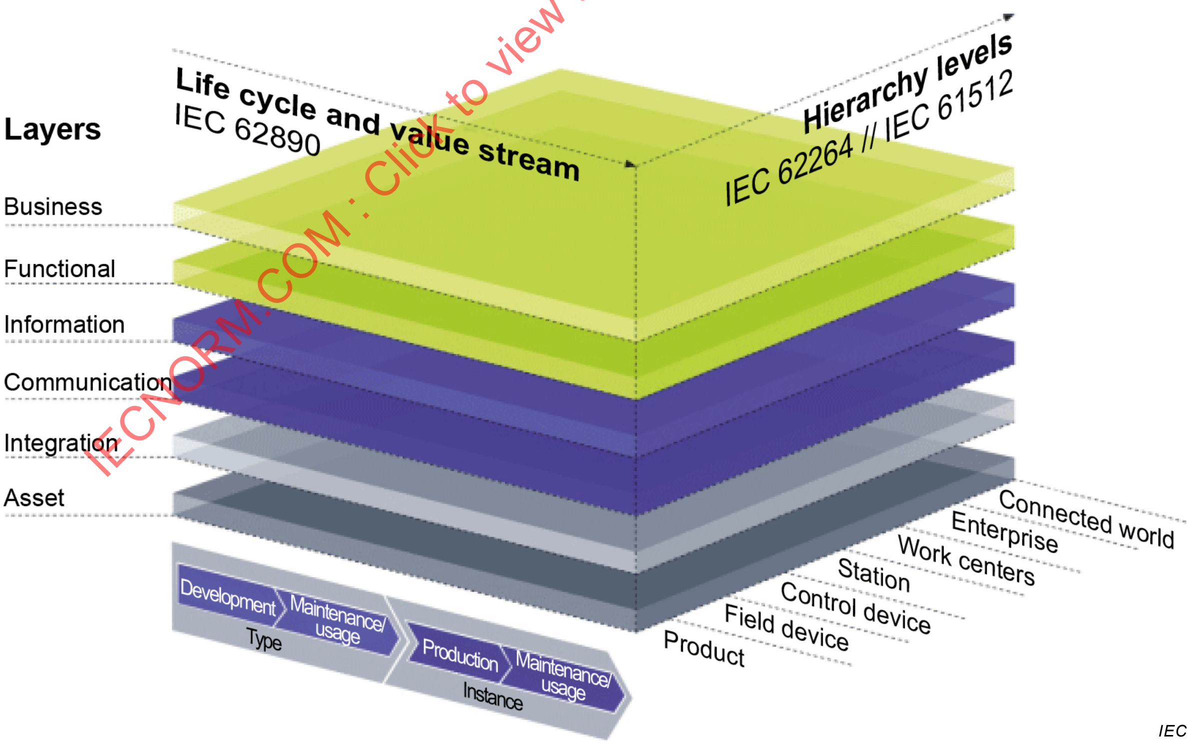

Figure 8 – Reference architecture model Industry 4.0 (RAMI4.0)

5.2 Architecture axis (“Layers”)

5.2.1 Overview

The vertical axis describes the architecture in terms of properties and system structures with their functions and function-specific data in the form of layers.

The six architectural layers are used on the vertical axis to describe the structural properties of an asset or combination of assets:

– business;
– functional;
– information;
– communication;
– integration;
– asset.

Layers do not always have to have content.

There is a loose connection between the layers. Interactions may only take place between two adjacent layers or within a layer. Layers are never skipped. Interactions may be passed through.

5.2.2 Business layer

The “Business” layer describes the commercial view. This includes:

– general organizational boundary conditions (such as order commissioning, general ordering conditions or regulatory provisions);
– monetary conditions (price, availability of resources, discounts, etc.);
– ensuring the integrity of functions in the value-added chain;
– modelling rules that the I4.0 system shall follow;
– mapping business models and the resulting business processes;
– general legal and regulatory conditions;
– orchestration of services on the “Functional” layer;
– links between different business processes;
– receipt of events in order for a business process to go to the next stage.

NOTE The functionality of the “Business” layer is not related to specific solutions, such as Enterprise Resource Planning (ERP). ERP functions are typically assigned to the “Functional” layer.

5.2.3 Functional layer

The “Functional” layer describes (logical) functions of an asset (technical functionality) with regard to its role in the Industry 4.0 system.

These include the:

– formal, digital description of functions;
– platform for horizontal integration of different functions;
– runtime and modelling environment for services and business processes;
– runtime environment for applications and technical functionality.

5.2.4 Information layer

The “Information” layer describes the data that is used, generated or modified by the technical functionality of the asset.

This includes the:

– runtime environment for (pre-)processing the event;
– execution of rules;
– formal description of models and rules;
– persisting of data represented by the models;
– ensuring the integrity of data;
– consistent integration of different data;
– acquiring new, higher quality data (data, information, knowledge);
– providing structured data via service interfaces;
– receiving events and transforming them into a suitable form for the data available to the functional layer;
– context pre-processing.

NOTE Context pre-processing is, for example, when one or more events have rules applied to them to generate one or more other events which then initiate processing in the functional layer.

5.2.5 Communication layer

The “Communication” layer describes Industry 4.0-compliant access to information and functions of a connected asset by other assets. In other words, it describes which data is used, where it is used and when it is distributed.

NOTE 1 Current field buses, RFID, QR codes, etc. are not part of the “Communication” layer, but part of the “Integration” layer.

NOTE 2 The transferred information and functions are not only of essential importance during their (operational) utilization, but also in all other phases of the asset’s lifetime.

EXAMPLE:

– Standardized I4.0 communication using a uniform data format;
– Providing services, for example as information functions based on a service-oriented architecture (SOA).

5.2.6 Integration layer

The “Integration” layer represents the transition from the physical world to the information world. It describes the infrastructure that exists in order to implement a function (resource). This layer is where the properties and process-related functions that make the asset usable for its intended purpose are stored.

NOTE The advantage of structuring in the asset layer and the integration layer is that in the higher layers it does not matter whether a subfunction is carried out in the physical world, i.e. physically in the integration layer, or in the form of software, in other words as a program in the functional layer.

The content of the integration layer includes:

– providing the representation of the actual resource of an asset by means of information on assets, physical objects, hardware, documents, software/firmware, etc.;
– describing the technical elements, such as RFID readers, sensors, human-machine interfaces (HMI) and signal converters;
– computer-aided control of technical (sub)processes;
– generating events from real assets;
– a human-machine interface (HMI).

Each important event in the real world generates an event in the virtual world, in other words in the integration layer and possibly higher layers too. If reality changes in the physical world, this event is reported to the integration layer.

Relevant events can therefore trigger events in the information layer and higher layers via the communication layer.

5.2.7 Asset layer

The “Asset” layer represents reality, i.e. the asset that actually exists in the physical world. It is the material reality which is virtually represented in the layers above it.

For every relevant item in the “Asset” layer, an item shall exist in the higher-level layers of the digital world. However, not every relevant item in the digital world has a corresponding item in the “Asset” layer.

EXAMPLE: A relevant property of an existent machine part appears as a representation in the “Integration” layer. If the machine part is scrapped, it disappears from the physical world, but remains, for example, as a plan in the archives in the information world of the “Integration” layer or the “Information” layer.

The “Asset” layer represents

– the physical world, that is all real, existing assets as defined by Industry 4.0 and by humans, e.g. physical elements such as linear axes and sheet metal parts, services, documents, circuit diagrams, ideas and archives,
– the interface between humans and the information world, and
– the connection of the assets to the “Integration” layer.

Multiple assets described according to RAMI4.0 in the “Asset” layer can be combined to form a more complex asset. For this, all the individual assets and the new, more complex asset shall be described according to the rules of the reference architecture model.

5.3 Life cycle & value stream axis

The “Life cycle & value stream” axis is used to describe an asset at a particular point in time during its lifetime, from its production and value-added use right up to its disposal.

On this axis, the asset is characterized by its state at a particular time at a particular location.

5.4 Hierarchy axis

The “Hierarchy” axis is based on the reference architecture model for a factory along the lines of IEC 62264-1 and IEC 61512-1, the standards for integrating enterprise IT and control systems. To ensure a consistent consideration across as many sectors as possible from factory automation to the process industry, the terms “enterprise”, “work centres”, “station” and “control device” have been taken from the above-mentioned standards (see Figure 9). The following hierarchy levels have been modified and supplemented to reflect the needs of Industry 4.0:

– “Connected world” describes the relationship between an asset or combination of assets (such as an installation or company) and another asset or combination of assets (another installation or company), in other words, for example, a network of factories;
– “Field device” has been added as a hierarchical level;
– “Product” denotes the cooperating or collaborating product to be manufactured as an integral part of an Industry 4.0 value-added process.

NOTE For the asset “production plant” for example, the reference architecture model Industry 4.0 thus enables a homogeneous consideration of the product to be manufactured and the production plant, with all their dependencies and relationships.

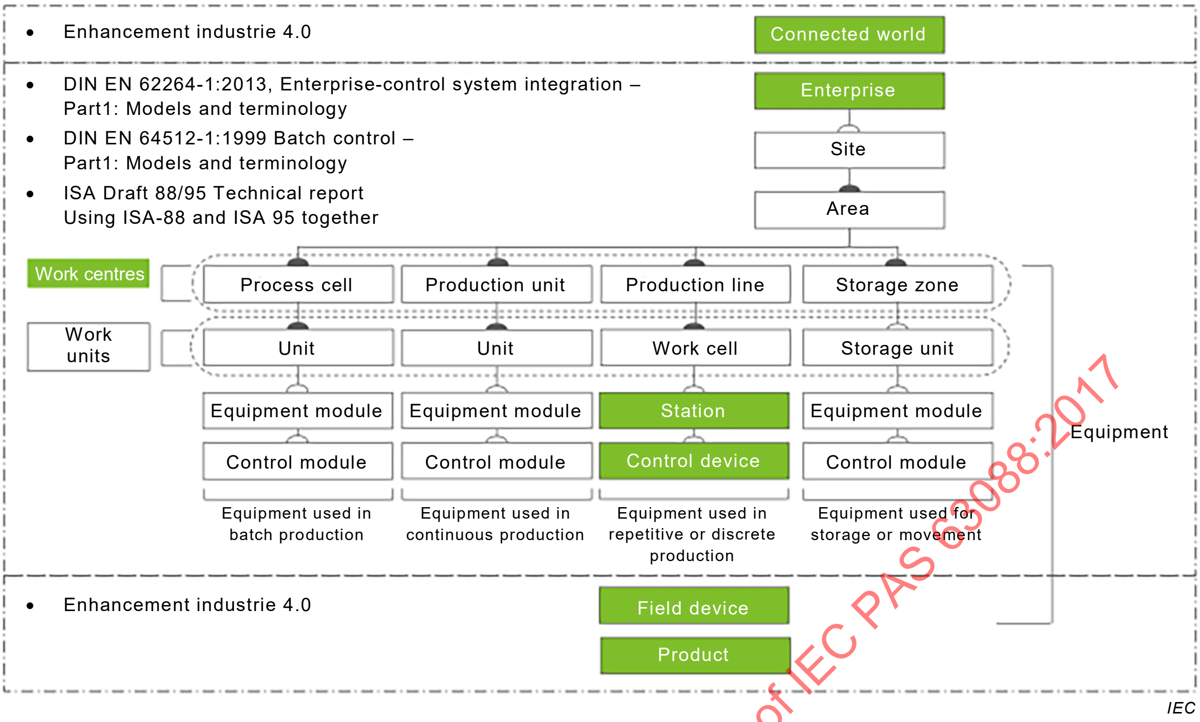

Figure 9 – Hierarchical levels of RAMI4.0

6 Industry 4.0 components

6.1 General

6.1.1 Overview

Industry 4.0 components (I4.0 components) are globally and uniquely identifiable participants capable of communication, and consist of the administration shell and the asset (as in Figure 10) with a digital connection within an I4.0 system (corresponding to CP24, CP34 or CP44), and offer services there with defined quality of service (QoS) properties.

Assets of different types with different communication capabilities can be implemented as I4.0 components. I4.0 components offer graduated protection for services and data, including information security, at a level appropriate to their use.

In industrial applications, an I4.0 component can be a production system, an individual machine or unit, or a module within a machine.

Figure 10 shows that an asset is not necessarily an I4.0 component. Only if it is an entity, has at least passive communication capability and has been equipped with an "administration shell" does an asset become an I4.0 component.

The administration shell includes the relevant information for representing the asset and its technical functionality. It provides the information world with information on the asset or multiple assets, structured according to RAMI4.0.

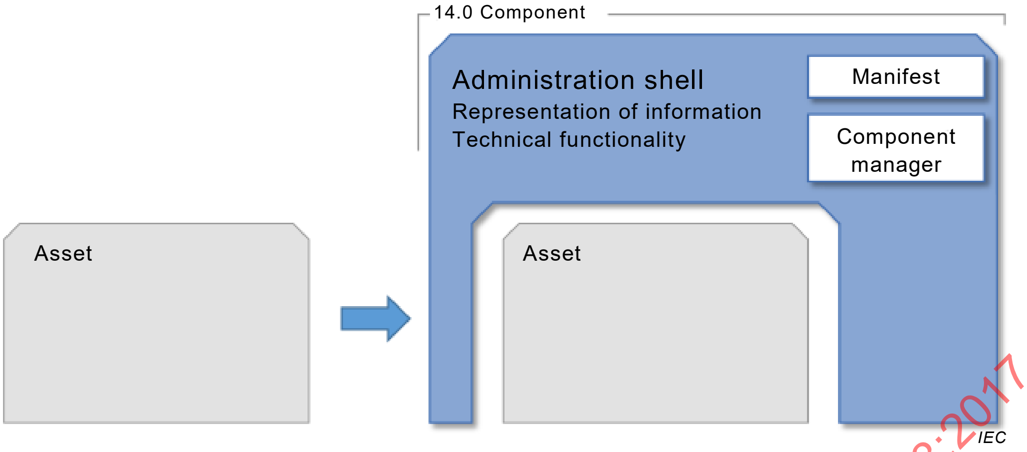

Figure 10 – An I4.0 component as a necessary connection between the asset and the administration shell

6.1.2 Properties of I4.0 components

The term "component" is a general one. It denotes an asset in the physical world or the information world which performs or is intended for a specific role in its system environment. A component can be a pipe, a PLC function module, a lamp or a valve to an intelligent drive unit, for example. What is important is that it be viewed as a unit, and the role (technical functionality) that an I4.0 component should perform or already performs in a system. An I4.0 component is a special type of component. I4.0 components are characterized by the fact that they meet certain requirements with regard to the classification properties described above.

NOTE An I4.0 system can also include components that do not meet I4.0 requirements and are therefore not I4.0 components.

To present information on its assets in the information world, an I4.0 component has the following properties based on the specifications in 4.4. It is:

– clearly identifiable as an entity,
– either a "type" or an "instance" in terms of a specific point in its lifetime,
– capable of active or passive I4.0-compliant communication (digital connection within an I4.0 system),
– a representation of an asset by means of information, and
– may have a technical functionality

with a level of protection appropriate for its use. The security capabilities of an asset shall comply with the required security capabilities of the administration shell.

6.1.3 Identifiability

An I4.0 component is uniquely identifiable in the network, which means that the physical asset it represents can be found using a unique identifier (ID). If it is a CP34 or CP44 component (as described in 4.8), it can be contacted via a communication address (such as an IP address). An active I4.0 component can perform I4.0-compliant communication by itself, while for a passive I4.0 component this is done by the necessary infrastructure.

6.1.4 State in the lifetime ("vita")

The information in Subclause 4.6 applies here.

Because each I4.0 component is part of a network with particular tasks, and these tasks have to be carried out in processes in a coordinated manner, it shall be possible at all times for other users to query the state of each I4.0 component in an I4.0-compliant communication network. This information is used, for example, for local administration of other I4.0 components and global administration for coordinating processes.

A distinction shall be made between types and instances of assets, so that a relationship can also be established between component producers and users that makes it possible to pass on refinements of assets as a type to users when required, and conversely to pass on feedback from users to the producer.

6.1.5 Secure I4.0-compliant communication, services and quality of service

I4.0 components communicate with each other on the basis of a service-oriented architecture (SOA), including common I4.0-compliant semantics. An I4.0 component provides information about itself using services based on a service model. An appropriate profile for an I4.0 component describes which services are implemented, and what technology is used for this.

It shall be possible for I4.0 components to use different communication protocols. Therefore, it should be possible to load optional protocols and application functions later on.

A distinction is to be made between the addressing of the I4.0 component and the addressing of its (application) objects. These are addressed using a globally unique ID that is independent of the manufacturer.

I4.0 components support the generally standardized (and also subsequently loadable) service functions and states for an I4.0 system. They possess the properties required for this task in the form of qualities of service (QoS), which also include (information) security properties. With regard to use in automation technology, these shall be properties which are agreed or stored in a profile, such as:

– the real-time range for productive communication, e.g. determinism with real time capability of D1 ms;
– maximum fail-safe security as regards the surrounding network architecture (robustness);
– sufficiently granular clock synchronization;
– interoperability;
– diagnosis and engineering based on uniform rules;
– establishment of ad hoc connections.

Depending on the requirements for the administration shell and associated assets, the following is essential for security:

– The confidentiality, integrity of the data, functions and availability of the technical functionality shall be ensured, also as regards the functions of the associated asset (CIA: confidentiality, integrity, availability). This also applies to saved information which is to be transferred.
– When using data beyond company boundaries (for example in the cloud), pseudo- or full anonymization of personal data is to be taken into account, as is any inter-company system of identity and rights management.

6.1.6 Representation by information with I4.0-compliant semantics

An I4.0 component provides its representation, including its dynamic behaviour, using standardized, I4.0-compliant semantics.

This information is generated according to RAMI4.0 as a virtual, structured representation of the real asset in an I4.0-compliant data format. One part of this representation is the manifest, which shall have I4.0-compliant semantics.

The properties and functions of the asset are classified using the following data elements:

- general business conditions (Business);
- mechanics (Construction);
- functionality (Function);
- place (Location);
- capability (Performance).

IEC TR 62794 applies to the specification of data elements, and IEC 61360-1 and IEC 61360-2 apply to the specification of properties.

Each I4.0 component has a minimum infrastructure for ensuring the (information) security function. Because security is only assured if the production process is included in the considerations, the security infrastructure of an I4.0 component is a necessary functionality, but not in itself sufficient. The requirements of the “security by design” principle (SbD) shall be fulfilled.

In addition, applications for functional safety also require an infrastructure where functional safety and information security cannot negatively affect each other.

6.1.7 I4.0 system consisting of I4.0 components

An I4.0 system consists of I4.0 components and components of a lower CP classification;

- it serves a particular purpose,
- has specified properties and
- supports standardized services and states.

Such an I4.0 system can be an I4.0 component of its own in another I4.0 system.

A network of I4.0 components shall be structured in such a way that connections are possible between different end points (I4.0 components). The I4.0 components and their content comply with a common semantic model. Assets which are combined can form any kind of system. If they are I4.0 components, they form an I4.0 system. From the point of view of the system, I4.0 components have the following important properties:

- nestability;
- encapsulability.

6.1.8 Nestability

As shown in Figure 11, any I4.0 component can consist of other I4.0 components, which means an I4.0 component can be logically nested (including temporarily if necessary). Higher-level systems should have limitable, purpose-related access to all I4.0 components, even if they are (temporarily) logically assigned.

NOTE In the context of this PAS, I4.0 components represent assets such as production systems, machinery, units and conceptually important parts, such as machine modules. This means a machine can be an I4.0 component. It can itself consist of separate I4.0 components. In turn, individual machine modules can be composed of I4.0 components. From a technical point of view, this can be implemented in such a way that the higher-level asset (such as the machine) has two I4.0-compliant communication interfaces, so that there is a clear logical and physical separation between higher-level and subordinate I4.0 components (see Figure 11, no. 1). Another option is that I4.0-compliant communication upwards and downwards are physically the same thing, but logically separated from each other (see the dotted line in Figure 11, no. 2). To organize a logical assignment of subordinate I4.0 components, the administration shell can contain its own component manager. It can then represent the state of the machine appropriately in the level above, for example.

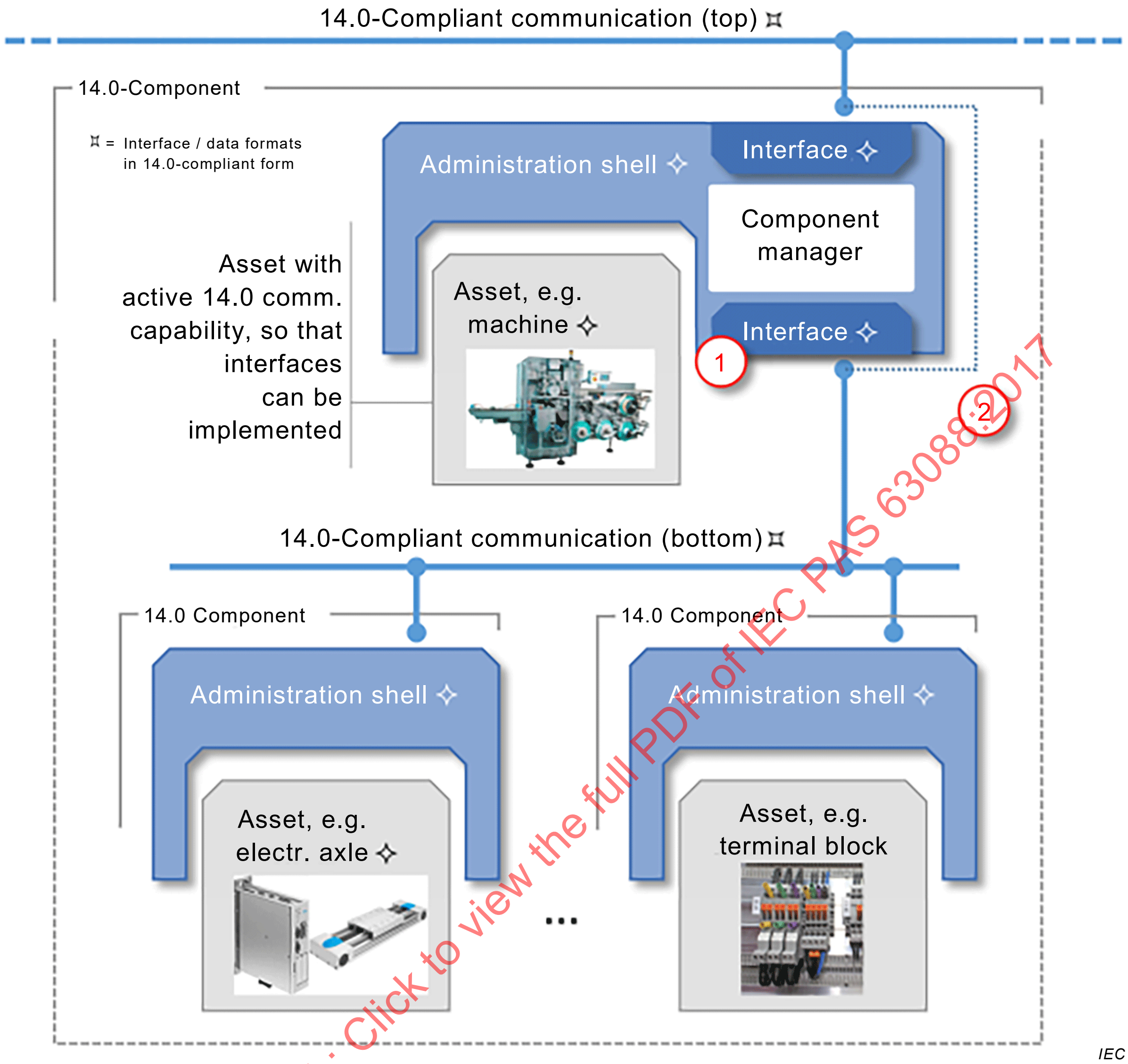

Figure 11 – Nestability of I4.0 components

6.1.9 Encapsulability

The I4.0 component should be able to establish all necessary connections within an I4.0 system (see Figure 12, no. 1). However, connections shall not lead to any restriction of the core functionality (see Figure 12, no. 2). The ability to retain this core functionality unimpaired even if the external network is disrupted is called “encapsulability”. The I4.0 component, in particular its administration shell, the functionality contained in it and the associated protocols, shall be capable of encapsulation. Communications can take place via a single connection (see Figure 12, no. 3).

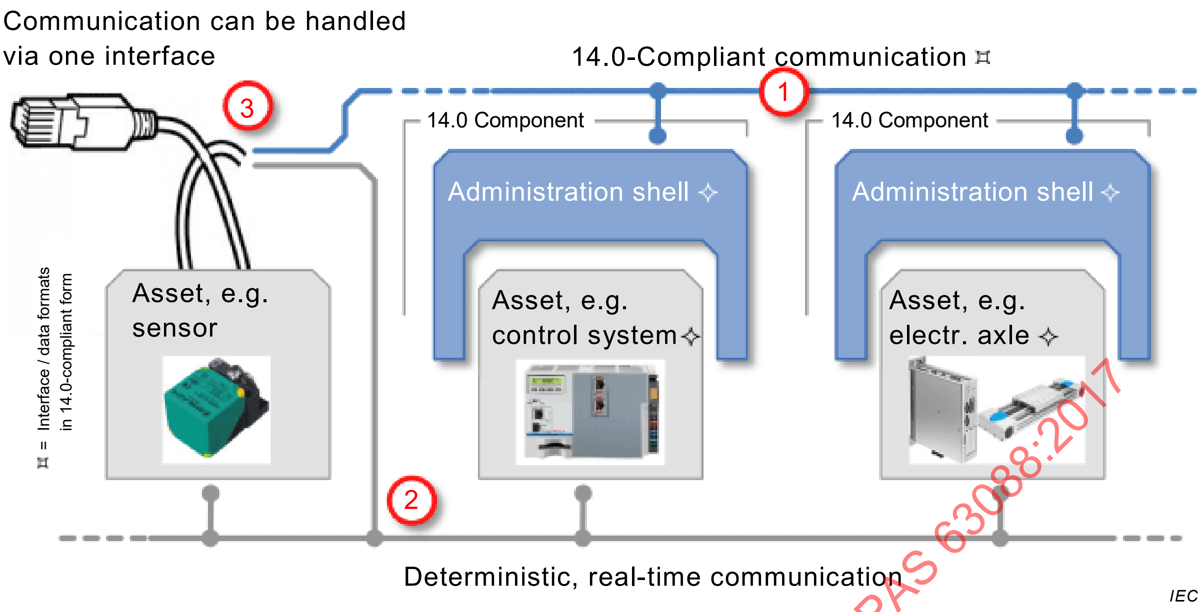

Figure 12 – Encapsulability of I4.0-compliant and deterministic real-time communication

6.1.10 Domain specific functionality and state model

An I4.0 component possesses a technical functionality necessary to exercise its role.

EXAMPLE:

- general functionality of the asset;
- software for "local planning" in conjunction with the asset, such as welding planning, software for labelling terminal blocks, etc.;
- software for project planning, configuration, operation, maintenance;
- manuals and documentation;
- technical functionalities relevant to the execution of business logic.

The state of an I4.0 component can be read by other users of an I4.0 system based on a defined state model.

The state model shall have state variables which provide a detailed view of the state of the asset and its technical functionality, in order to allow consistent querying of the state of the I4.0 component at a particular point in time (for example for the purposes of statistically correct data analysis).

6.2 Administration shell of I4.0 components

6.2.1 General

The administration shell is what converts an asset into an I4.0 component. It is the virtual digital and active representation of an asset in an I4.0 system.

In an asset implemented as an embedded system, the administration shell and its objects can be stored in the asset itself (provided it has active, I4.0-compliant communication capability) or it can be distributed on one or more IT systems.

The administration shell records life cycle data of the asset and converts it into information (e.g. the present position and currents of a servo drive). The associated information should be accessible in the form of views (as described in 6.2.4.3). The services of the component manager are provided by the I4.0-compliant service-oriented API (Application Programming Interface).

6.2.2 Basic structure of the administration shell

Figure 13 shows the basic structure of the I4.0 administration shell. It is divided into the DF header and the DF body. The prefix DF unambiguously assigns the partial models to a domain (DF = Digital Factory). The distinction between header and body follows the specifications of IEC TS 62832-1. At the very least, the administration shell contains the administration shell management in the form of the component manager and the manifest.

The administration shell is divided into partial models for different purposes. Each partial model contains information in the header and body sections.

6.2.3 DF header and DF body

The header carries information to identify and designate the specific asset in the I4.0 system and contains information on the administration and use of the asset. It refers to selected capabilities of the asset and to views. The header information (including identification of the administration shell and assets) shall be regarded as properties in the sense of requirements for graduated security (as in 6.2.5, e)).

The body is where the actual information on the asset is stored. This information is not directly dependent on the utilization specific to a factory or process plant. This means the body is the actual information carrier.

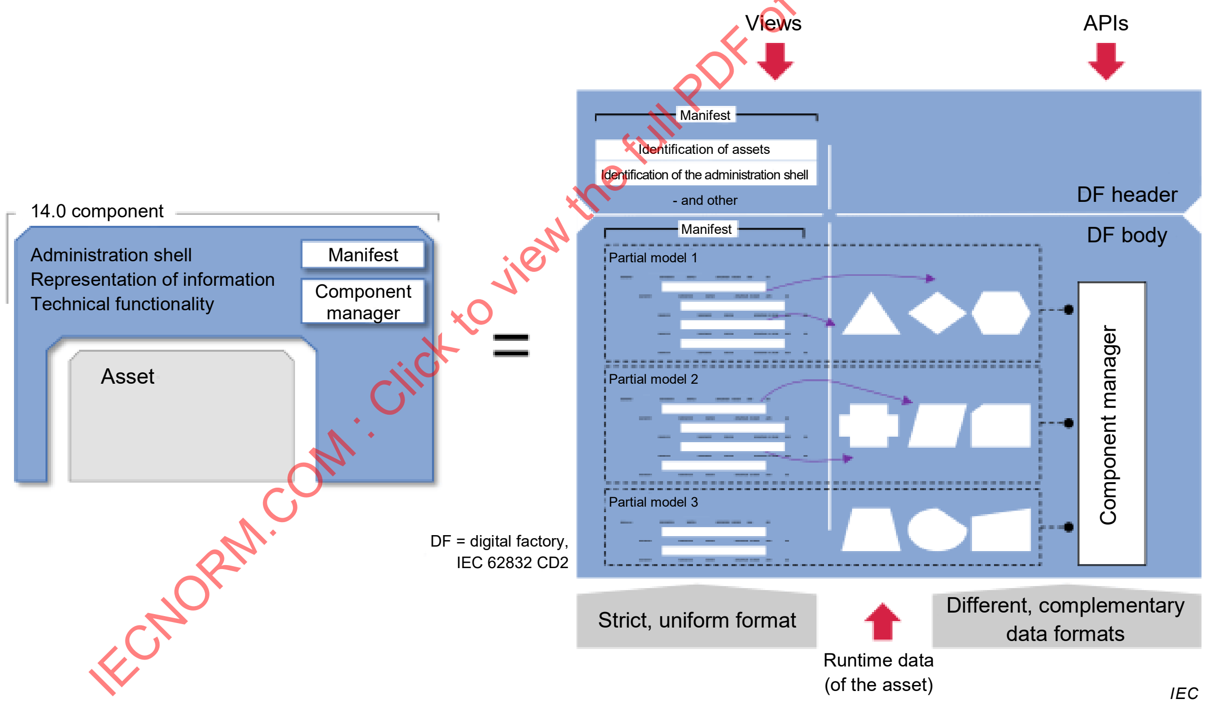

Figure 13 – Diagram of an I4.0 administration shell

The administration shell contains separate partial models with properties and functions from different domains, which are updated with different version numbers independently of each other. The partial models are created in compliance with I4.0, which means using RAMI4.0 and in terms of properties and functions, using the data elements described in 6.1.6.

Security requirements may necessitate a graduated security model for properties, even in different partial models.

6.2.4 Partial models and views

6.2.4.1 General

The administration shell can contain any number of I4.0-compliant partial models. Each partial model has hierarchically organized properties referring to individual data and functions.

6.2.4.2 Creating the partial models

The upcoming Industry 4.0 reference models propose partial models specified by experts with experience in the domain. Each partial model specifies its properties, data and functions according to uniform rules for the header and the body separately. Agreed partial models are available for system-wide I4.0 integration in the administration shells. Figure 14 shows examples of partial models for various horizontal and vertical domains.

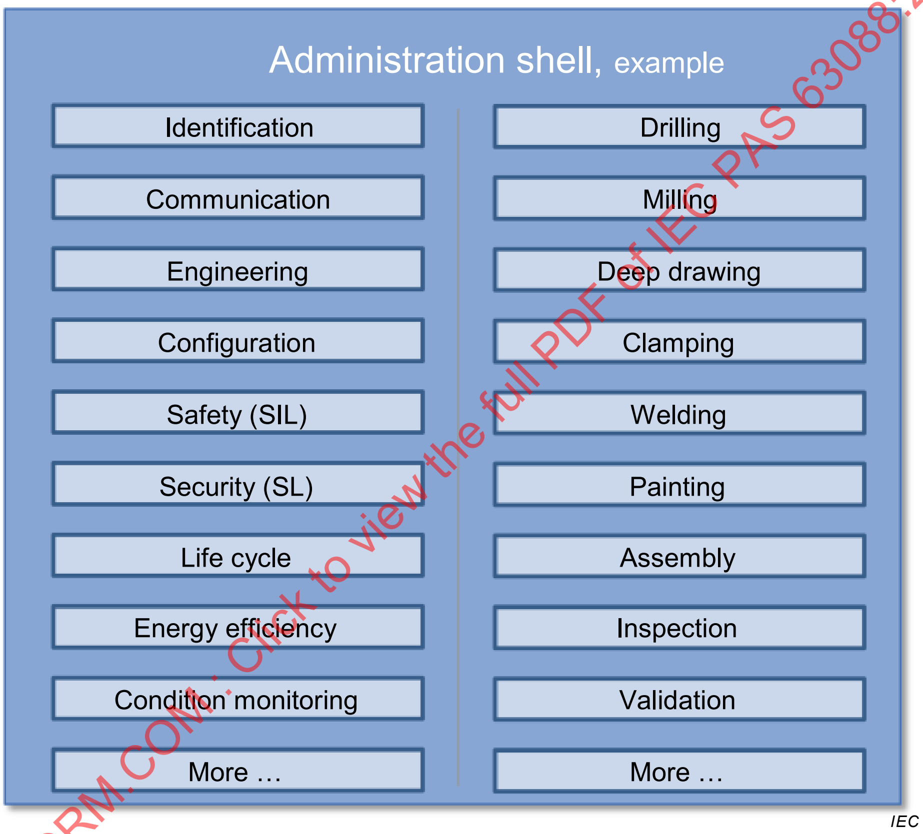

Figure 14 – Examples of domain specific models

6.2.4.3 Views in partial models

Each partial model shall provide at least the basic views by means of properties, data and functions. Figure 15 shows how views are created.

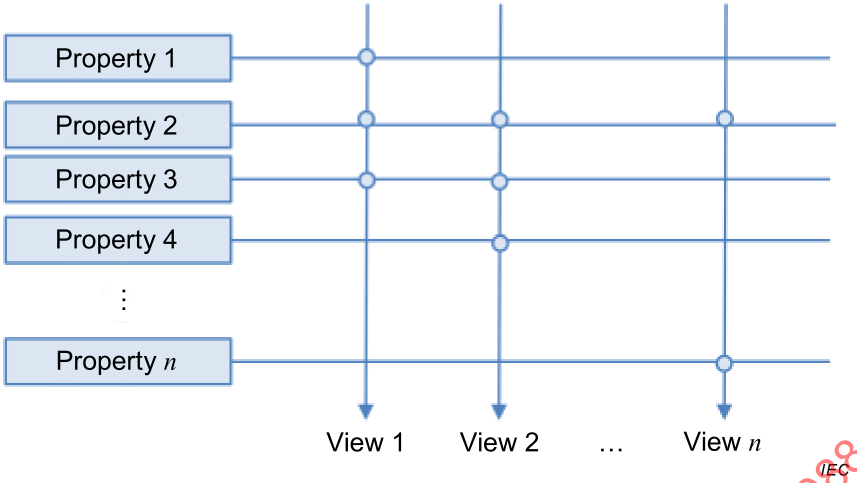

Figure 15 – Diagram of how views are created

Table 1 shows the basic views which are mandatory for all partial models. Additional views can be created if needed.

Table 1 – Basic views of a partial model

Basic view	Best practice / examples
Business	Data and functions are stored which make the component suitable and effective for the life cycle phases of procurement, design, operation and utilization. Examples: prices, terms of delivery, ordering codes.
Design	Contains properties that are relevant to the use of the component, i.e. for selection and structuring. Contains a structure classification and numerous properties for physical dimensions and for input, processing and output variables of the component (see IEC 81346). Contains a modular view of partial components and a device structure. Allows an automation view with inputs and outputs of various signal types.
Performance	Describes performance and behaviour properties to allow summary assessment and virtual commissioning (VCOM) of a system as a whole.
Functional	Makes statements on the function IEC 81346 and on the function of the partial components. Localization of the individual functions of the technical functionality also take place here, i.e. the skills and the design, commissioning, calculation or diagnostic functions of the component.
Local	Makes statements on positions and local context of the component, its parts, or its inputs and outputs. The actual position of the component is part of the header data.
Security	Can flag a property as relevant to security. This property should be included in any assessment of security.
Network view	Makes statements on the electrical, fluid, material flow and logical connection of the component
Life cycle	Contains data on the current state and past use throughout the lifetime of the component. Examples: Assignment to production, maintenance logs, past uses.
Human	In all views, properties, data and functions should be prepared in such a way that human users can understand individual elements, relationships and can control causal chains.

6.2.5 Properties

Meaningful values of I4.0-compliant "basic properties" ensure that all I4.0 components and other systems can access and use these basic properties, values and functions of the administration shell. In addition, there are the following property classes: mandatory properties, optional properties and free properties. Table 2 shows their characteristics.

Table 2 – Property classes

Property class	Explanation
Basic properties	I4.0-compliant properties which are mandatory and standardized for all administration shells.
Mandatory properties	I4.0-compliant properties which are mandatory and standardized for partial models of administration shells.
Optional properties	I4.0-compliant properties which are standardized but not mandatory for partial models of administration shells.
Free properties	Properties for partial models of administration shells, such as manufacturer-specific properties, which are not standardized and not mandatory. These may not be used by different manufacturers.

Without restricting general applicability, the concept is established that the manifest (as described in 6.2.6.3) of the administration shell manages information elements in the form of properties, and that the administration shell itself can also include data objects and technical functionality.

The following applies to individual properties, data and functions:

a) It shall be possible to use the properties and other information elements in the administration shell for types and instances.

   Just like the administration shell as a whole, the individual properties and other data and functions shall be suitable for allowing a distinction between types and instances of administration shells for the asset in question. In specific cases, this can mean that individual properties of an instance keep a record of whether they are added, modified or deleted for this instance, or whether it should be ensured that the information is identical to the data in the type administration shell.

b) Hierarchical and enumerable structuring of properties shall be possible.

   The number of properties to be organized is already large and will further increase as Industry 4.0 develops. To make them manageable for people and machines, properties shall be structured hierarchically. Because a property can contain multiple equal-ranking alternatives or detailed information, for example a list of languages or certificates, there should be enumerable structures, such as fields.

c) Properties shall be able to reference other properties, including those in other administration shells.

   As with the administration shell as a whole, the individual properties shall also be able to reference I4.0-compliant entities and information outside their own administration shell. Thus information can be linked and becomes knowledge. In the same way, different knowledge domains (for example properties from different standards) can be linked to each other.

   NOTE 1 Specifically, this makes views possible by representing the view or information hierarchically (see 6.2.5, b)), and the other views link to it by referencing.

   NOTE 2 This requirement should also make it possible to make links using designated relationships (as required with semantic technologies).

d) Properties shall be able to reference data and functions of an administration shell (at least within it).

   As part of the manifest, properties shall be able to reference data and functions within the administration shell. In this way, standardized properties can act as anchor points for different data. In the same way, it can be ensured that the functions of the technical functionality of an asset can be found, described and accessed.

e) Properties shall fulfil aspects of information security for graduated availability, integrity, confidentiality, visibility and authenticity.

   Properties, data and functions will also carry information which not every participant within a value-added network or organizational unit should be able to access, or whose integrity and availability should be maintained. Therefore, right from the start, the structure of the