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Foreword

This DIN SPEC has been developed according to the PAS procedure. The development of a DIN SPEC according to the PAS procedure is carried out in DIN SPEC-consortiums and does not require the participation of all stakeholders.

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Introduction

Industrie 4.0 provides the contextual ecosystem for implementing and operating novel industrial applications like data-driven business models and innovative service models. Typically, machines of different vendors are operated inside production sites. Remote services operated in IT backend systems (on premise or cloud) will leverage business success and decisive key success factor. Therefore, machines' heterogeneous data and functionalities shall be integrated and delivered to IT systems beyond the factory floor. As a result, companies operating a production site are forced to deliver data of their machine park to a variety of external companies providing services for optimized component, machine and plant operation, and, by that, finally ensuring competitiveness.

Increasingly more companies in the field of mechanical and plant engineering as well as component suppliers (e.g. PLCs (Programmable Logic Controller), sensors, and actuators) provide their own cloud-based services. A prerequisite for using these services is the provisioning of component or machine data which leads often to the installation of additional gateways — and it is common that multiple gateways are required for unveiling the full potential and taking advantage of different remote services from various providers. Increasingly higher maintenance costs and, from an IT security point of view, obscure communication, and network settings hard to maintain are only two exemplary consequences of this situation.

In order to address aforementioned challenges and ensure investment reliability in data-driven Industrie 4.0 projects, a consensus on the communication and data exchange between field devices and IT backend systems is inevitable. By that, currently isolated solutions are opened, the freedom of choosing one or more adequate cloud systems is strengthened, and it is made possible that plant operators can store, manage, filter and abstract machine and plant data while satisfying the data needs of remote services. Therefore, the concept of “Industrial Cloud Federation” (ICF) is introduced here by means of a reference architecture ensuring the interoperability of involved stakeholders and, by that, the data exchange from field devices to and among cloud systems, and finally, to cloud service endpoints.

1 Scope

This document specifies a reference architecture model for Industrial Cloud Federation which denotes communication between endpoints of cloud services and endpoints of devices physically located in a production shop floor. By that, the communication will cross one or more administrative company borders and cloud systems.

This document considers the communication of edge components to the cloud of the manufacturing company as well as cross-company communication to other cloud systems. Within this activity, only applications from the area of Industrie 4.0 — i.e. production, mechanical and plant engineering — are considered. The reference model specified here relies on concepts of Industrie 4.0 and (industrial) IoT and combines them in a sound manner. Finally, the objective of this DIN SPEC is to assure interoperability and communication between involved endpoints of IT (sub-)systems and physical devices.

A variety of stakeholders are involved in developing and operating an Industrial Cloud Federation. This DIN SPEC specifies necessary interoperability criteria that shall be met by each stakeholder to ensure a seamlessly functioning Industrial Cloud Federation. Thereby, especially the core questions and stakeholders depicted in Figure 1 are addressed.

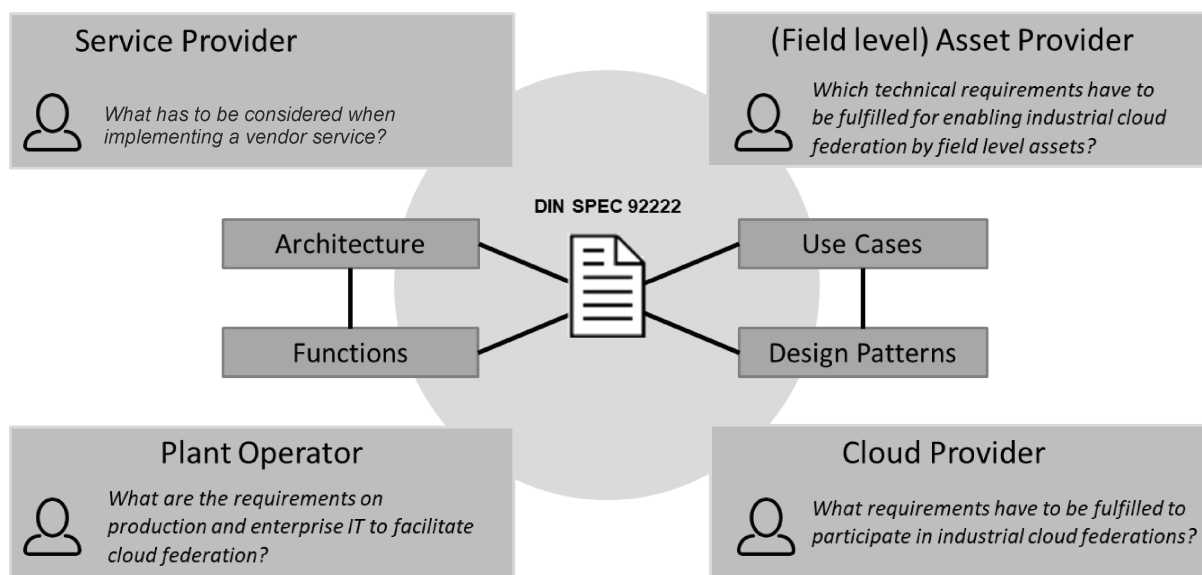


Figure 1 — Overview of stakeholders and major building blocks of this document

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.

DIN SPEC 16593-1, RM-SA — *Reference Model for Industrie 4.0 Service Architectures — Part 1: Basic Concepts of an Interaction-based Architecture; Text in English*

DIN SPEC 91345:2016-04, *Reference Architecture Model Industrie 4.0 (RAMI 4.0)*

IEC/PAS 63088:2017, *Smart manufacturing — Reference architecture model industry 4.0 (RAMI 4.0)*

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:

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

DIN and DKE maintain terminological databases for use in standardization at the following addresses:

- DIN-TERMinologieportal: available at <https://www.din.de/go/din-term>
- DKE-IEV: available at <http://www.dke.de/DKE-IEV>

3.1

asset

item which has value for an organization, and which is administrated individually for this reason

[SOURCE: Plattform Industrie 4.0 — Glossary]

3.2

Information Technology Entity

Cloud

non-physical asset, which follows the rules of Cloud Computing

Note 1 to entry: A cloud can be connected to another cloud and is able to exchange information based on communication patterns as specified by the RA4ICF.

Note 2 to entry: In a special case there is only one single cloud that is involved in ICF and that communicates to the edge. In this case, the cloud is necessarily an entity of the industrial domain.

3.3

Cloud Computing

paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand

Note 1 to entry: Examples of resources include servers, operating systems, networks, software, applications, and storage equipment.

[SOURCE: ISO/IEC 17788:2014, 3.2.5]

3.4

Edge Computing Entity

edge

non-physical asset, which enables communication between a thing and cloud services via communication endpoints and follows the rules of Edge Computing

3.5

cloud federation

communication between cross-company communication between endpoints of cloud services

3.6

Industrial Cloud Federation

communication between endpoints of cloud services and endpoints of Edge Computing Entities

Note 1 to entry: An Industrial Cloud Federation is the application of a cloud federation in the industrial domain.

Note 2 to entry: Industrial Cloud Federation defines a set of architectural and infrastructure components that enable communication with and between cloud environments according to agreed policies between the stakeholders involved.

Note 3 to entry: The Industrial Cloud Federation may include the distribution, forwarding (routing), storage, filtering and rewriting of communication.

Note 4 to entry: If several clouds are involved in Industrial Cloud Federation, it is possible that these belong to different domains. In this case at least one cloud must have industrial application.

3.7

communication endpoint

software interface which exposes or uses one or more network interfaces

Note 1 to entry: There are two types of communication endpoints: endpoints located on an edge or endpoints located on a cloud. The endpoints located on a thing contribute to the internal communication between the edge and thing.

Note 2 to entry: A communication endpoint may be addressed by a specific communication standard.

3.8

cloud service

I4.0 service deployed on a cloud

Note 1 to entry: A cloud service has one specific communication endpoint i.e. the endpoint of a cloud service. A cloud service relates exactly to one cloud, whereas several cloud services can be deployed on one cloud.

3.9

service

mechanism to enable access to one or more capabilities where the access is provided by a prescribed interface and is exercised consistent with constraints and policies as specified by the service description

[SOURCE: OASIS SOA-RM:2006, 3.1]

3.10

service platform

implementation of a software infrastructure to build and run specific services on a cloud-based infrastructure

3.11

I4.0 service

service that is an Industrie 4.0 asset

Note 1 to entry: Services are considered as I4.0 services if they apply the rules for an Industrie 4.0 asset.

3.12

Operational Technology Entity

thing

physical asset, which is located on the shop floor

Note 1 to entry: Within the Industrial Cloud Federation, it is located below the edge.

Note 2 to entry: The thing can be a product, a field or control device, a station or a work center.

3.13**item**

unit which exists objectively, is demarcated and identifiable

Note 1 to entry: An item can be a device, subsystem, software program, plan, living organization or the like.

3.14**stakeholder**

<system>individual, team, organization, or classes thereof, having an interest in a system

Note 1 to entry: A system of interest is usually provided or utilized by a stakeholder and can be a specific entity of the ICF, i. e. a thing, an edge or a cloud, or a cloud service.

[SOURCE: ISO/IEC/IEEE 42010:2011, 3.10, modified – Note 1 to entry has been added.]

3.15**gateway**

item connecting one or more things to a wide-area network

3.16**reference architecture**

architecture framework used as a template when developing or validating an architecture description for a particular solution

[SOURCE: ISO/IEC 20924:2021, 3.1.28]

4 Abbreviated terms

CM4ICF	Conceptual Model for Industrial Cloud Federation
ICF	Industrial Cloud Federation
RAMI 4.0	Reference Architectural Model Industrie 4.0
RAM4ICF	Reference Architecture Model for Industrial Cloud Federation
RA4ICF	Reference Architecture for Industrial Cloud Federation
OPCUA	Open Platform Communications Unified Architecture
MQTT	Message Queuing Telemetry Transport

5 Conceptual structure of the document**5.1 General**

This clause shows the overall conceptual structure for Industrial Cloud Federation (ICF). Figure 2 depicts the main elements and their relations and gives numerical references to respective clauses as described in this document.

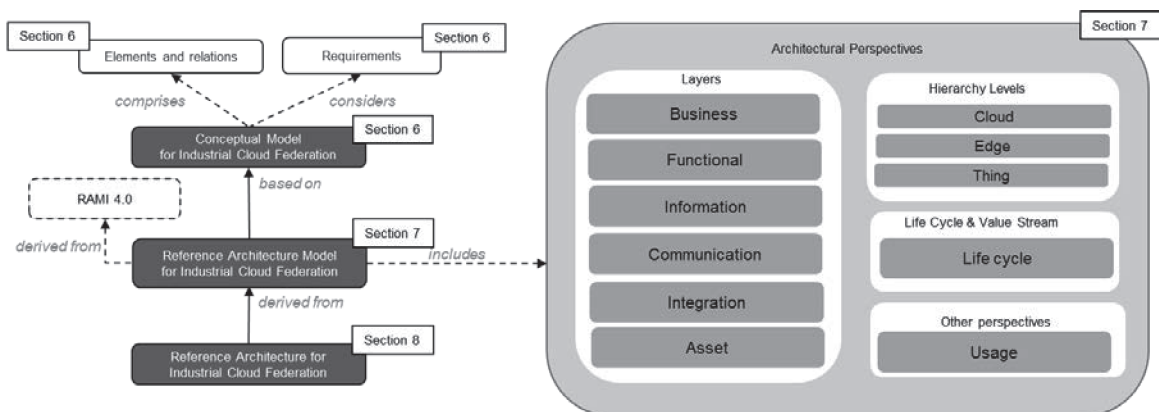


Figure 2 — Overall conceptual structure for Industrial Cloud Federation

NOTE The conceptual structure for ICF is aligned with the architectural descriptions defined in ISO/IEC/IEEE 42010 and is inspired by the Internet of Things Reference Architecture provided in ISO/IEC 30141.

5.2 Elements and relations

5.2.1 Conceptual model for Industrial Cloud Federation

The Conceptual Model for Industrial Cloud Federation (CM4ICF) is a composition of the ICF concepts and comprises of a set of conceptual elements and their relations. The CM4ICF serves as a solid fundament for describing the requirements for a Reference Architecture Model for Industrial Cloud Federation (RAM4ICF) as well as the reference architecture (RA4ICF) itself. Additionally, the CM4ICF enables derivation of the fundamental requirements between stakeholders that are involved in the ICF scope (see Figure 1). The CM4ICF is described in detail in Clause 6.

5.2.2 Reference Architecture Model for Industrial Cloud Federation

The Reference Architecture Model for Industrial Cloud Federation is described on the basis of the CM4ICF and includes a set of Architectural Perspectives. The primary standardization objective of RAM4ICF is to transform all aspects necessary for the realization of the ICF into a unified model, so that the main conceptual elements of CM4ICF receive a comprehensible, functional and practical application in the industrial domain.

The RAM4ICF is commonly based on the Reference Architecture Model Industrie 4.0 (RAMI 4.0) according to DIN SPEC 91345:2016-04 and the usage perspective.

The RAM4ICF includes RAMI 4.0-specific architectural perspectives that represent various levels of abstraction, i.e. Layers, Hierarchy Levels, as well as Life Cycle and Value Stream, and are embedded in a three-dimensional model of RAMI 4.0 respectively. RAM4ICF identifies an additional perspective, the Usage Perspective, which focuses on the ICF user and addresses such important aspects as roles, activities, and relative tasks.

NOTE The Usage Perspective is not defined in RAMI 4.0 but is essential for the ICF concept.

The RAM4ICF and the architectural perspectives are described in detail in Clause 7.

5.2.3 Reference Architecture for Industrial Cloud Federation

The Reference Architecture for Industrial Cloud Federation (RA4ICF) is commonly based on RAM4ICF and is used to denote common rules for the implementation of industrial applications at various levels of abstraction.

The RA4ICF is described in detail in Clause 8.

6 Conceptual Model for Industrial Cloud Federation

6.1 General

The Conceptual Model for Industrial Cloud Federation (CM4ICF) describes the basic view of ICF, comprises the main conceptual elements, and specifies relations between these elements. The CM4ICF contributes to a better understanding of the structural organization of the ICF concept and serves as a conceptual input for RAM4ICF as well as RA4ICF.

The main purposes of the CM4ICF are to visualize the relationships between the core elements and to show the compliance with the specified requirements.

6.2 Elements and relations

6.2.1 General

The main elements of the CM4ICF and their relations are shown in Figure 3.

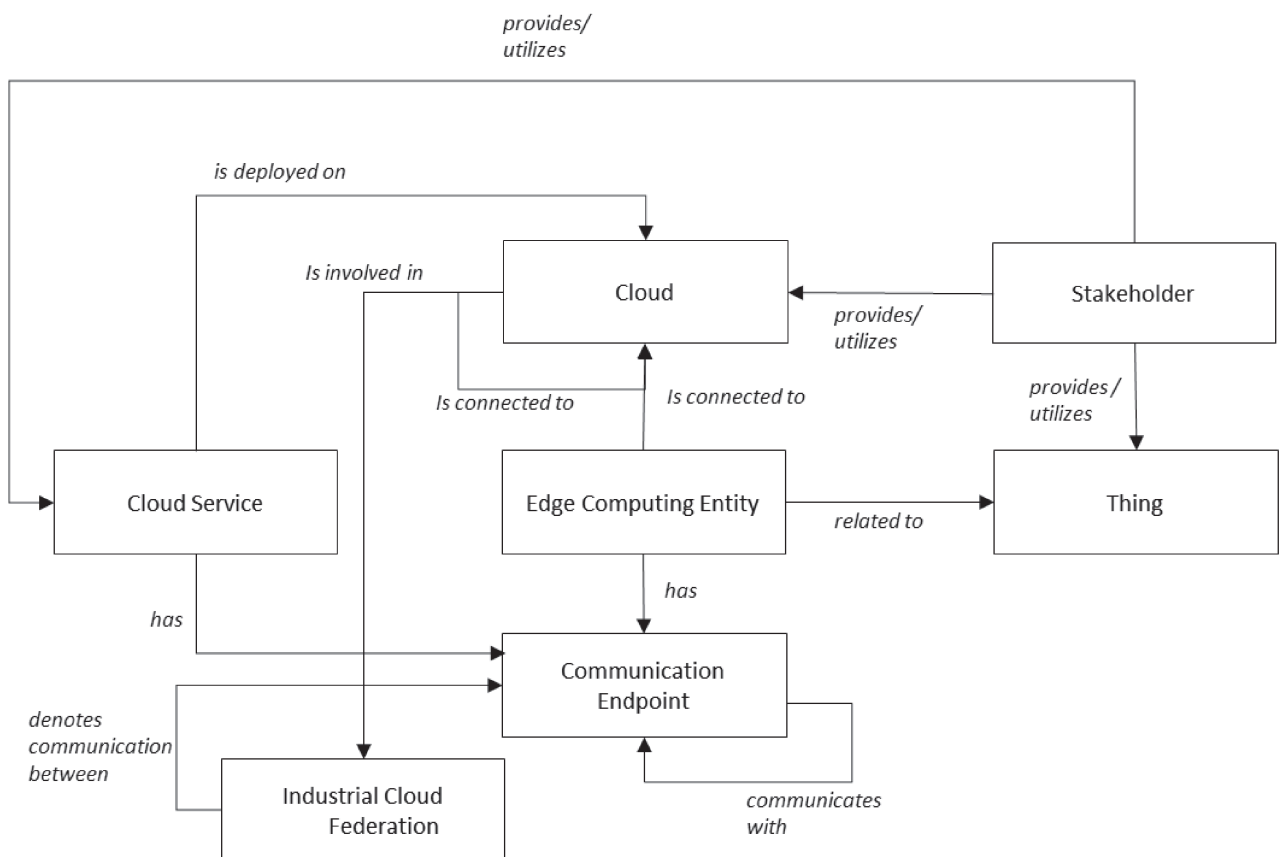


Figure 3 — Elements of Conceptual Model for Industrial Cloud Federation

An **Industrial Cloud Federation** denotes communication between **Communication Endpoints**, i.e. **Communication Endpoints** communicate with each other. A **Cloud Service** is deployed on a **Cloud**. An **Edge Computing Entity** is related to a **Thing**. Both have **Communication Endpoints**, and consequently are able to communicate with each other. **Edge Computing Entities** and **Cloud Services** are utilized or provided by **Stakeholders** of an **Industrial Cloud Federation**. Within ICF, communication from an **Edge Computing Entity** across different one or more **Clouds** which are involved in an **Industrial Cloud Federation** towards a **Cloud Service** is supported. As a consequence, **Edge Computing Entities** are connected to **Clouds** and, in turn, **Clouds** are connected to each other.

NOTE Elements of the conceptual model for Industrial Cloud Federation depicted in Figure 3 are written bold whereas relations between these concepts are written italic.

6.3 Requirements

6.3.1 General

This clause lists the requirements of the RAM4ICF.

6.3.2 Interoperability

ICF shall support the ability of cloud services to interact with things via standardized communication endpoints among different clouds federated in an ICF, and by that, enables exchanging information between each other. Consequently, interoperability between connected clouds federated in an ICF is also required,.

EXAMPLE After the ICF has been set up, a cloud service is able to consume data from or access functionality provided by a thing (both via the Edge Computing Entity). This also applies if there is no direct communication between the cloud (where the cloud service is deployed) and the thing but via another set of clouds that are connected to each other.

6.3.3 Scalability and flexibility

The ICF should support horizontal scalability and provide a capability to add additional communication endpoints with limited effort. Moreover, the ICF should manage a number of different communication endpoints involved in the ICF communication, offering the potential for flexibly adding a number of new communication endpoints.

6.3.4 Shareability

Shareability is the property of things that communicate with multiple cloud services via the edge and vice versa. This means that a set of cloud services is able to access information and functionality of a single thing (via the edge) as well as a single cloud service is able to access information and functionality of a set of things (via the edge), using the ICF communication patterns.

6.3.5 Connectivity

Connectivity is one of the core concepts of ICF, according to which communication endpoints are able to communicate between each other via communication networks and using the ICF communication patterns.

6.3.6 Resilience

To support resilience, the ICF elements should have the ability to continue to perform a required function if any faults or errors occur.

EXAMPLE One of the critical issues is the ability to preserve the connection even if there is a temporal disconnection between communication endpoints.

6.3.7 Configurability

The ICF shall provide the possibility for stakeholders to set parameters for manipulating the behavior of the ICF.

EXAMPLE An ICF enables configuring communication patterns to be used, routings among different clouds or accessibility of functionality and information of a thing via the edge.

6.3.8 Security and integrity

To provide secure access to digital resources, ICF shall consider security issues related to protection of communication endpoints and information flow, authentication, authorization, access provisioning, network configuration, data protection, and other security control features to protect information that is transferred between communication endpoints.

Furthermore, ICF shall provide data and service integrity by ensuring that data is not manipulated, lost or altered during transmission between communication endpoints.

EXAMPLE Communication networks are subject to various kinds of threats related to access to confidential production data. Thus, it is important to protect the information involved in communication within ICF to prevent i.e. omissions and alteration of messages, illegal changes in routing services, unauthorized disclosure and inaccurate transmissions of information and other malicious impacts.

7 Reference Architecture Model for Industrial Cloud Federation

7.1 General

The Reference Architecture Model for Industrial Cloud Federation (RAM4ICF) is based on RAMI 4.0 according to DIN SPEC 91345:2016-04 and includes specific architectural perspectives that represent various levels of abstraction. Furthermore, the RAM4ICF is derived from the CM4ICF that serves as a main point of reference.

The RAM4ICF includes conceptual elements with their relations as well as the necessary requirements and specification for ICF defined in 6.1.

The following four perspectives represent the major aspects of the ICF and make it possible to classify involved systems and their relations in the RAM4ICF.

The **Layers Perspective** provides technical description of various entities of the ICF based on six superimposed RAMI 4.0 layers (see 7.5).

The **Hierarchy Level Perspective** represents the different functionalities within a factory or a system involved in ICF and reflects the Industrie 4.0 environment (see 7.3).

The **Life Cycle and Value Stream Perspective** displays the life cycle of systems when involved in the ICF process (see 7.4).

The **Usage Perspective** addresses the usage of various entities that are involved in ICF and are usually provided or utilized by a stakeholder. This perspective focuses on main roles, activities and tasks involving humans that interact with the ICF to benefit from the main objectives (see 7.6).

The Usage Perspective is inspired by the Usage Viewpoint defined in the fundamental concepts of the Industrial Internet Reference Architecture (IIRA) [1].

NOTE According to RAMI 4.0, humans are commonly a part of the Asset Layer and can be usually addressed as a specific “living” asset. Thus, RAMI 4.0 includes the ability of humans to connect to upper layers of the virtual world via the Integration Layer. How humans interact with other things in the virtual world is closely described by RAMI 4.0 and its basic concepts. Due to this fact, the usage perspective, as it is required by the ICF, cannot be fully derived from RAMI 4.0.

7.2 RAMI 4.0 derivation

Layers Perspective, Hierarchy Level Perspective, and Life Cycle and Value Stream Perspective of the RAM4ICF are each embedded in the three-dimensional model of RAMI 4.0. Due to a specific application and usage scope of ICF, the application area of RAM4ICF is visualized by two blocks as it is depicted in Figure 4. By the colored blocks depicted in Figure 4, the scope of ICF within RAMI 4.0 is visualized which is described in detail in the following clauses.