

# Architecture Alignment and Interoperability

An Industrial Internet Consortium and Plattform Industrie 4.0 Joint Whitepaper

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The internet has brought about an age of ubiquitous connectivity and seamless information exchange, transforming the way we live, work, produce and consume. It is now enabling a revolution in industrial systems, through the Industrial Internet of Things (IIoT). High-speed networks, open architectures and intelligent infrastructures that communicate with each other are creating technological innovations at a rate unseen since the first Industrial Revolution.

As industrial components and equipment are increasingly connected forming large IIoT systems, how to enable reliable communication and interaction between them seamlessly and cost-effectively has become crucial for the success of the IIoT. Therefore, it is important to ensure interoperability of connected components and products as soon as they are built until they are deployed and used in their operational environment in various industries.

Two key industry consortia are advancing the development of the IIoT. Plattform Industrie 4.0<sup>2</sup> is the German strategic initiative to maintain Germany's leadership in providing advanced manufacturing solutions. It is set to revolutionize manufacturing and production and usher in the fourth industrial age. It represents a new stage of organization and control of the entire value chain and the lifecycle of products with keen attention to the legal and human impact.

The Industrial Internet Consortium (IIC)<sup>3</sup> is the world's leading organization that serves to transform business and society by accelerating the adoption of IIoT. It accomplishes this by enabling trustworthy industrial internet systems, where systems and devices are securely connected and controlled to deliver transformational outcomes across multiple industries. These industries include healthcare, transportation, energy, public domain infrastructures as well as manufacturing.

The Industrial Internet Consortium and Plattform Industrie 4.0 have independently developed reference architecture (models)<sup>4</sup> for the industrial internet: The Industrial Internet Reference Architecture (IIRA)<sup>5</sup>, and Plattform Industrie 4.0's Reference Architecture Model for Industrie 4.0 (RAMI 4.0)<sup>6</sup>, respectively. Naturally, questions have been asked how these two approaches relate to one another. In 2015, representatives from both organizations met to:

- explore the potential alignment of their two architecture efforts,
- understand the technical issues from both perspectives and

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<sup>2</sup> Industrie 4.0 describes the combination of production methods with state-of-the-art information and communication technology, while Plattform Industrie 4.0 is the German cross-industry and government initiative to support the implementation of Industrie 4.0. (<http://www.plattform-i40.de/I40/Navigation/EN/Home/home.html>).

<sup>3</sup> <http://www.iiconsortium.org/>

<sup>4</sup> We will simply refer to both as reference architectures in this document.

<sup>5</sup> <http://www.iiconsortium.org/IIRA.htm>

<sup>6</sup> [https://www.vdi.de/fileadmin/vdi\\_de/redakteur\\_dateien/gma\\_dateien/5305\\_Publikation\\_GMA\\_Status\\_Report\\_ZVEI\\_Reference\\_Architecture\\_Model.pdf](https://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/gma_dateien/5305_Publikation_GMA_Status_Report_ZVEI_Reference_Architecture_Model.pdf)

- reduce market confusion.

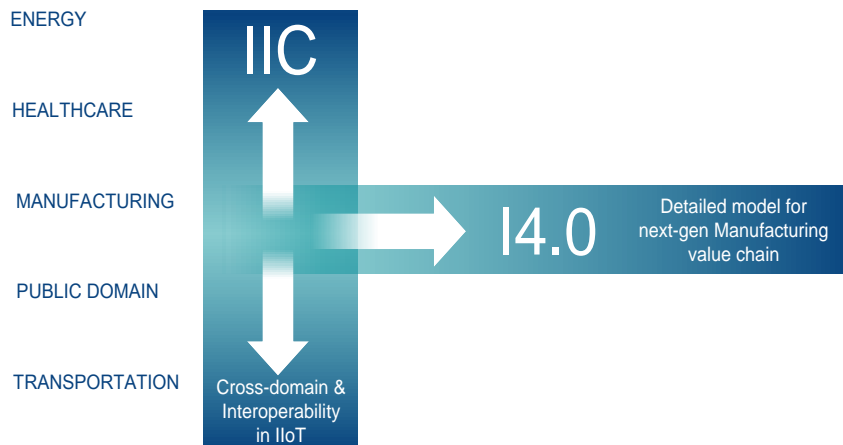


Figure 1 IIC addresses concerns about IIoT across industries broadly; Plattform Industrie 4.0 focuses mainly on manufacturing in depth.

An initial key finding of the collaboration is that the effort of IIC and Plattform Industrie 4.0 is highly complementary as depicted in Figure 7: IIC addresses concerns about IIoT across industries broadly stressing cross-industry commonality and interoperability; Plattform Industrie 4.0 focuses mainly on manufacturing in depth. Therefore, it is important and valuable for IIRA and RAMI 4.0 to enable interoperability among IIoT systems that are built based on these reference architectures.

Since then, IIC and Plattform Industrie 4.0 have embarked on an ongoing collaboration.<sup>7</sup> While IIC advances the adoption of the industrial internet on a global scale that transcends industry boundaries, Plattform Industrie 4.0 has been coordinating the Industrie 4.0-driven digital transformation of the German industry. This cross-consortia collaboration is an important milestone in the global advancement of the digitalization of industrial production.

This whitepaper maps and aligns the two reference architectures that contain similar and complementary elements for addressing IIoT challenges from different perspectives and across different industrial domains. Based what we have learned, the two organizations wish to collaborate further to enrich each reference architecture, improve requirements for standards and drive interoperability for the easy and wide adoption of IIoT.

### THE REFERENCE ARCHITECTURES: IIRA AND RAMI 4.0

Both IIRA and RAMI 4.0 have been created with the same goal of converging of the physical and digital worlds, specifically the convergence of Information Technology (IT) and Operational

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<sup>7</sup> <http://www.iiconsortium.org/iic-and-i40.htm>

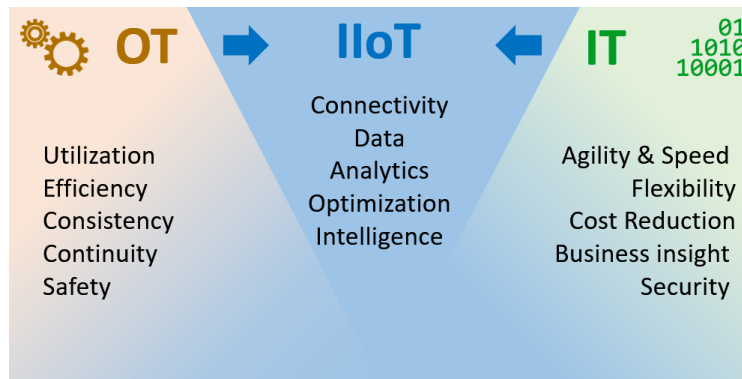


Figure 2 IloT as a transformational force driving the convergence of OT and IT.

Technology (OT).<sup>8</sup> Traditionally, OT emphasizes efficiency, utilization, consistency, continuity and safety,<sup>9</sup> while IT drives agility and speed, flexibility, cost reduction, business insight and security. IloT is a transformational force that focuses on connectivity, data, analytics, optimization and intelligent operations and it is driving the convergence between IT and OT. The two reference architectures are expected to play an important role in this transformation.

Though each architecture was developed independently with different objectives, scopes and approaches, our joint work shows that their applications, technology and architectures are more complementary than conflicting. There is a clear opportunity to map and align between them to reach a better understanding of their complementary nature. This effort to reconcile the architectures, along with collaboration on testbeds and infrastructure designs, will drive cooperation across industries and, eventually, interoperability among systems. All these have the potential to lead to more compelling IloT systems that deliver greater business value and outcomes.

### MAPPING OF IIRA AND RAMI 4.0

In a nutshell, Industrie 4.0 is about *making* things smartly, while the industrial internet is about making things *work* smartly. In other words, Industrie 4.0 is about making products by managing the entire value chains along with product lifecycles, while the industrial internet is about building, deploying and operating large connected systems. Since the industrial internet also covers manufacturing as one of the industries, industrial internet and Industrie 4.0 are both applicable in manufacturing. IIC emphasizes broad applicability and interoperability of its IloT technical frameworks - with its reference architecture - across industries. Industrie 4.0 reaches much deeper in digitalization and interoperability of manufacturing. For instance, Industrie 4.0 includes many aspects of manufacturing value chains with the full product lifecycles from the first idea to end-of-life.

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<sup>8</sup> OT systems include what is sometime considered as IT systems in the shop floor – such as industrial automation systems.

<sup>9</sup> In a manufacturing environment, the high-level goals also include efficiency, quality and cost.

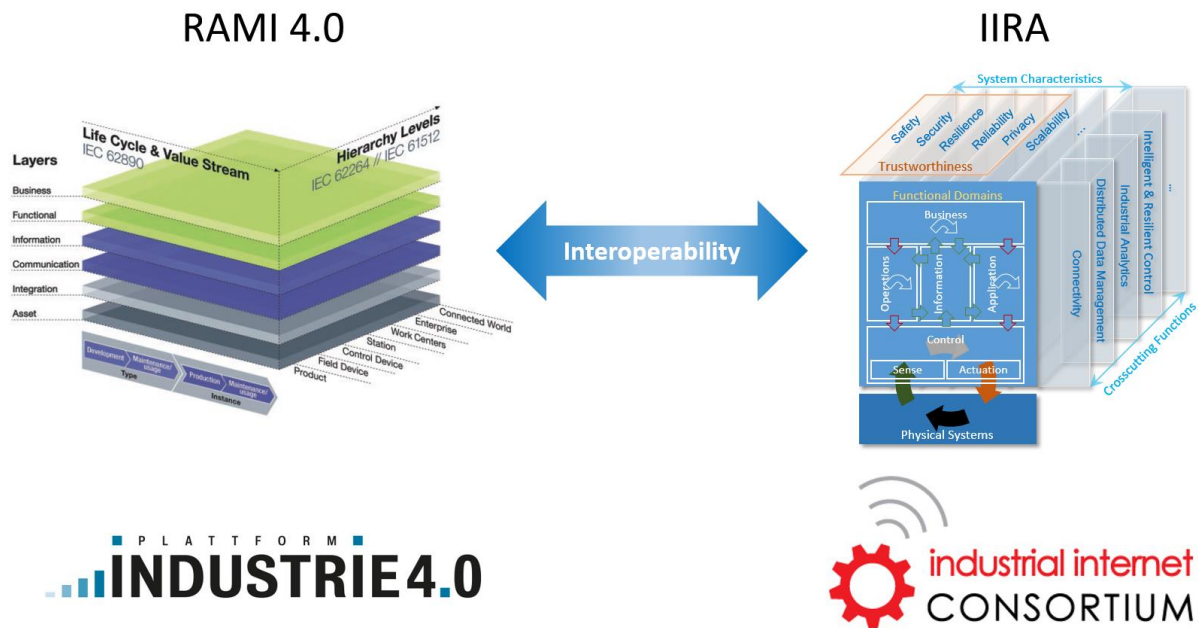


Figure 3 IIC and Industrie 4.0 are working together to map architectures and provide eventual interoperability.

These two priorities are reflected in these two reference architectures.

#### THE SCOPE AND PURPOSE OF THE TWO REFERENCE ARCHITECTURES

Both IIRA and RAMI 4.0 are reference architectures containing concepts and methods for developing concrete architectures, but they are not specific architectures for concrete systems. The application of these concepts and methods leads to concrete system architectures.

IIRA is a standards-based open architecture for IIoT systems. Its broad industry applicability maximizes its value. It provides an architecture framework, including methods and templates, to design industrial internet systems, without making specific recommendations for standards or technologies that comprise these systems. Core to IIRA are the different business and technical perspectives described as viewpoints for identifying and addressing architectural concerns.

With the three-dimensional architecture model, RAMI 4.0 provides a flexible Service-Oriented Architecture (SOA) framework combining services and data to facilitate and promote main aspects of Industrie 4.0:

- horizontal integration through value networks, e.g. in factories and between plants,
- vertical integration, e.g. within a factory, including from products on one end and the Cloud on the other,
- lifecycle management, and end-to-end engineering and
- human beings orchestrating the value stream.

RAMI 4.0 offers a way to classify existing standards along three axes to show their interrelations and to initiate the creation of new standards necessary for Industrie 4.0 from a strategic point of view. To guarantee interoperability, RAMI 4.0 makes specific recommendations for standards and technologies.

**SIMILARITIES AND DIFFERENCES**

The fundamental concepts underlying the two reference architectures are shown in Figure 4 and it illustrates similar and complementary concepts as well as concepts specific for each of the reference architectures:

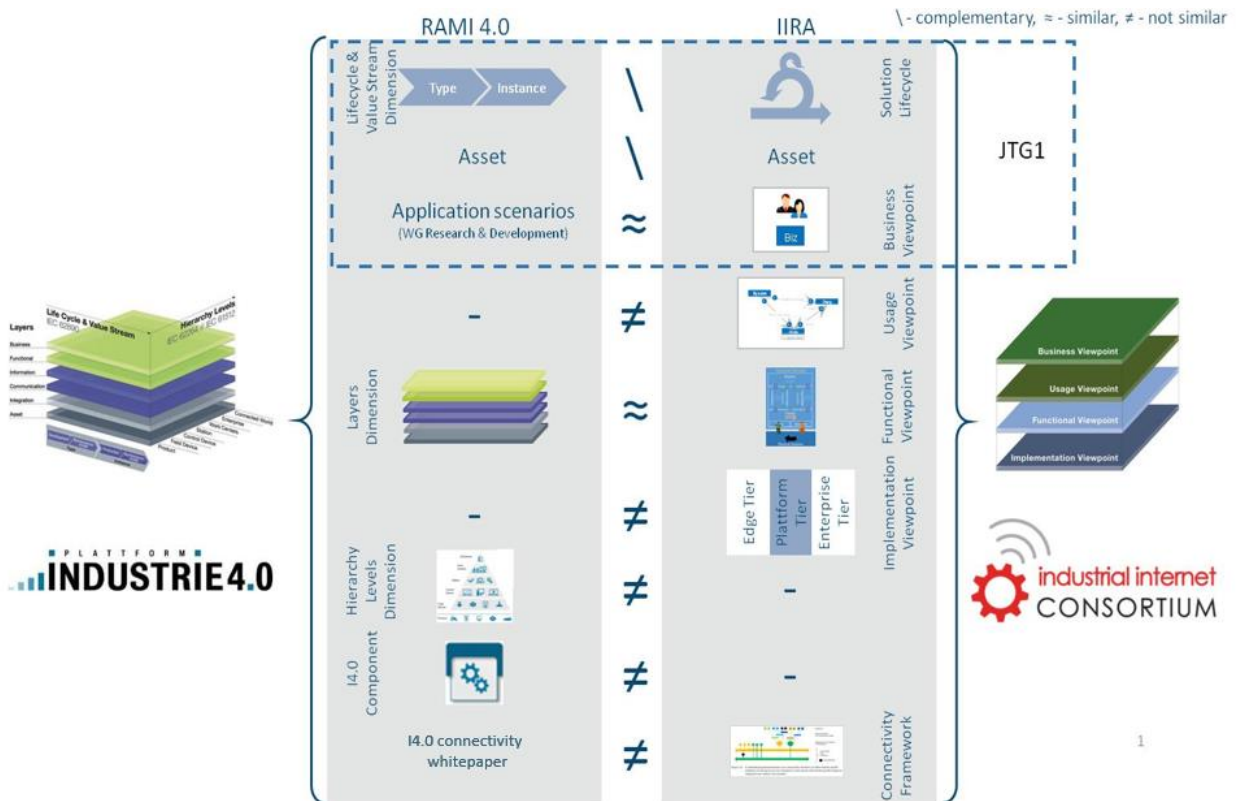


Figure 4 Fundamental concepts of the IIRA and RAMI 4.0, their similarity and complementarities.

*IIRA comprises the following concepts:*

IIRA is an IIoT reference architecture that is business-value-driven and concern-resolution-oriented. It identifies and classifies common architectural concerns into the four viewpoints: business, usage, functional and implementation, where the concerns are analyzed systematically and resolved. The outcomes from the analysis and resolution of concerns are documented as models and other representations in the respective views associated with the viewpoints. The viewpoints and their respective views form the structure and the content of the architecture

description. The analysis of concerns and their resolution in the viewpoints inform and enhance each other, generally through an iterative process.

The *business viewpoint* identifies stakeholders and their business vision, value and objectives of an IIoT system.

The *usage viewpoint* describes how the IIoT system is expected to be used in order to deliver the intended business objectives.

The *functional viewpoint* focuses on the functional components and the structure in which they are interrelated and interact with each other and with external elements in the environment in such a way to support the intended usages.

The *implementation viewpoint* determines the technologies needed to implement functional components, their communication schemes and their lifecycle procedures.

*RAMI 4.0 comprises the following concepts:*

As a reference architecture model, RAMI 4.0 provides an opportunity to uncover Industrie 4.0 use cases from which standards required for those use cases can be identified. Through this process, concepts and methods in the relevant standards are reviewed to ascertain the extent to which they are suitable for applications in the Industrie 4.0 environment. Then the best-fitting standards are explicitly recommended to guarantee full interoperability.

The *Layers* describes six layers in terms of properties and system structures with their functions and function-specific data.

The *Life Cycle and Value Stream* describes assets in the value stream from idea, development and maintenance with respect to an asset type and the production, usage and maintenance of the concrete instances of the asset type. *Assets* are objects that have a value for an organization.

The *Hierarchy Levels* describes the functional hierarchy of a factory, embedded in the value-added processes. It is extended at the bottom by the value-added processes of the product itself within and outside the factory and at the top by the connection to cross-enterprise value-added processes.

Industrie 4.0 components are globally and uniquely identifiable objects with the capability of communication. They consist of the administration shell and the asset. The *administration shell* includes the relevant information for managing the asset and its technical functionality.

The lifecycle process of IIoT system and RAMI 4.0 Life Cycle and Value-Stream will be elaborated in a separate whitepaper to be published jointly by the two organizations. The following sections discuss the similarity between the RAMI 4.0 Layers and the IIRA functional viewpoint.



## FUNCTIONAL MAPPING OF IIRA AND RAMI 4.0

IIRA models how an IIoT system is developed and operates primarily based on ISO/IEC/IEEE 42010.<sup>10</sup> RAMI 4.0 models how a manufacturing plant operates primarily based on the *Smart Grid Architecture Model (SGAM)*.<sup>11</sup> These differences introduce some variations of meaning for common terms used in both reference architectures. For example:

- The *business* layer in RAMI 4.0 is about managing the whole business life cycle over all functional hierarchies. With the combination of all functions and information, RAMI 4.0 can show all the new business opportunities within Industry 4.0.

The *business* viewpoint in IIRA is primarily about the rationale and value of developing an IIoT system. On the other hand, the *business* functional domain in IIRA refers to business systems that IIoT functions interact with to complete the end-to-end (manufacturing) business applications or processes.

- *Assets* in RAMI 4.0 refers mostly anything (machines, personnel, product, raw material and software) of value that participates in the business processes.

*Assets* in IIRA mostly refers to the physical *thing* being monitored and controlled.

- *Functional* in RAMI 4.0 refers to a layer in which e.g. standard functions and concrete applications (e.g. MES) are run and integrated.

*Functional* in IIRA refers to a viewpoint where a system is decomposed functionally into various *functional* domains.

### IIRA FUNCTIONAL DOMAINS, CROSSCUTTING FUNCTIONS AND SYSTEM CHARACTERISTICS

Highlighting the important functional building blocks common to IIoT systems across industries, IIRA presents a functional view decomposing a typical IIoT system into five functional domains:

*Control domain*: Functions performed by the industrial assets or control systems executing closed-loop control that may involve sensing, control and actuation.

*Operations domain*: Functions for assets and control systems management and maintenance to ensure their continuing operations. These functions may include remote health monitoring, configuration and update, diagnosis and preventive maintenance.

*Information domain*: Functions for collecting, transforming and analyzing data to acquire high-level intelligence of the entire system.

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<sup>10</sup> IIRA is developed using concepts and models from ISO/IEC/IEEE 42010:2011, Systems and software engineering — Architecture description, <https://www.iso.org/standard/50508.html>

<sup>11</sup> [http://gridscientific.com/images/Smart\\_Grid\\_Reference\\_Artitecture.pdf](http://gridscientific.com/images/Smart_Grid_Reference_Artitecture.pdf)

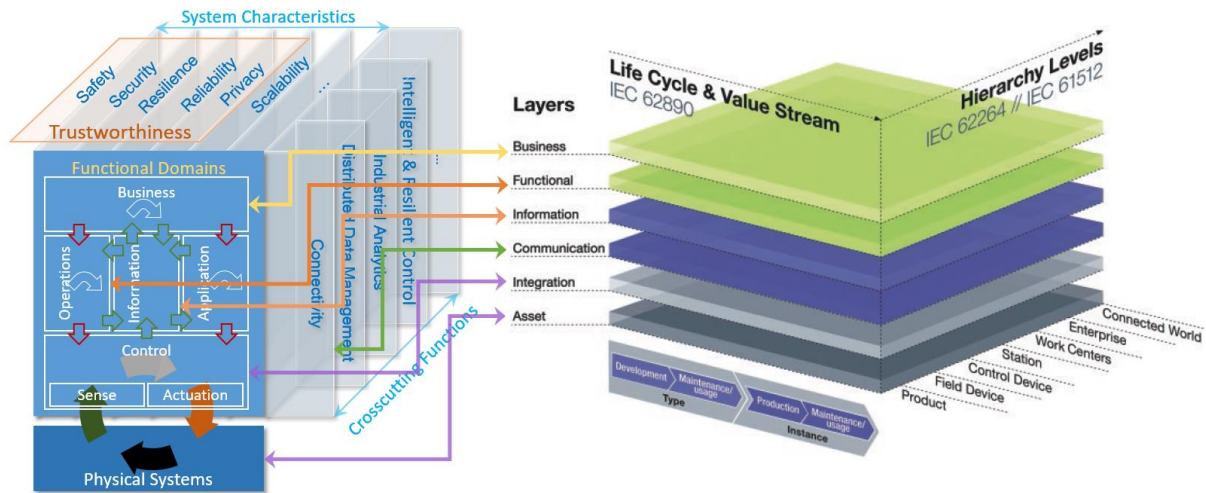


Figure 5 IIRA and RAMI 4.0 Functional Mapping.

**Application domain:** Functions for applying use-case-specific logic, rules and models based on the information obtained from the information domain to achieve system-wide intelligent and optimal operations.

**Business domain:** Functions for integrating information across business systems and applications to achieve business objectives, such as work planning, customer relationship management (CRM), enterprise resource planning (ERP), manufacturing execution system (MES).

The IIRA functional domains are major system functions generally required to support generic IIoT usages and to realize generic IIoT system capabilities for business purposes. To support these major system functions, IIRA also identifies a set of crosscutting functions that include connectivity, distributed data management and integration and industrial analytics.

IIRA also identifies a set of system characteristics: emergent behaviors or properties resulting from the interactions between the different parts of a complex system. The primary system characteristics highlighted in IIRA include safety, security, reliability, resilience, privacy<sup>12</sup> and scalability.

In IIRA, the functional domains and crosscutting functions are largely concerned with how the system works while the system characteristics emphasize how well the system works.

<sup>12</sup> Safety, security, reliability, resilience, privacy, together, are also called trustworthiness in the Industrial Internet Security Framework (<http://www.iiconsortium.org/IISF.htm>) and IIRA.

### RAMI 4.0 ARCHITECTURE LAYERS

The layered structure along the vertical in the Reference Architecture Model Industry 4.0 (RAMI 4.0) represents various properties of an Industrie 4.0 entity or system. It consists of the following architecture layers:

The *business layer* orchestrates functions to form business processes and links between different business processes in support of the business models under the legal and regulatory constraints.

The *functional layer* describes (logical) functions of an asset (technical functionality) in regard of its role in an Industrie 4.0 system.

The *information layer* describes the services and data that are offered, used, generated or modified by the technical functionality of the asset.

The *communication layer* provides standard communication for service and event/data to the information layer, and services and control commands to the integration layer.

The *integration layer* represents the physical assets and their digital capability and provides computer-aided control of the technical process and generates events from the assets.

The *assets layer* represents the physical world such as physical components, software, documents and human actors.

### MAPPING BETWEEN IIRA FUNCTIONAL DOMAINS/CROSSCUTTING FUNCTIONS AND RAMI 4.0 ARCHITECTURE LAYERS

There are obvious correspondences between the functional domains and crosscutting functions in IIRA and the architecture Layers in RAMI 4.0 as outlined in the table below:

IIRA Functional Domains and Crosscutting Functions	RAMI 4.0 architecture Layers
<i>Physical Systems</i> (not formally defined)	Physical aspect of <i>the Assets Layer</i> Physical components, documents, software and human actors
<i>Control Domains</i> Functions performed by the industrial assets or control systems executing closed-loop control that may involve sensing, control and actuation.	<i>Integration Layer</i> Digitally represents the physical assets and their digital capability; Provides computer-aided control of the technical process; generates events from the assets  <i>Functional Layer</i>

	If the functions are Industry 4.0 compliant then they refer to the functional layer
<p><i>Connectivity and Distributed Data Management and Integration Crosscutting Function</i></p> <p>(See the section about connectivity below)</p>	<p><i>Communication Layer</i></p> <p>Provides standard communication for services and event/data to the information layer</p> <p>Provides control commands to the integration layer</p>
<p><i>Information Domain</i></p> <p>Functions for collecting, transforming and analyzing data to acquire high-level intelligence of the entire system</p>	<p><i>Information Layer</i></p> <p>Describes (logical) services and events/data of an asset (technical functionality) with regard to its role in the Industrie 4.0 system (as a “semantic self-description”).</p>
<p><i>Operations and Application Domains</i></p> <p>Functions for assets and control systems management and maintenance to ensure their continuing operations</p> <p>Functions for applying use-case-specific logic, rules and models based on the information obtained from the information domain to achieve system-wide optimization of operations</p>	<p><i>Functional Layer</i></p> <p>The runtime environment for applications and technical functionality enabling tasks in support of the business processes</p>
<p><i>Business Domain</i></p> <p>Functions for integrating information across business systems and applications to achieve business objectives, such as work planning, customer relation management (CRM), enterprise resource planning (ERP), manufacturing execution system (MES), etc.</p>	<p><i>Business Layer</i></p> <p>Orchestrating functions to form business processing and linking between different business processes in supporting of the business models under the legal and regulatory constraints</p>

Strictly speaking, part of the business domain functions as defined in IIRA, specifically concrete systems such ERP, CRM and MES map to the functional layer in RAMI 4.0. On the other hand, the business processes are not explicitly highlighted in IIRA.

Making the industrial and manufacturing operations intelligent by digitally orchestrating and optimizing their processes is a common goal of both IIRA and RAMI 4.0. IIRA puts industrial analytics front and center in its architecture, emphasizing the cyber-physical closed-loop of

collecting and analyzing machine data, and applying the analytic insights to the decision-making in the operational and manufacturing processes and eventually to the machines. On the other hand, RAMI 4.0 builds a solid foundation of service-oriented interoperability especially in the lower tiers of the cyber-physical systems (the concept of an Industrie 4.0 component in RAMI 4.0). In an Industrie 4.0 component, a common information model is established concerning identification, data models, semantic schemes, service interfaces. The Industrie 4.0 component model enables easy and reliable integration of products, parts and machines with each other and with the digital processes. It also facilitates the easy and reliable collection of machines data for analytics. It is clear that these two major complementary aspects of IIRA and RAMI 4.0 would be a powerful combination to achieve their common goal of intelligent processes.

## MAPPING CONNECTIVITY/COMMUNICATION MODELS AND STANDARDS

### INDUSTRIAL INTERNET CONNECTIVITY FRAMEWORK

The *Industrial Internet Connectivity Framework (IICF)*<sup>13</sup> published by IIC extends the IIRA to map the rich landscape of IIoT connectivity. It clarifies IIoT connectivity with a new IIoT stack model, defines an open connectivity reference architecture, and helps practitioners to categorize, evaluate and determine the suitability of a connectivity technology for the IIoT system at hand.

The connectivity challenges in IIoT systems include meeting diverse requirements, supporting many transports and connecting an overwhelming array of “things” from small devices to huge,

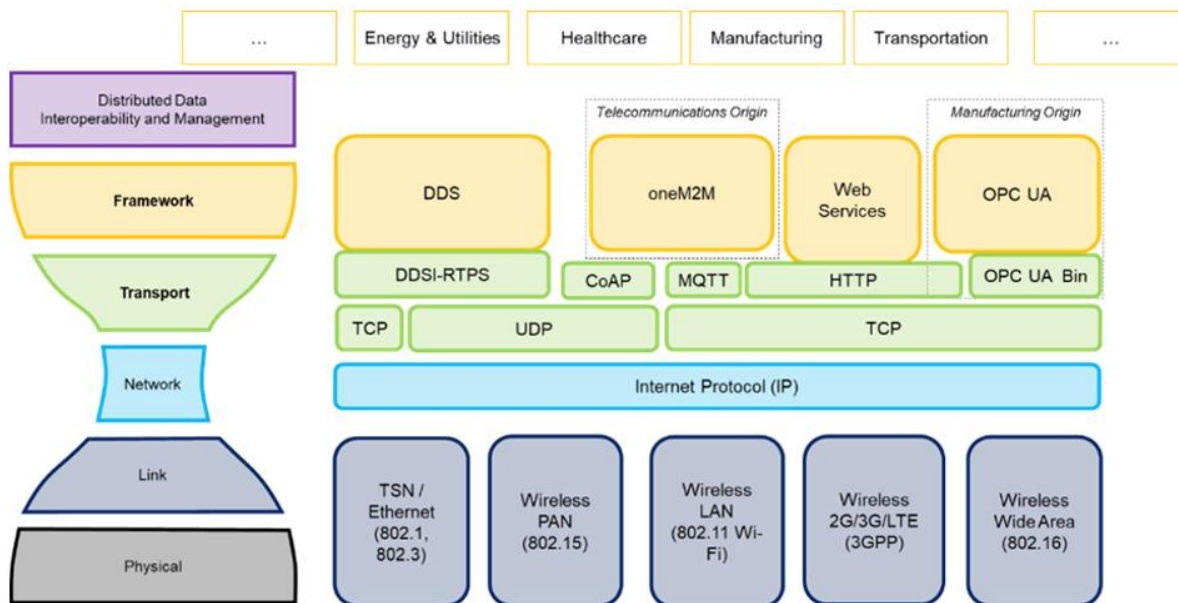


Figure 6 IIoT connectivity stack from IICF

intelligent networks of complex subsystems. To meet these challenges, IICF applies the IIRA

<sup>13</sup> <http://www.iiconsortium.org/IICF.htm>

viewpoints: business, functional, usage and implementation viewpoints to analyze IIoT connectivity, resulting in a connectivity framework extending and supporting IIRA and assessment templates for connectivity standards.

From these assessments, IICF presents an IIoT connectivity stack with mapping of the connectivity standards, as shown in Figure 6. It focuses on the transport and framework layers that have emerged and less well-understood standards. It puts forward DDS, OPC UA, Web Services and OneM2M as candidates for core connectivity standards from which IIoT system architects can choose to adopt based on their specific system needs. Existing networks and devices with legacy connectivity technologies can then be bridged to the core standards to ensure interoperability. These core connectivity standards can also be bridged by gateways to each other to ensure interoperability between IIoT systems. Furthermore, more than one core standards, such as DDS and OPC UA, can be deployed in a single IIoT system to take advantage of each other's strengths. For example, OPC UA is adept at device integration and interchangeability and DDS ideal for software integration. However, any additional gateway or bridge would often introduce an increase of costs and a reduction in quality of service, for example in latency and reliability.

In industries other than manufacturing, IIoT applications, such as smart medical systems, autonomous transportation and distributed power systems, largely use the data-centric DDS standard to meet the software integration challenges.

IICF presents a connectivity interoperability model in which device-to-device, device-to-application and application-to-application interoperability between IIoT subsystems can be achieved. In this manner, with standard gateways bridging core connectivity standards, RAMI 4.0 and other IIoT subsystems (that are based on other core connectivity standards like DDS, OneM2M and Web Services) can be integrated to provide interoperability.

### RAMI 4.0 COMMUNICATION LAYER

The RAMI 4.0 communication layer describes the Industrie 4.0-compliant access to information and functions of a networked asset using a unified Industrie 4.0 communication with a uniform Industrie 4.0 data format. It enables communication across multiple axes: over the life cycle of an asset (from development to production to service) and over the functional hierarchical levels

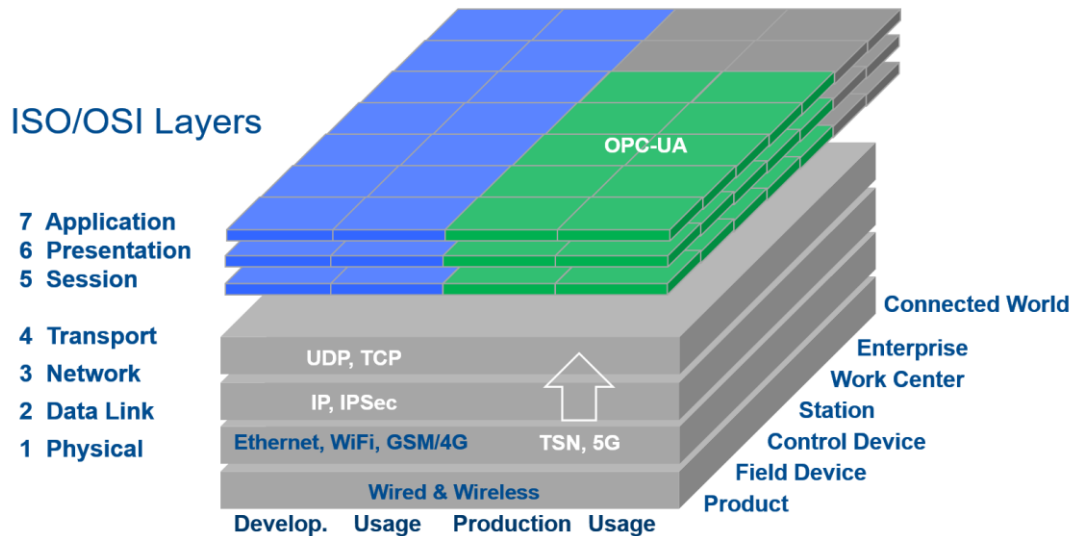


Figure 7 RAMI 4.0 Communication Layers mapped to the ISO/OSI Model

(from products to connected world). Thus, the communication layer is partitioned into individual small blocks in the RAMI 4.0 cube model, each can be described separately.

The RAMI 4.0 communication layer focuses on the transmission mechanism, whereas the services descriptions and data model transmitted are specified in the information layer. Overall, the communication layer describes the network discovery of Industrie 4.0 components and the initiation of connections between them. To guarantee interoperability, RAMI 4.0 gives preference to the use of standards for implementing its communication layer, as illustrated in Figure 7, where the communication layer is expanded using ISO/OSI layer model in which different standards are specified.

To reach interoperability, Industrie 4.0 gives a preference to an overall TCP/UDP/IP communication (wired and wireless). In the future, Time Sensitive Networking (TSN) and 5G may be added. In the ISO/OSI layers 5-7, Industrie 4.0 gives a preference in the area production/service (usage) and product up to the work center for OPC UA (green area in figure 7). The grey area as cloud-to-cloud and enterprise-to-cloud communication and the blue area for the whole development section are still in discussion within the Industrie 4.0 community.

### CORRESPONDENCE BETWEEN IICF AND RAMI 4.0 COMMUNICATION LAYER

To enable interoperability in one or cross industry domains, IIC and Plattform Industrie 4.0 understand the need to harmonize and improve the connectivity standard(s) including the *lingua franca* for IIoT.

In the manufacturing environment, RAMI 4.0 specifies OPC UA as the core connectivity standard (using the IICF terminology) for connecting manufacturing product, equipment and process software. Furthermore, RAMI4.0 specifies TCP/UDP/IP communication with a possible future extension to TSN and 5G.

In IICF there are four core standards specified. One of them is OPC UA for manufacturing. Additionally, TCP/UDP/IP, TSN and wireless technologies are described in IICF.

This common ground is a good starting point for the collaboration between IIC and the Plattform Industrie 4.0.

### INTEROPERABILITY BETWEEN SYSTEMS BASED ON IIRA & RAMI 4.0

With the sharp focus of RAMI 4.0 on manufacturing (to optimize the complete manufacturing operations to deliver, operate and maintain industrial products) and the broad applicability of IIRA across various industries (to optimize the operations of the products as assets), an important interoperability scenario stands out. On one hand, products are built in a manufacturing environment based on RAMI 4.0 as they move through the product life cycle, from material to parts to components and finally to be installed on a location as assets outside manufacturing, such as wind turbines in a wind farm. On the other hand, once they are installed and commissioned into operation, they may be operated and maintained under an IIoT system based on IIRA. Therefore, industrial products (where RAMI 4.0 applies) appear in multiple industries (where IIRA applies) so they must interoperate.

To enable optimal operation and maintenance of the installed assets, deep technical domain knowledge about materials, parts, components and the entire machines are required from their original manufacturers—part of this knowledge may be reflected in the software and analytics models deployed into the parts, components and at the machine (asset) level. The assets with their software are subject to an ongoing development and upgrade. Therefore, these software components and analytics models require routine maintenance and updates from the original manufacturers. Moreover, suppliers of materials and parts are also interested in gaining access to usage data from their respective elements in the installed assets for providing feedback to their own product life cycle process from design to maintenance to recycle. These scenarios require the manufacturing systems and the operational systems all to be connected and provide bidirectional data and information flows.



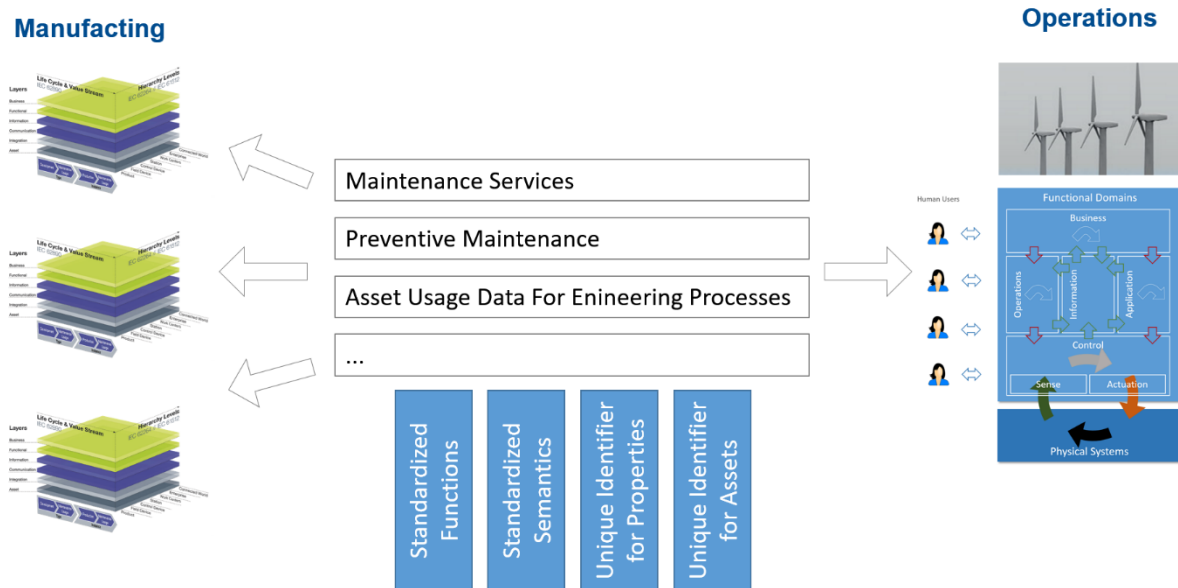


Figure 8 Interoperability between RAMI 4.0 and IIRA systems.

To enable bidirectional data and information flows between IIoT systems built based on IIRA and Industrie 4.0 systems built based on RAMI 4.0, we need to define the functional requirements driving the interoperability and from there define functions and semantics that can be understood by these systems, unique identifier for properties and the assets (parts, components and machines) and means of communications between these systems.

Therefore, the identification, communication, semantic and functional mapping between IIRA and RAMI 4.0 is a foundational step toward enabling interoperability.

## SUMMARY

The two organizations, IIC and Plattform Industrie 4.0, have collaborated in analyzing their respective reference architectures. The results are presented in this whitepaper that:

- reinforces the general understanding that *IIRA emphasizes broad applicability and interoperability across industries while the service-oriented RAMI 4.0 reaches deeper in describing models for the digitalization of manufacturing,*
- *maps and aligns* the two reference architectures that contain similar as well as complementary elements for addressing IIoT challenges from different perspectives and across different industrial domains,
- concludes that the *similarities* of concepts, methods and models for developing concrete architectures in IIRA and RAMI 4.0 can be mapped to each other well, despite each being based on different architecture framework standards. These similarities are identified and outlined,

- also concludes that much of the differences between IIRA and RAMI 4.0 lie in the *different emphasis* in scope and depth, and from different perspectives in examining architecture models in manufacturing where they overlap. Consequently, much of these differences are complementary and help rather than hinder in addressing IIoT challenges in the digitalization of manufacturing and beyond. For example, industrial analytics, an idea that is emphasized in IIRA would be beneficial for building intelligent Industrie 4.0 systems. On the other hand, the Industrie 4.0 component would help enable broad interoperability for Industrie 4.0 and IIoT systems within manufacturing environments and elsewhere,
- highlights the need of interoperability between IIoT systems built based on IIRA and Industrie 4.0 systems built based on RAMI 4.0 and
- provides a model or method for interoperability between devices and components in IIoT systems built based on the two reference architectures at the connectivity and communication levels.

This analysis and learning builds a sound foundation for these two organizations to further collaborate to enrich each reference architecture, to improve requirements for standards and to drive interoperability—all for the easy and wide adoption of IIoT. As next steps, the collaboration will attempt to:

- address the semantic interoperability between the two models and
- deepen analyses on how to leverage analytics from IIRA for RAMI 4.0 and leverage Industrie 4.0 components from RAMI 4.0 for smart components and devices in IIRA.

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Plattform Industrie 4.0 is the central network in Germany to advance digital transformation towards Industrie 4.0. In close cooperation with politics, industry, science, associations and trade unions, over 300 stakeholders from 159 organizations are actively involved in the platform. The platform develops and coordinates information and networking services to raise awareness on Industrie 4.0 solutions among companies and to deploy them on-site. As one of the largest international and national networks, it supports German companies – particularly medium-sized companies – in implementing Industrie 4.0. ([www.plattform-i40.de](http://www.plattform-i40.de))

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