D2.7 – i4Q Reference Architecture and Viewpoints Analysis v2

WP2 – DESIGN: i4Q Framework Design

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RESPONSIBLE AUTHOR	Cinzia Rubattino (ENG)			
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DELIVERABLE CONTEXT/ DEPENDENCIES	This document has a preceding document, D2.1 "i4Q Reference Architecture and Viewpoints Analysis". The activity was carried out in close cooperation and synergy with other work in progress activities in WP1 and WP2; in particular: • T1.3 Use Cases Scenarios and KPIs • T1.4 Requirements Analysis and Functional Specification • T1.5 Regulation and Trustworthy System / Data Management • T2.1 i4Q Reference Framework • T2.3 Business Viewpoint • T2.4 Usage Viewpoint • T2.5 Functional Viewpoint • T2.6 Implementation Viewpoint Specifically, this document received input preliminary information gathered in WP1 and WP2 from: • D1.3 Demonstration Scenarios and Monitoring KPIs Definition (M4). • D1.4 Requirements Analysis and Functional Specification (M4). • D2.1 i4Q Reference Architecture and Viewpoints Analysis (M3)			

	• D2.2 Digital Models and Ontologies (M3) • D2.3 Report on Business Viewpoint (M7). D2.7 "i4Q Reference Architecture and Viewpoints Analysis v2" (M9) has been defined in parallel with: • D1.8 Demonstration Scenarios and Monitoring KPIs Definition v2 (M9) • D1.9 Requirements Analysis and Functional Specification v2 (M9) • D2.4 Report on Usage Viewpoint (M9) • D2.5 Report on Functional Viewpoint (M9) • D2.6 Report on Implementation Viewpoint (M9) This document has no further iterations.
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ABSTRACT	This document delivers the second release of the i4Q RA, representing the second output of T2.1. The first released of i4Q RA, delivered at M3, was not designed from scratch; as presented in D2.1 the preliminary version of the i4Q RA was mainly inspired by IIRA architectural model, based on the three-tiers approach. According to IIRA approach, the task of i4Q RA definition was performed in parallel with those of its viewpoints analysis (T2.3, T2.4, T2.5, T2.6). Another key input has been the definition of the digital models and ontologies (T2.2) to be used in the i4Q Framework. The operational needs characterising the realization, deployment and use of each solution represented a valid input and helped to better identify the RA, refining its modules, components and functionalities. The definition of the second version of the RA also took into account all the considerations formalized in the description of the use case scenarios and the requirements collection (T1.3 and T1.4); special attention was paid to the needs emerging from the pilots, which have been mapped in detailed blueprints to verify the alignment between the specific components to be used for industrial problems and the RA building blocks.

Document History

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0.1	21-July-2021	ToC	Table of Contents	ENG
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ABBREVIATIONS/ACRONYMS

AAS	Asset Administration Shell
AI	Artificial Intelligence
AF	Architecture Framework
API	Application Programming Interface
AQ	Autonomous Quality
BDA	Big Data Analytics
BDVA	Big Data Value Association
C2NET	Cloud Collaborative Manufacturing Networks
CAEX	Computer Aided Engineering Exchange
CEP	Complex Event Processing
CNN	Convolutional Neural Network
CPS	Cyber Physical System
CPV	Critical Process Variable
CREMA	Cloud-based Rapid Elastic Manufacturing
DAIRO	Data, AI and Robotics Association
DBMS	Database Management System
DFA	Digital Factory Alliance
DIN	Deutsches Institut für Normung
DoA	Description of Action
DSA	Digital Shopfloor Alliance
DS-RA	Digital Service Reference Architecture
DSS	Decision Support System
DT	Digital Transformation
ERP	Enterprise Resource Planning
FaaS	Fog as a Service
FDI	Field Device Integration
FMI	Functional Mock-up Interface
FOF	Factories of the Future

GDP	Gross domestic product
HPC	High Performance Computing
HSM	Hardware Secure Module
IAM	Identity and Access Management
ICT	Information and communications technology
IDSA	International Data Spaces Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IIC	Industrial Internet Consortium
IIRA	Industrial Internet Reference Architecture
IIS	Industrial Internet System
IIoT	Industrial Internet of Things
IMSA	Intelligent Manufacturing System Architecture
IOT	Internet of Things
IPR	Intellectual Property Rights
ISO	International Organization for Standardization
IT	Information technology
I4MS	ICT Innovation for Manufacturing SMEs
KPIML	Key Performance Indicator Markup Language
LSTM	Long Short Term Memory
MQTT	Message Queue Telemetry Transport
MES	Manufacturing Execution System
ONNX	Open Neural Network Exchange
OPC UA	Open Platform Communications United Architecture
OT	Operational Technology
PAS	Publicly Available Specification
PKCS	Public-Key Cryptography Standards
PPP	Public Private Partnership
RA	Reference Architecture
RAF	Reference Architecture Framework

RF	Reference Framework
RAMI4.0	Reference Architectural Model Industry 4.0
RAS	Reliability, Availability, and Serviceability
REST	Representational State Transfer
RIDS	Reliable Industrial Data Services
SDK	Software Development Kit
SDN	Software-Defined Networking
SOA	Service Oriented Architecture
SRIA	Strategic Research and Innovation Agenda
SSL	Secure Sockets Layer
vf-OS	Virtual Factory Operating System
ZDM	Zero-Defects Manufacturing
ZDMP	Zero Defects Manufacturing Platform

Executive summary

i4Q Project aims to provide a complete set of solutions consisting of **IoT-based Reliable Industrial Data Services (RIDS)**, the so-called 22 i4Q Solutions, able to manage the huge amount of industrial data coming from cheap cost-effective, smart, and small size interconnected factory devices for supporting manufacturing online monitoring and control.

One of the challenges in implementing quality control processes and solutions is the development of the i4Q **Reference Architecture (i4Q RA)** for industrial data services in smart manufacturing, based on innovative technologies and on relevant sector-specific standards.

This document delivers the second release of the i4Q RA, representing the second output of Task 2.1. T2.1 "i4Q Reference Framework" is devoted to the design of an architecture for IoT-based **Reliable Industrial Data Services (RIDS)** ready to deal with large amounts of data. To this purpose, in D2.1 "i4Q Reference Architecture and Viewpoints Analysis" the preliminary conceptualisation of the i4Q Reference Architecture followed the ISO/IEC/IEEE 42010 "Systems and software engineering – Architecture", starting from a deep understanding and alignment among the most common reference architectures in the manufacturing domain.

The first released of i4Q RA, delivered at M3, was not designed from scratch, being strongly based on the most relevant outcomes of other previous Research and Innovation activities and releases of International Communities. As presented in D2.1 the preliminary version of the i4Q RA was mainly inspired by IIRA architectural model, based on the three-tiers approach.

According to IIRA approach, the task of i4Q RA definition was performed in parallel with those of its viewpoints analysis, namely T2.3 "Business Viewpoint", T2.4 "Usage Viewpoint", T2.5 "Functional Viewpoint", T2.6 "Implementation Viewpoint"; viewpoints offered a framework to think iteratively through the architectural issues that arose during its conception and later on.

So, the analysis across the four key viewpoints served as input for the architecture, which at the same time influenced them. The combination of the results obtained from the different viewpoints was derived into a detailed reference architecture. Results included: business, regulatory and stakeholders' key inputs (from the business viewpoint); an identification of tasks, roles or activities to be performed by the framework (from usage viewpoint); a decomposition into its Control, Operations, Information, Application and Business domains (from the functional viewpoint); an identification of associated flows and analysis and selection of the technologies required for its implementation (from implementation viewpoint).

Another key input has been the definition of the digital models and ontologies to be used in the i4Q Framework (T2.2 "Digital Models and Ontologies"). The analysis performed in D2.2 represented the basis for mapping activity to establish the best data models and ontologies for each architectural tier.

The works performed in task T1.3 "Use Cases Scenarios and KPIs" and T1.4 "Requirements Analysis and Functional Specification" paved the way for an in-depth analysis of the i4Q Solutions, performed in close collaboration with Solution Providers, and how they fit into the i4Q RA. The operational needs characterising the realization, deployment and use of each solution represented a valid input and helped to better identify the RA, refining its modules, components and functionalities.

The definition of the second version of the RA also took into account all the considerations formalized in the description of the use case scenarios and the requirements collection (T1.3 and T1.4); special attention was paid to the needs emerging from the pilots, which have been mapped in detailed blueprints to verify the alignment between the specific components to be used for industrial problems and the RA building blocks.

It is therefore clear that the design of the i4Q RA has been an iterative and parallel process, in which the results provided by several activities have been gathered and included in a systematic project vision. All of the information gathered in this deliverable will lay the groundwork for future project steps.

Document structure

Section 1 i4Q Architectural Framework and i4Q Solutions: This chapter presents the first version of the i4Q RA, proposed at M3 in D2.1 "i4Q Reference Architecture and Viewpoints Analysis", and focuses on architecture analysis and refinements. The mapping activities of the i4Q Solutions against the RA, already started in D2.1, have been carried on. This activity is finalized to gather feedback from Solutions Providers to verify the understanding and completeness of the building blocks and represents the basis for RA evolution.

Section 2 i4Q RA: Viewpoints: i4Q RA was not designed from scratch, being strongly based on the most relevant outcomes of other previous Research and Innovation activities and releases of International Communities, with a special attention to IIRA. According to IIRA approach, the viewpoints (business, usage, functional and implementation) definition represents a fundamental step for architecture definition. This section describes the methodology followed for the definition of the four viewpoints and provides a brief description of the main aims and outcomes for each of them. As well as Solutions Providers' feedbacks, they paved the way for the second release of i4Q RA.

Section 3 Data Models and Ontologies: Interoperability specification is fundamental for i4Q RA: for this purpose, Data Models and Ontologies drive the flow and exchange of digital data across different tools and platforms. Starting from T2.2 outputs, this chapter summarizes which standards better fit each architectural layer.

Section 4 Final version of i4Q Reference Architecture: This chapter presents the final version of i4Q RA, based on previous analysis and considerations. i4Q Solutions will be based on RA building blocks and will be developed in WP3, WP4 and WP5 activities during the next months. To further validate i4Q RA and to demonstrate how it fulfils pilots' needs, the blueprints have been formalized for each pilot.

Section 5 Conclusions and Next Steps: This chapter summarizes how i4Q RA paves the way for next the period, focused on solutions development.

1. i4Q Architectural Framework and i4Q Solutions

This chapter presents the first version of the i4Q RA as defined in D2.1 "i4Q Reference Architecture and Viewpoints Analysis" and the mapping activities of the i4Q Solutions against it. This activity is crucial to have a common understanding of the different blocks and layers of the architecture and to collect feedback from the solution providers that have been considered for the refinement of the architecture.

1.1 First version of i4Q Reference Architecture

The i4Q Reference Architecture (i4Q RA) defines a conceptual framework aiming to be the canvas for the design, implementation and integration of the i4Q Solutions. The first released of i4Q RA, delivered at M3, was not designed from scratch, being strongly based on the most relevant outcomes of other previous Research and Innovation activities and releases of International Communities. The i4Q RA is aligned to the most common standard reference architectures in the manufacturing domain. As presented in D2.1 the preliminary version of the i4Q RA was mainly inspired by IIRA architectural model (IIC, 2019). In particular, two approaches have been adopted:

- The IIRA three-layers architectural pattern as the main design driver.
- The IIRA layered databus pattern in order to make the solution data-driven.

The mapping between the layered databus pattern with the three-tier architecture pattern is as follows:

- The Machine Databus is mapped with the physical Assets and Smart Products.
- The Unit Databus is mapped with the Edge Tier.
- The Site Databus is mapped with the Platform and Enterprise Tiers.
- The Inter-Site Databus enables ecosystems and inter-factory communications.

The i4Q RA Security and Compliance Layer supports the communication between all tiers, providing a common security layer for accessing and retrieving data and physical assets (sensing and actuation).

Furthermore, the i4Q RA can support data (and services) description through the most significant meta-models (i.e., IIRA Characteristics of IIoT Information Models[1]), common ontologies and digital models analyzed in T2.2 and described in D2.2. Finally, the Interoperability Assurance Layer guarantees interoperability inside the i4Q ecosystem considering the broad-spectrum of raw and elaborated data that can be processed by the different solutions.

[1] https://www.iiconsortium.org/pdf/Characteristics-of-IIoT-Information-Models.pdf

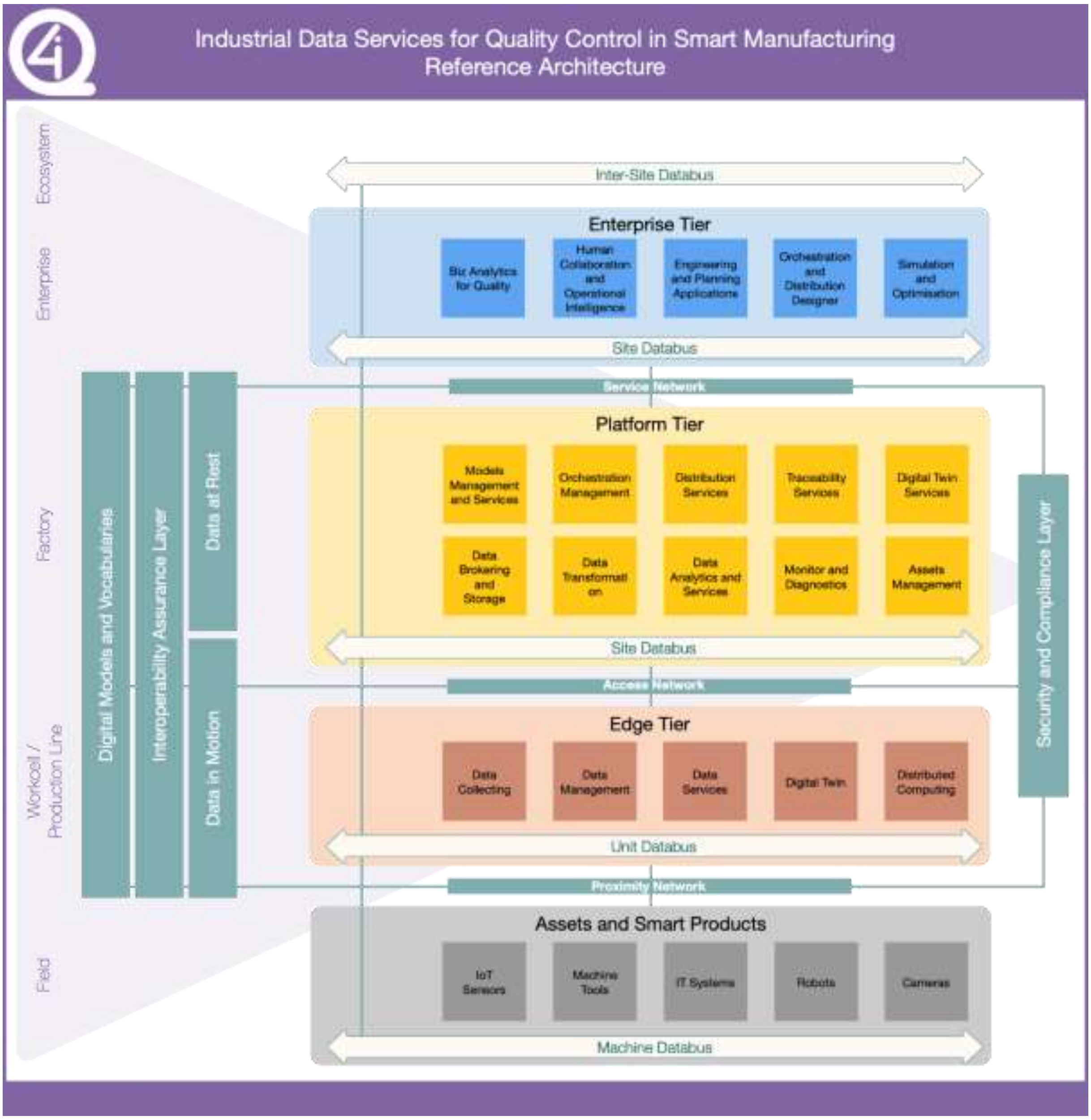

Figure 1. First version of i4Q Reference Architecture

1.1.1 Edge Tier

The Edge Tier aims to implement the sensor and control domain. It allows connecting the physical assets and systems, collecting and processing data in the "proximity network". Furthermore, it supports the Digital Twin (enabling advanced use, i.e., data filtering for generating a more precise virtual object, real-time analytics, etc.) and the Distributed Computing for sustaining distributed workloads and models. The Edge Tier, typically, process real-time data (Data in Motion).

The Edge Tier includes applications and services for describing and managing data, supports the digital twins reducing the connectivity and latency issue, and the distributed computing devising a typical edge-cloud orchestration system.

1.1.2 Platform Tier

The Platform Tier contains applications and services for supporting the data flow (abstracted data) acting as a middleware between the Edge Tier and the Enterprise Tier (and between access and service network). It supports services for quality control (modelling, orchestration, traceability, etc.) and historical data processing (Data at Rest).

The Platform Tier includes subcomponents for integrating third-party systems and architectures, the Digital Twin services for interacting with the edge-related application, and the distribution services (i.e., resource management, data, and algorithms orchestration, etc.).

1.1.3 Enterprise Tier

The Enterprise Tier implements business-specific applications related to quality control, providing interfaces for end-users. It integrates engineering and management applications for supporting command generations, operational intelligence operations, big data analytics and service orchestration.

The Enterprise Tier includes an "open" (not exhaustive) catalogue of use case/domain-specific applications. The usage of standard APIs and commons ontologies drives the definition of the common interfaces and facilitates the integration of (user and system) legacy and newer applications.

1.2 Mapping i4Q Solutions against i4Q RA

This first version of the i4Q Reference Architecture has been designed basing on the project view and main principles. This architecture will guide future developments for the "building activities" in WP3, WP4 and WP5, where the 17 tools (part of the 22 i4Q Solutions) will be implemented. So, it is very important to have a strong connection between the RA and the 22 i4Q Solutions. In order to have a coherent inclusive vision provided by the i4Q RA, the mapping activity, started in D2.1 with a limited subset of solutions in the RA, has been finalized, providing interesting inputs for the final i4Q RA.

1.2.1 i4Q^QE QualiExplore for Data Quality Factor Knowledge

i4Q will cover the wider, strategic and more narrow, operational aspects of manufacturing data quality. This scope requires the systematic identification and presentation of the various factors that influence data quality in manufacturing. Factors will range from the hardware-related aspects, such as measurement system characteristics, to the analytics processes including AI methods, and organizational procedures that drive manual data collection. A computer-supported knowledge base (QualiExplore) makes these contents accessible to organizations and can be one instrument within a manufacturing data quality strategy.

ID	01_i4Q_QE
Responsible task	T3.1 "Manufacturing Data Quality Strategy"
Solution name	i4Q QualiExplore for Data Quality Factor Knowledge

Solution definition			The QualiExplore implementation provides a 2-staged user interface to support learning about production-related information quality and the factors that influence it. The first stage serves as a filter because the high number of factors can cause information overload for users. Relevant filter categories are the user's goals, quality (information characteristics), and channels/sources. The goals include the perspective of the information user and the information creator/author. This is useful because it emphasises that many measures to avoid quality problems require the involvement of both parties. Each category has several statements that represent areas where the user should be or might want to be aware of information quality problems and their related factors. The indicated factor categories structure the factors and provide a link between statements and factors.
Details	Functionalities offered		1. Read quality factor descriptions 2. Create, update, delete quality factor descriptions 3. Interact via GUI and natural language
	Relies (Highlighted in orange below)	#1	**ON: Digital Models and Vocabularies** FOR: Data models.
	Offers (Highlighted in red below)	#1	WHAT: Data quality awareness. **TO: Human Collaboration and Operational Intelligence**
	Technical background		This solution relates to the Digital Models and Vocabularies part of the architecture. It is not connected to any of the tiers (no data exchange) as it serves as a knowledge base. Its data model (knowledge base) will be developed in T3.1 along with the data quality guideline.

Table 1. i4Q^{QE} solution analysis

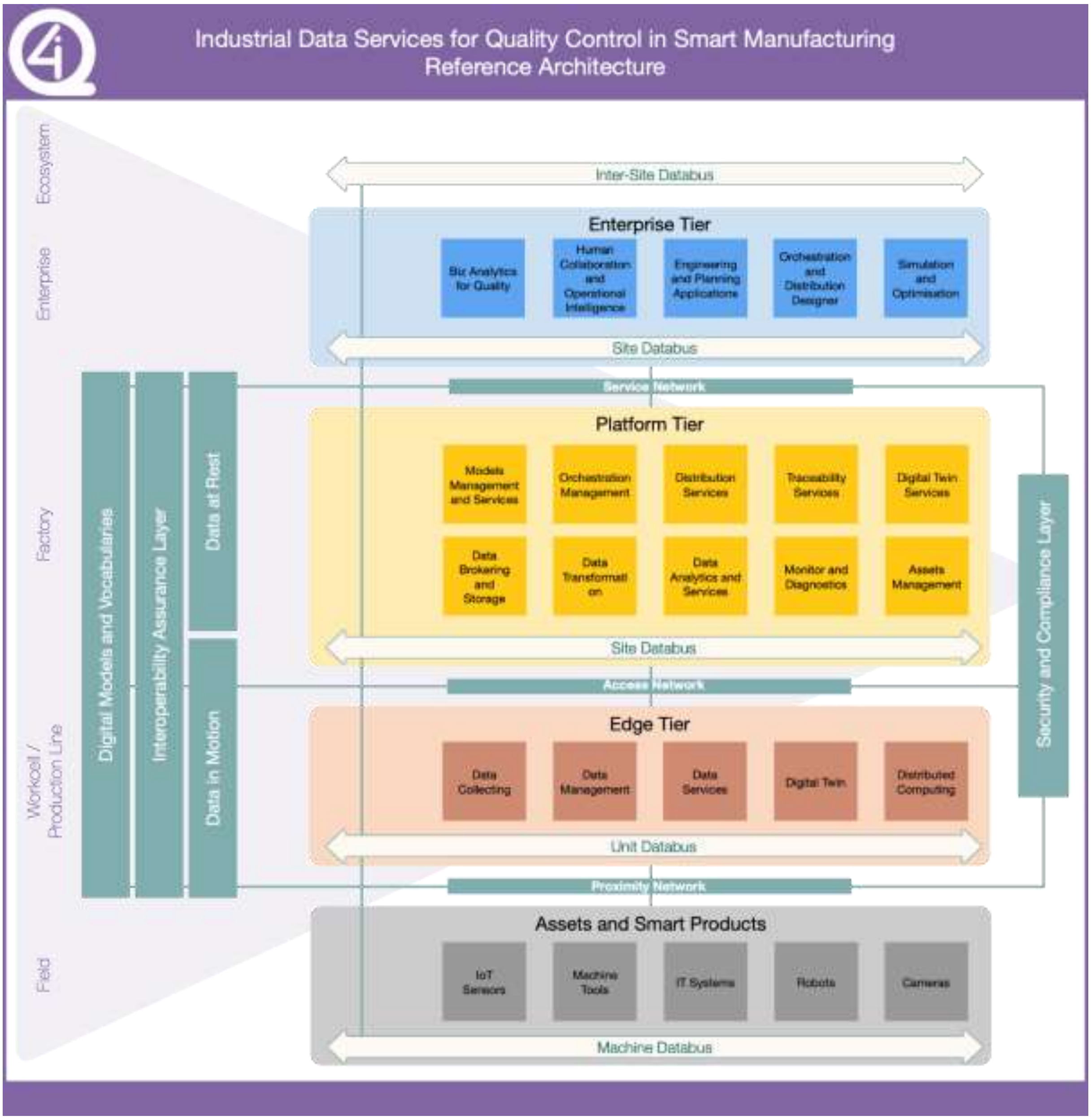

Figure 2. i4Q RA mapping with i4Q[QE]

1.2.1.1 RA critical analysis: strengths and weaknesses

Strengths:

- A life cycle perspective on manufacturing data quality and related factors facilitates an integrated view of the i4Q solutions. The interplay between different processing steps from lower tiers to higher ones becomes transparent and, thus, manageable.

Weaknesses:

- The knowledge base is dynamic and will require continuous maintenance to be recent, accurate, and precise. A potential solution for this issue is to make the knowledge base public and apply a crowd sourcing approach.

1.2.2 i4Q^BC Blockchain Traceability of Data

The Blockchain Traceability of Data solution aims to enhance the level of trust that different solutions and components can place on data. Thus, it shall serve as one of the cornerstones of data storage services to be consumed by different solutions. This solution shall provide services of immobility and finality of data, serving as the source of truth, enabling trust in data by providing the possibility for full provenance and audit trail of data stored. Thus, the main functionality offered by this solution is comprised of. Data trust traceability, enabling a full audit trail of assets and data.

<table>
<tr><td colspan="3">ID</td><td>03_i4Q_BC</td></tr>
<tr><td colspan="3">Responsible task</td><td>T3.2 “Manufacturing Data Trustiness and Traceability”</td></tr>
<tr><td colspan="3">Solution name</td><td>Blockchain Traceability of Data</td></tr>
<tr><td colspan="3">Solution definition</td><td>i4Q^BC provides tools to ensure trust in data and full traceability; enhancing the level of trust by employing a blockchain-based data service, improving acceptability by providing security and trust in the data that flows directly to the blockchain, serving as a single point of truth, preserving provenance, and supporting non-repudiation. The service provides an audit trail for all inserted data, guaranteeing immutability and finality.</td></tr>
<tr><td rowspan="6">Details</td><td colspan="2">Functionalities offered</td><td>1. Data trustiness and traceability
2. Full audit trail of assets and data</td></tr>
<tr><td rowspan="2">Relies (Highlighted in orange below)</td><td>#1</td><td>ON: Data Brokering and Storage
FOR: Data storage</td></tr>
<tr><td>#2</td><td>ON: Data Collecting
FOR: Configuration changes tracking.</td></tr>
<tr><td rowspan="2">Offers (Highlighted in red below)</td><td>#1</td><td>WHAT: Full audit trail of assets.
TO: Assets Management</td></tr>
<tr><td>#2</td><td>WHAT: Data trustworthiness.
TO: Traceability Services</td></tr>
<tr><td colspan="2">Technical background (Data models, containerization technology, I/O, etc.)</td><td>Blockchain technology enables data traceability, which is a capability provided by i4Q^BC. Blockchain provides the underlying technology for ensuring immutability, finality, and provenance contributing to non-repudiation of the stored state. i4Q^BC shall</td></tr>
</table>

		provide primitives within or on top of the base blockchain infrastructure to provide these capabilities in a smart manufacturing environment, for storing and querying manufacturing related data, configuration changes decisions and AI accountability.

Table 2. i4Q^{BC} solution analysis

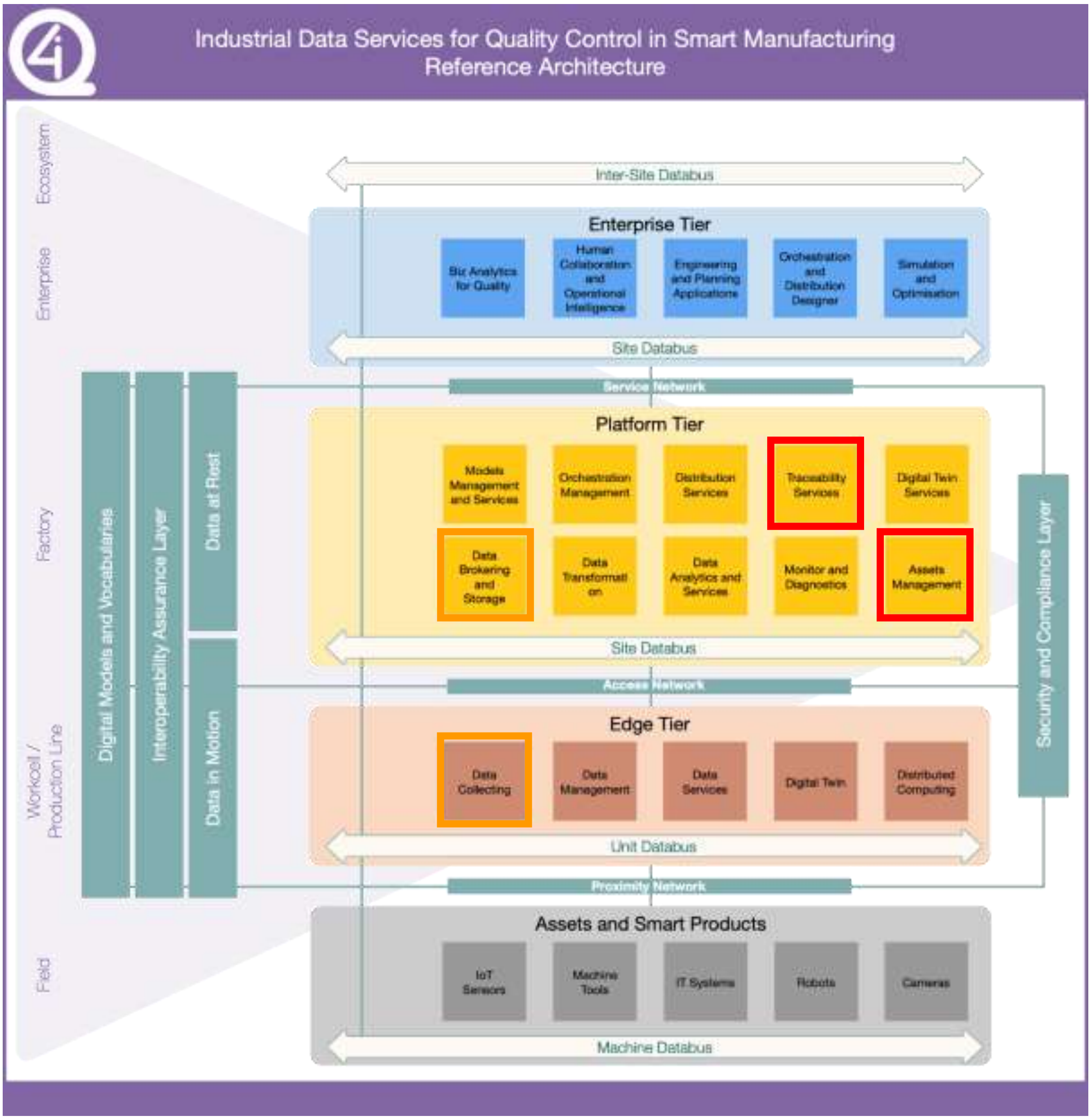

Figure 3. i4Q RA mapping with i4Q^{BC}

1.2.2.1 RA critical analysis: strengths and weaknesses

The i4Q^{BC} solution provided capabilities are mapped to the Platform Tier of the i4Q Reference Architecture. This solution shall be utilized by various additional components at different levels, this service shall bel be analysed in terms of its weaknesses and strengths:

Strengths:

- **Platform Tier:** One of the sub-components to be used is "Data Brokering and storage", enabling various components to access data exhibiting different characteristics in a unified manner.
- **Edge Tier:** The mapping to "Data collecting", enables the introduction of data stemming from multiple levels, including the edge to be integrated within this solution. This capability will enable specifically support configuration changes tracking at the edge tier.

Weaknesses:

- **Platform Tier:** The mapping to "Data Brokering and Storage" subcomponent and "data collecting" should take into consideration that this solution is not intended for high-rate ingestion and query.

1.2.3 i4Q^TN Trusted Networks with Wireless & Wired Industrial Interfaces

i4Q^TN solution includes a set of communication technologies to collect data from different industrial processes and systems. The use of different technologies makes it possible to cover a wide range of applications, using wired solutions to connect with already deployed networks; wireless for mobile and difficult-to-access areas; and low power networks to deploy a large number of nodes or carry out itinerant measurements with a low cost. All these technologies guarantee the precision, accuracy and reliability expected in industrial communications, using an SDN controller to orchestrate network resources from different communication technologies.

ID		04_i4Q_TN
Responsible task		T3.3 "Manufacturing Data Trusted Communication and Distribution"
Solution name		i4Q Trusted Networks with Wireless & Wired Industrial Interfaces
Solution definition		i4Q^TN is a software-defined industrial interface for data communication, characterized by predictability and determinism, high reliability, trustability and low consumption while reducing the cost of new communication infrastructures. i4Q^TN ensures high-quality data collection, providing connectivity to industrial data sources through Trusted Networks able to assess and ensure precision, accuracy, and reliability.
Details	Functionalities offered	1. Provide a reliable and secure communication infrastructure 2. Low Latency communications 3. High availability, scalability and flexibility

			using private infrastructure 4. Wired and wireless interfaces 5. QoS guarantees, orchestrating network resources using a SDN controller
	Relies (Highlighted in orange below)	#1	**ON: Assets and Smart Products** FOR: Trusted networks allow to interconnect all these assets to data collection.
	Offers (Highlighted in red below)	#1	WHAT: Provide a reliable and low latency communication infrastructure to digitize different assets such as IoT sensors, legacy and modern equipment, systems, etc. **TO: Data Collecting**
	Technical background		i4Q^TN or Trusted Networks with Wireless & Wired Industrial Interfaces, is mainly mapped to the Data Collecting sub-component of the Edge Tier. The solution provides the needed reliable infrastructure to interconnect and digitize the information from different data sources. The solution is based on different communication technologies to meet different requirements, such as reliability with IWSN or low latency with TSN networks. All of them are orchestrated by a centralized SDN controller that can optimize the use of the network resources.

Table 3. i4Q^TN solution analysis

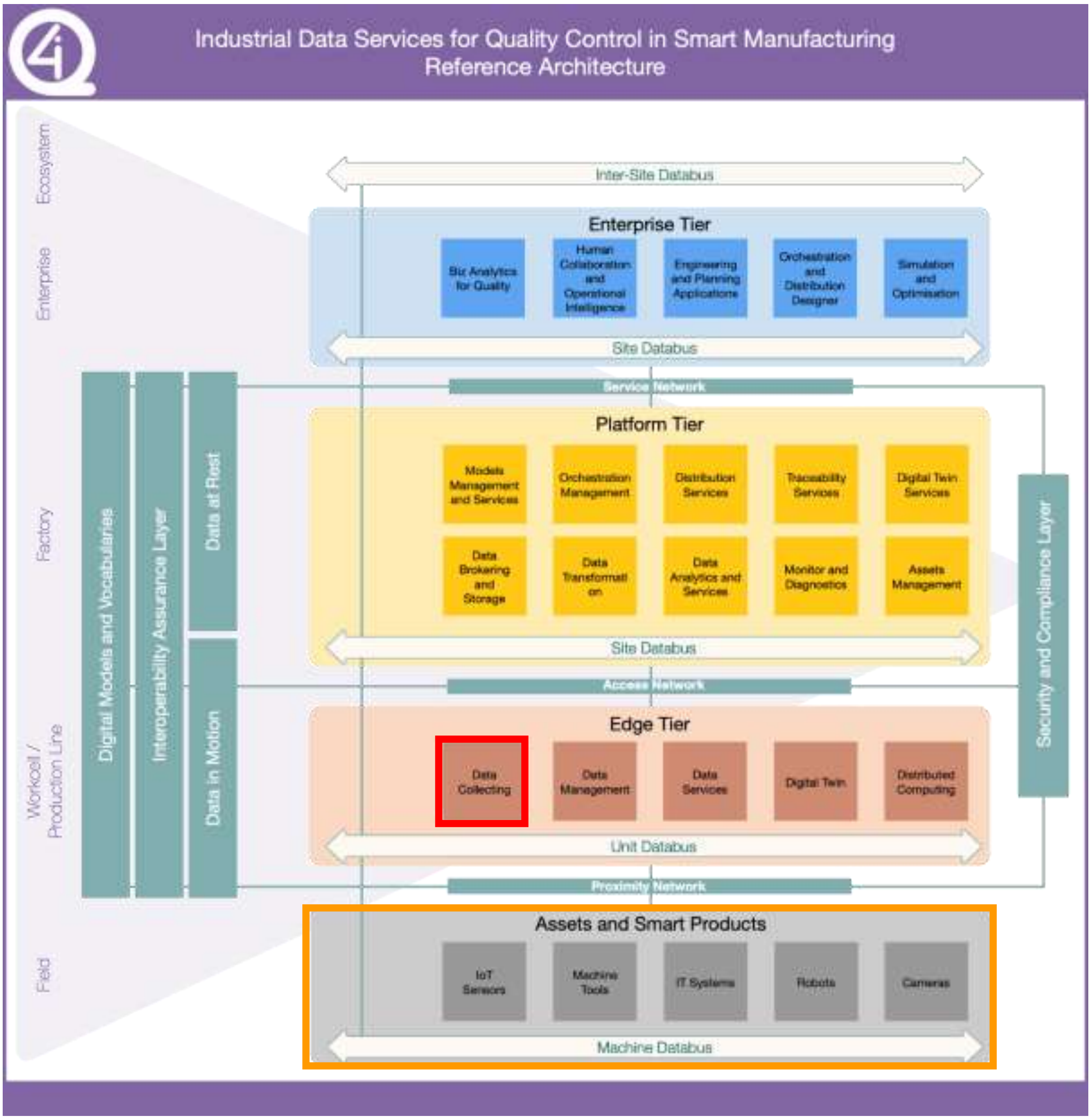

Figure 4. i4Q RA mapping with i4Q^{TN}

1.2.3.1 RA critical analysis: strengths and weaknesses

The processes and services that are being included in the i4Q^{TN} are mapped to the Edge Tier Layer in the i4Q Reference Architecture. The strengths and weaknesses of i4Q^{TN} solution regarding the aforementioned mapping are presented below:

Strengths:

- **Edge Tier**: The solution covers the main communication interfaces that are needed in different industrial scenarios, using wired, wireless and low power IoT systems. Although the solution is mapped in Edge Tier, the information exchange through i4Q^{TN} solution can be used by any other solution at any RA level.

Weaknesses:

- **Edge Tier**: Legacy equipment and communication protocols remain isolated. Additional integration of legacy technologies must be done because it is not covered by this solution. The scope of the network mapping and the type of technologies used for the Pilot scenarios should be reviewed.

1.2.4 i4Q^{SH} IIoT Security Handler

The Security Handler distributes trust among the smart factory environment by means of managing the digital identity life cycle of x509 certificates. This enables authentication, authorization, and encryption operations based on asymmetric cryptography.

The Security Hander also enables Hardware Secure Operations offering the capabilities of a PKCS#11 interface. This means that other i4Q solutions can perform cryptography operations with cryptography tokens (secrets) stored in a hardware secure module (HSM).

ID			05_i4Q_SH
Responsible task			T3.4 “Manufacturing Data Security”
Solution name			IIoT Security Handler
Solution definition			i4Q^{SH} is a cloud service that distributes trust across the architecture using a hardware secure module as trust anchor point. Once the trust is distributed, the software enables the mechanisms to expose cryptography operations that other i4Q Solutions can consume, adjusting security and safety policies at different levels to ensure trustability and privacy of data.
Details	Functionalities offered		1. Managing the lifecycle of digital x509 certificates among the smart factory environment 2. Providing authentication, authorization, and encryption for the different Tiers' operations
	Relies (Highlighted in orange below)	#1	**ON: Security and Compliance Layer** FOR: providing security functions to accomplish necessary requirements.
	Offers (Highlighted in red below)	#1	WHAT: Managing the lifecycle of digital x509 certificates among the smart factory environments. **TO: Edge, Platform and Assets/Smart products tier.**

		#2	WHAT: Providing authentication, authorization, and encryption for the different Tiers' operations. **TO: Edge, Platform and Assets/Smart products tier.**
	Technical background		i4Q^{SH} relies on asymmetric cryptography and public key infrastructure technology to provide trusted digital identities to use them among other i4Q solutions or pilot components. With those identities different entities are endorsed to implement security mechanisms such us: authentication, authorization and encryption. i4Q^{SH} manages the life cycle of the trusted digital identities. i4Q^{SH} offers cryptography operations with hardware root of trust (HSM). In this case, i4Q solutions or pilot components can outsource security operations to i4Q^{SH}. Some operations are sign, verify, encrypt and decrypt data.

Table 4. i4Q^{SH} solution analysis

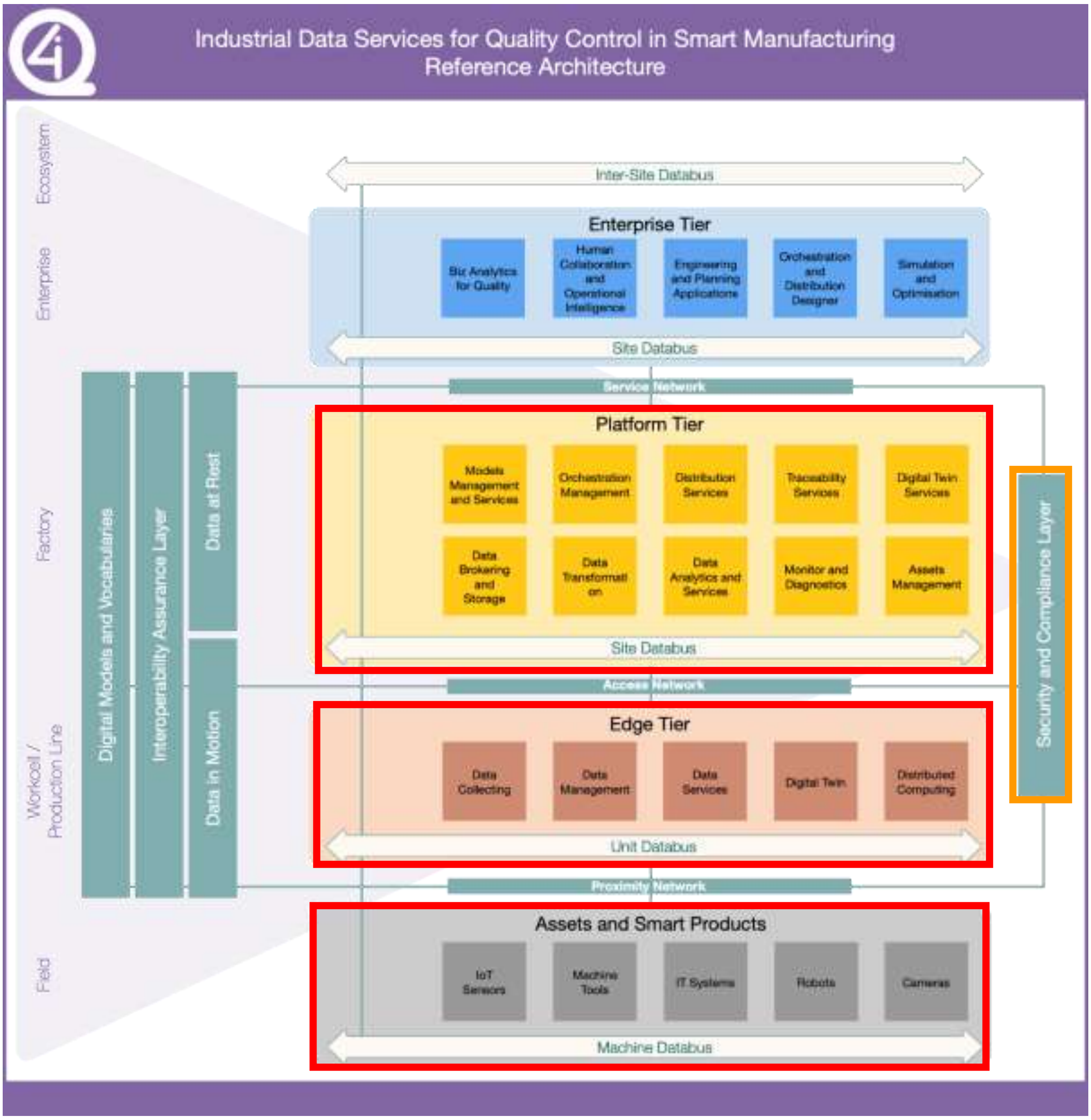

Figure 5. i4Q RA mapping with i4Q^SH

1.2.4.1 RA critical analysis: strengths and weaknesses

The processes and services that are being included in the i4Q^SH are mapped to the Security and Compliance Layer in the i4Q Reference Architecture. The strengths and weaknesses of i4Q^SH solution regarding the aforementioned mapping are presented below:

Strengths:

- Security Handler will be offering other solutions a secure endpoint to manage the life cycle of theirs x509 certificates and API REST/PKCS#11 endpoint to perform cryptography operations with a hardware secure module. Both endpoints enable the distribution of trust among the smart factory. In the first case, the private key of the x509 certificate is under i4Q solutions domain, and in the second case, the private key is under the i4Q^SH domain, leveraging different kinds of trust between i4Q solutions. When data is moved in a secure way between i4Q solution, first, each one, needs to set the trust boundaries by means of the i4Q^{SH} and after, the solution itself is responsible for moving the data.

Weaknesses:

- Because i4Q^{SH} is transversal to any solution or, any component used during the pilots, it is not clear where or who is going to use it. Even with the security requirements coming from the pilots, is not clear how to implement a data security transfer between solutions, because the security handler only sets the trust boundaries with x509 certificates or PKCS11 operations but it does not move the data itself, and it is not clear how the solutions will perform such data movement operations.

1.2.5 i4Q^{DR} Data Repository

i4Q^{DR} solution is composed of many technologies and tools to support the storage of both structured and structured data. The storage of structured data is offered by means of DBMSs that may be relational SQL-based, document (e.g. JSON-based), general NoSQL tools, etc. The storage of unstructured data is offered through tools that offer support for blobs like some of the previous ones or even specific ones (e.g. Minio).

The solution is also in charge of ensuring regulated access to the data and the related tools. For this, an IAM tool is envisioned, in order to have an access control system that ensures that data is only accessed by the authorised entities.

ID		07_i4Q_DR
Responsible task		T3.5 “Manufacturing Data Storage and Use”
Solution name		i4Q Data Repository
Solution definition		i4Q^{DR} is a distributed storage system for supporting a high degree of digitization in companies with most manufacturing devices acting as sensors or actuators and generating vast amounts of data. i4Q^{DR} is able to absorb large volumes of data coming into the system at high speeds. i4Q^{DR} is elastic to adapt the required computing resources to the existing demand and ready to use additional resources, either local to the factory or from remote systems like public or private clouds.
Details	Functionalities offered	1. Access control 2. Management of structured data 3. Management of blobs 4. Queries 5. Data import and export

			6. Access control configuration 7. Management of the data repository
	Relies (Highlighted in orange below)	#1	**ON: Distributed Computing** FOR: Provides execution environments (containers, virtual machines, etc.) to support data replication.
		#2	**ON: Data Collecting** FOR: Provides the flows of data to store.
		#3	**ON: Data Management** FOR: Provides the definition of the structures of the data to store and the queries to execute to retrieve data.
	Offers (Highlighted in red below)	#1	WHAT: Provide data storage services **TO: Any other solution that requires them (typically, the Enterprise and Edge Tiers)**

Table 5. i4QDR solution analysis

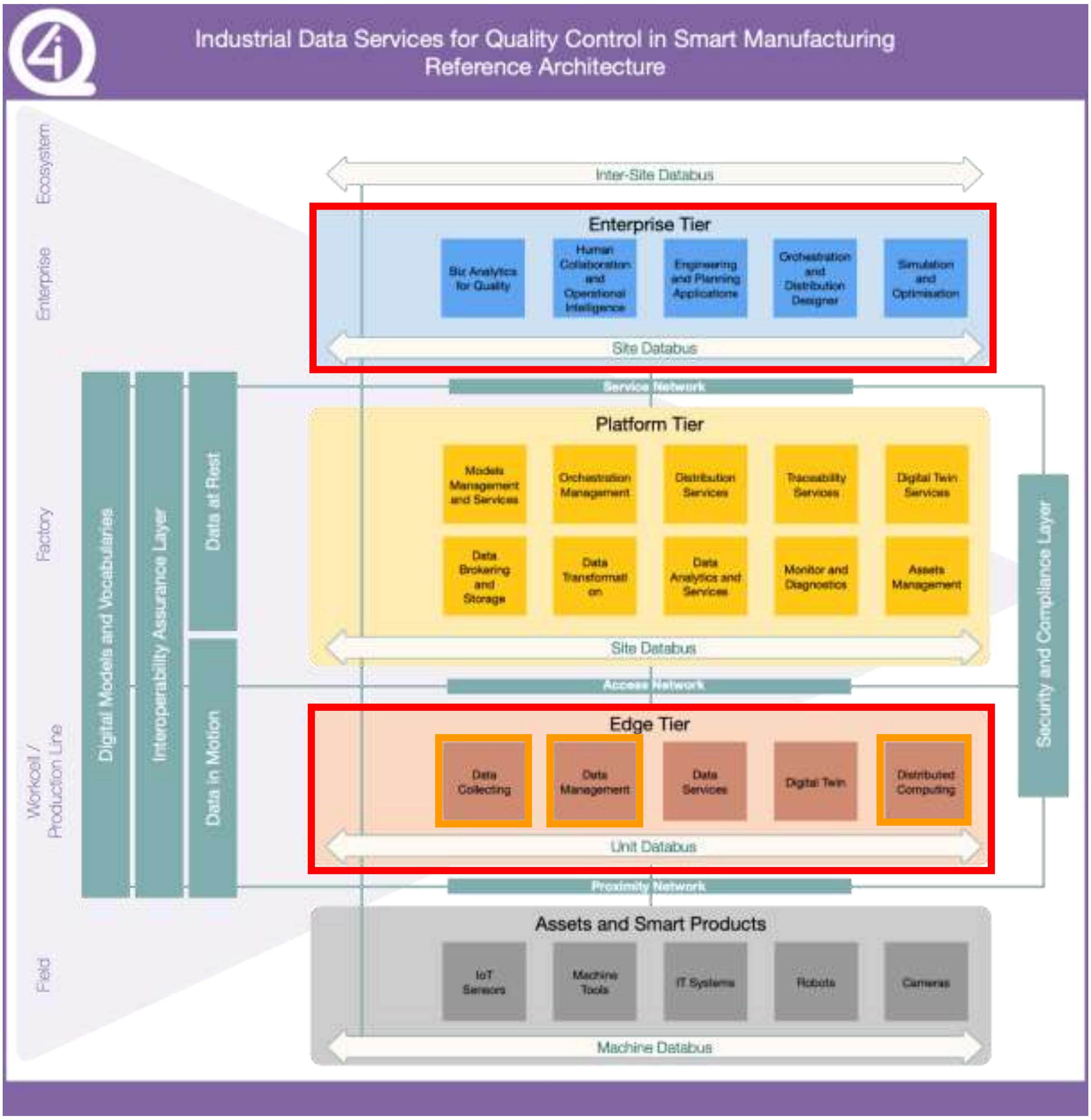

Figure 6. i4Q RA mapping with i4Q[DR]

1.2.5.1 RA critical analysis: strengths and weaknesses

The i4Q[DR] solution is mapped to the Data Brokering and Storage sub-component of the Platform Tier. This solution centralizes the functionality related to the storage of data in the whole i4Q system. Indeed, the functionality it offers is required in all the pilots and by a large subset of the i4Q solutions. This central position yields some strengths and weaknesses:

Strengths:

- The central nature of this solution allows taking and applying in a centralized manner some decisions related to the organization, management and access to the data (for instance, access control criteria and policies criteria related to high availability and fault tolerance of the data storage tools, etc.), that are required for the proper design and the implementation of certain mechanisms related to data storage. Hence, such decision-making processes benefit from the central nature of this solution.

- Moreover, when it comes to putting into practice mechanisms and tools, this central nature of the solution avoids the duplication of efforts and more importantly, some problems derived from such duplicity, starting from having divergent criteria and ending in devoting duplicated efforts to the same tasks.

Weaknesses:

- This solution tries to cover the data storage needs of the whole system, which can be numerous and diverse. This may translate into the need for many different tools devoted to data storage. For instance, the whole system may need relation DBMSs, document-oriented databases, graph-oriented databases, file- and blob-based storages, etc. all at once. Moreover, due to the specific needs of other i4Q solutions, several tools of each type may be needed, in the worst possible scenario. Such a situation is undesirable for different reasons: it is complex to manage, it is expensive, it may lead to awkward data duplication problems. To prevent such a situation, a huge effort is required to homogenize the needs of each solution. Moreover, quite a notable flexibility is advised and asked for by the solution providers when taking decisions related to the data repository.

1.2.6 i4Q^{DIT} Data Integration and Transformation Services

i4Q^{DIT} is the solution that aims to provide a software tool capable of reading\importing data either from data repositories such as i4Q^{DR} or real-time from the shop floor during the manufacturing process. The main function of this solution is to pre-process, transform and fuse data coming from different sources (e.g. different sensors) so that the integration with the other solutions can be seamless.

ID		09_i4Q_DIT
Responsible task		T4.1 "Manufacturing Data Integration and Fusion"
Solution name		Data integration and transformation services
Solution definition		i4Q^{DIT} is a distributed server-based platform able to prepare manufacturing data for being efficiently processed by microservice applications. The elements that are included in i4Q^{DIT} and required for manufacturing data stream management are: reading, cleaning, storing, indexing, enriching, searching & retrieving, maintaining, and correspondence of open APIs.
Details	Functionalities offered	1. Read different types of data from different sources, produced by the manufacturing workflows.

			2. Solution will work as the data input component for other solutions. 3. It should be able to read data from the DR, directly from sensors, from various databases used in the project. 4. Data preparation: cleaning, preprocessing, feature extraction, data filtering, data harmonization. 5. Provide integrated datasets with a homogenous structure of different recordings from multiple sources, so as to prepare the manufacturing data for further analysis.
	Relies (Highlighted in orange below)	#1	**ON: Data Collecting** FOR: Sensor measurement collection
		#2	**ON: Data Management** FOR: General management procedures of data.
		#3	**ON: Data Services** FOR: Distributing the cleaned/integrated datasets.
		#4	**ON: Distributed Computing** FOR: Distributing the solution.
		#5	**ON: Data at Rest and Data in Motion** FOR: Importing/Reading data.
	Offers (Highlighted in red below)	#1	WHAT: Data preprocessing and transformation so that the measurements can be efficiently processed by microservice applications. **TO: Data Transformation**
		#2	WHAT: Integrated datasets **TO: Data Analytics and Services**
	Technical background		i4Q[DIT] or Data Integration and Transformation Services mainly resides at the Edge Tier but is also mapped to the Platform Tier through the Data Transformation. At the platform tier, data transformation is the main focus of this solution where data will be prepared so that they can be processed by the microservice

		applications. Edge Tier mostly includes services regarding data collection, management and analysis. The inputs of this solution are sensors and other types of manufacturing data that need to be integrated and pre-processed. The output includes databases with clean and integrated data that will later be fed to other components for further processing and analysis.

Table 6. i4Q^{DIT} solution analysis

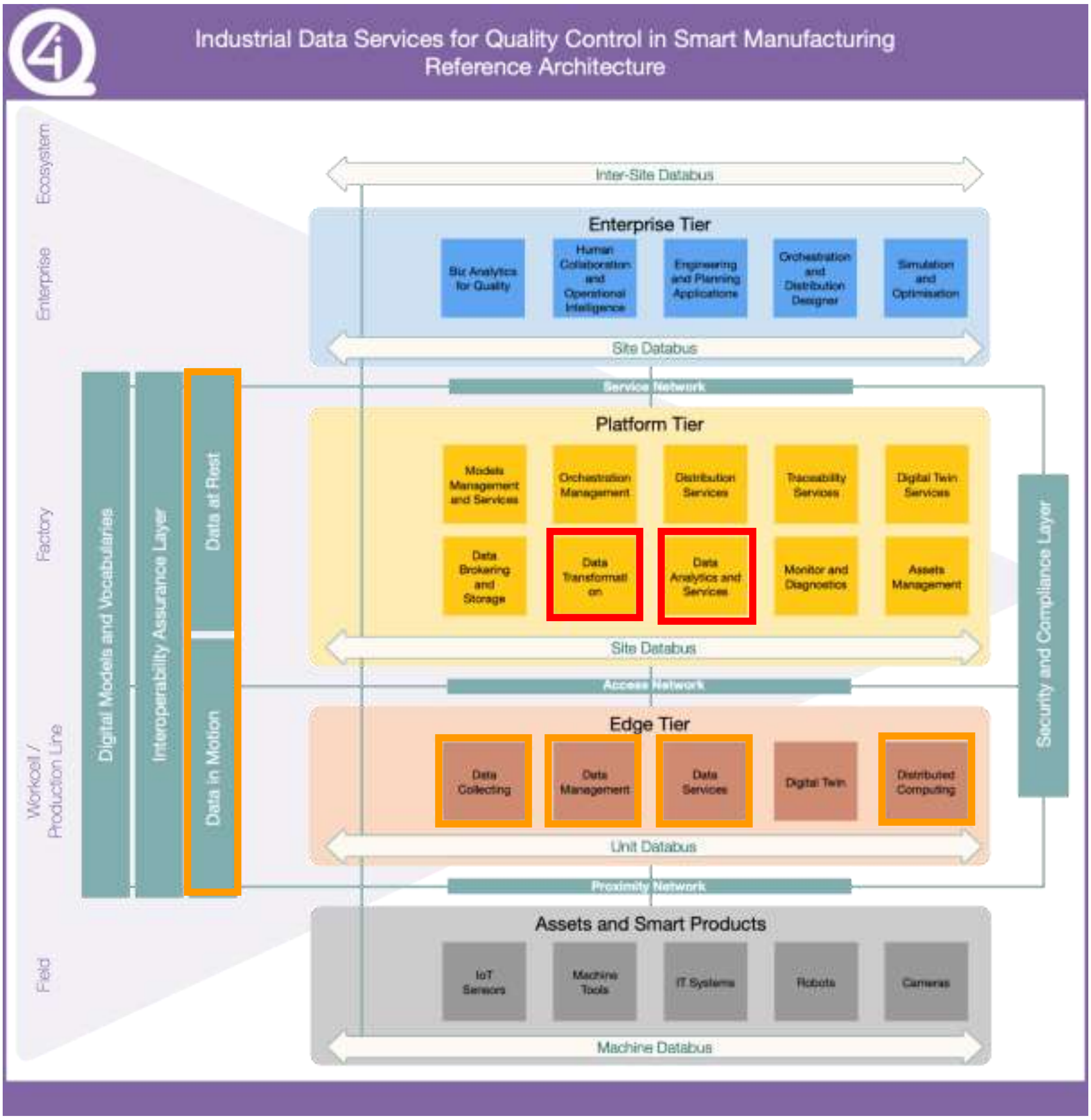

Figure 7. i4Q RA mapping with i4Q^{DIT}

1.2.6.1 RA critical analysis: strengths and weaknesses

The processes and services that are being included in the i4Q^DIT software tool are mapped to two tiers in the i4Q Reference Architecture, Platform and Edge Tier. i4Q^DIT is one of the most commonly used solutions in the i4Q and for that reason, some strengths and weaknesses arise.

Strengths:

- **Platform Tier**: "Data Transformation" is one of the most important services of this solution, as it is responsible for transforming the data (usually post-processing) for each individual need for the microservices that require them. The main benefit of this service is that it can obtain and use data from repositories, already stored and ready to be transformed to a usable form. This gives the ability to use this solution without the need for newly acquired data.
- **Edge Tier**: i4Q^DIT is the main solution responsible for the transformation and integration of data. Such operation requires services such as "Data Collecting", "Data Management", "Data Services" and "Distributed Computing". "Distributed Computing" provides a model in which components of the software tool are shared among multiple computers(nodes) that allow deploying and running AI workloads on the edge. The benefit of this service is that the solution can be used on the manufacturing floor. "Data Collecting", "Data Management" and "Data Services" can all be considered part of a pipeline, from data ingestion (collecting raw data from the facilities and storing them to make them available for pre-processing), to data management and transformation (pre-processing the data so that they can be fit to be used by other solutions). The use of these services is crucial for the proper development and operation of this solution.

Weaknesses:

- **Platform Tier**: "Data Transformation" is the principle of this solution and will work both with data from repositories and in real-time. Any disruption of data will not allow this service to work properly.
- **Edge Tier**: "Data Collecting", "Data Management", "Data Services" and "Distributed Computing" will mostly use real-time data. For these services to work seamlessly is important to establish an uninterrupted flow of sensor data from the shop floor.

1.2.7 i4Q^DA Services for Data Analytics

This i4Q solution aims to be a tool capable of analysing manufacturing-generated raw data, in order to provide an optimization of the production process, by using machine learning.

ID	10_i4Q_DA
Responsible task	T4.2 "Manufacturing Data Analysis for Quality Qualification"
Solution name	i4Q Services for Data Analytics
Solution definition	i4Q^DA provides a set of specialised analytic functions and incremental algorithms, operating on data streams with fast incremental updates, suitable for analytic

			processing of high-speed data streams.
Details	Functionalities offered		1. Big Data Processing 2. Machine Learning & Data Mining 3. Deep Learning
	Relies (Highlighted in orange below)	#1	**ON: Data Collection** FOR: Tapping into the data sources to feed the Data Analytics Services.
		#2	**ON: Data Management** FOR: Tapping into the data sources to feed the Data Analytics Services.
		#3	**ON: Data Services** FOR: Tapping into the data sources to feed the Data Analytics Services.
		#4	**ON: Distributed Computing** FOR: Managing the available hardware resources to leverage the efficiency of the Data Analytics Services' execution.
		#5	**ON: Distribution Services** FOR: Managing the available hardware resources to leverage the efficiency of the Data Analytics Services' execution.
		#6	**ON: Data Brokering and Storage** FOR: Pre-processing and storing data going to and coming from the Data Analytics Services.
		#7	**ON: Data Transformation** FOR: Pre-processing and storing data going to and coming from the Data Analytics Services.
		#8	**ON: Data in Motion and Data at Rest** FOR: The Services for Data Analytics will be available for both data in motion (streaming) and data at rest (batch).
		#9	**ON: Digital Models and Vocabularies** FOR: The models will be used by the Data Analytics Services as the basis for the results given by this solution.

	Offers (Highlighted in red below)	#1	WHAT: Data Analytics services, supported by the integration of several state-of-the-art tools, methods, and libraries, ranging from Big Data Processing and Analytics to Machine Learning, Data Mining and Deep Learning. **TO: Data Analytics and Services**
	Technical background		$i4Q^{DA}$ or Services for Data Analytics, is mainly mapped to the Data Analytics and Services sub-component of the Platform Tier. The solution provides a set of data analytics functions such as Big Data Processing and Analytics, Data Mining, Machine Learning and Deep Learning. The solution is based on a number of technologies for Big Data Processing (Spark, Flink, Storm, etc.), Machine Learning and Data Mining (Scikit Learn, Spark MLLib, Weka on Spark, etc.) and Deep Learning (TensorFLow, Keras, PyTorch).

Table 7. $i4Q^{DA}$ solution analysis

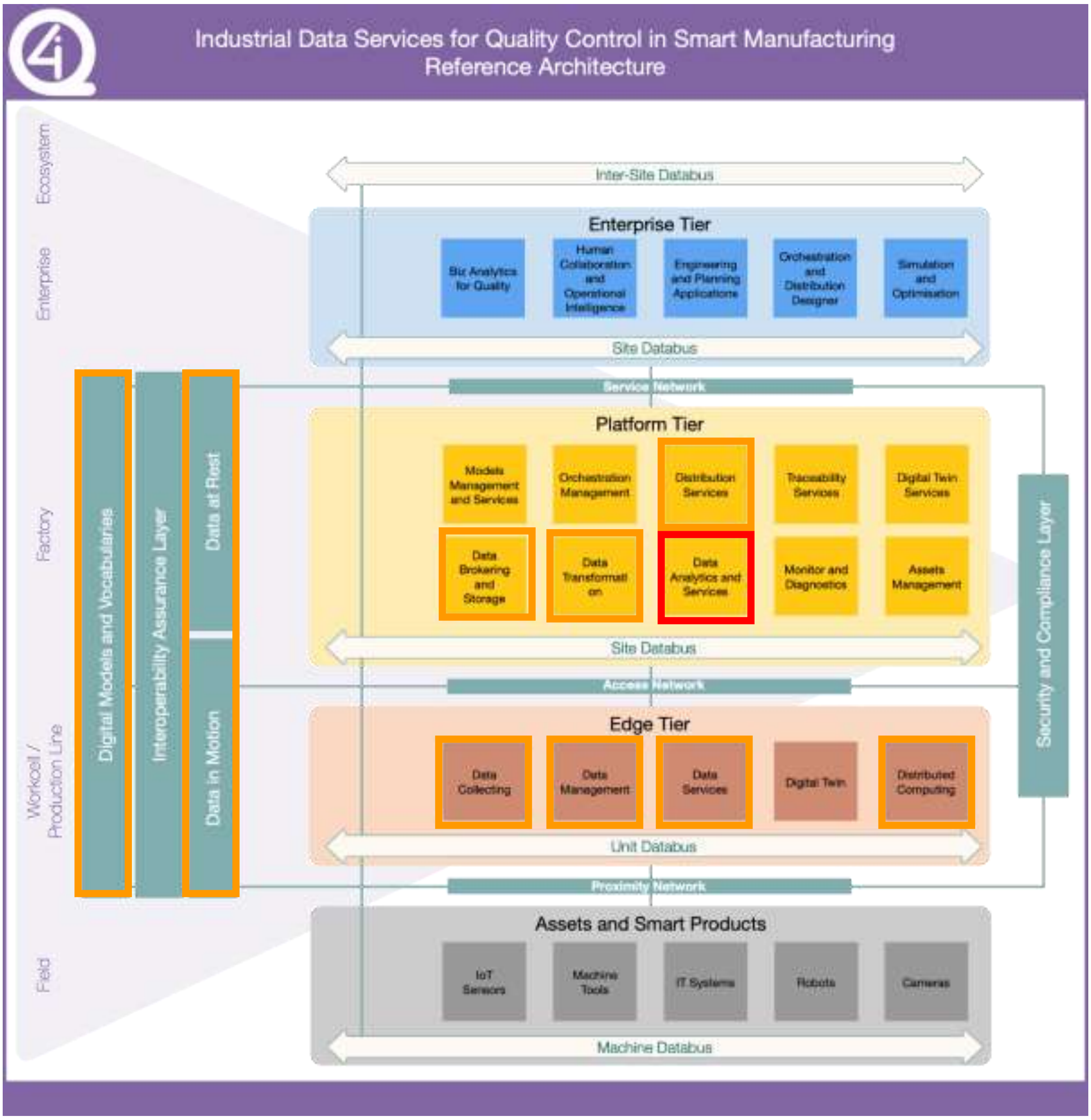

Figure 8. i4Q RA mapping with i4Q^{DA}

1.2.7.1 RA critical analysis: strengths and weaknesses

The i4Q^{DA} solution includes processes and AI models which are mapped to the Platform and Edge Tiers of the i4Q Reference Architecture. The strengths and weaknesses of i4Q^{DA} solution regarding the aforementioned mapping are presented below:

Strengths:

- **Platform Tier**: The services that are being used in this tier are the "Distribution Services", the "Data Brokering" and "Storage, Data Transformation" and the "Data Analytics". Amongst these services, the most important for this solution is the "Data Analytics and services", which is in charge of analyzing big amounts of data that can come in streams or as in a batch while providing many types of data analytic techniques aided by machine learning, that can be adapted based on the data type and the type of analysis.

This customization, which can be done by the end-user, makes this a versatile analytical tool.

- **Edge Tier**: The i4Q^{DA} solution is comprised of the "Data Collecting" and "Data Management" services, which will be present in the tool itself and are fundamental for the data analytics, and the "Distributed Computing" services, which will allow this tool to be executed in any type of computer/device.

Weaknesses:

- **Platform Tier**: This solution relies heavily on the "Data Transformation" and "Data Brokering and storage" components and will work both with data at rest and data streams in real-time. Any disruption of this data and/or data flow will not allow these services to work properly.
- **Edge Tier**: The "Data Collecting", "Data Services" and the "Distributed Computing" are reliant on one another, meaning that if one of these components fails, the whole pipeline structure will cease to work properly.

1.2.8 i4Q^{BDA} Big Data Analytics Suite

This solution will have similar functionality as the Data Analytics solution, but in this case, this solution will be provided as a Bundle, which will be previously configurated by the user, to be implemented on the user premises.

ID			11_i4Q_BDA
Responsible task			T4.2 "Manufacturing Data Analysis for Quality Qualification"
Solution name			i4Q Big Data Analytics Suite
Solution definition			i4Q^{BDA} provides core functions related to clustering, regression, classification, anomaly detection and temporal correlation of data generated by sensors and other Cyber Physical Systems mounted on industrial facilities. The key property of i4Q^{BDA} is speed and ability to support intensive data streams.
Details	Functionalities offered		1. Big Data Processing 2. Machine Learning & Data Mining 3. Deep Learning 4. Provide custom-built deployment bundles
	Relies (Highlighted in orange below)	#1	**ON: Data Collection** FOR: Tapping into the data sources to feed the Data Analytics Services.
		#2	**ON: Data Management** FOR: Tapping into the data sources to feed the

			Data Analytics Services.
		#3	**ON: Data Services** FOR: Tapping into the data sources to feed the Data Analytics Services.
		#4	**ON: Distributed Computing** FOR: Managing the available hardware resources to leverage efficiency of the Data Analytics Services' execution.
		#5	**ON: Distribution Services** FOR: Managing the available hardware resources to leverage efficiency of the Data Analytics Services' execution.
		#6	**ON: Data Brokering and Storage** FOR: Pre-processing and storing data going to and coming from the Data Analytics Services.
		#7	**ON: Data Transformation** FOR: Pre-processing and storing data going to and coming from the Data Analytics Services.
		#8	**ON: Orchestration Management** FOR: To manage and orchestrate the services depending on the target deployment environment.
		#9	**ON: Data in Motion and Data at Rest** FOR: the Services for Data Analytics will be available for both data in motion (streaming) and data at rest (batch).
		#10	**ON: Digital Models and Vocabularies** FOR: The models will be used by the Data Analytics Services as the basis for the results given by this solution.
	Offers (Highlighted in red below)	#1	WHAT: Provide custom-built deployment bundles that can contain all the necessary tools, methods, libraries, and code to deploy and run the selected Data Analytics tasks in a panoply of environments, from centralized, distributed on-premises or Cloud. **TO: Data Analytics and Services**
	Technical background		$i4Q^{BDA}$ is mainly mapped to the Data Analytics and Services sub-component of the Platform

		Tier. The solution intends to provide several technologies for Big Data Processing (Spark, Flink, Storm, etc.), Machine Learning and Data Mining (Scikit Learn, Spark MLLib, Weka on Spark, etc.) and Deep Learning (TensorFLow, Keras, PyTorch), bundled and ready to be deployed on cloud or on-premises. This solution relies on containerization tools like (Docker, kubernetes) custom-build deployment bundles that can contain all the necessary tools, methods, libraries, and code to deploy and run the selected Data Analytics tasks in a panoply of environments, from centralized, distributed on-premises or Cloud.

Table 8. i4Q^{BDA} solution analysis

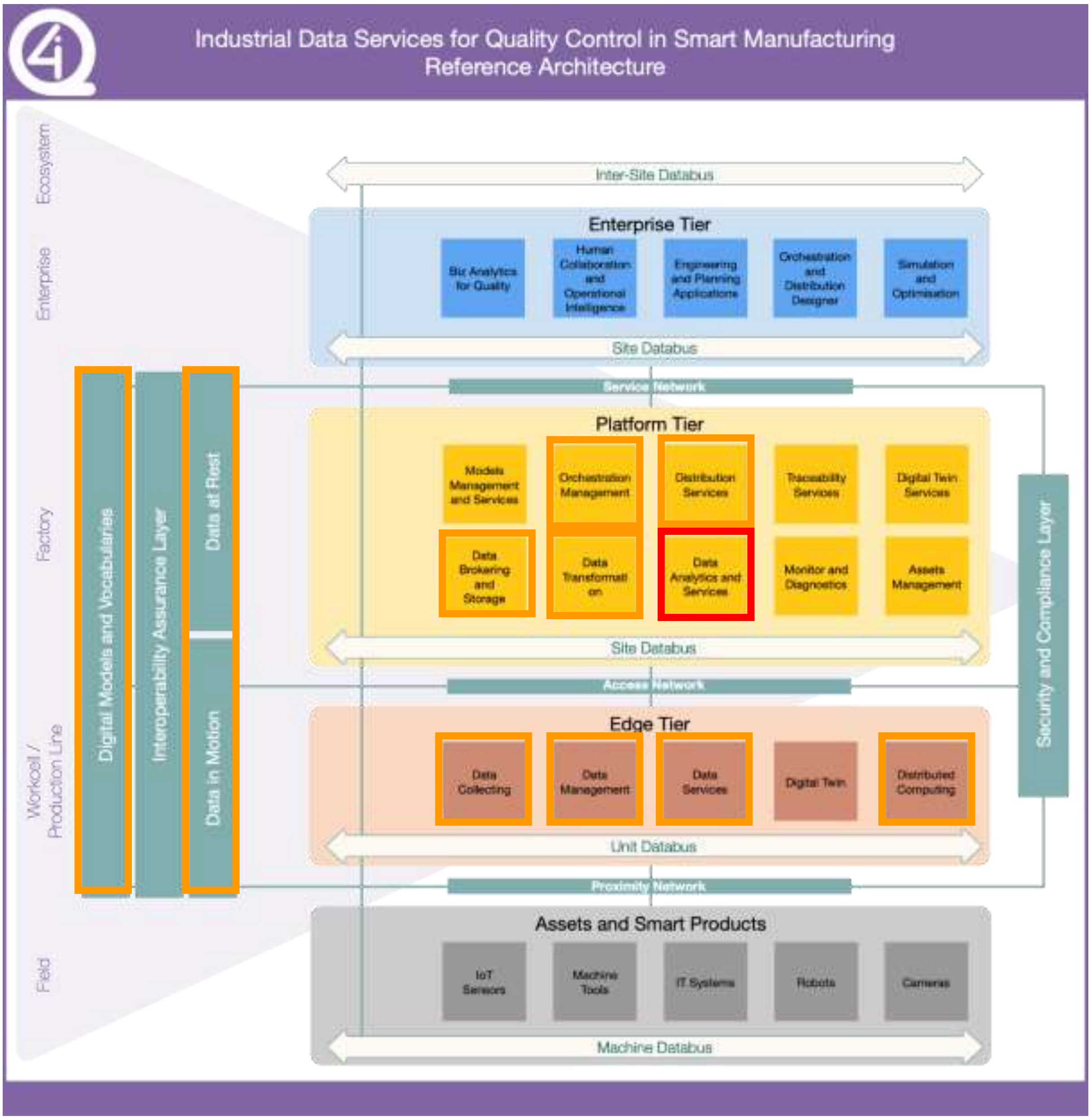

Figure 9. i4Q RA mapping with i4Q^BDA

1.2.8.1 RA critical analysis: strengths and weaknesses

The i4Q^BDA solution includes processes and AI models which are mapped to the Platform and Edge Tiers of the i4Q Reference Architecture. The strengths and weaknesses of i4Q^BDA solution regarding the aforementioned mapping are presented below:

Strengths:

- **Platform Tier**: The services that are being used in this tier are the "Distribution Service"s, the "Data Brokering and Storage", "Orchestration Management", "Data Transformation" and the "Data Analytics". Amongst these services, the most important for this solution is the "Data analytics and services", which is in charge of analyzing big amounts of data that can come in streams or as in a batch while providing many types of data analytic techniques aided by machine learning, that can be adapted based on the data type and the type of analysis. Since this solution will be provided as a bundle, it can be deployed in the client premises, or in any given cloud provider, making it more versatile.

- **Edge Tier**: The i4Q^{DA} solution is comprised of the "Data Collecting" and "Data Management" services, which will be present in the tool itself and are fundamental for the data analytics, and the "Distributed Computing" services, which will allow this tool to be executed in any type of computer/device.

Weaknesses:

- **Platform Tier**: This solution relies heavily on the "Data Transformation" and "Data Brokering and storage" components and will work both with data at rest and data streams in real-time. Any disruption of this data and/or data flow will not allow these services to work properly. Another weakness is connected to the "Distribution Services", since it relies on the user to input the specifications of the infrastructure where the bundle will be deployed, making it hard to optimize the bundle for different types of infrastructures.
- **Edge Tier**: The "Data Collecting", "Data Services" and the "Distributed Computing" are reliant on one another, meaning that if one of these components fails, the whole pipeline structure will cease to work properly.

1.2.9 i4Q^{AD} Analytics Dashboard

This i4Q solution aims to provide a graphical interface where it will be possible to visualize any kind of Data and/or other types of information provided by other solutions.

ID			12_i4Q_AD
Responsible task			T4.2 "Manufacturing Data Analysis for Quality Qualification"
Solution name			i4Q Analytics Dashboard
Solution definition			i4Q^{AD} is a reporting interface that allows monitoring industrial data with fully flexible visualization drill-down charts and flexible dashboard to provide meaningful analytics to users in a real-time basis using incremental algorithms.
Details	Functionalities offered		1. Providing visual analytics tools and methods
	Relies (Highlighted in orange below)	#1	**ON: Data Analytics** FOR: The Dashboard will present results from these sub-components.
		#2	**ON: Digital Twin Services** FOR: The Dashboard will present results from these sub-components.

		#2	**ON: Data in Motion and Data at Rest** FOR: The Analytics Dashboard will provide visualisations and visual analytics methods for both Data at Rest and Data in Motion.
	Offers (Highlighted in red below)	#1	WHAT: To monitor and optimize production efficiency. **TO: Monitor and Diagnosis**
		`#2	WHAT: Help manufacturers gain insight in specific operations, to aid in the decision-making process. **TO: Biz Analytics for Quality**
	Technical background		i4Q^AD is mapped to the Monitor and Diagnosis sub-component of the Platform Tier and to the Business Analytics for Quality of the Enterprise Tier. This solution relies on multiple visualization technologies depending on the desired visualizations as well as the technical requirements. These tools include Grafana, Apache Superset, Jupyter notebooks and Apache Zeppelin.

Table 9. i4Q^AD solution analysis

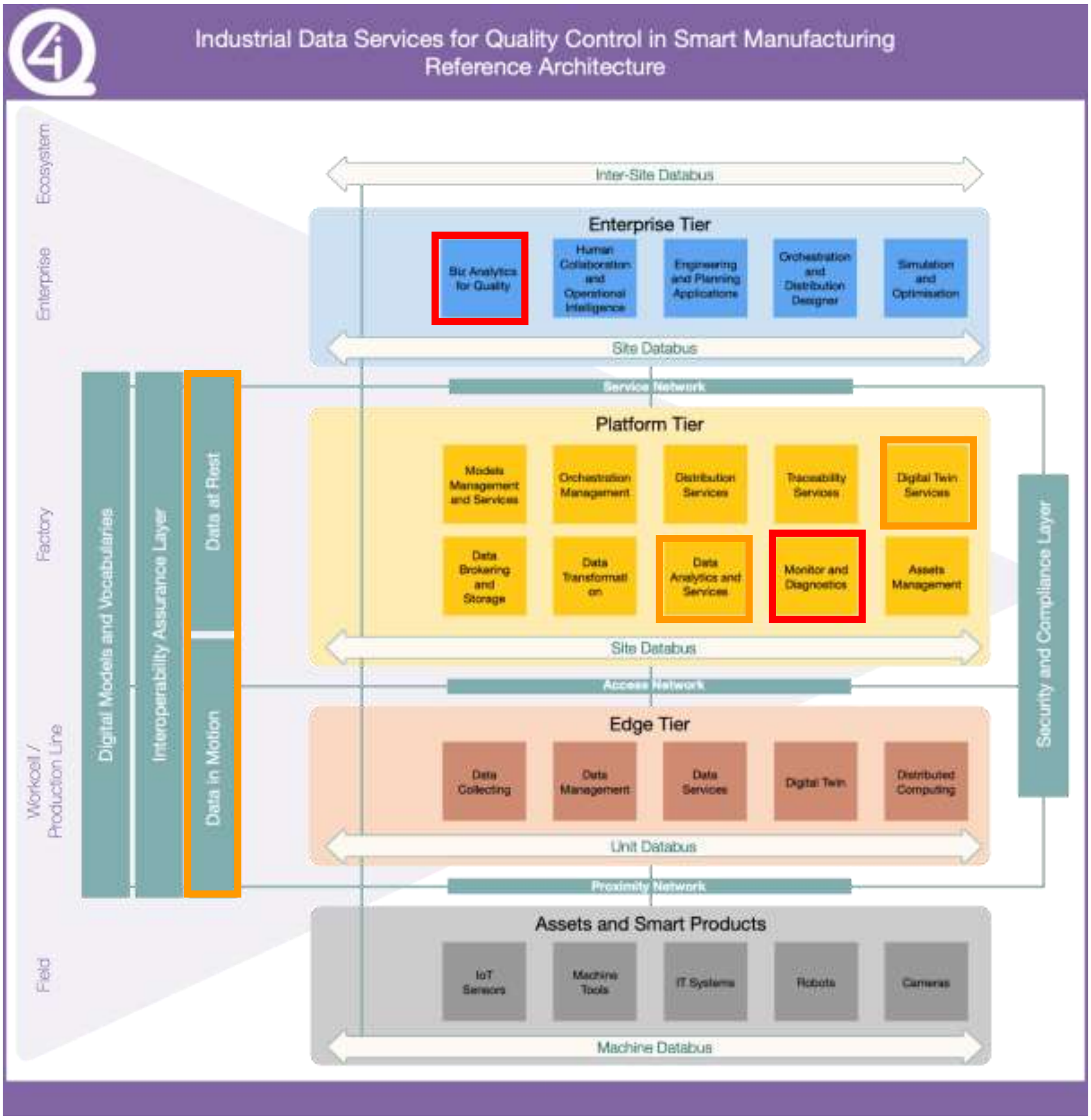

Figure 10. i4Q RA mapping with i4Q^AD

1.2.9.1 RA critical analysis: strengths and weaknesses

The i4Q^AD solution includes processes and services which are mapped to the Enterprise and Platform Tiers of the i4Q Reference Architecture. The strengths and weaknesses of i4Q^AD solution regarding the aforementioned mapping are presented below:

Strengths:

- **Enterprise Tier**: The i4Q^AD mapping to the "Biz Analytics for Quality" subcomponent. It provides a visualization tool capable of delivering analytics to allow management to monitor the processes and quality indicators in real-time, this helps manufacturers gain insight in specific operations, to aid in the decision-making process.
- **Platform Tier**: The i4Q^AD mapping to the "Monitor and diagnostics" subcomponent provides an easy way for a user to monitor and optimize production efficiency. By using

multiple visualization techniques, this tool will have bigger flexibility in terms of the types of visualization that can be presented, making it more adaptable and allowing for other components like the Data analytics and services or the digital twin services to utilize their visualization features with ease.

Weaknesses:

- **Platform Tier**: This solution relies heavily on the "Data Analytics and Services" component and will work both with data at rest and data streams in real-time. Any disruption of this data and/or data flow will not allow this tool to work properly.

1.2.10 i4Q^{AI} AI Models Distribution to the Edge

This solution provides assisted capabilities for distributing AI models to the edge. It includes the synchronization of information and state between a cloud-based entity and the models placed at the edge to be used by AI workloads orchestrated at the edge. AI models have a different life cycle than AI workloads and thus they require differential treatment, and possibility to place them at correct locations at the edge, monitor their effectiveness, and be able to receive feedback that may lead to retraining and redistribution of refined models to the edge.

ID			13_i4Q_AI
Responsible task			T4.3 "Scalable Policy-based Model Distribution from Cloud to Edge"
Solution name			i4Q^{AI} Models Distribution to the Edge
Solution definition			The objective of i4Q^{AI} is to address the management of AI-based models in a hybrid cloud-edge manufacturing environment. This capability is realized via the deployment of a multi-tier infrastructure covering the cloud as well as the edge. The main aim of i4Q^{AI} is to distribute AI models to the edge where they are expected to be used by locally running workloads. i4Q^{AI} ensures that the cloud and the edge are synchronized and respond together to the changing environment. The AI model distribution is coordinated with the workload distribution mechanism to ensure that the right set of AI models is made available for the workload that uses them.
Details	Functionalities offered		1. Distribution of AI models to the edge 2. Collect feedback from the running models 3. Redeploy models when changes take place
	Relies	#1	**ON: Distribution Service**

	(Highlited in orange below)		FOR: placing models at the chosen location
		#2	**ON: Orchestration and Distribution Designer** FOR: obtaining the models to be used
	Offers (Highlited in red below)	#1	WHAT: model management implementation **TO: Models Management and Services**
		#2	WHAT: AI models handling on the edge **TO: Distributed Computing**
	Technical background		i4Q^AI should work seamlessly well for small to very large multi-site infrastructure common in smart manufacturing environments. Thus, the scope may span from a small local plant to multiple sites organizations. This is achieved by employing on the one hand a discovery mechanism that keeps track of all relevant running components of the distributed system, and on the other hand, a policy-based placement mechanism that eases the task of the controller by enabling the specification of rules for eligible targets in a simplified manner (such as the model type, model version, geographic area, or the existence of specific resources). i4Q^AI is mainly mapped to the Platform Tier, but relies on services at the edge tier, and enables interaction with the enterprise tier. At the platform tier the most related components are the models management services and the distribution services. At the edge tier this solution is mapped to the distributed computing service, enabling the operation across a cloud and edge environment. Finally, at the enterprise tier there's a mapping with "orchestration and distribution designer", which enables easy specification of the parameters and criteria for the correct operation of this solution. Input consists of placement rules or models to be distributed. Output consists of a running model tied to a corresponding workload, and an updated view of the state at the edge.

Table 10. i4Q^AI solution analysis

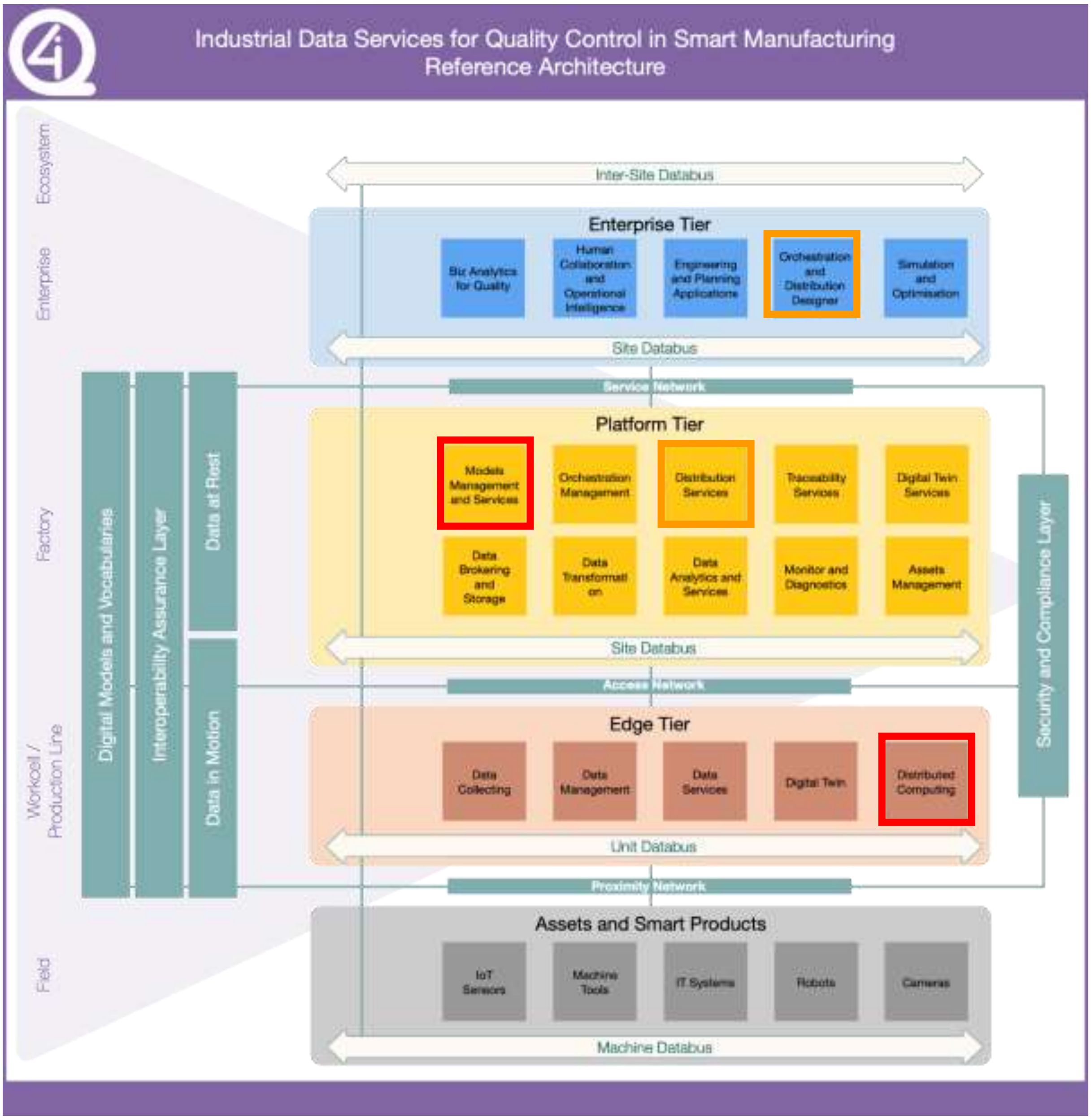

Figure 11. i4Q RA mapping with i4Q^AI

1.2.10.1 RA critical analysis: strengths and weaknesses

This solution includes different processes, which are mapped to the Platform Tier and to the Edge Tier of the i4Q Reference Architecture. Considering that this solution shall operate at various levels of the architecture, it will be analysed in terms of its weaknesses and strengths:

Strengths:

- **Platform Tier:** "models management and services" will enable the backbone for the realization of the capabilities of this solution. This shall serve as the hook between the enterprise tier authoring to the actual edge-based model deployment, while handling the corresponding specific lifecycle. Shall rely on the distribution service at the platform

tier for placing models at the chosen edge locations. Will interface with the "orchestration and distribution designer" for creating and updating the edge models to be deployed.
- **Edge Tier:** The solution mapping to "Distributed Computing" subcomponent, enabling AI models handling on the edge. This allows to deploy and run AI models deployed on the edge. This enables processing at the edge and transmitting any required data back to the cloud, taking into account different conditions.

Weaknesses:

- **Enterprise Tier**: this solution relies on the orchestration and distribution designer to feed the initial model, handle incoming feedback, and provide updated versions of the model. Any problems in communication between the edge and the cloud will slow down this process. Needs to take into account the velocity and heterogeneity of data

1.2.11 i4Q^EW Edge Workloads Placement and Deployment

This solution provides assisted capabilities for distributing AI workloads to the edge. It includes the workloads being placed at the edge to be used in conjunction with the corresponding AI models. AI workloads shall be handled by edge-based orchestrators. AI workloads have a different life cycle than AI models, and thus they are handled differently. Rules and policies are used first for the efficient distribution of workloads to the edge, with the final aim of having the workloads and the corresponding models to meet and collaborate at the right edge locations.

ID			14_i4Q_EW
Responsible task			T4.4 "AI Workload Placement and Deployment"
Solution name			i4Q Edge Workloads Placement and Deployment
Solution definition			This solution provides capabilities to deploy and run AI workloads at the edge. i4Q^EW enables workloads to execute efficiently on the edge, including placement and deployment services. Target deployment environment may be very heterogeneous and dynamic, thus deployment needs to take a variety of criteria into consideration. The dynamic environment may require re-deployment of the entire workload. A multi-tier Cloud/edge architecture provides efficient and flexible management of edge workloads with deployment on an orchestrator.
Details	Functionalities offered		1. Deploy and run AI workloads at the edge 2. Re-deploy workloads upon need
	Relies	#1	**ON: Distribution Services**

	(Highlited in orange below)		FOR: placing AI workloads at the chosen location.
		#2	**ON: Orchestration and Distribution Designer** FOR: obtaining the workloads to be used.
	Offers (Highlited in red below)	#1	WHAT: AI workloads management implementation **TO: Orchestration Management**
		#2	WHAT: AI workloads handling on the edge **TO: Distributed Computing**
	Technical background		i4Q^{EW} mainly resides at the Platform Tier, but relies on services at the edge tier, and enable interaction with the enterprise tier. At the platform tier, the most related components are the orchestrator management and the distribution services. The distribution services cover the placement and deployment of workloads at the edge. Workload placement and deployment shall ease the orchestration within the entire platform. At the edge tier, this solution is mapped to the distributed computing service, enabling the operation across a cloud and edge environment. Finally, at the enterprise tier there's a mapping with the "orchestration and distribution designer", which uses the orchestration management to carry out operations in the field. Input consists of a workload to be deployed at the edge. The output consists of a running edge workload and an updated view of the state at the edge.

Table 11. i4Q^{EW} solution analysis

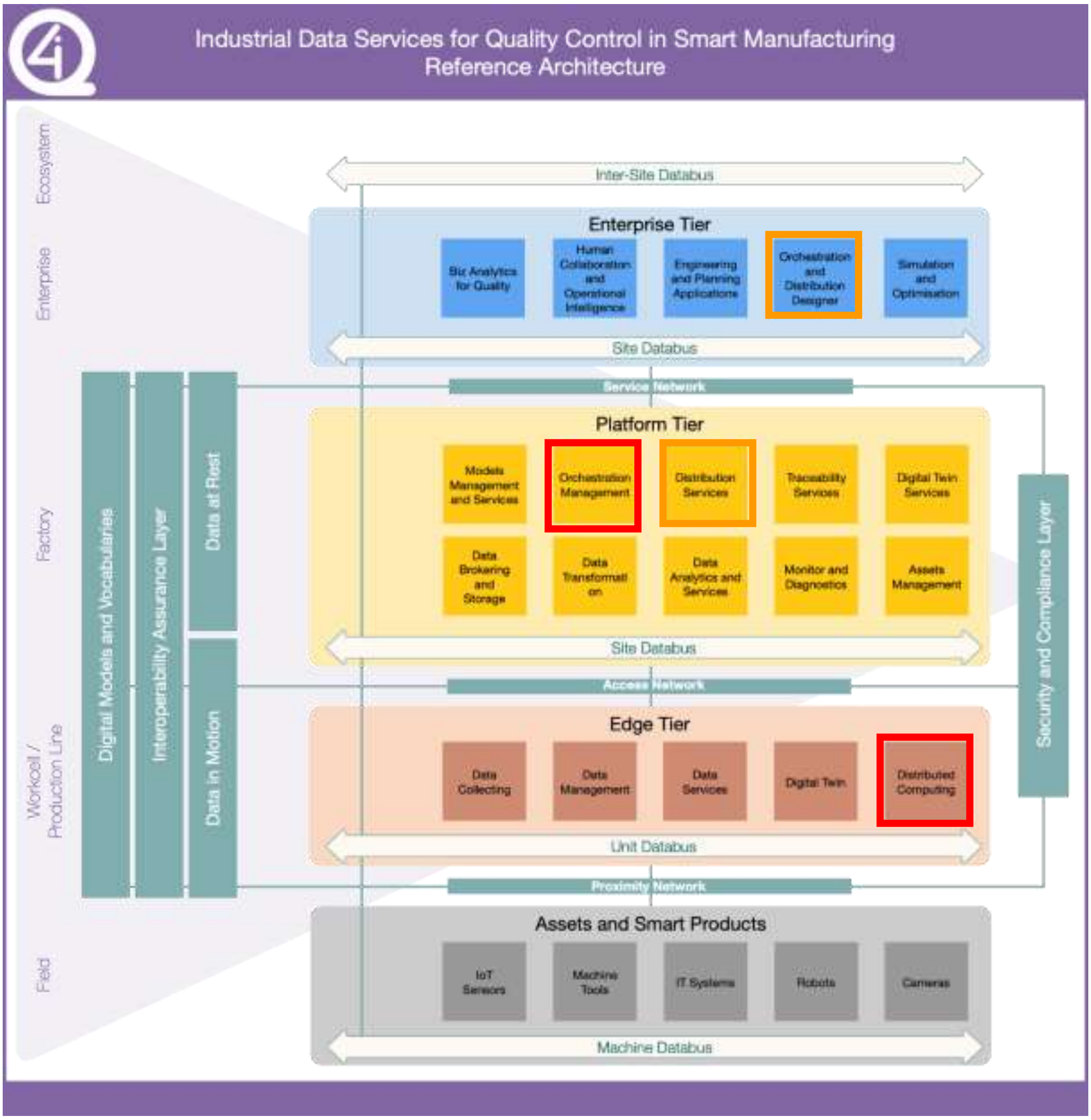

Figure 12. i4Q RA mapping with i4Q^EW

1.2.11.1 RA critical analysis: strengths and weaknesses

This solution includes different processes, which are mapped to the Platform Tier and to the Edge Tier of the i4Q Reference Architecture. Considering that this solution shall operate at various levels of the architecture, it will be analyzed in terms of its weaknesses and strengths:

Strengths:

- **Platform Tier:** "Orchestration Management" shall be used for the AI workloads management implementation. This shall serve as the hook between the enterprise tier authoring to the actual edge-based workload deployment while handling the corresponding specific life cycle of workload deployment and redeployment upon need. This component shall rely on the distribution service at the platform tier for placing workloads at the designated edge locations. It shall interface with the "orchestration and distribution designer" for creating and updating the edge workloads to be deployed and redeployed upon need.

- **Edge Tier:** The solution mapping to "Distributed Computing" subcomponent, enabling AI workloads handling on the edge. This allows to deploy, run, and redeploy AI workloads on the edge upon need. This enables processing at the edge and aided by the monitoring component, send concise and useful data back to the cloud-based operator to be able to analyze the state of the workloads and models.

Weaknesses:

- **Enterprise Tier**: this solution relies on the orchestration and distribution designer to feed the initial workload, handle incoming feedback, and provide updated versions of the workload to be redeployed upon need. Any problems in communication between the edge and the cloud will slow down this process. Needs to take into account the velocity and heterogeneity of data

1.2.12 i4Q^IM Infrastructure Monitoring

i4Q^IM assists in monitoring other solutions along with the production lines/workloads. It is responsible for predicting/detecting problems and failures in manufacturing processes, and for providing alerts.

ID			15_i4Q_IM
Responsible task			T4.5 "Smart Manufacturing Monitoring and Alerting"
Solution name			i4Q Infrastructure Monitoring
Solution definition			i4Q^IM provides an ensemble of monitoring tools for smart manufacturing workload orchestration and predictive failure alerting, including monitoring the health of workloads and productively alerting and taking corrective actions when a predicted problem is detected. i4Q^IM supports industrial companies to reach autonomous operation and eliminate defects in manufacturing environments.
Details	Functionalities offered		1. Monitoring of other analytical solutions that can assist in detecting faults. 2. Multi-level monitoring of the manufacturing processes. 3. Predictive failure alerting. 4. Taking corrective actions upon failure and harmful events detection.
	Relies	#1	**ON: Data Collecting**

	(Highlighted in orange below)		FOR: Collecting data from manufacturing asset repository (e.g., sensors).
		#2	**ON: Data Brokering and Storage** FOR: Importing data from Data repository and Data integration solutions, respectively.
		#3	**ON: Models management and services** FOR: Management of AI algorithms and monitoring of other analytical solutions.
		#4	**ON: Data Management** FOR: Managing input data derived from other solutions to achieve their homogenisation and synchronization.
	Offers (Highlighted in red below)	#1	WHAT: Alerts for harmful events **TO: Monitor and Diagnostics**
	Technical background		i4Q[IM] or Infrastructure Monitoring, is mainly mapped to the Monitor and Diagnostics sub-component of the Platform Tier. The solution will monitor the health of workloads and produce alerts when a problem is predicted. Using AI-based models trained on historical data collected from the various sensors installed in the machinery, will enable the prediction of imminent failures and provide corrective countermeasures in order to fix the problem in time and prevent a production line shutdown. By continuously gathering data from the sensors and using them to further improve the performance of the AI models, this solution seeks to achieve a fully autonomous operation in manufacturing environments.

Table 12. i4Q[IM] solution analysis

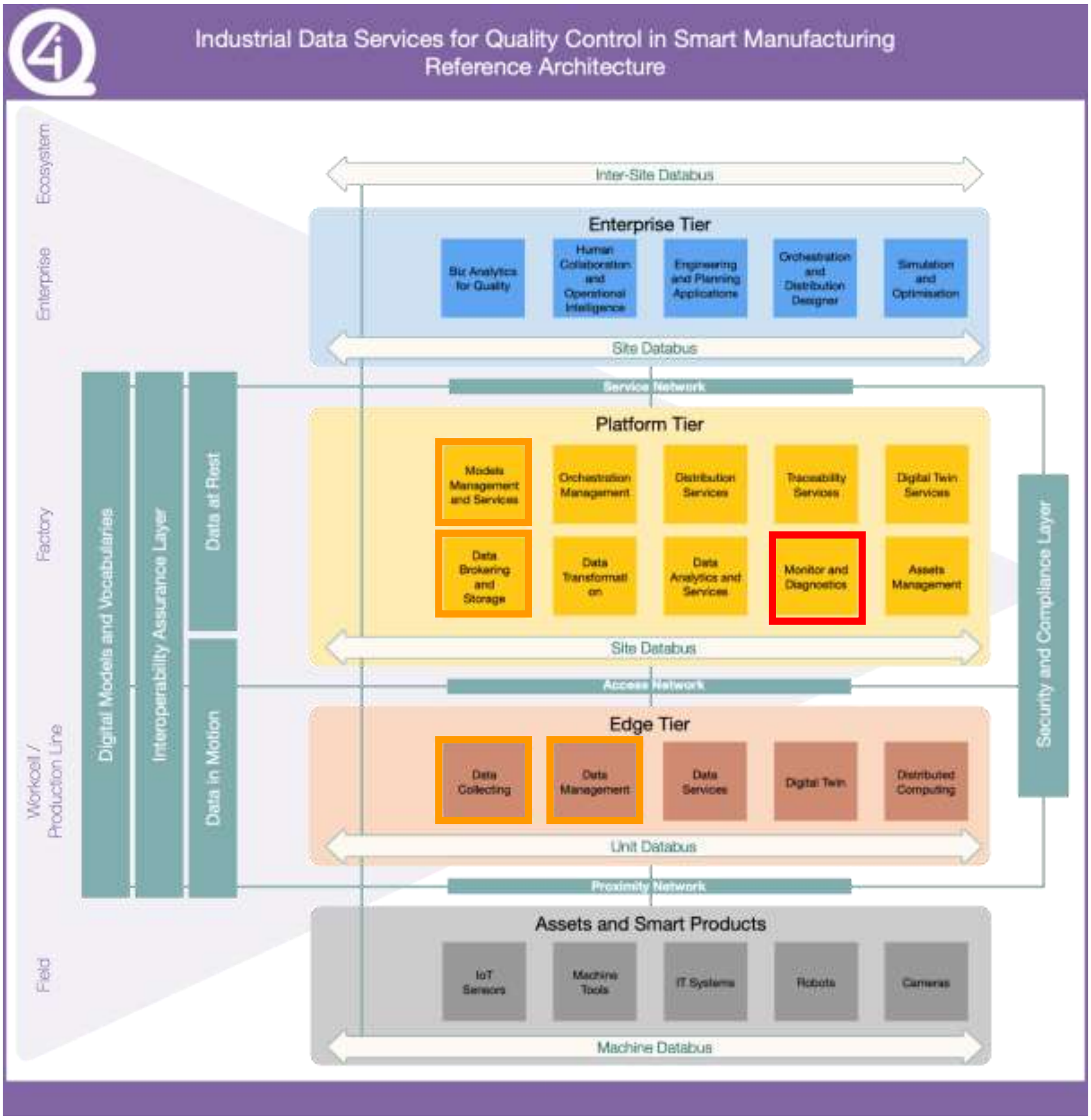

Figure 13. i4Q RA mapping with i4Q[IM]

1.2.12.1 *RA critical analysis: strengths and weaknesses*

i4Q[IM] solution includes processes and AI models which are mapped to the Platform and Edge Tiers of the i4Q Reference Architecture. The strengths and weaknesses of i4Q[IM] solution regarding the aforementioned mapping are presented below:

Strengths:

- **Platform Tier**: The i4Q[IM] mapping to "Data Brokering and Storage" provides access to a rich multi-source data pool. This process enables optimal predictive model training and thus a more accurate and reliable alerting system. The i4Q[IM] mapping to "Models Management and Services" sub-component enables the effective monitoring of multiple analytical solutions. Analysis of their individual analytical results and its own predictive analysis are combined into ensemble models to ensure highly accurate infrastructure monitoring. The i4Q^{IM} mapping to "Monitor and Diagnostics" sub-component provides a standalone or a multi-model alerting system that can notify either human operators or other related i4Q solutions to take necessary corrective actions when a machine failure has been detected. The predictive alerting mechanisms may eliminate defects, ensure avoiding costly repairs and production downtime, and achieve optimal trade-offs between manufacturing production rate and product quality.

- **Edge Tier**: The i4Q^{IM} mapping to "Data Collecting" sub-component enables collecting data from sensors in the manufacturing lines, to provide real-time prediction and detection of failures lying in a manufacturing process. The i4Q^{IM} mapping to "Data Management" sub-component ensures the efficient analysis of the imported multi-source data (i4Q^{DR} data, i4Q^{DIT} data, sensor data). Correlation/causality analysis may reveal the latent relationships governing the time series coming from other solutions and manufacturing asset repositories.

Weaknesses:

- **Platform Tier**: The i4Q^{IM} mapping to Data Brokering and Storage sub-component should provide fast delivery and adequate pre-processing of the data in order for the monitoring tool to operate in real-time. The i4Q^{IM} mapping to "Models Management and Services" sub-component should track closely and precisely the real-time data coming from other analytical solutions. To obtain accurate and time consistent infrastructure monitoring the data derived from different analytical solutions should be efficiently synchronized and properly processed. The i4Q^{IM} mapping to "Monitor and Diagnostics" sub-component should be highly accurate and reliable to avoid false alarming while ensuring the detection/prediction of imminent failures. To achieve this, robust AI models and high-quality data are mandatory.
- **Edge Tier**: The i4Q^{IM} mapping to "Data Management" sub-component should provide adequately fast pre-processing of the imported multi-source data, to ensure the efficiency of the online monitoring processes. The i4Q^{IM} mapping to "Data Collecting" sub-component should be able to collect and closely track large scale data from several sensors.

1.2.13 i4Q^{DT} Digital Twin simulation services

The Digital Twin simulation services solution provides a connected 3D production simulation environment. It enables virtual validation/visualisation and productivity optimisation. It will make use of both pre-existing data and simulated data (virtual sensors) obtained with the developed model. It will also make use of data from different factory levels (small cell to entire factory).

ID	16_i4Q_DT
Responsible task	T4.6 "Manufacturing Digital Simulation Models"
Solution name	Digital Twin Simulation Services
Solution definition	i4Q^{DT} provides an environment that enables the generation of physics-based or data-driven

			models based on predefined libraries, as well as loading already existing models to the solution. Thus, the solution will be able to launch simulations using the models, feeding them with data obtained at different stages and levels of a factory.
Details	Functionalities offered		1. Providing the capability of generating models and stablishing the relationships between the inputs of the model and the collected data (contextualization) 2. Providing the capability of running simulations on the models
	Relies (Highlighted in orange below)	#1	**ON: Data Collecting** FOR: providing inputs to the Digital Twin models.
	Offers (Highlighted in red below)	#1	WHAT: generated models with the relationship between the inputs of the model and the collected data. **TO: Digital Twin**
		#2	WHAT: capability of running simulations on the models **TO: Digital Twin Services**
	Technical background		The i4Q^{DT} solution is mapped to the Digital Twin subcomponent of the Edge Tier providing the capability of generating models and establishing the relationships between the inputs of the model and the collected data (contextualization) and the Digital Twin Services subcomponent of the Platform Tier providing the capability of running simulations on the models. It will also be using the Data Collecting subcomponent of the Edge Tier for providing inputs to the Digital Twin models. The models of the i4Q^{DT} can be either data-driven or physic-based. The former consists of supervised learning algorithms that allow predicting future events based on historical data. The latter relies on differential equations

		that represent the physics behind the systems to be modelled. Potentially, this kind of models will be generated using the FMI standard. In order to construct the models, the i4Q^{DT} will use a set of predefined libraries for both approaches. Moreover, data will be needed as an input to construct the models in the data-driven approach, and in both approaches to update and simulate the models. These data will be obtained from the i4Q^{DR}. These data will consist of time-series recorded and previously processed, as well as a set of features.

Table 13. i4Q^{DT} solution analysis

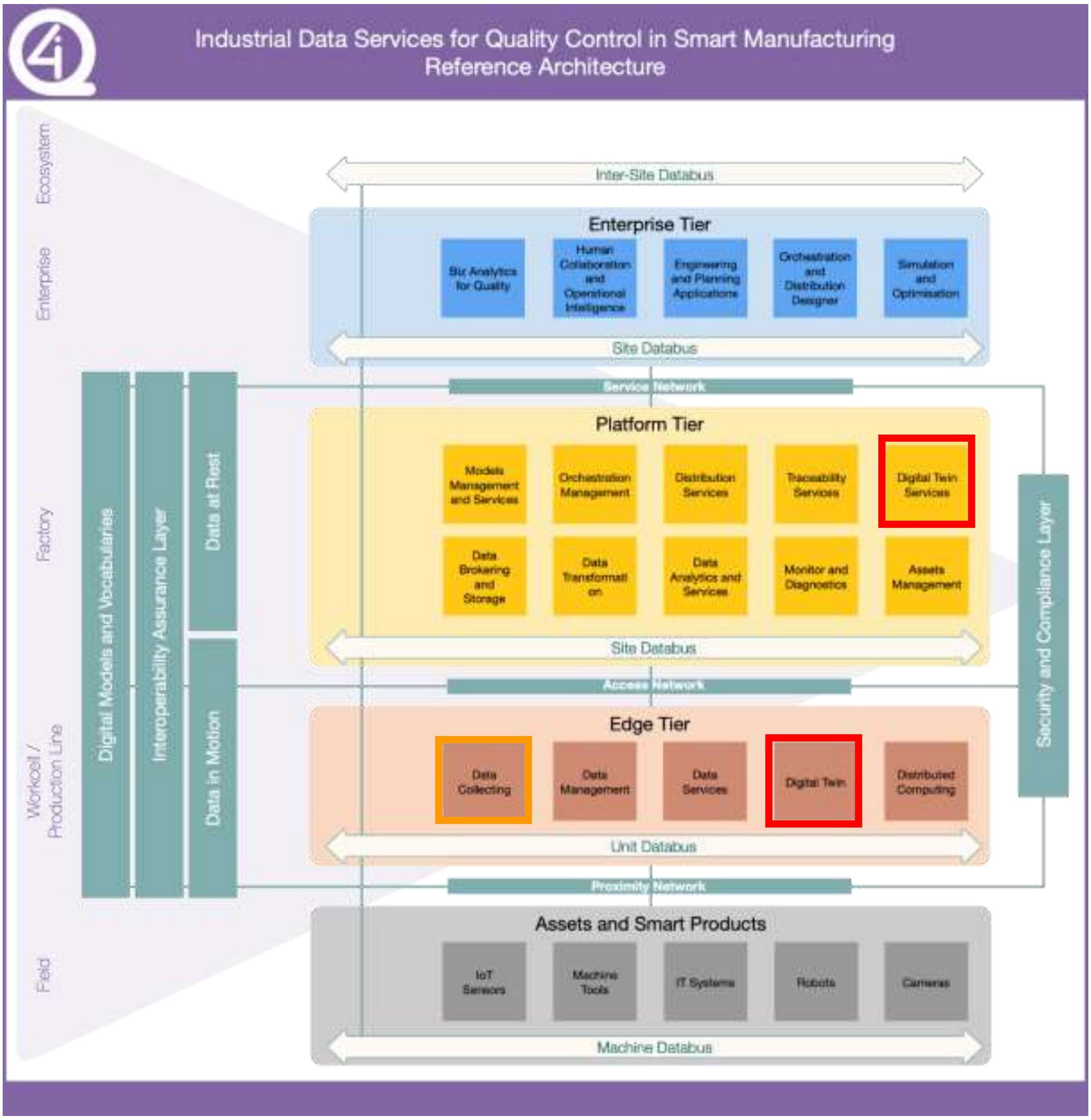

Figure 14. i4Q RA mapping with i4Q^DT

1.2.13.1 RA critical analysis: strengths and weaknesses

The processes and services that are being included in the i4Q^DT software tool are mapped to two tiers in the i4Q Reference Architecture: the Platform Tier and the Edge Tier. The strengths and weaknesses of i4Q^DT solution regarding the aforementioned mapping are presented below:

Strengths:

- **Platform Tier**: The service that is being used in this tier is the "Digital Twin Services". Here the Digital Twin will be offering other solutions simulations as a service, in order for the results to be exploited by them with any other purpose.
- **Edge Tier**: The i4Q^DT solution is comprised of the "Digital Twin" and the "Data Collecting" services, giving the Digital Twin the ability to represent with high fidelity the specific component, asset or plant.

Weaknesses:

- **Edge Tier**: The "Data Collecting" is critical for the i4Q^DT as it requires data to launch the simulations. If this component fails, many of the capabilities of the solution will not be exploited.

1.2.14 i4Q^PQ Data-driven Continuous Process Qualification

Process Qualification is a common tool to evaluate machine parameters in relation to quantitative quality measurement. Keeping these parameters in a predefined range is crucial for manufacturing products of the same quality. Therefore, descriptive statistics is required to check samples to a desired level of confidence if all produced goods stay in the same range of quality. Since this approach can only evaluate already manufactured products and is not including a real-time component, all produced goods between the time a failure was identified and the current point of time are classified as waste. To counteract these day-to-day issues, sensor data that describes important process parameters are combined to a predictive statistical model which will forecast the process quality in a specific time frame to a certain level of confidence. Furthermore, the collection of real-time data enables a continuous as-is evaluation to interact when the prediction was not precise enough.

ID	17_i4Q_PQ
Responsible task	T5.1 "Manufacturing Line Continuous Process Qualification"
Solution name	i4Q Data-driven Continuous Process Qualification
Solution definition	This solution provides a continuous Process Qualification concerning KPIs like Process Capability and Process Performance which are essential during ramp-up and after reconfiguration of production processes. Thus, not only descriptive monitoring is possible. By

			running data through predictive algorithms, it will also provide forecasts for each KPI within a given time frame.
Details	Functionalities offered		1. Continuous process qualification monitoring in real-time 2. Prediction of process qualification on an individual time frame 3. Parallel running model evaluation
	Relies (Highlighted in orange below)	#1	**ON: Data Brokering and Storage** FOR: Reading machine sensor data via an established data pipeline for feeding the algorithm.
		#2	**ON: Data Management** FOR: Receiving the data in a proper way at the right time.
		#3	**ON: Data Services** FOR: Deploying the provided code in a convenient infrastructure.
		#4	**ON: Data in Motion** FOR: Deploying the algorithm.
		#5	**ON: Data at Rest** FOR: Learning the algorithm and for model building.
	Offers (Highlighted in red below)	#1	WHAT: Providing information about the status of the process capability and performance to further interact with the machine. **TO: Human Collaboration and Operational Intelligence**
		#2	WHAT: Future process capability and performance can be used for the digital twin as input parameter. **TO: Digital Twin Services**
		#3	WHAT: Typical post-processed data in visualized format for better understanding of the algorithm output. **TO: Data Transformation**
		#4	WHAT: Continuous monitoring of performance

			and process capability **TO: Monitor and Diagnostics**
	Technical background		The solution takes pre-processed machine sensor data and feeds it into a time series neural network like CNN or LSTM to learn and predict process anomalies. This is visualized by a scorecard with individual upper and lower control limits defined by a user. When the prediction is out of this range, an alert is sent to the process owner. This information can be used for the Infrastructure Monitoring to highlight occurring anomalies or as input parameter for the digital twin (if needed).

Table 14. i4Q[PQ] solution analysis

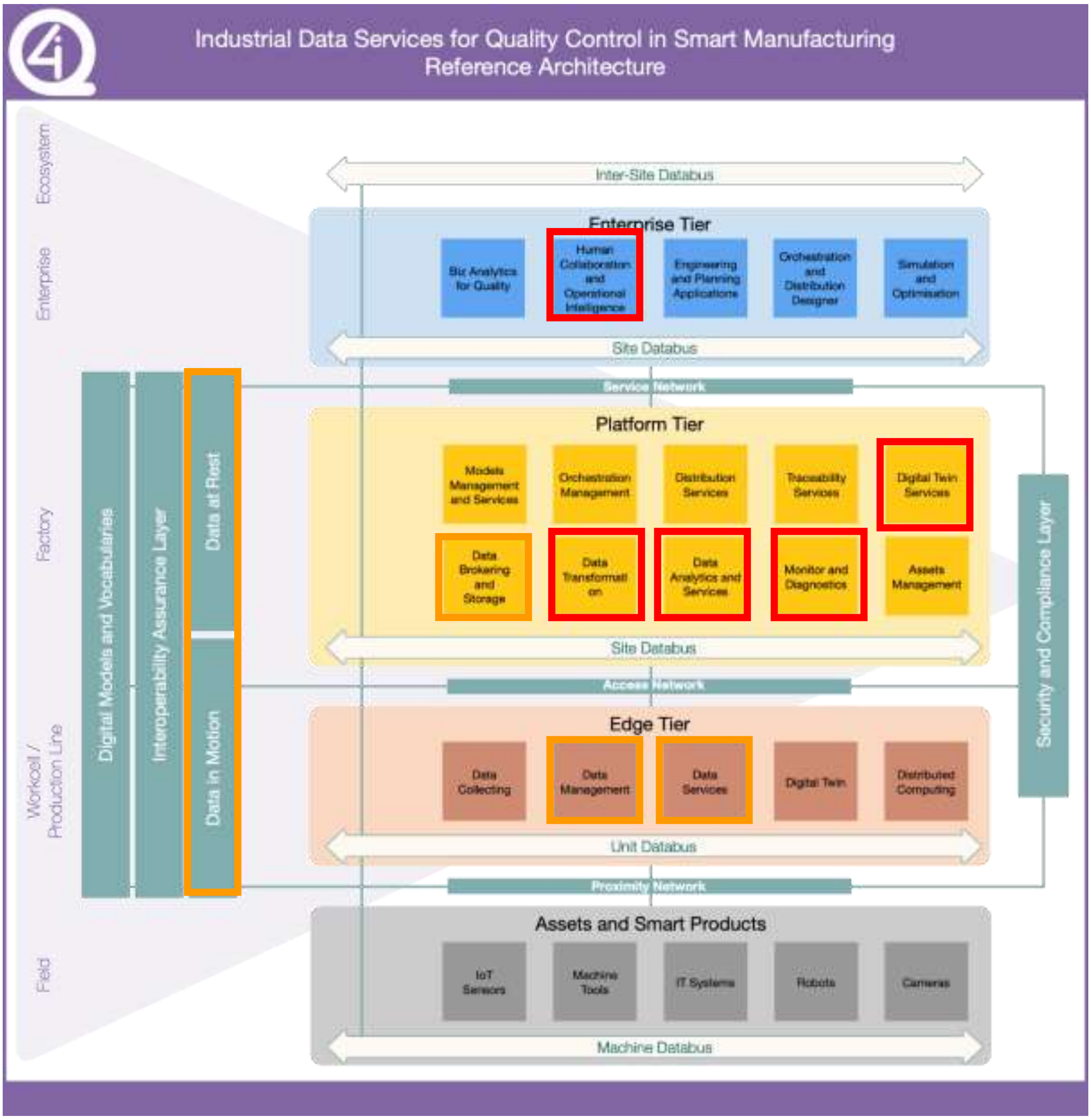

Figure 15. i4Q RA mapping with i4QPQ

1.2.14.1 RA critical analysis: strengths and weaknesses

The solution i4Q^PQ is mapped to several components of the i4Q Reference Architecture. The strengths and weaknesses of i4Q^PQ solution regarding the aforementioned mapping are presented below:

Strengths:

- **Platform Tier**: Since the provided information includes a prediction of the process capability, all process parameters are evaluated concerning the process quality. This information can be added to several other solutions in their own needs on the platform tier. However, the main aspect is to provide predictive decision support to the process owner (Human Collaboration and Operational Excellence) if the process quality will get out of the desired range of quality.

Weaknesses:

- **Platform Tier:** For the deployment of the algorithm a stable data pipeline with standardized transformation steps is necessary. Furthermore, the prediction is only possible if a vast amount of historical data is used for the algorithm training. This is completely dependent on the use case but needs to be taken into account when transferring and storing data.

1.2.15 i4Q^{QD} Rapid Quality Diagnosis

i4Q^{QD} solution is responsible for the online quality diagnosis of products and processes in manufacturing lines. It evaluates/predicts the product quality, the machine condition, and the possible cause of failures on the fly. Action recommendations (e.g., "stop the machine") are provided whenever it is necessary, to eliminate production defects and to prevent/avoid any potential damages in the machine/production line. Finally, the analytical results and the evaluation metrics derived from the i4Q^{QD} solution are visualized.

ID			18_i4Q_QD
Responsible task			CERTH
Solution name			T5.2 "Manufacturing Line Quality Diagnosis and Smart Alerting"
Solution definition			i4Q^{QD} is a micro-service for providing rapid diagnosis of manufacturing line on the possible cause of failures, evaluating data fidelity, product-quality and process condition, and providing action recommendations for sensor/data processing recalibrations, process line/machine reconfiguration or maintenance actions.
Details	Functionalities offered		1.Diagnosing the condition of the manufacturing line 2. Failure detection 3.In-process product quality prediction 4 Informing the need for sensor calibration and machine reconfiguration to achieve maintenance
	Relies (Highlighted in orange below)	#1	**ON: Data Brokering and Storage** FOR: Import data from Data Repository, Data Integration, Digital Twin solutions, and other databases
		#2	**ON: Digital Twin Services** FOR: Import information from the Digital Twin

			solution to assist the training of the AI models and further improve their performance using virtual data.
		#3	**ON: Data Management** FOR: Managing data derived from different solutions.
	Offers (Highlighted in red below)	#1	WHAT: Visualizations about quality diagnosis and evaluation metrics of the models that provide the diagnosis. The output is stored in i4Q[DR]. **TO: Data Brokering and Storage**
		#2	WHAT: Analytical results through the development/deployment of AI models **TO: Data Analytics and Services**
	Technical background		i4Q[QD] or Rapid Quality Diagnosis, is mainly mapped to the Monitor and Diagnostics subcomponent of the Platform Tier. The solution provides smart alerting and quality diagnosis. It is a micro-service for providing rapid diagnosis of manufacturing line on the possible cause of failures, evaluating data fidelity, product quality, and providing action recommendations for sensor/data processing recalibrations, process line/machine reconfiguration or maintenance actions. It detects failures in the quality of the products during manufacturing and sends notifications/alerts to the system operator.

Table 15. i4Q[QD] solution analysis

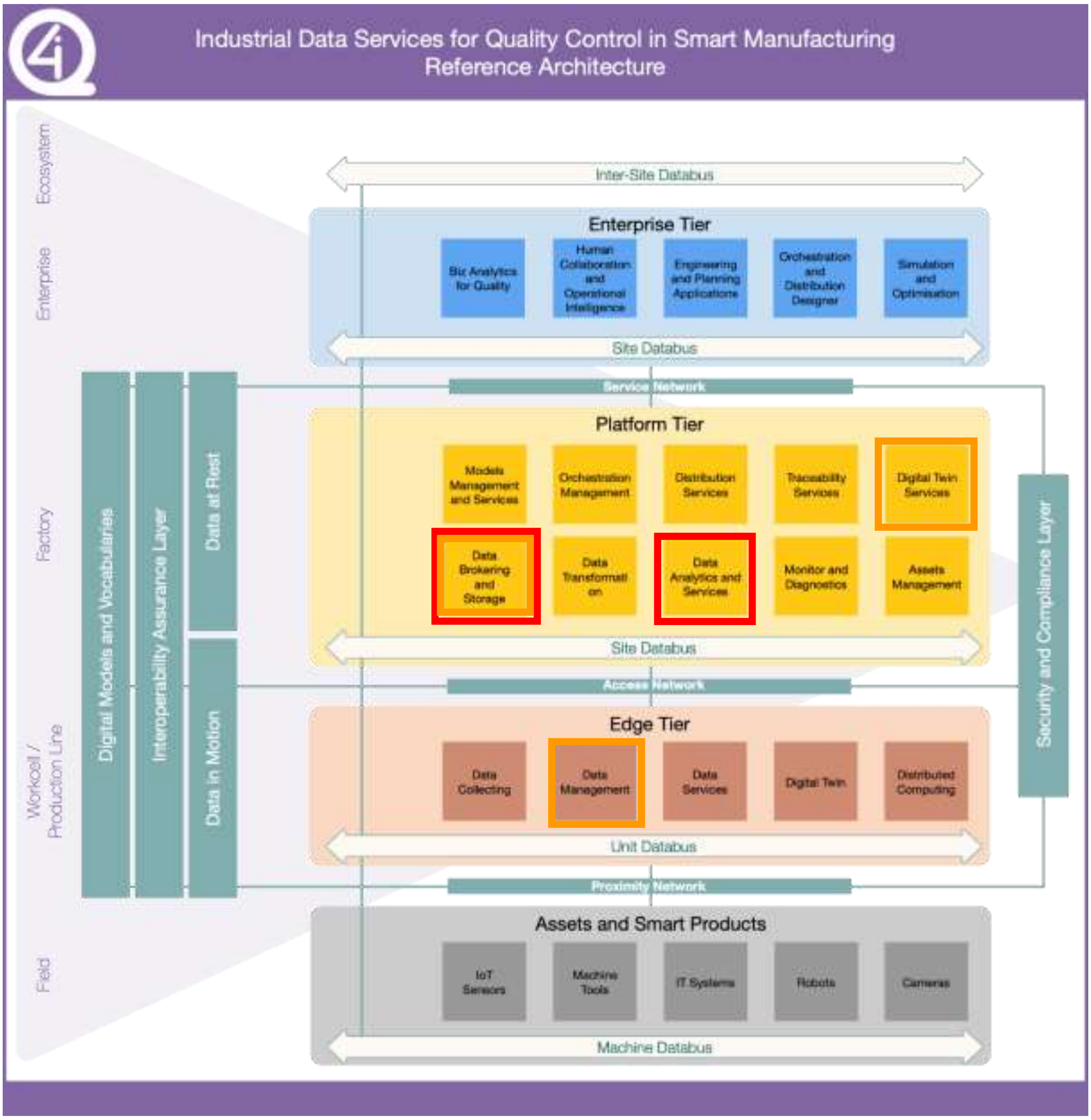

Figure 16. i4Q RA mapping with i4Q^{QD}

1.2.15.1 RA critical analysis: strengths and weaknesses

i4Q^{QD} solution includes processes and AI models which are mapped to the Platform and Edge Tiers of the i4Q Reference Architecture. The strengths and weaknesses of i4Q^{QD} solution regarding the aforementioned mapping are presented below:

Strengths:

- **Platform Tier**: The i4Q^{QD} mapping to "Data Brokering and Storage" sub-component allows for accessing a rich multi-source data pool. This process enables optimal predictive model training and thus a more accurate and reliable quality diagnosis system. The analysis results of i4Q^{QD} are stored in i4Q^{DR}. The i4Q^{QD} mapping to "Data Analytics and Services" sub-component allows the solution to provide the analytical results obtained by the performed quality diagnosis to other i4Q solutions. The information derived from its analysis may suggest either the reconfiguration of the machine upon the detection of low quality and damaged products or the emergency shutdown of the machine to avoid further defective products in case the problem is not possible to be fixed. The i4Q^{QD} mapping to "Digital Twin Services" sub-component allows the AI models, responsible for the quality diagnosis, to be further trained using the data generated through virtualization. In contrast with the historical data accessed from the data repositories that are limited, the abundance of virtual data can prove beneficial to the optimization of the models.

- **Edge Tier**: The i4Q^{QD} mapping to "Data Management" sub-component ensures the effective feature engineering and data processing imported from several sources (i4Q^{DR}, i4Q^{DIT}). To reveal the latent structure of the imported data, correlation analysis will be applied.

Weaknesses:

- **Platform Tier**: The i4Q^{QD} mapping to "Digital Twin services" sub-component should involve consistent data synchronization to ensure the correctness of real-time operations. The i4Q^{QD} mapping to "Data Brokering and Storage" sub-component should involve the proper forming and storing of the analysis results in Data Repository in order to facilitate information analysis, retrieval, and output visualization. The i4Q^{QD} mapping to "Data Analytics and Services" sub-component should ensure the development of robust AI models which provide highly accurate estimations/predictions and analysis results. Fundamental signal processing analysis and efficient mathematical approaches should be applied to guarantee exceptional product quality.
- **Edge Tier**: Within the context of i4Q^{QD} mapping to "Data Management" sub-component a large amount of data should be pre-processed at high speeds.

1.2.16 i4Q^{PA} Prescriptive Analysis Tools

The Prescriptive Analysis Tool provides mainly simulations as a service. It exploits the Digital Twin developed to test different configuration parameters and analyze the effect small changes can produce in the production. It makes use of manufacturing resources, production planning and process condition. The prescriptive analysis will come from exhaustive simulation with no specific optimization algorithm implemented.

ID	19_i4Q_PA
Responsible task	T5.3 "Simulation and Optimisation for Smart Manufacturing Line"
Solution name	Prescriptive Analysis Tools
Solution definition	i4Q^{PA} will allow the user to launch a wide range of simulations of a model, even if the model has been generated in the i4Q^{DT} solution or not. These simulations will be evaluated according to some metrics and evaluation criteria that a user can define in the solution. Thus, the i4Q^{PA} will provide a ranking

			for the different configurations defined for the simulations, providing a prescription based on the evaluation criteria.
Details	Functionalities offered		1. Providing the capability of defining several scenarios to run simulations of the Digital Twin.
	Relies (Highlighted in orange below)	#1	**ON: Data Analytics and Services** FOR: evaluating the performance of each simulation run.
		#2	**ON: Orchestration Management** FOR: efficiently handle the execution of the defined simulations.
		#3	**ON: Simulation and Optimization** FOR: exhaustive simulation performed to identify the ranking of scenarios.
	Offers (Highlighted in red below)	#1	WHAT: definition of several scenarios to run simulations of the Digital Twin. **TO: Digital Twin Services**
	Technical background		i4Q^{PA} is mapped to the Digital Twin Services sub-component of the Platform Tier, providing the capability of defining several scenarios to run simulations of the Digital Twin. It is also related to the Data Analytic and Services subcomponent to evaluate the performance of each simulation run, and the Orchestration management to efficiently handle the execution of the defined simulations, both from the same Tier and the Simulation and Optimisation sub-component of the Enterprise Tier performing exhaustive simulation to identify the best scenario proposed. The i4Q^{PA} will use the kind of models already described in the i4Q^{DT} solution, as well as the same kind of data to perform the simulations. Apart from that, once the simulation results are obtained from the i4Q^{DT}, the i4Q^{PA} will use performance evaluation algorithms in order to rank all the simulations. Thus, different evaluation criteria will be defined based on

		the KPIs or the time series that the i4Q^DT results provide.

Table 16. i4Q^PA solution analysis

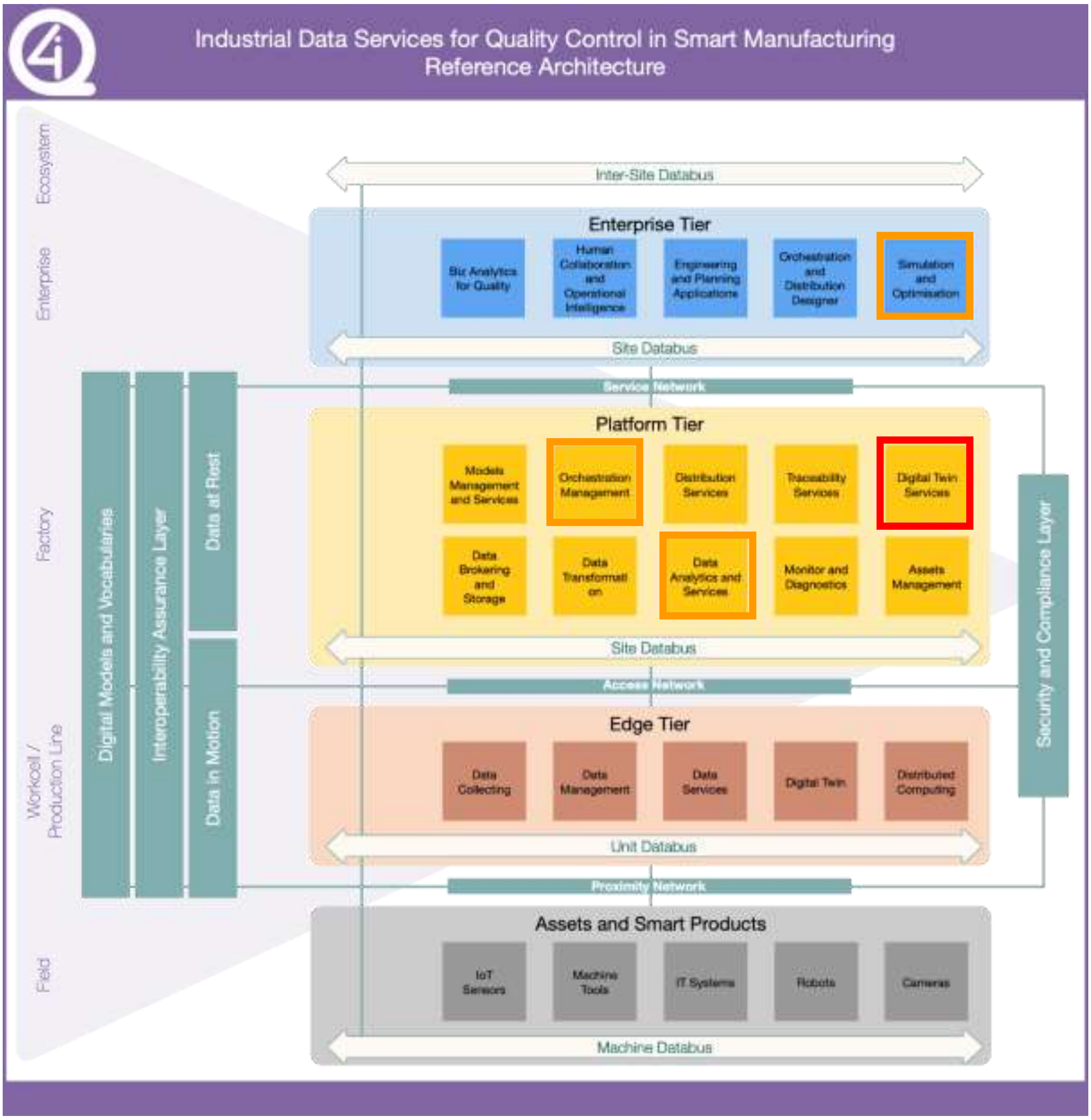

Figure 17. i4Q RA mapping with i4Q^PA

1.2.16.1 RA critical analysis: strengths and weaknesses

The processes and services that are being included in the i4Q^PA software tool are mapped to two tiers in the i4Q Reference Architecture: the Enterprise Tier and the Platform Tier. The strengths and weaknesses of i4Q^PA solution regarding the aforementioned mapping are presented below:

Strengths:

- **Enterprise Tier:** The i4Q^PA mapping to "Simulation and Optimization" sub-component enables the capability of obtaining prescriptions after the execution of multiple simulations in order to identify best and worse scenarios, as well as a full ranking, and establishing some thresholds in certain variables.
- **Platform Tier:** the Digital Twin services is providing the capability of simulating a model under some specific conditions which is the core of this solution, whereas the Orchestration management will allow the correct handling of all the simulations to be launched, Data Analytics and Services will be providing the capability to evaluate the performance of each model.

Weaknesses:

- **Platform Tier:** This is an offline tool prepared to give a prescription, but there is a lack of a closed-loop.

1.2.17 i4Q^LRT Manufacturing Line Reconfiguration Toolkit

i4Q^LRT solution is a tool that aims to increase productivity and reduce the manufacturing line reconfiguration effort through AI. This toolkit consists of a set of analytical components to solve known optimisation problems in the manufacturing process quality domain by finding the optimal configuration for the modules and parameters of the manufacturing line. It will allow to set up machines along the line focusing on quality standards, using as a basis some examples of problems that i4Q^LRT solves for manufacturing companies.

ID	20_i4Q_LRT
Responsible task	T5.4 "Manufacturing Line Reconfiguration"
Solution name	Manufacturing Line Reconfiguration Toolkit
Solution definition	i4Q^LRT is a collection of optimisation micro-services that use simulation to evaluate different possible scenarios and propose changes in the configuration parameters of the manufacturing line to achieve improved quality targets. i4Q^LRT AI learning algorithms develop strategies for machine parameters calibration, line setup and line reconfiguration. The objective of Manufacturing Line Reconfiguration Toolkit is to increase productivity and reduce the efforts for manufacturing line reconfiguration through AI. This tool consists of a set of analytical components (e.g., optimisation algorithms, machine learning models) to solve known optimisation problems in the manufacturing process quality domain, finding the optimal configuration for the modules and parameters

			of the manufacturing line. Fine-tune the configuration parameters of machines along the line to improve quality standards or improve the manufacturing line set-up time are some examples of the problems that the $i4Q^{LRT}$ solves for manufacturing companies.
Details	Functionalities offered		1. It provides the possibility to deploy algorithms at the edge of the network, via distributable files. 2. Provides informations necessary to understand the use, characteristics and needs of the algorithm.3. Offers the ability to instantiate an algorithm. 4. Allows algorithms to be run and solved at the edge of the network, obtaining information directly from the production line. In this way, the algorithms can optimise the production line automatically.
	Relies (Highlighted in orange below)	#1	**ON: Digital Twin Services** FOR: The services of digital twin are used to optimise the analysis of the algorithms used with our solution.
		#2	**ON: Distributed Computing** FOR: Distributed Distributable file at Edge.
		#3	**ON: Data Brokering and Storage** FOR: Client connect for taking data.
	Offers (Highlighted in red below)	#1	WHAT: This tool provides optimisation results of the production line configuration, which are dumped on clients for their use. **TO: Simulation and Optimisation**
		#2	WHAT: Deploy new configuration data to the different clients **TO: Data Brokering and Storage**
	Technical background		$i4Q^{LRT}$ or Manufacturing Line Reconfiguration Toolkit, is mapped to the **Simulation and Optimisation** sub-component of the Enterprise tier. To facilitate the interconnection between

		processes and to scale the deployment of solutions across different industries and sectors. Regarding the **Digital Twin Services** of models and algorithms with the underlying physical architecture, they should be regarded as (virtual) assets. For instance, an algorithm to optimise (i.e., fine-tune) the configuration parameters of a machine should be regarded as a feature of its digital twin, and in that sense, the services provided by the interoperability layer should be mappable as features of the digital twin. Some of these workflows may require that models be executed at the edge tier, close to the data source, to minimise latency. Therefore, the interoperability layer must ensure that the algorithms are deployable at the edge, through the **Distributed Computing**, and manageable by the **Orchestration Management** Sub-component. Finally, **Data Brokering and Storage** will be used to manage the connection with the different clients, be it data storage, files, and communication methods, which will allow data to be managed both for input and output.

Table 17. i4Q^{LRT} solution analysis

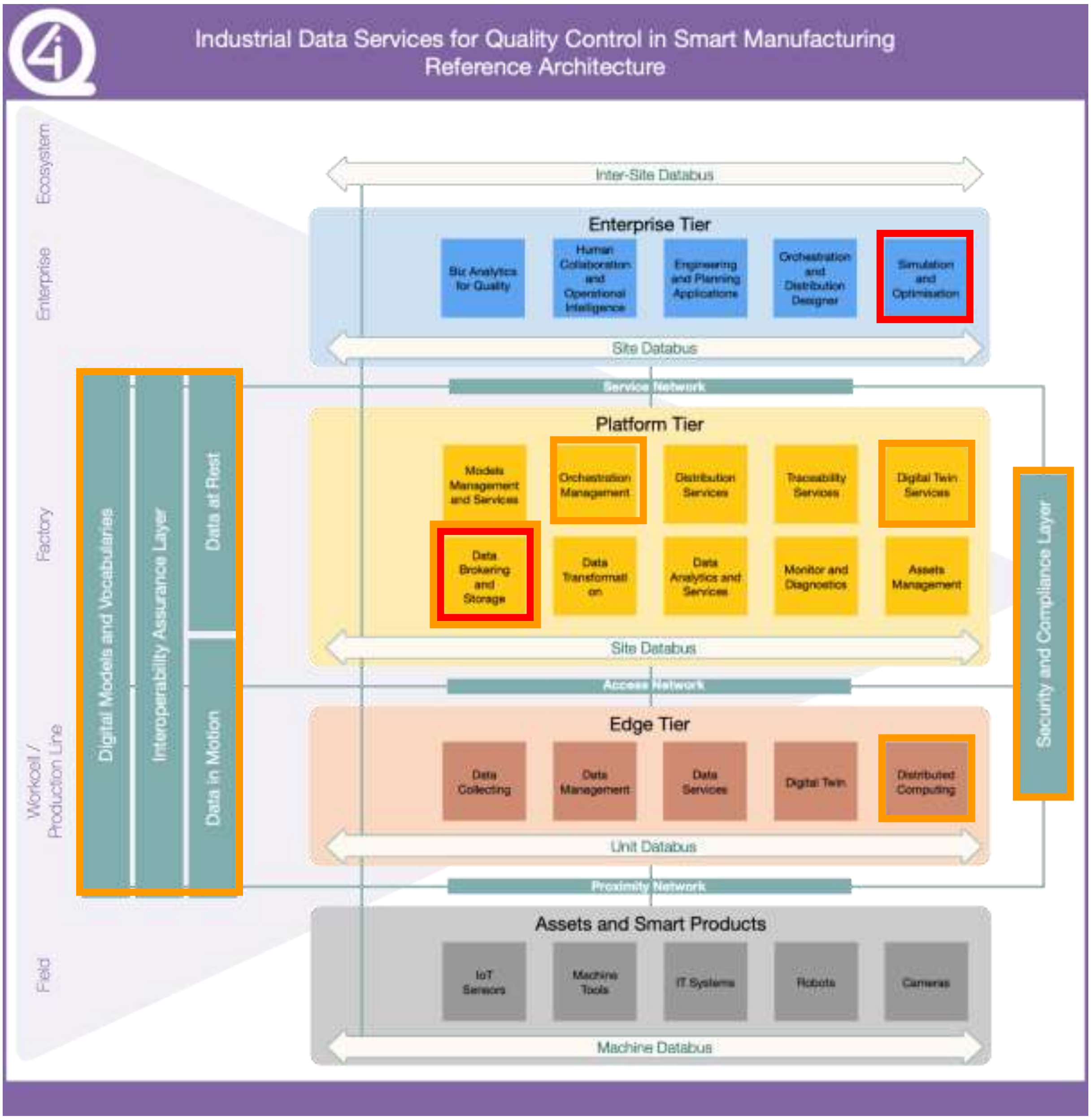

Figure 18. i4Q RA mapping with i4Q^LRT

1.2.17.1 RA critical analysis: strengths and weaknesses

i4Q^LRT solution includes different processes, functions and AI models which are mapped to the Enterprise Tier to the Edge Tier of the i4Q Reference Architecture. Considering that it is a solution found at various levels of the architecture, it will be analyzed in terms of its weaknesses and strengths:

Strengths:

- **Enterprise Tier:** The i4Q^LRT mapping to "Simulation and Optimization" sub-component enables the effective monitoring of multiple analytical solutions from Enterprise Tier. This ensures the comprehensive analysis of possible simulations
- **Platform Tier:** One of the sub-components not foreseen at the beginning, which is currently one of the most important, is "Data Brokering and storage". Thanks to the

solutions hosted in this sub-component, such as i4QDR or i4QDIT, it will be able to work directly with different clients located in the Edge Tier from the application. Either to test or validate, or simply run some algorithms to see their result using the stored data to train them.

- **Edge Tier:** The i4QLRT mapping to "Distributed Computing" subcomponent. This allows to deploy and run workloads of the different algorithms deployed on the edge. This enables efficient analysis and fast action when reconfiguring the production line.

Weaknesses:

- **Platform Tier:** The i4QLRT mapping to "Data Brokering and Storage" subcomponent should be able to access the data in real-time. Any problems in the transmission of data by the different sensors can lead to disruptions in the correct use of this tool and not obtain a good optimization of the manufacturing processes.

2. i4Q RA: Viewpoints

According to IIRA approach, the i4Q RA final version incorporates all the relevant perspectives (which in i4Q we call 'viewpoints') involved in the smart manufacturing process and in particular related to addressing the data reliability challenges in turn related to the smart manufacturing, high-quality production process. i4Q RA will be structured around four viewpoints to offer a framework to think iteratively through the architectural issues that may arise during its conception. This section describes the methodology followed for the definition of the four viewpoints (Business, Usage, Functional and Implementation) and provides a brief description of the main aims and outcomes for each of them.

2.1 Methodology

i4Q RA is structured around four viewpoints to offer a framework to think iteratively through the architectural issues that may arise during its conception:

- The business viewpoint, which identifies the stakeholders that engage in the development, deployment and operation of the system, including their business vision and objectives. The business viewpoint takes into account the overall business and regulatory context, in which the system operates. A brief description of the business viewpoint is reported in section 2.2, while the complete report (D2.3) was delivered at M7.
- The usage viewpoint, which specifies the actual usage of the system. This usage is illustrated based on sequences of activities that may be performed by human actors and/or logical components (e.g., system or system components). A brief description of the usage viewpoint is reported in section 2.3, while the comprehensive description is reported in D2.4.
- The functional viewpoint, which specifies the functionalities of the system. To this end, it illustrates the functional components that comprise the system along with their interfaces and interactions. It also presents any interactions with external logical modules (e.g., external subsystems). A brief description of the functional viewpoint is reported in section 2.4, while the whole characterization is reported in D2.5.
- The implementation viewpoint, which comprises the implementation technologies that are used to implement the functional components, along with information about their lifecycle and the realization of the communication between them. A brief description of the implementation viewpoint is reported in section 2.5, while the complete description is reported in D2.6.

The viewpoints are interrelated by an interaction pattern: decisions from a higher-level viewpoint guide and impose requirements on the viewpoints below it. On the other hand, the deliberation of the concerns in a lower viewpoint, validate and in some cases cause revisions to the analysis and possibly the decisions in the viewpoint above it.

The first version of the i4Q Reference Architecture has been taken as a base for the definition of the key viewpoints, which, at the same time, has served as input for its revision and the release of the final version.

The development of each viewpoint has followed an incremental and iterative approach where different iterations were foreseen. At each sprint successive refinements and increments were done. Each sprint ended with a sprint validation, where the viewpoints were released and the feedback was elicited, and a sprint retrospective, where the lessons and the improvement for the following iteration were identified for each viewpoint.

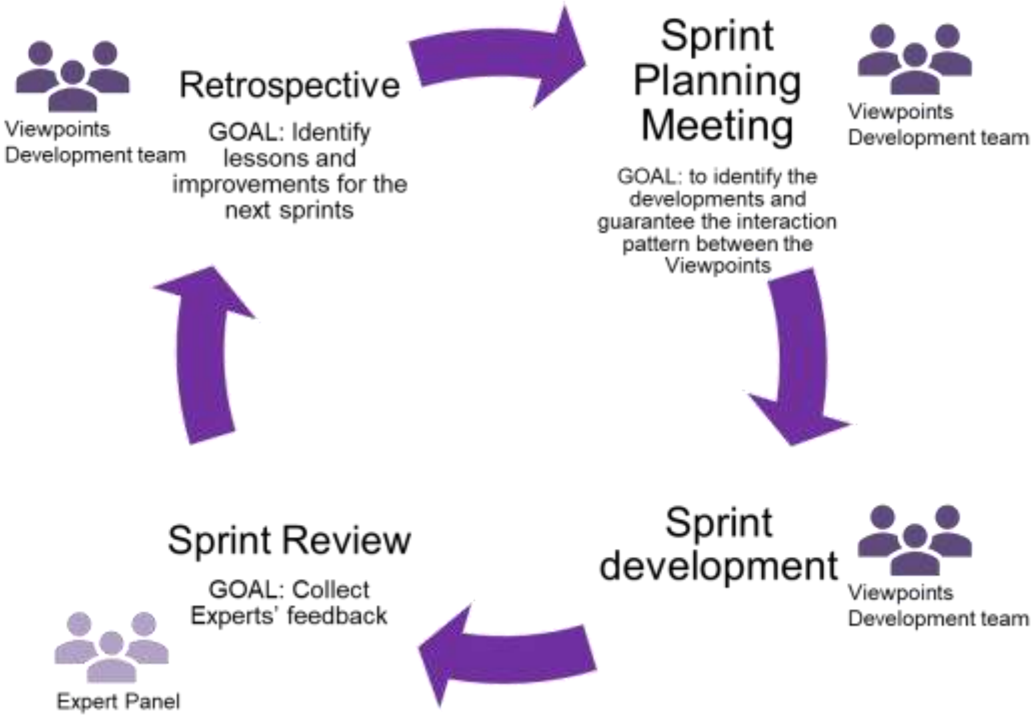

Figure 19. Viewpoints Sprint Cycle

The sprint validation was performed by an Experts' panel formed by a representative from pilots and technology providers partners, by replying to a simple survey. The answers have been analysed by the development team providing insights for both the retrospective and the following sprint planning meeting. The main feedback has been collected and analysed also in view of the validation and eventually the revision of the i4Q Reference Architecture.

The questionnaires have been developed taking into consideration some simple principles. First, the main aims of each iteration were to validate the work done during the sprint development, clarify doubts and collect information useful for the following sprint. Once clarified that, the questions were sketched. The questions and answers were kept as simple as possible giving preference to close-ended questions and exploiting open-ended questions to provide the possibility for communicating specific experiences or expectations from the members of the panel.

Due to the heterogeneity of the experts and the different topics to be addressed, both at the business and technological level, sometimes two specific questionnaires have been developed to address the right questions to the right users.

Following IIRA principles and the Viewpoint iteration process described above, the viewpoints development followed a designed and agreed plan (see **Figure 20**), where each viewpoint was implemented in three complete sprints by delivering four versions till the final release.

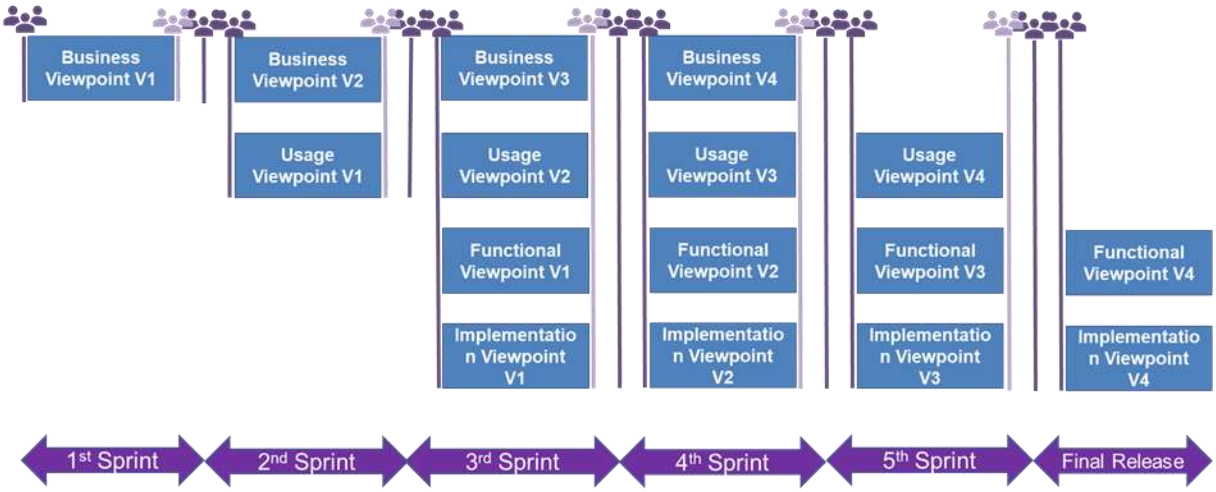

Figure 20. Viewpoints Development Plan

Using the methodology reported above, both the technology providers and the pilots' users are involved in the definition of the i4Q Reference Framework. Keeping the pilots in the loop and making changes according to their feedback, ensure that the final definition of the solution is truly corresponding to their requirements and improve the chances to deliver value to possible customers. Working in iterations allows each sprint to be better than the last one and previous mistakes won't be repeated. Moreover, it increases the collaboration among partners and guarantees the interrelation between the four viewpoints and the reference architecture.

2.2 Business Viewpoint

In the RA definition, one of the main objectives is to avoid the risk of a "technology-centric"' approach; for this reason, the viewpoints' definition started with the analysis of a business point of view. This has allowed incorporating already in the (early) design requirements and needs that are closer to real-world, operation needs. The business viewpoint has been defined in task T2.3 (Business Viewpoint) and focused on framing the vision, values, and key objectives; this task T2.3 investigated business-related considerations, leading to a different analysis of i4Q RIDS.

The definition of the business viewpoint started with the analysis of stakeholders (Smith, 2000).

Stakeholders have a major stake in the business and strong influence in its direction. It is important to identify major i4Q stakeholders and engage them early in the process of evaluating these business-oriented concerns. In conceptualizing and defining the i4Q Solutions, technological and business factors have been considered, including external influences from technological trends, specific market conditions and potential, customer inputs, and regulatory requirements (in the areas of, e.g., safety, privacy, environmental and labour).

Stakeholders have been gathered into two main categories:

- Primary stakeholders, people and organizations who seek, receive, manage and provide IoT based services for quality improvement, having a direct impact on defining main solutions' functionalities;
- Secondary stakeholders, users of information maintained by the primary stakeholders' systems or providers of information needed by the primary stakeholders.

Concerning both categories, different types of stakeholders have been identified:

- Decision-Makers, defining the business objectives;
- Technical Personnel (e.g., Product Managers, System Engineers,) defining the technical goals and functional capabilities needed to reach the business objectives.

Business-oriented concerns such as business value, expected return on investment, cost of maintenance and product quality have been evaluated and connected to technical evaluations for the i4Q RIDS to solve business problems.

After the initial **Stakeholders**' classification, main elements have been considered: **Vision**, describing a future state of an organization; **Values**, reflecting how the vision may be perceived by the stakeholders involved in the implementation and usage of the i4Q Solutions; **Key objectives**, quantifiable high-level technical and ultimately business outcomes; **Fundamental capabilities**, referring to high-level specifications of the essential ability of the i4Q Solutions to complete specific major business tasks. For the i4Q objectives, both types of stakeholders (business and technical) have been analysed in different phases to identify these fundamental elements.

Output in terms of objectives and functional capabilities represented the input for the Usage Viewpoint analysis.

Indeed, starting from the Business Viewpoint, the Usage Viewpoint consolidated various aspects of the system's usage, continuing the initial design efforts.

- Stakeholders' analysis supported to identify tasks (the basic unit of work), roles (dealing with the responsibilities of executing a task) and parties (intended as an agent, human or automated, that has autonomy, interest and responsibility in the execution of tasks), considering both users and software systems.
- At the same time, the key objectives, fundamental capabilities and recommendations here identified helped to derive usage activities and system requirements of the Usage Viewpoint.

According to IIRA layered-perspective and the adopted iterative approach, the Usage Viewpoint guides the development of the Functional and Implementation Viewpoints.

2.3 Usage Viewpoint

The goal of the Usage Viewpoint is to help deriving usage activities and system requirements. It is composed of some key elements: tasks, roles, parties and activities.

The **task** is the basic unit of work, such as the invocation of an operation, a transfer of data or an action of a party. A task consists of:

- A role or more roles responsible for the execution of the task.
- A functional map that describes the association with functions or functional components.
- An implementation map that describes the dependencies with implementation components.

A **role** is a set of capabilities assumed by an entity to participate in the execution of some tasks and are often associated with certain security properties (authorization, privileges and permissions). Roles are assumed by one or more parties.

A **party** is an agent, human or automated, that has autonomy, interest and responsibility in the execution of tasks. A party executes a task by assuming a role that has the right capabilities for the execution of the task.

An **activity** represents the coordination of tasks (and possibly other activities) required to realize a well-defined process of the system. An activity consists of:

- A trigger. One or more conditions under which the activity is initiated. It may be associated with one or more roles responsible for initiating or enabling the execution.
- A workflow describing the organization (sequential, parallel, conditional, iterative) of tasks.
- An effect that describes the difference in the state of the system after the activity is successfully completed.
- Constraints are system characteristics that must be preserved during execution and after the new state is achieved, such as data integrity, data confidentiality or resilience.

The Usage Viewpoint guides the development of the Functional and Implementation Viewpoints. The link between these works is defined within each task's functional map and implementation map which links each task with the different functions and implementation components. These are described in detail in deliverable D2.4.

2.4 Functional Viewpoint

The objective of this section is to provide a better understanding of the digital models and ontologies as seen in deliverable D2.5. The focus is to foster interoperability, facilitate data exchange, and data processing, both between i4Q solutions as well as with other connected systems and services, taking into account the defined architecture. Several of the i4Q solutions consume data from the systems under operation with a monitoring and control purpose in a defined workload.

During the development of the functional viewpoint in deliverable D2.5, three domains of the i4Q solution architecture were highlighted: the **Data Flow**, the **Control Flow** and the **Workload Distribution Flow**.

- **Data Flow:** Refers to the data block, from the collection, processing and utilisation of data for the use of the different i4Q solutions. This Flow analyses the data between the different solutions, from the asset and intelligent product level to the platform level. Here we see the solutions involved mainly i4Q_DiT and i4Q_DR.
- **Control Flow:** Several of the i4Q solutions consume data from the system under operation with a monitoring and control purpose. These solutions, usually placed in the Platform tier, or even in the Enterprise tier can trigger several control actions that can have different purposes, from corrective to preventive. To trigger these actions, they process, interpret, model or make sense out of the data coming from the "Assets and Smart Products" and the Edge tiers through the data flows. This process may require

applying rules and logic or mathematical models to obtain through machine learning or other AI techniques.

- **Workload Distribution Flow:** The workload distribution architecture uses distribution services in the reference architecture to scale solutions horizontally. Let us differentiate two different architectures for i4Q solutions: Cloud architecture, adopted by solutions that do not require that functional component are executed at the edge (close to the data source) and Cloud/Edge architecture for those that do require a distributed execution environment. In the cloud, workload distribution is achieved using load balancing functions that provide runtime logic that distributes the workload across the available IT assets. Referring to the Industrial IoT architecture, we find an Edge/Cloud model. This architecture allows: i) concentrating device resources at the edge, ii) processing data at the edge, and iii) filtering it and sending it to the cloud.

Considering the three levels seen above, the structure of the architecture will look as follows.

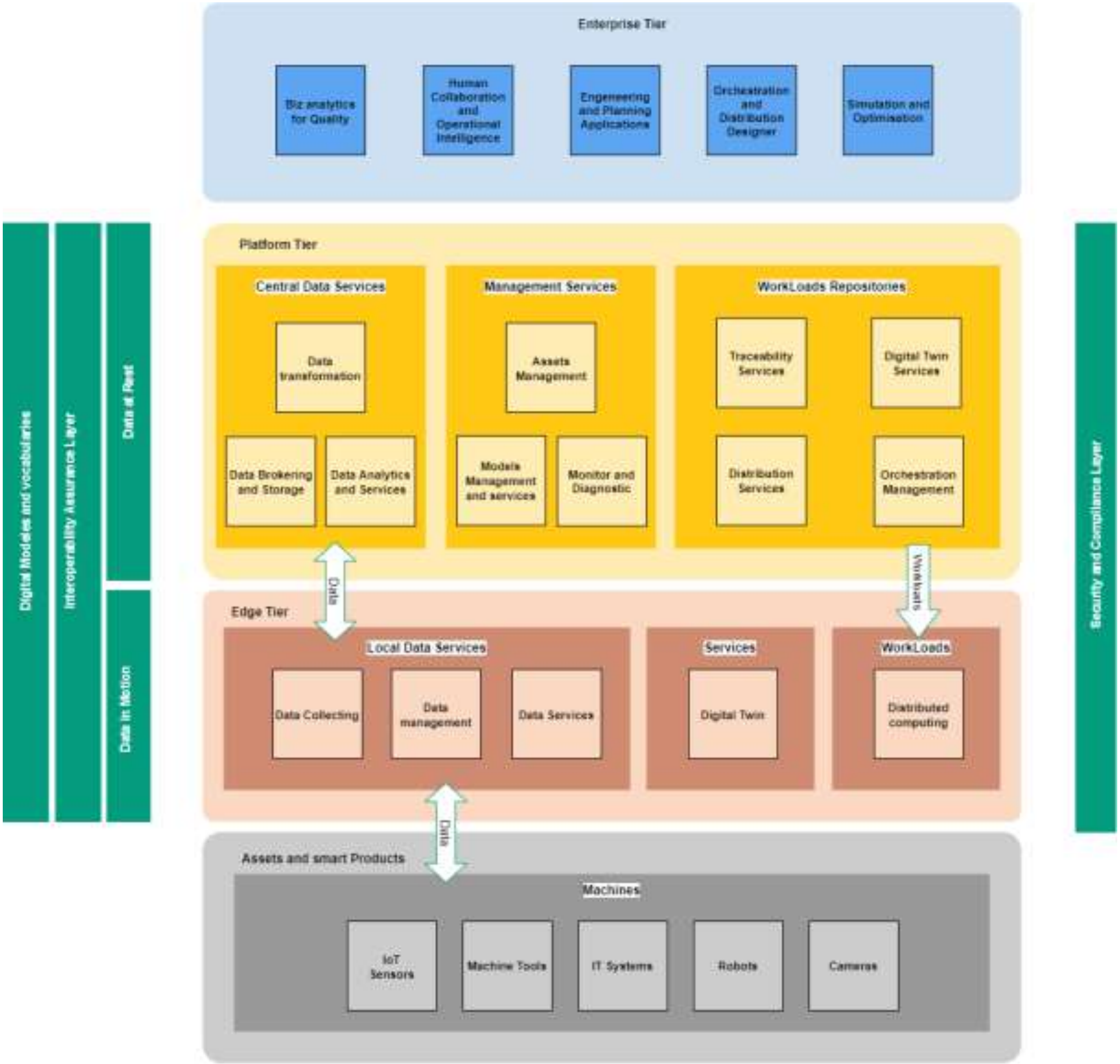

Figure 21. i4Q Conceptual Architecture

These three groups can be found for each Tier:

- **Data Services:** refer to all the components that store and manage data. This group includes data flow and therefore data solutions (i4Q_DR and i4Q_DIT). The components included are (Data transformation, Data Brokering and Storage, Data Analytics and Services, Data Collecting, Data Management and Data Services). Some standards that can be used in this group are FDI, OPC UA, MQTT, MIMOSA, KPI-XML, OData, OpenAPI and AsyncAPI.
- **Management Services:** These are components that work directly with data to offer a service. This relationship between data and solutions is linked to Control Flow. In this flow, the solutions will exercise control over the physical system through a set of physical actuators, closing the loop started with the data flows with a series of control flows that will define the actions or actuations required to achieve a particular purpose. The components included are (Assets Management, Models Management and services, Monitor and Diagnostic, Digital Twin). Some of the solutions found in this group are (i4Q_BC, i4Q_DA, i4Q_BDA, i4Q_AD, i4Q_IM, i4Q_DT, i4Q_QD). Some standards that can be used in this group are KPIML, OpenO&M, AutomationML, CAEX, COLLADA, OpenAPI, KPIML and OpenO&M.
- **Workload Distribution:** Define the components that require physical elements such as servers or virtualization to be able to deploy their functionality. This group includes solutions that manage IT resources, the deployment of solutions or scalability by adding new nodes for each of the resources found. The components included are (Traceability Services, Distribution Services, Digital Twin Services, Orchestration Management, Distributed Computing). Some of the solutions found in this group are (i4Q_BC, i4Q_AI, i4Q_EW, i4Q_DT, i4Q_LRT). Some standards that can be used in this group are PMML, FMI, ONNX, OpenO&M and Digital Twin.

2.5 Implementation Viewpoint

The **Implementation** viewpoint deals with the technologies needed to implement functional components (**Functional** viewpoint) of i4Q Solutions, their communication schemes and their lifecycle procedures. These elements are coordinated by activities (**Usage** viewpoint) and supportive of the system capabilities (**Business** viewpoint).

The i4Q Implementation viewpoint will describe:

- **General architecture** of the i4Q IIoT system, its structure and the distribution of components, and the topology by which they are interconnected, over the base of already selected technologies that are required for its implementation;
- A **technical description of its components**, including interfaces, protocols, behaviours and other properties;
- An **implementation map** of the **activities** identified in the Usage viewpoint to the Functional components, and from Functional components to the Implementation components; and
- An implementation map for the key system characteristics.

Based on **IIRA**, the **Implementation** viewpoint is concerned with the technical representation of an **Industrial Internet of Things** (**IIoT**) system and, the technologies and system components required to implement the activities and functions prescribed by the Usage and Functional viewpoints. In turn, IIoT system architecture and the choice of the technologies used for its implementation are also guided by the Business viewpoint, including cost and go-to-market time constraints, business strategy in respect to the targeted markets, relevant regulation and compliance requirements and planned evolution of technologies.

i4Q **IIoT Reference Framework** follows well-established Three-Tier architectural patterns, that comprises edge, platform and enterprise tiers, that have specific roles in processing the data flows and control flows involved in Usage activities, and they are connected by three networks, proximity, access and service network, as shown on the below figure.

From the point of view of the Three-Tier architecture, components combine platforms, management services, applications, etc..., that map to the functional domains of functional viewpoint. From the tier and domain perspective:

- **Edge** tier implements most of the control domain;
- **Platform** tier most of the information and operations domains;
- **Enterprise** tier most of the application and business domains.

Implementation Viewpoint additionally provides a detailed architecture based on cloud computing patterns. Next technologies and platforms, in this sense, **Edge computing**, **Microservice applications and Function as a Service (FaaS)** platforms, are instrumental to implement the i4Q Solutions.

3. Data Models and Ontologies

In the development of Task 2.2, different digital models and ontologies have been considered. These models have been assigned to different categories, which are as follows:

- **Open Automation:** Models and ontologies to support the digital representation of manufacturing assets, and the exchange of operational data, from design to operations.
- **Vertical Integration:** Models and ontologies to support the integration of OT and IT systems.
- **Open Data:** Models and ontologies to model open data interfaces and support the open exchange of data between distributed systems.
- **Open Analytics and AI**: Models and ontologies to support the modelling and distribution of analytic functionalities including machine learning.

The candidate data models and ontologies is mapped with the different functional domains of the i4Q reference architecture. Once the data models and ontologies are aligned with the functional domains of the reference architecture, they are compared according to different criteria:

- **Coverage**: Capability to model the different use cases (pilots). The positive or negative evaluation is related to the fitness, appropriateness, and usefulness of the application of technology in the different pilots from the project.
- **Maturity/reach**: Level of maturity and market reach. A positive evaluation means that the model or ontology is widely adopted as an industry standard and that there is a range of commercial solutions available.
- **Ease of use**: An estimation of the usage complexity, when applicable estimated from the number of classes or entities and their corresponding attributes involved in coverage. A positive evaluation means that the model or ontology is easy to use in the pilot use cases
- **Integration and deployment complexity**: Availability of open-source tools, liaison documents and companion specifications to support the specification, instantiation, implementation, and deployment of data models in the pilot use cases. A positive evaluation means that it is not complex to integrate or deploy.

From the analysis of the different criteria, these standards have been selected for different categories:

- **Open Automation:** OPC-UA, AutomationML, CAEX, COLLADA
- **Vertical Integration:** KPIML, OpenO&M and Key Performance Indicators for Manufacturing
- **Open Data:** OpenAPI, AsyncAPI and Odata
- Open Analytics and AI: PMML, ONNX and FMI

The different categories can be aligned with the functional domains of the reference architecture of IIRA. Open Automation with Control, Vertical integration with operations, Open Data with Information and application, and finally, Open Analytics and AI with Business. Considering this analysis, these solutions, presented in the three different flows (data, control and workload distribution) and the categories seen in task 2.2 aligned with IIRA (Control Operations, Information, Application and Business), the different standards can be linked to the tiers of the architecture (Enterprise, Platform, Edge and Smart Assets and Products). This mapping would be as follows:

- Enterprise Tier:
  - KPIML: Key Performance Indicator Markup Language is an XML implementation of the ISO 22400 standard consist of a set of XML schema written in the XML Schema language (XSD). KPI-ML describes by means of its formula different elements, units of measurement, time and other characteristics.
  - OpenO&M: Operation and Maintenance is an initiative composed of multiple organizations, whose objective is to create open industry standards for the exchange of operation and maintenance data with business applications.
  - MIMOSA: Machinery Information Management Open System Alliance standards support key functional and interoperability requirements for Critical Infrastructure Management on a cross-sector basis, addressing the highly heterogeneous and interdependent nature of critical infrastructure.
- Platform Tier:
  - COLLADA: COLLAborative Design Activity constitutes an interchange file format for storing interactive 3D models and /or 3D applications.
  - AutomationML: Automation Markup Language is a data format designed to exchange and storage engineering information's data which typically exists inside a factory environment.
  - CAEX: Computer Aided Engineering Exchange is a neutral data exchange format for plant engineering data, which handles heterogeneous or integrated data representations, allows hierarchical object information to be stored, and aims at interoperability.
  - PMML: This standard provides a way for analytic applications to describe and exchange predictive models produced by data mining and machine learning algorithms, and also supports common models such as logistic regression and other feed forward neural networks.
  - ONNX: Open Neural Network Exchange (ONNX) is an open ecosystem that enables interoperability among AI models. It can be used to provide flexibility in working with AI models, reduction of running time among others.
  - FMI: The Functional Mock-up Interface (FMI) is a free standard that defines a standardized interface and container to develop complex cyber-physical systems for systems' computer modelling, simulation, validation and test.
- Edge Tier:
  - OpenAPI: Defines a standard, programming language-agnostic interface description for REST APIs, which allows both humans and computers to discover and understand the capabilities of a service without requiring access to source code.
  - AsyncAPI: It is an open-source standard to work with REST APIs. That does form documentation to code generation.
  - OData: It enables the creation and consumption of REST APIs.
- Assets and Smart Products:
  - OPC UA: This model is a machine-to-machine communication protocol for industrial automation developed. The standard OPC UA enabled the communication of real-time plant data between control devices from different manufacturers.

- **MQTT**: Message Queuing Telemetry Transport or MQTT is a lightweight, publish-subscribe network protocol that transports messages between devices.
- **FDI**: The Field Device Integration (FDI) is a standard device integration technology. FDI is a simplified software installation whit configuration, maintenance and management of field instruments and host systems.

However, while many of these standards can be related to and used at one level of the i4Q RA, some of these standards could be used at multiple tiers.

4. Final version of i4Q Reference Architecture

This section presents the final version of i4Q RA and the blueprints for the pilots.

The final version of i4Q RA fulfils the considerations coming from the viewpoints developments, the pilots' needs and solution providers mapping activity.

Given the weakness and strength analysis conducted by Solution Providers and comments received from Advisory Board, i4Q Reference Architecture has been revised to overcome past limits and issues, introducing Data Space Tier which extends and enhances interoperability with future manufacturing data spaces by the means of IDS Connectors, according to main principles defined by International Data Space Association (IDSA).

The International Data Spaces (IDS) is a virtual data space leveraging existing standards and technologies, as well as governance models well-accepted in the data economy, to facilitate secure and standardized data exchange and data linkage in a trusted business ecosystem. It thereby provides a basis for creating smart-service scenarios and facilitating innovative cross-company business processes, while at the same time guaranteeing data sovereignty for data owners (IDSA, 2019).

The IDS Connector is the central technical component for secure and trusted data exchange that allows the data provider to define exactly how often someone can use the data, which data they can see, whether they can store and pass it on, which data they pay for and how much it costs. The connector sends the data directly to the recipient from the provider’s data source in a trusted, certified data space, so the original data provider always maintains control over the data and sets the conditions for its use. The connector works with a wide variety of different devices and applications, offering four different security levels to choose (Basefree, Base, Trusted and Trust+), enabling the sharing of data using any device you need to connect to the IDS.

i4Q Reference Architecture, thus, has been enriched with data sovereignty and sharing capabilities taking into account the needs of a constantly updated knowledge base to determine and present quality factors in manufacturing.

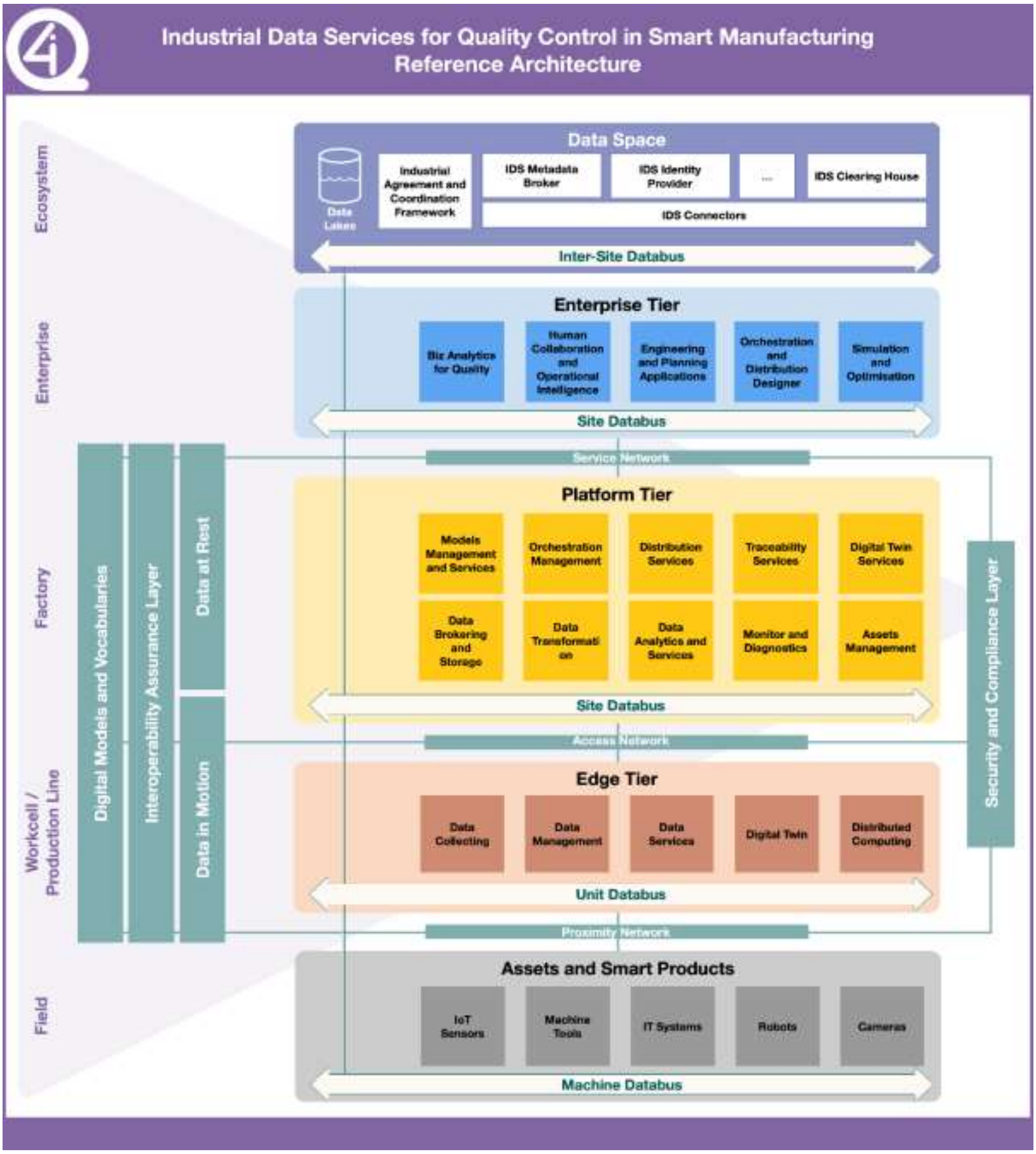

Figure 22. Final version of i4Q Reference Architecture

4.1 RA Building Blocks

i4Q Reference Architecture is made up of several building blocks which can be categorized as follows:

Data Space:

- Industrial Agreement and Coordination Framework: A guidance to satisfy requirements in order to obtain a certification, including business, organizational and operational agreement;
- IDS Metadata Broker: A comprehensive connector that provides the necessary interfaces for communicating with any other International Data Spaces connector. More

specifically, it is capable of handling messages from IDS connectors, indicating a status update, such as new data being available;

- IDS Identity Provider: An intermediary offering services to create, maintain, manage and validate identity information of and for Participants in the International Data Spaces;
- IDS Clearing House: An intermediary providing clearing and settlement services for all financial and data exchange transactions within the International Data Spaces;
- IDS Connectors: A dedicated communication server for sending and receiving data in compliance with the general Connector specification; different types of Connectors can be distinguished (Base Connector vs. Trusted Connector, or Internal Connector vs. External Connector.

Enterprise Tier:

- Biz Analytics for Quality: Applications built on top of underneath services (e.g: Models Management and Services, Data Analytics and Services) aiming to pursue excellence in quality focusing on zero-waste context;
- Human Collaboration and Operational Intelligence: CRM,CSM,DSS and ERP/MES and other services that provide smart alerting and quality diagnosis;
- Engineering and Planning Applications: CAD,CAE,CAM and AR/VR and everything related to the the joint and integrated use of software systems for computer-aided design and computer-aided manufacturing;
- Orchestration and Distribution Designer: Engineering Enviroment for definining pipelines and distributions such as a scalable, easy to use, policy-based distribution mechanism to ease the task of distributing AI/ML models and other metadata to the edge;
- Simulation and Optimisation: Simulation and Optimisation applications for optimising manufacturing processes.

Platform Tier:

- Models Management and Services: Management of Models and related Services enabling the holistic vision of data across i4Q Infrastructure;
- Orchestration Management: Services for orchestration management enabling high resiliency and responsiveness workloads;
- Distribution Services: Distribution and deployment services enabling plug&play reconfiguration and installation of workloads;
- Traceability Services: Robust and Rapid Traceability Service (i.e., DLT) to provide an audit trail for all inserted data, guaranteeing immutability and finality;
- Digital Twin Services: Digital Twin (Management Services) services that enable industrial companies to virtual validation/visualisation and productivity optimisation using pre-existing and/or simulated data and data from different factory levels;
- Data Brokering and Storage: Services for data brokering and storage management supporting a high degree of digitisation in companies with most manufacturing devices acting as sensors or actuators and generating vast amounts of data;
- Data Transformation: Services for data transformation (typically post-processing);

- Data Analytics and Services: Services for data analytics on top of the data infrastructure with several incremental algorithms (i.e. operating on data streams with fast incremental updates) suitable for analytic processing of high-speed data streams;
- Monitor and Diagnostics: Services for near/real-time monitoring and diagnostics monitoring the health of workloads, predict problems and take corrective actions, predict failures and provide alerts;
- Assets Management: Services for assets management for managing and track facilities' assets.

Edge Tier:

- Data Collecting: Solutions for data ingestion, collecting raw data from the facilities and store them to the data lake or make them available for the processing;
- Data Management: Solutions for data management, transformation (typically pre-processing), harmonization and loading;
- Data Services: Data Services to enable ingestion use and maintenance;
- Digital Twin: Digital Twin (Operational Services) to achieve a connected 3D production simulation with a digital twin for manufacturing;
- Distributed Computing: Digital Twin (Operational Services) to achieve a connected 3D production simulation with a digital twin for manufacturing.

Assets and Smart Products: an ecosystem of heterogeneous devices (IoT Sensors, Machine Tools, Robots, Cameras, etc.) from which gather data to process on the upper Tiers of i4Q RA.

Digital Models and Vocabularies: Open standards/models guidelines allowing interoperability across all levels of i4Q RA.

Interoperability Assurance Layer: Interoperability ETL Tools that ensure interoperability across all the levels of i4Q RA.

Data in Motion: Real-time data, typically coming from sensors and IoT devices.

Data at Rest: Batch and historical data, typically stored in IT and legacy systems.

4.2 Work Packages mapping toward i4Q

The operational needs identified helped to better define the RA representing a valid input for the implementation activities: WP3 - Reliable Industrial Data Services Infrastructure - dealing with methodologies, tools and infrastructure to ensure the necessary data quality; WP4 - Big Data Services - dealing with data integration and fusion for analytics and simulation models; WP5 - Manufacturing Line Qualification and Reconfiguration – dealing with strategies and methods for process qualification and optimization.

The following figures shows how the different work packages are expected to contribute, in terms of specification and reference implementation, to the concrete realization of the i4Q RA.

The colour schema used in the picture uses the following notation:

- "WP3 – BUILD: Manufacturing Data Quality " is represented using **Blue boxes;**
- "WP4 – BUILD: Manufacturing Data Analytics for Manufacturing Quality Assurance" is represented using **Green boxes;**

- “WP5 – BUILD: Rapid Manufacturing Line Qualification and Reconfiguration “ is represented using **Purple boxes.**

The definition of RA building blocks paves the way for implementation activities in the next months.

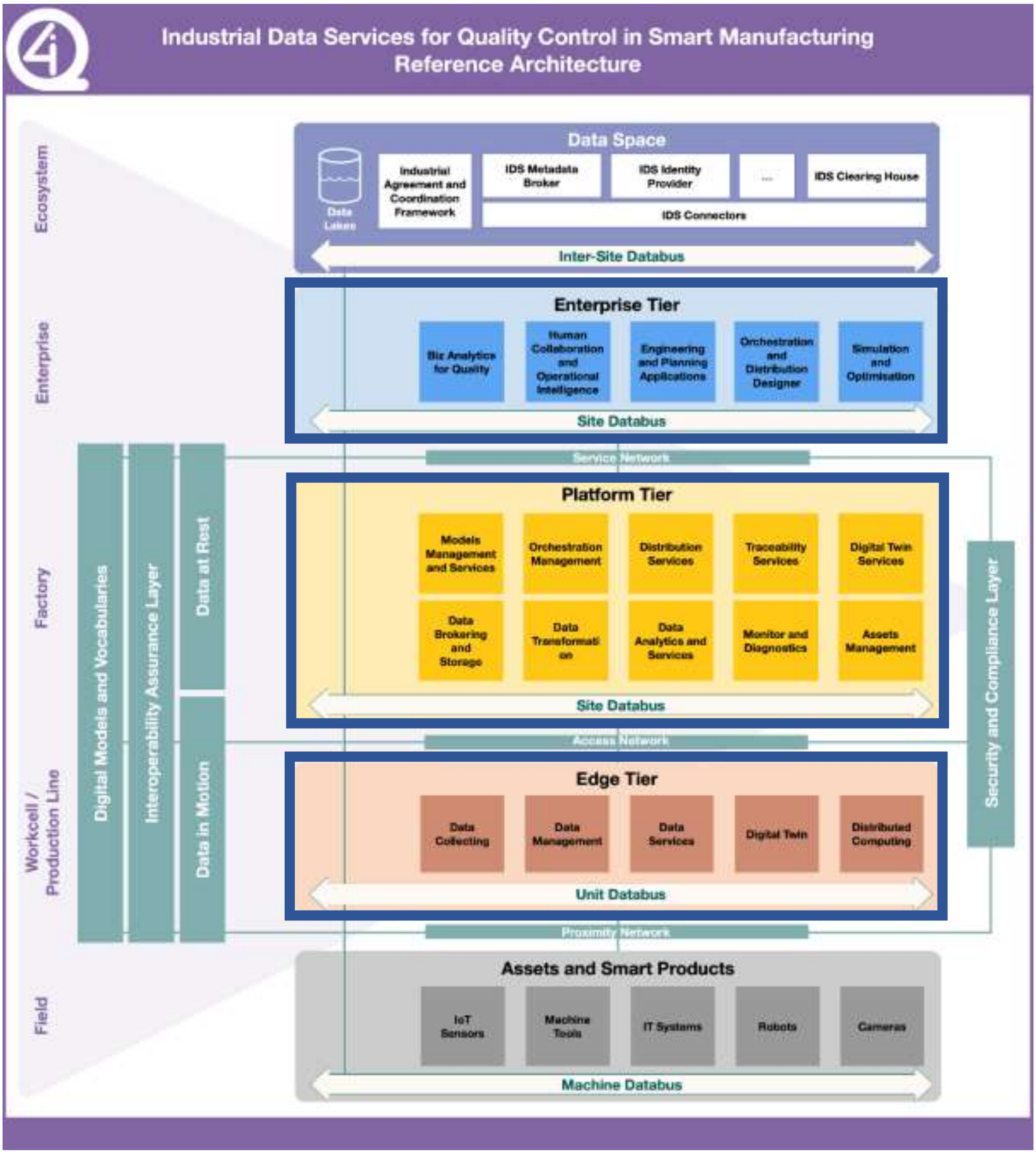

Figure 23. WP3 Mapping toward i4Q RA

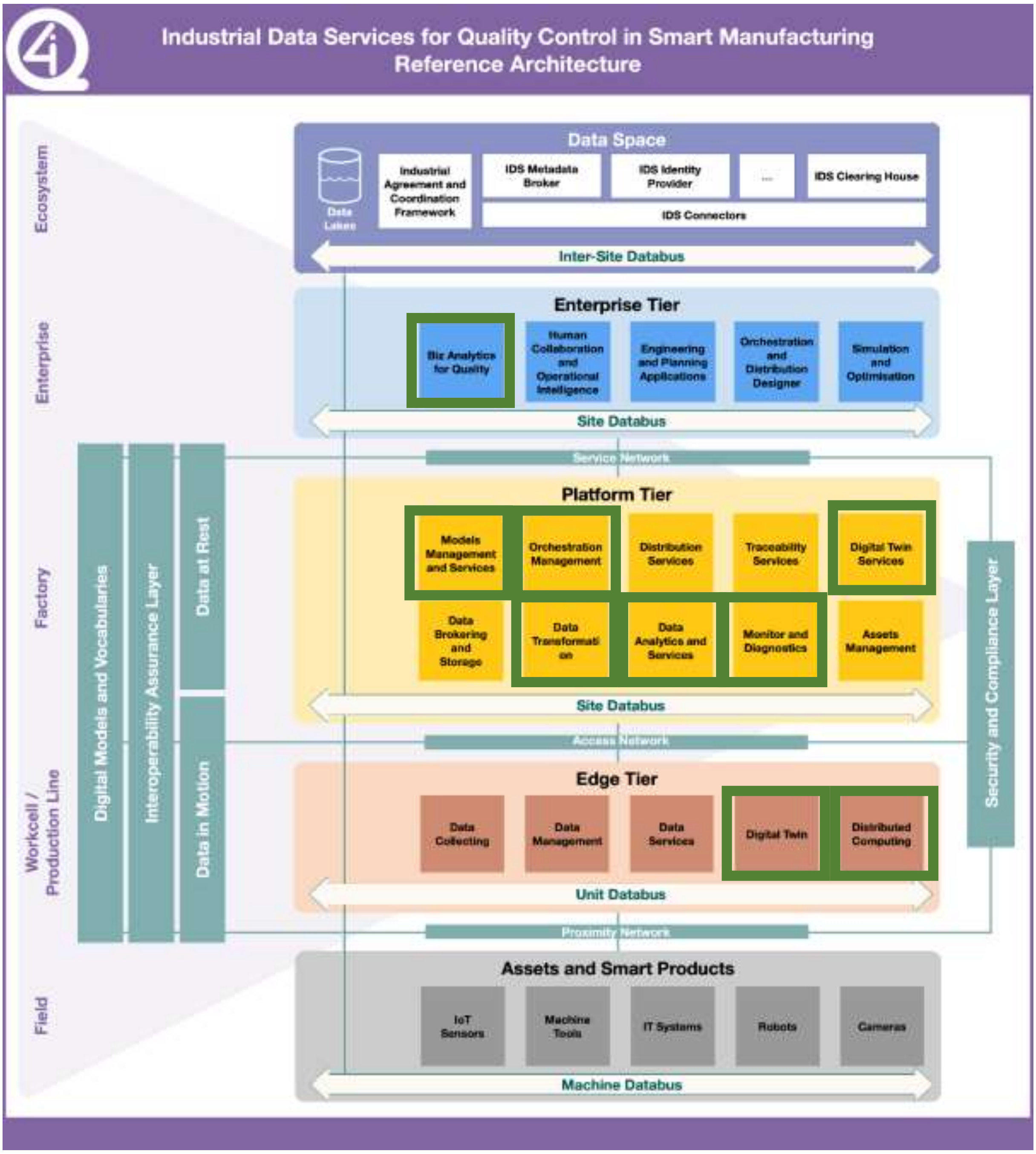

Figure 24. WP4 Mapping toward i4Q RA

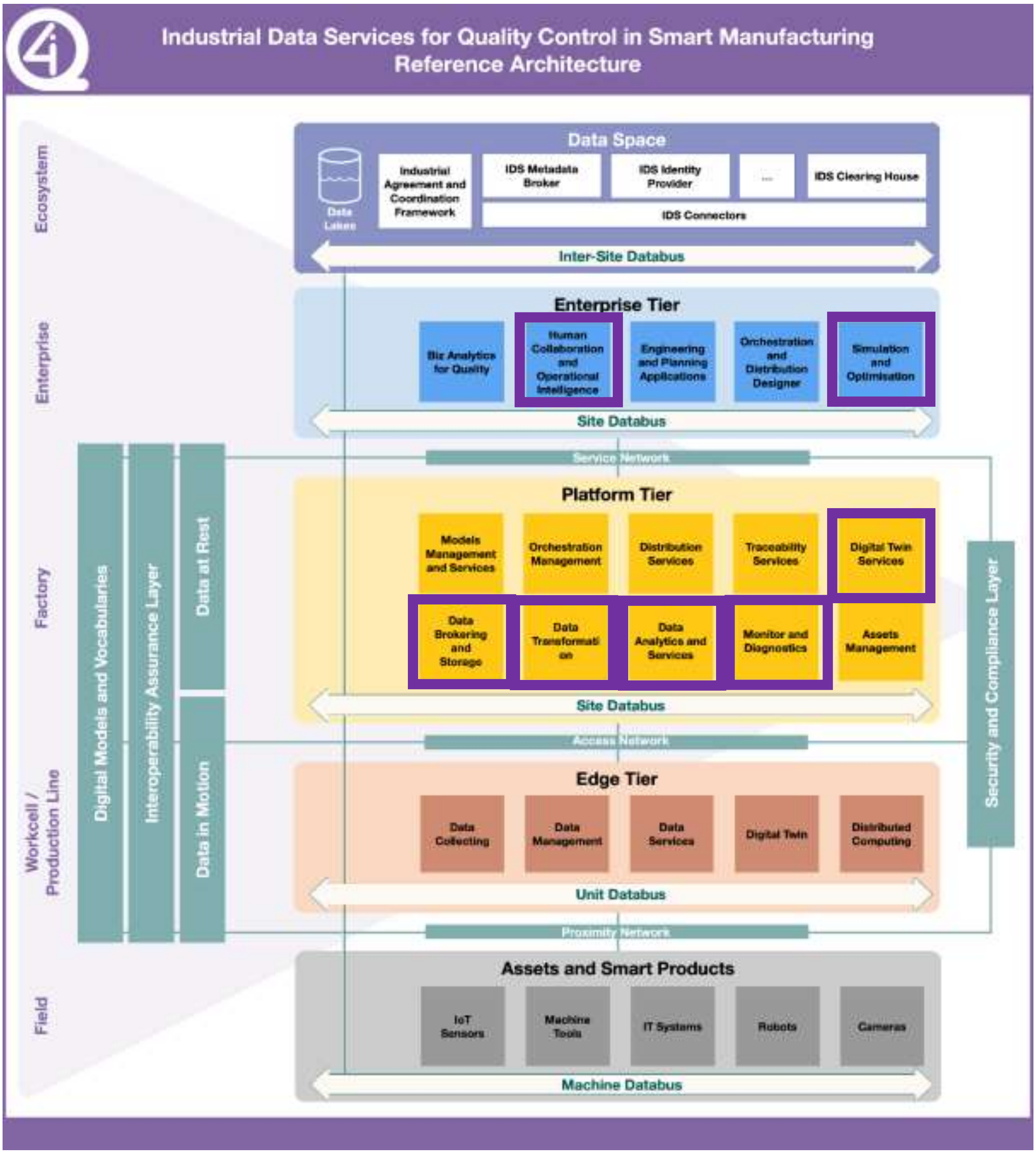

Figure 25. WP5 Mapping toward i4Q RA

4.3 RA blueprint for pilots

Further validation of the defined RA was carried out considering the needs expressed by the 6 project pilots. In this section, a methodological approach to map the pilots of the project with i4Q RA is presented: the objective is to verify that the architecture includes all potential components useful for implementing solutions to meet pilots needs. In particular, pilots have identified which solutions from i4Q RIDS (results from WP3, WP4 and WP5) will be applied on their pilot defining blueprints for i4Q. The mapping of the i4Q RIDS continues further as pilots have also described a background to justify their implementation in the pilot, offering a full perspective of the implementation choices.

4.3.1 Pilot 1 – FIDIA

Pilot ID		#1
Pilot name		FIDIA
i4Q RIDS	**Solution name**	**09_i4Q_DIT**
	Solution background	This solution is used to perform high-abstraction level management operations on data like reading, cleaning, storing, indexing, enriching, searching & retrieving, maintaining, and correspondence of open APIs. The goal is to prepare and use the data to perform analysis and make decisions.
	Solution name	**07_i4Q_DR, 08_i4Q_DRG**
	Solution background	These solutions are mainly used to store the relevant data (process operation, sensed data, results of analysis, AI models, results of decisions like rejecting an item or stopping a production line), schedules, etc.). These solutions are used as well to perform additional operations on data like regular queries or any required update.
	Solution name	**13_i4Q_AI**
	Solution background	This solution is used (in combination with i4Q^{DR}) to store AI models.
	Solution name	**10_i4Q_DA, 11_ i4Q_BDA**
	Solution background	These solutions are used to perform some operations related to data analytics like training and apply AI models, compute derived quality evaluation data (e.g., FFT), suggest processing parameters, foresee parameters

		related to the quality of the items produced or the operation of the machines, etc.
	Solution name	12_i4Q_AD, 18_i4Q_QD
	Solution background	These solutions are used to take (and reflect) decisions related to the production lines, like admitting, rejecting or discarding items, admitting new raw materials, etc.
	Solution name	18_i4Q_QD,19_i4Q_PA
	Solution background	These solutions are used to make predictions (e.g. about the quality of produced items, the automatization of the reconfiguration of production lines, the modification of machine parameters, etc.).
	Solution name	20_i4Q_LRT, 21_i4Q_LRG, 22_i4Q_LCP
	Solution background	These solutions are used to apply decisions on the machines, production lines, etc. (e.g. maintain the production equipment, stop a machine, stop a production line, etc.).

Table 18. Pilot 1 - FIDIA analysis

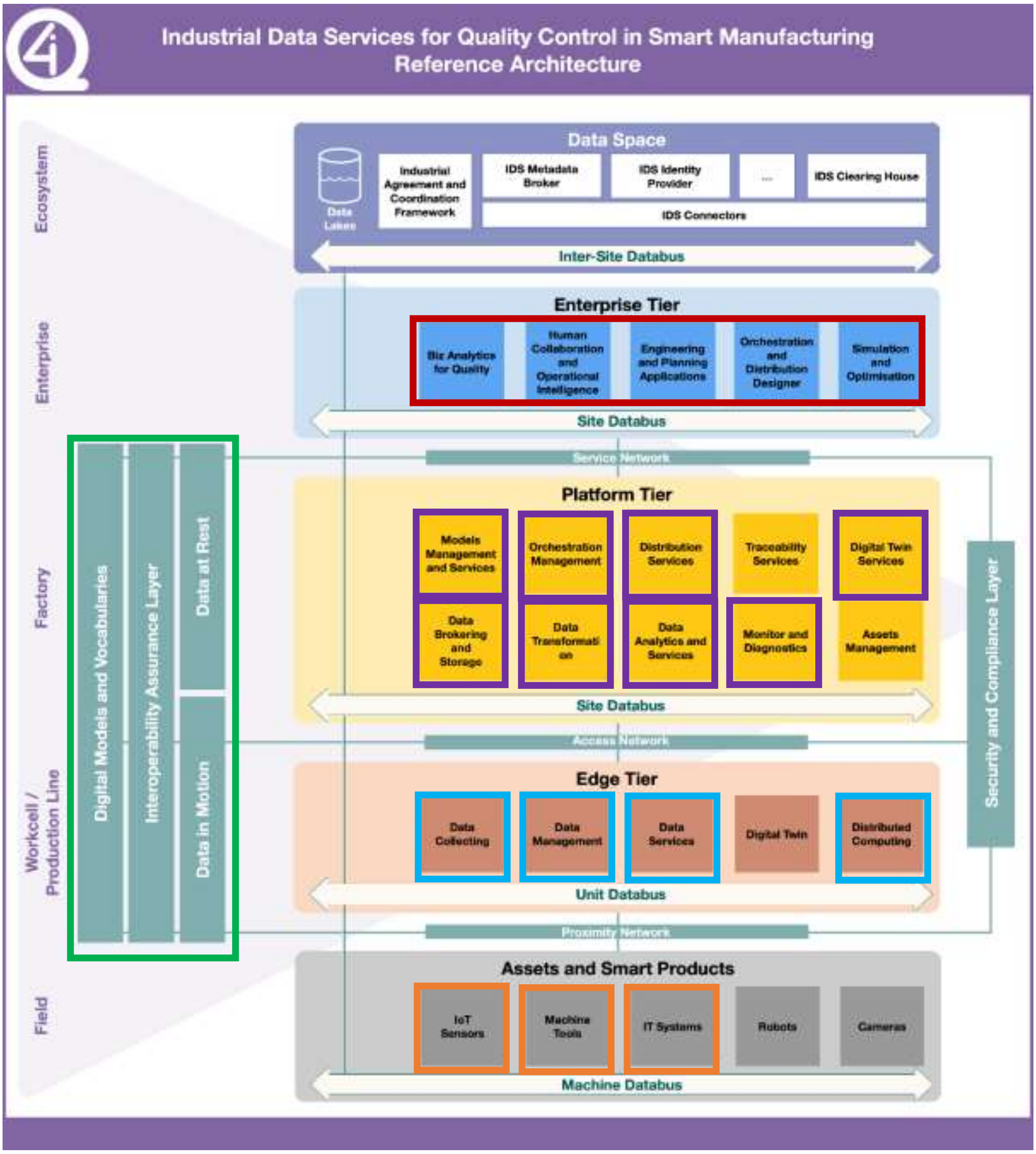

Figure 26. Mapping of FIDIA Pilot within the i4Q RA

4.3.2 Pilot 2 – BIESSE

Pilot ID		#2
Pilot name		BIESSE
i4Q RIDS	Solution name	04_i4Q_TN and 05_i4Q_SH
	Solution background	These solutions will be used to securely transfer data from i4Q solutions to cloud level (SOPHIA) once analysis has been completed

	Solution name	07_i4Q_DR, 08_i4Q_DRG
	Solution background	This solution will be used to provide a repository where the CNC can store the main raw data coming from the plant at a given frequency (every 2ms)
	Solution name	09_i4Q_DIT
	Solution background	This solution will be used to synchronize and align data coming from different data sources at different sample rates and to read data from Biesse Raw Log File, located on each machine pc, in case of i4Q_DR being not available
	Solution name	10_i4Q_DA, 11_i4Q_BDA
	Solution background	These solutions will be used to intercept failure of machineries and notify, in ascending order of priority, the event type to SOPHIA Cloud Platform, by the means of messages, containing diagnostic information (e.g., suspected component, type of problem; priority, etc.).
	Solution name	12_i4Q_AD
	Solution background	This solution will provide BIESSE of a self-diagnosis "maintenance interface", for support activities, that contains the information available for the customer and all the other outputs from the i4Q solutions (e.g., confidential data, outputs from experimental algorithms, .etc.).
	Solution name	16_i4Q_DT
	Solution background	This solution will be used to collect machine setup data to perform a test cycle according to the given constraints.
	Solution name	20_i4Q_LRT
	Solution background	This solution will be used to gather data acquisition parameters using federated access.

Table 19. Pilot 2 - BIESSE analysis

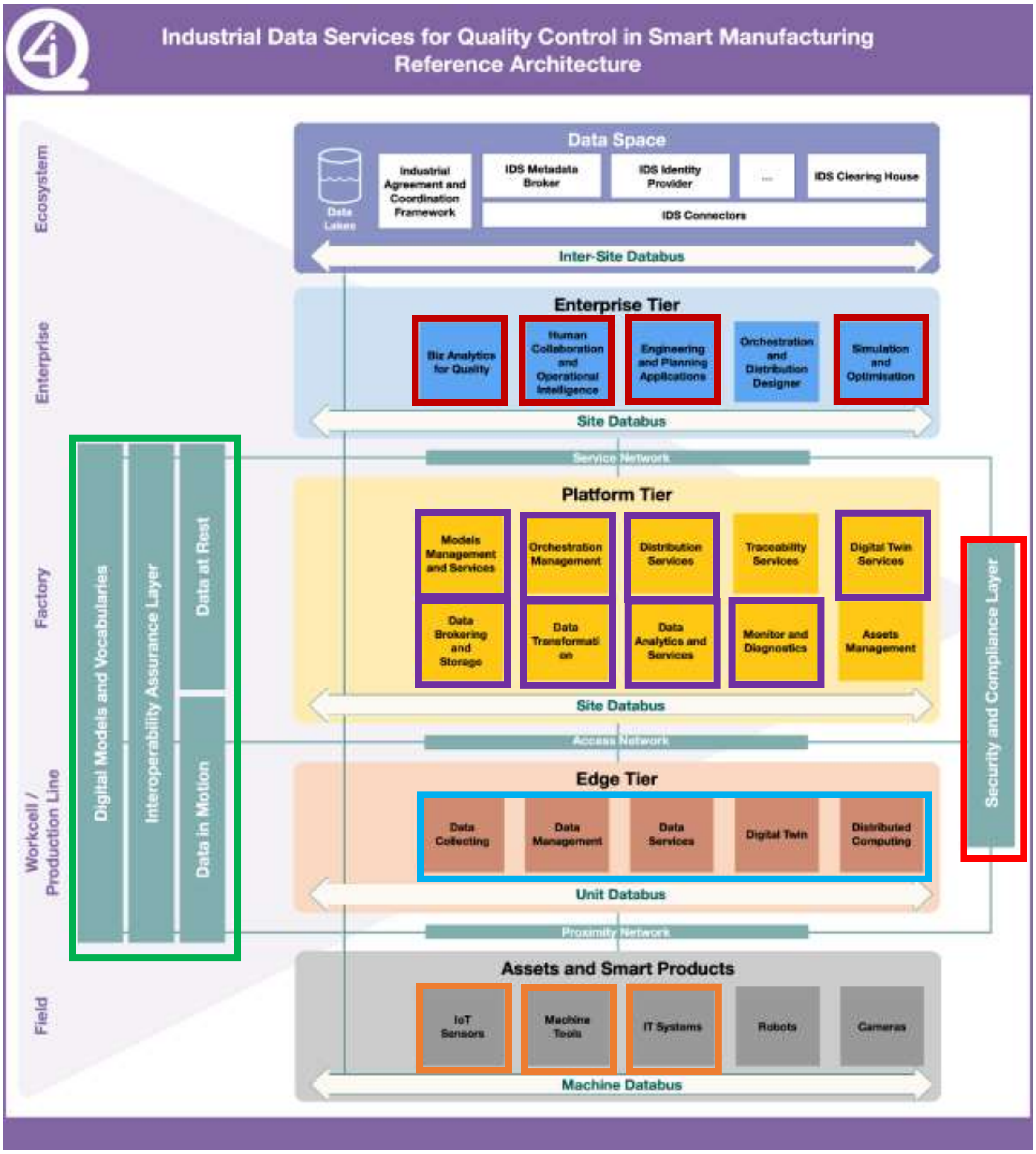

Figure 27. Mapping of BIESSE Pilot within the i4Q RA

4.3.3 Pilot 3 – WHIRPOOL

Pilot ID		#3
Pilot name		WHIRLPOOL
i4Q RIDS	Solution name	01_i4Q_QE, 02_i4Q_DQG
	Solution background	These solutions will be used to predict products conformity based on full production data generated by the shopfloor.

	Solution name	09_i4Q_DIT
	Solution background	This solution will be adopted to access data stored in the WHR Google Cloud Platform.
	Solution name	10_i4Q_DA, 19_i4Q_PA
	Solution background	This solution will be used to develop a DSS, performing Threshold and Importance analysis (using historical data for training) and adopting AI/ML algorithms.
	Solution name	10_i4Q_DA, 16_i4Q_DT
	Solution background	These solutions will be used to perform virtual tests of the products resulting from the manufacturing process
	Solution name	11_i4Q_BDA
	Solution background	This solution will be adopted to generate an alert for non-conformity situations
	Solution name	07_i4Q_DRG , 08_i4Q_DR
	Solution background	This solution will be adopted to store input data coming from Google Cloud Platform in an internal repository, according to a given format. Moreover, it will be used to store output/results from AI analyses.
	Solution name	12_i4Q_AD
	Solution background	This solution will be used to develop a visualization tool to display the results of AI analysis in an ad-hoc dashboard. The tool should also be user-friendly to be easily used by the multi-functional Quality teams

Table 20. Pilot 3 - WHIRPOOL analysis

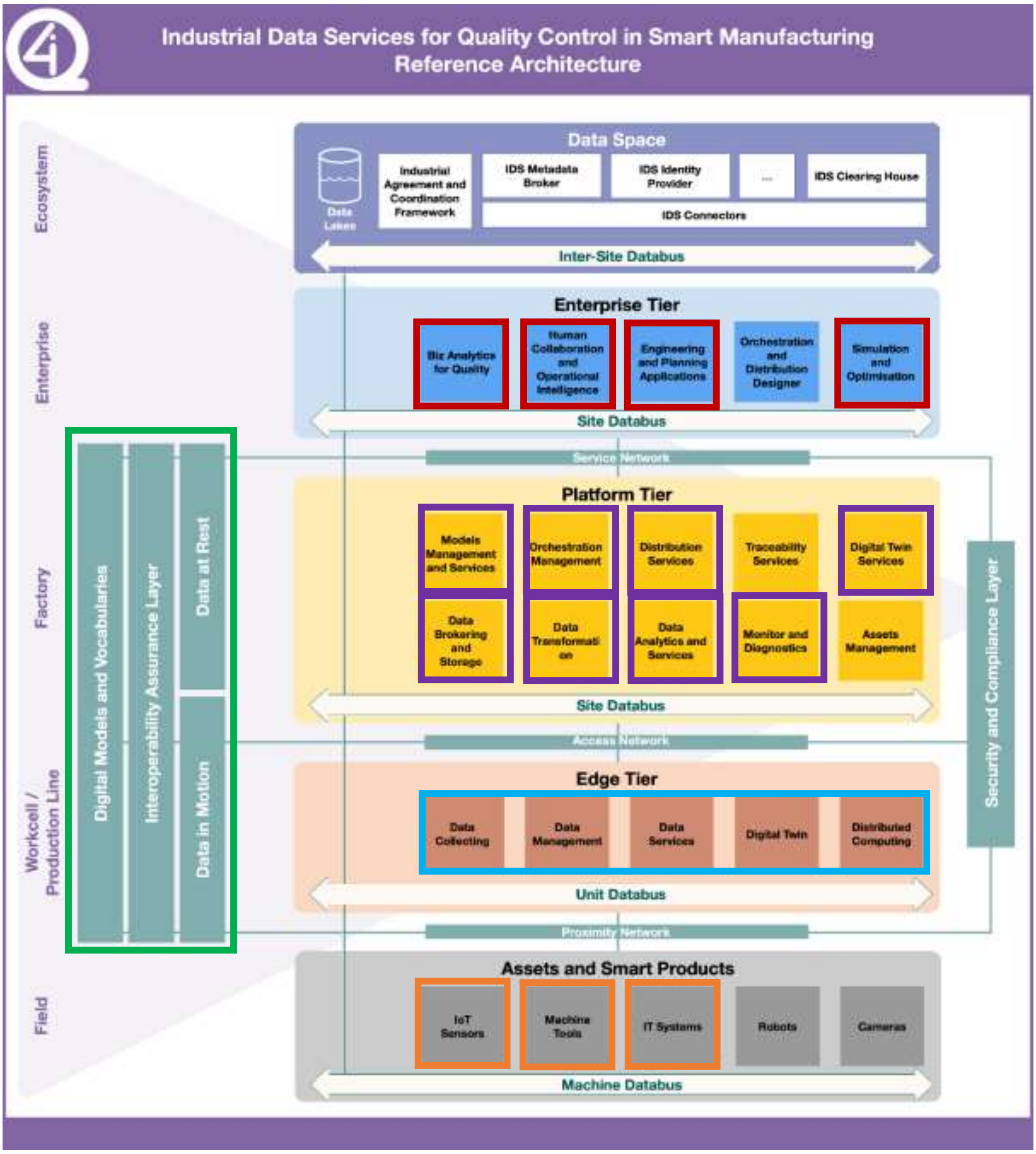

Figure 28. Mapping of WHIRLPOOL Pilot within the i4Q RA

4.3.4 Pilot 4 - FACTOR

Pilot ID		#4
Pilot name		FACTOR
i4Q RIDS	**Solution name**	**04_i4Q_TN**
	Solution background	With this solution, the system must be able to collect the data associated with the machine, the tool, the production order (customer, industry...) and the part. On the other hand, to save online the data/comments entered manually by the user (quality requirements). In addition, it must be able to collect and save all the part measurement data provided by the measuring equipment automatically in digital format. Therefore, this solution is used to ensure reliability in the exchange of information, ensuring traceability and security over the exchange.
	Solution name	**07_i4Q_DR**
	Solution background	This solution aims to be able to store data in various formats and keep them ready for use by other solutions or by further human analysis.
	Solution name	**09_i4Q_DIT**
	Solution background	This solution aims to be able to process the data and perform the necessary calculations and cleaning to convert this data into a useful and intelligible form for other solutions.
	Solution name	**10_i4Q_DA**
	Solution background	Through this solution, it should be possible to predict process deviations or tool wear. For this, they will use different algorithms and data collected during manufacturing.
	Solution name	**11_i4Q_BDA**
	Solution background	Using the BDA solution, algorithms will be built that will allow the other solutions to have a way to act in order to avoid quality failures and improve the process. Thanks to this, BDA will be able to correlate dependent and independent variables (speed-temperature, temperature-

		material), aided by the Digital Twin.
	Solution name	**12_i4Q_AD**
	Solution background	This solution is used as a method to send information to an interface, where the data can be evaluated and some information can be entered. The visualisation should be able to be configured (graphs, distributions, etc.).
	Solution name	**15_i4Q_IM**
	Solution background	This solution will be used as a measurement method for the different parts to be produced. The intention is to provide a clear and direct message of whether or not a measurement is met or not by means of a notification.
	Solution name	**16_i4Q_DT, 19_i4Q_PA**
	Solution background	The Digital Twin should enable a simulation of the CNC machine process, which will be used by 19_i4Q_PA to perform continuous simulations that should find the boundaries of the different variables involved in the machining process.
	Solution name	**17_i4Q_PQ**
	Solution background	This solution will be used to report and operate, changing the process if trends go out of range to keep the process stable.
	Solution name	**18_i4Q_QD**
	Solution background	This solution shall be used when it is not possible to automatically adjust the parameters of a machine. The solution will stop the machine and calculate the KPI 412.
	Solution name	**20_i4Q_LRT**
	Solution background	It is used to correct the working parameters when a possible quality deviation is about to happen.

Table 21. Pilot 4 - FACTOR analysis

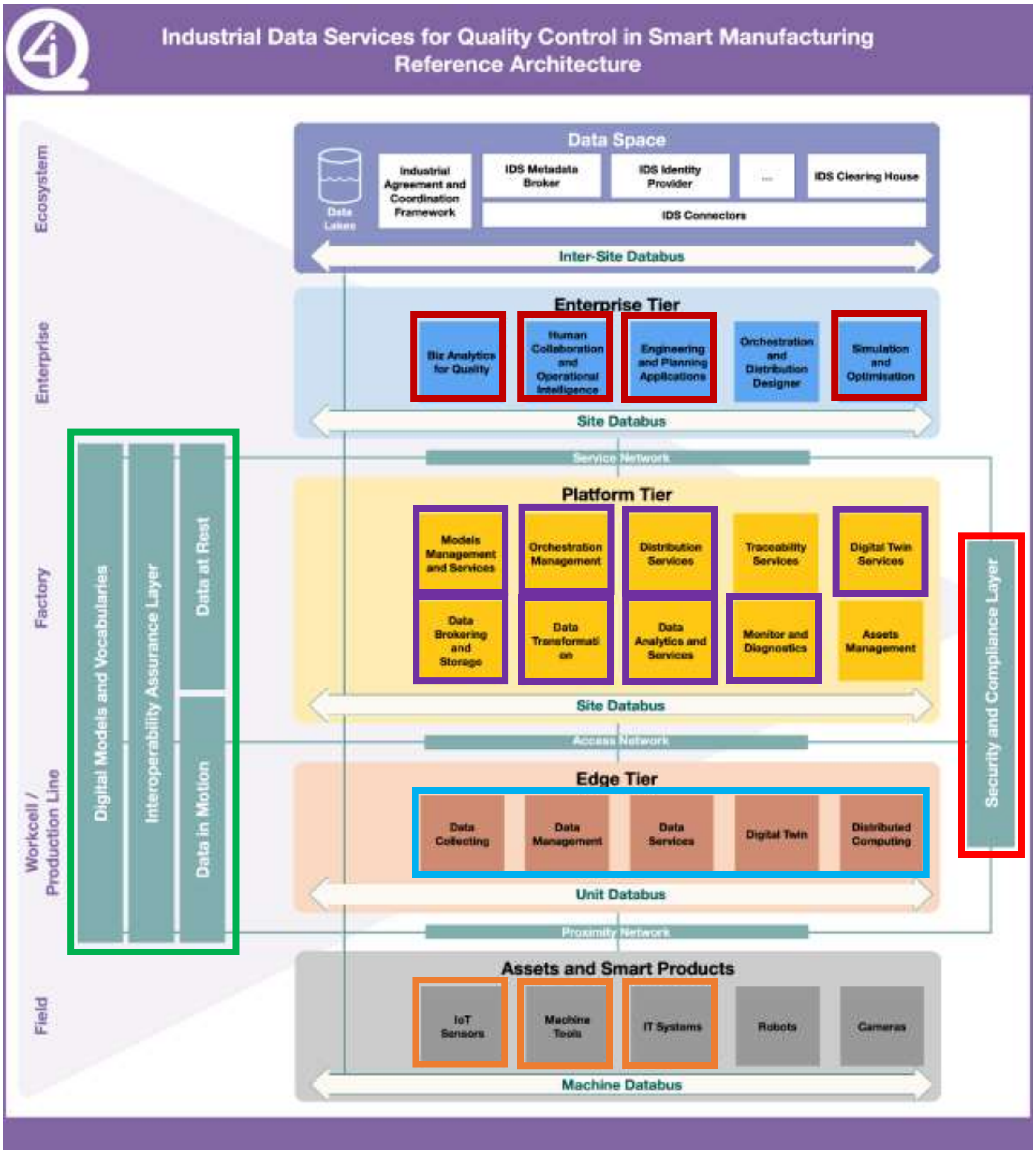

Figure 29. Mapping of FACTOR Pilot within the i4Q RA

4.3.5 Pilot 5 - RIASTONE

Pilot ID		#5
Pilot name		RIASTONE
i4Q RIDS	Solution name	07_i4Q_DR
	Solution background	This solution will be used to store in a safe and accessible way the manufacturing data coming from the manufacturing plant.
	Solution name	09_i4Q_DIT
	Solution background	This solution will be used to gather and prepare the manufacturing data for usage and storage.
	Solution name	10_i4Q_DA
	Solution background	This solution will be used to provide analytics on the manufacturing data
	Solution name	11_i4Q_BDA
	Solution background	This solution will be in charge of providing a bundle capable of analysing data and providing analytics on-premises.
	Solution name	12_i4Q_AD
	Solution background	This solution will be used to visualize the data and/or the results from the data analytics. This will aid in the optimization of the production line and the quality of the product.
	Solution name	15_i4Q_IM
	Solution background	This solution will be used to detect the faulty quality of raw mater and adapt manufacturing parameters in real-time to optimize the product quality.
	Solution name	17_i4Q_PQ
	Solution background	This tool will analyse the raw matter composition and granulometry and assist the quality control.
	Solution name	18_i4Q_QD
	Solution background	This solution will evaluate the quality of the raw matter that is delivered to the factory.

Table 22. Pilot 5 - RIASTONE analysis

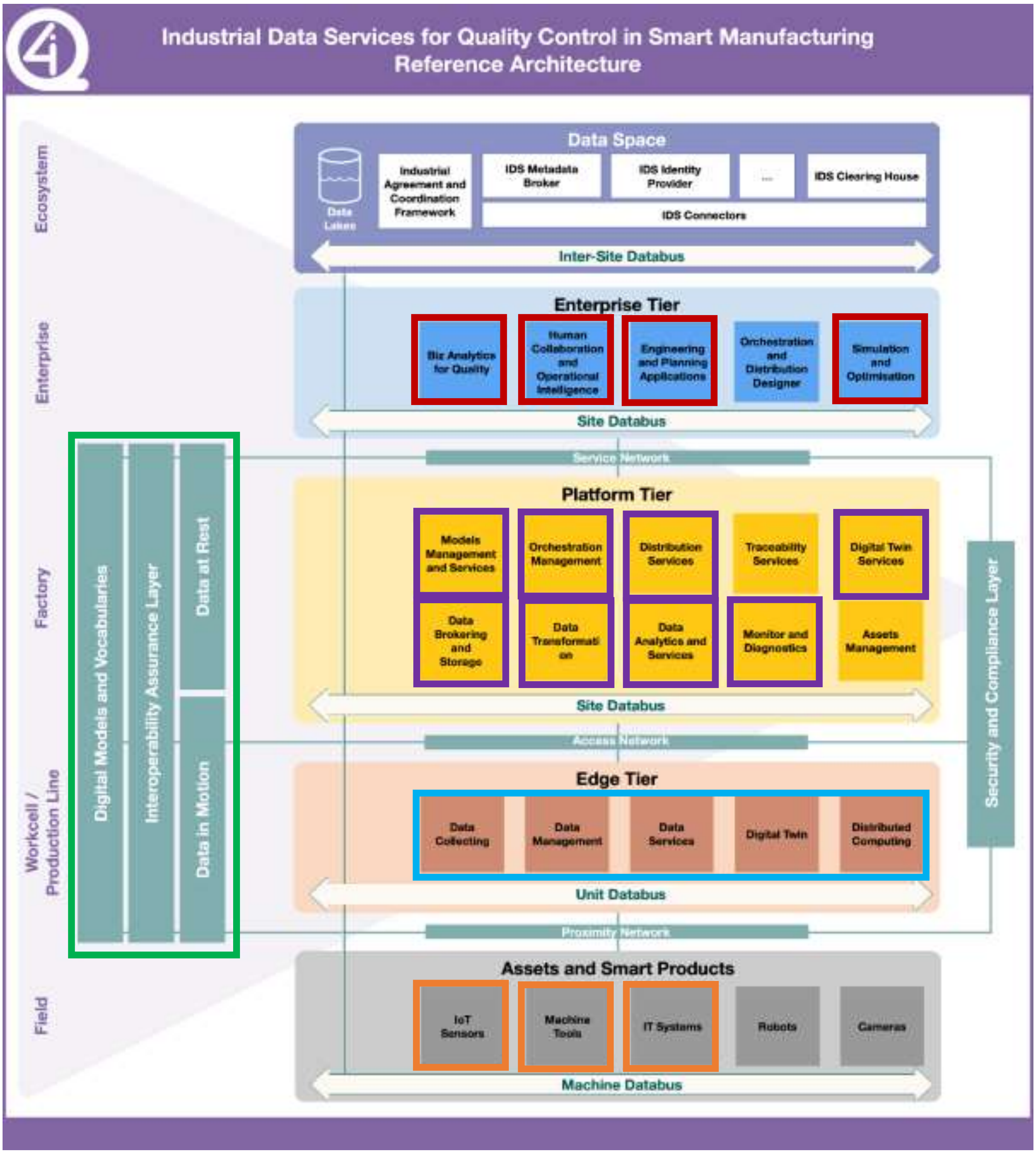

Figure 30. Mapping of RIASTONE Pilot within the i4Q RA

4.3.6 Pilot 6 – FARPLAS

Pilot ID		#6
Pilot name		Automatic Advanced Inspection of Automotive Plastic Parts
i4Q RIDS	Solution name	04_i4Q_TN
	Solution background	Used to ensure reliable exchange of information between sensors, machines and the database. It ensures security and

		traceability on data exchanges.
	Solution name	05_i4Q_SH
	Solution background	Leverages levels of trust between the different data sources at different levels (i.e., sensors, machines, databases on edge and cloud). It will ensure the safe movement of data from factory to cloud level.
	Solution name	07_i4Q_DR, 08_i4Q_DRG
	Solution background	Store data generated by sensors and machines, managing the storage of historical data and lossless compression of images. It will also allow performing data transformations and queries.
	Solution name	09_i4Q_DIT
	Solution background	Collect data from sensors. Establish dataflows between the different machines (injection, water collector and energy analyser machines) and the database. Automatic initialization of the visual inspection process.
	Solution name	12_i4Q_AD
	Solution background	Visualizes relevant data and stats about each machine. It will also be used to import information and send signals at the factory level.
	Solution name	15_i4Q_IM
	Solution background	This solution is used to monitor each machine condition accessible at the factory level or from the company's network.
	Solution name	17_i4Q_PQ
	Solution background	Reduce waste material and workload by automatically offering accurate product quality predictions without manual tests and inspection.
	Solution name	18_i4Q_QD
	Solution background	It will aid in the automatic inspection of parts by tagging and recognizing the same piece throughout the quality inspection process and offer results based on the gathered data

		through a readily available interface. It will also display machine status and alerts.

Table 23. Pilot 6 - FARPLAS analysis

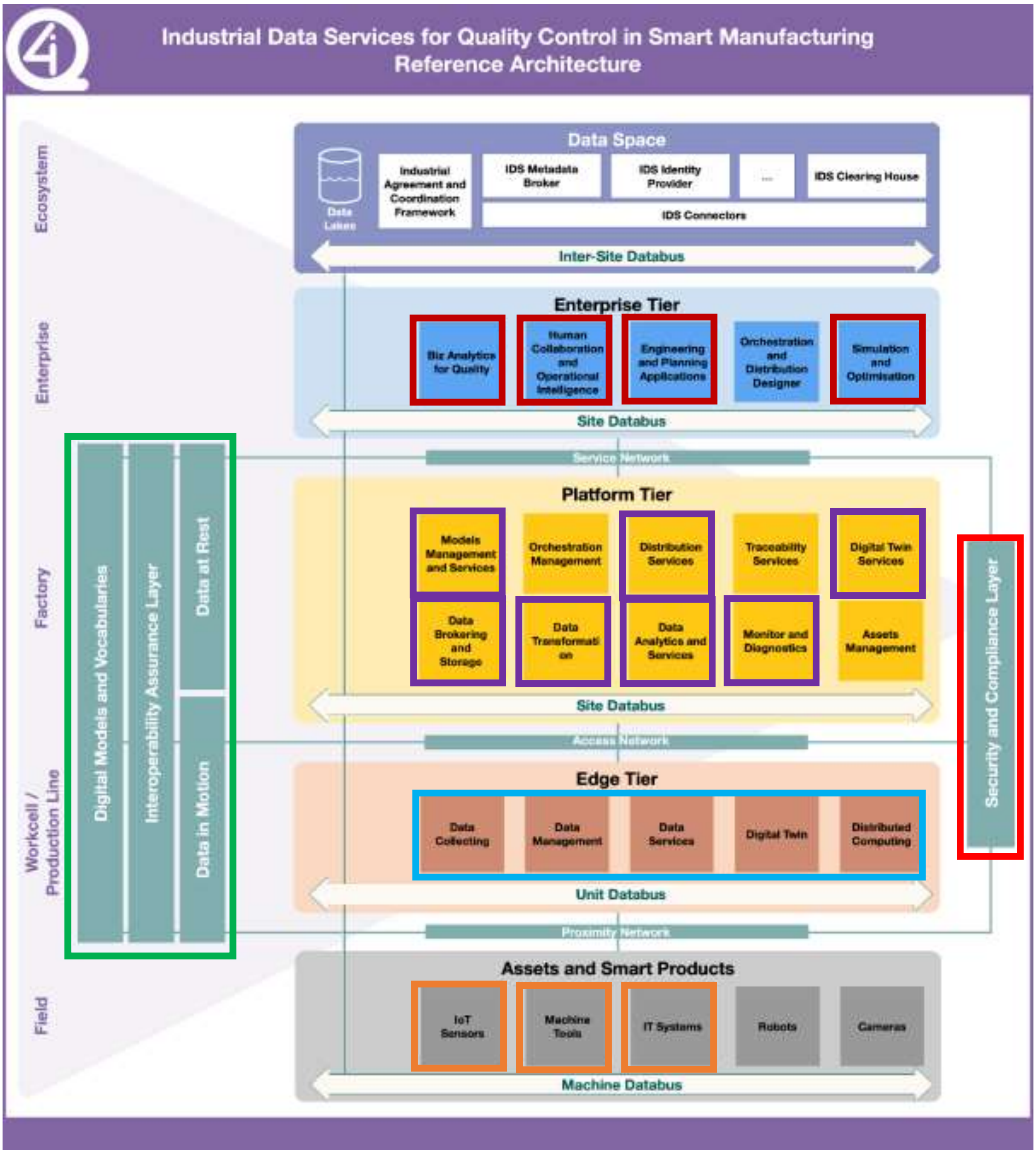

Figure 31. Mapping of FARPLAS Pilot within the i4Q RA

5. Conclusions and Next Steps

This deliverable describes the work performed to define the final release of the i4Q Reference Architecture. The design of the i4Q RA has followed an iterative approach, the results provided by several activities have been gathered and included in a systematic project vision.

The first version of i4Q RA has been taken as the basis, continuing the mapping activities of the i4Q Solutions against it and collecting the feedback from the solution providers. Another input for the architecture consisted in the analysis across the four key viewpoints (business, usage, functional and implementation), the architecture and the viewpoints are mutually correlated and continuous feedback from each other were exchanged during the activities performed in the different tasks of WP2 (T2.1, T2.3, T2.4, T2.5, T2.6). The iterative approach followed for the implementation of the viewpoints was crucial to guarantee the alignment between the different elements of the Reference Framework.

Another key input is the definition of the digital models and ontologies to be used in the i4Q Framework (T2.2). The analysis performed in D2.2 represents the basis for mapping activity to establish the best data models and ontologies for each architectural tier.

The definition of the second version of the i4Q RA has also taken into account all the considerations coming from the activities of WP1, formalized in the description of the use case scenarios, the requirements collection and the specifications of the i4Q RIDS. Special attention was devoted to the pilots' needs involving them in the activities of the viewpoints definition and defining blueprints.

The final version of the reference architecture and the four viewpoints will serve as input for the implementation activities: WP3 - Reliable Industrial Data Services Infrastructure - dealing with methodologies, tools and infrastructure to ensure the necessary data quality; WP4 - Big Data Services - dealing with data integration and fusion for analytics and simulation models; WP5 - Manufacturing Line Qualification and Reconfiguration – dealing with strategies and methods for process qualification and optimization.

6. References

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