Ref. Ares(2022)1486484 - 28/02/2022

QU4LITY

DIGITAL MANUFACTURING PLATFORMS FOR CONNECTED SMART FACTORIES

D4.10 Report on Equipment Interworking and Interoperability

Deliverable Id:	**D4.10**
Deliverable Name:	**Report on Equipment Interworking and Interoperability**
Status:	**FINAL**
Dissemination Level:	**PU**
Due date of deliverable:	**28/02/2022**
Actual submission date:	**28/02/2022**
Work Package:	**WP4**
Organization name of lead contractor for this deliverable:	**FAGOR/IKERLAN**
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Abstract: The deliverable details the equipment interworking and interoperability of each pilot on WP4. In particular, the interoperability of the different pilots at device, network and platform levels.

Co-funded by the Horizon 2020 Programme of the European Union

Contents

1 HISTORY

Version	Date	Modification reason	Modified by
0.1	12/01/2022	First draft QU4LITY_D4.10_v0.1	IKERLAN
0.2	25/02/2022	Final draft	IKERLAN
0.3	28/02/2022	Reviewed version	INNOVALIA
1.0	28/02/2022	Final version	IKERLAN

2 Summary

This deliverable describes the equipment interworking and interoperability of the pilots involved in the WP4. In contrast to the previous version of the deliverable, which presented the preliminary status of the pilots regarding the equipment interoperability at device, network and platform levels, this final version reflects the evolution of each of the pilots in terms of equipment interoperability as a result of the QU4LITY project.

Thus, the main goal of this deliverable is to analyze how the QUALITY project has impacted on the design and implementation techniques of the pilots for intelligent data exchange and interaction between different types of ZDM equipment. Hence, it will deal with data interoperability (through the Industrial Data Space of WP5) and machine-to-machine (M2M) interactions between two or more pieces of equipment. The implementation of M2M and data interoperability will be a foundation to the use of multiple ZDM equipment technologies for the implementation of ZDM processes in WP5 and in the scope of the pilots.

This deliverable shows the status and evolution of the pilots regarding the equipment interoperability through 3 different snapshots: the status prior to the QUALITY project, the intermediate status on M15, and the final status on M30. For each of these snapshots, the configuration of 6 machine pilots is presented regarding the data interoperability between their equipment in terms of the connectivity technologies, syntactics, semantics, security, solution, and licenses.

3 Introduction

3.1 Objectives and Approaches

Task 4.5 deals with the design and implement techniques for intelligent data exchange and interaction between different types of ZDM equipment. Hence, it will deal with data interoperability (through the Industrial Data Space of WP5) and machine-to-machine (M2M) interactions between two or more pieces of equipment. The implementation of M2M and data interoperability will be a foundation to the use of multiple ZDM equipment technologies for the implementation of ZDM processes in WP5 and in the scope of the pilots and are described in this document.

As QU4LITY focuses on a shared data-driven ZDM product and service model for Factory 4.0, interoperability of communications between equipment becomes critical for sharing data among different devices, platforms, and communication protocols. Therefore, the interoperability of the pilots must be enhanced with digital enablers based on the technology platforms that are available in the consortium.

Note that this version of the deliverable does not present the state of the art to shorten the length of the document and make it more readable and thus, to focus on the real content of the deliverable. Please, check the previous version (D4.9)

3.2 Relation to other deliverables and WPs

This deliverable has relations with other WPs.

On the one hand, it has relation to WP2 where the components to support Autonomous Quality for ZDM will be identified. Interoperability is essential for the integration and standardization of those components. The following task addresses this challenge:

- **T2.4 Standards Compliance and Interoperability Specifications**: will specify the standards to be followed by the QU4LITY reference architecture and digital platform implementations. More specifically deliverable D2.7 defines a common standardization strategy for zero-defect production within the framework of the QU4LITY project, but also as a general recommendation in the area of ZDM. The goal of such a strategy is to ensure agreement between the QU4LITY technology providers and end users to ensure effective implementations within each pilot as well as across the pilots. Among the objectives pursuit in this task the task is concerned on how to make technical choices regarding interoperability in order to ensure effective implementations within each pilot as well as across pilots. Another concern is how current standards in the ZDM space can be selected and used within pilots in order to maximize the common integration and interoperability chances.

In WP5 one of the tasks is concerned with the enhancement of digital platforms based on Open APIs and interoperability characteristics. This task is:

- **T5.4 Digital Platforms Open APIs and Process-Level Interoperability:** This task will augment all digital platforms of the project partners with Open APIs, in order to enable their integration and use in various manufacturing applications, but also their enhancement by third parties. QU4LITY technologies that do not provide Open APIs will be enhanced with such APIs. On the other hand, technologies that already offer some Open API will have to be reengineered and refactored in order to ensure that their APIs adhere to the ZDM data standards. In this way, the task will provide a basis for data interoperability of different technologies and processes. **D**eliverable D5.7 QU4LITY Digital Platforms Open APIs reports on the Application Program Interfaces brought to the attention of the project by the QU4LITY's partners through their technologies and field of expertise and exploitable within the Digital Platforms for End-to-End ZDM Processes addressed by WP5. The interoperability between those APIs is essential for the successful integration of ZDM equipment.

On the other hand, there are several work packages and tasks that will collect the results and conclusions obtained when implementing, deploying, and testing the digital enhancements (including interoperability enhancements). In WP6, ZDM developments will be validated, verified, and certified against standards and benchmarks at the equipment, platform, and process levels. In WP7 the enhancements will be tested and validated in real scenarios. The results and conclusions obtained will be included in the deliverables. There are no specific deliverables where the interoperability enhancement will be presented but the different pilots and benchmark trials will include these in their deliverables

4 Interoperability at different levels of the IoT platform

M2M communication is a critical aspect within industry to exchange information between different equipment. Interoperability is fundamental for realizing the vision of a global IoT ecosystem that supports business decision-making. However, industrial equipment is typically composed of heterogeneous IoT devices such as sensors or actuators, meaning that they provide data of diverse nature. Besides, each IoT device might use different communication protocols, which will depend on the nature of the device itself or the provider, among other factors. These facts hinder the M2M communication as each equipment might use a different communication language and it is, therefore, necessary to standardize the communications to enable interworking and interoperability between them. In this sense, several aspects must be considered at the time of making M2M communications compatible across the industrial equipment These aspects have already been described in various surveys [13]–[16]. Concretely, this document follows the interoperability taxonomy presented in [17]. Following this taxonomy, interoperability can be approached from five perspectives, which refer to device, network, semantic, syntactic, and platform interoperability. Each of these perspectives focuses on different areas of the IoT architecture to offer interoperability at different points, thus covering the entire platform together. Figure 1 shows how they are placed within a generic architecture. Next, these perspectives are analyzed. Finally, the security in IoT platforms and how it can affect the interoperability is briefly described.

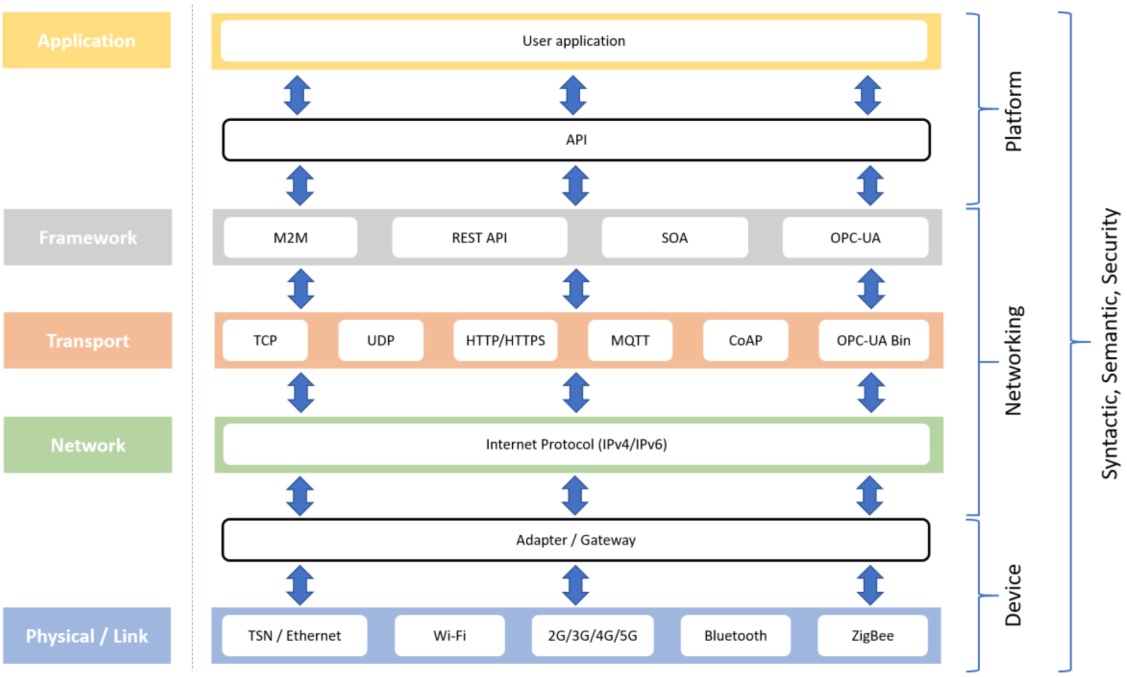

Figure 1 - Interoperability at different levels of the IoT platform

4.1 Device interoperability

Interoperability at device level refers to the communication technology or protocol that IoT devices use to connect and exchange data with other systems. The problem lies in that several communication standard protocols are currently available such as 3/4/5 G, Bluetooth, Wi-Fi, NFC, ZigBee, RFID, Z-Wave, or even others non-standard proprietary protocols like SIGFOX. At application layer, there are also other communication protocols such as MQTT, HTTP, HTTPS, CoAP, or XMPP. None of these protocols have been stablished as the de-facto communication protocol since the selection of which of them to use heavily depends on the current use case and the available computational resources. For instance, there are some standard protocols that require more resources to work and thus they might not be suitable for low capacity hardware. Notice that each communication protocol is not compatible with the others and that diverse IoT devices can be working at the same time in an industrial environment.

To achieve full interoperability, it is mandatory to integrate and support all these heterogeneous communication protocols to enable exchanging data between IoT devices regardless of the protocol they are using. Typically, dedicated adapters or gateways (hardware) are used to serve as intermediaries between two or more protocols although software functionalities can also be embedded into smart IoT devices. In this context, there are one-to-one gateway protocols which enable interoperability between two communication protocols. These types of gateways are not scalable since the number of required gateways will increase proportionally to the number of communication protocols. Instead, there exist one-to-many gateways that enable interoperability between multiple protocols.

4.2 Network interoperability

Interoperability at network level refers to the ability of exchanging messages through the network regardless of its type. This provides an end-to-end communication in which data is transmitted through different networks by managing issues such as intermittent and unreliable connectivity, addressing, routing, or security, among others. To achieve network interoperability, there are several approaches. The first one refers to virtual networks or Overlay-based solutions, which aim to create a virtual network on top of physical networks so that an end-to-end communication is enabled. Here, the virtual network is in charge of providing the interoperability to the network by making all the communications compatible across multiple protocols. As an alternative, IP-based approaches enable embedding the TCP/IP stack into the IoT devices and thus they can be directly connected to the IP network without a gateway. However, this is often not useful due to resource-constrained devices although researchers are working on lighter IP-based approaches. Software-defined networking (SDN) is another promising paradigm that relies on decoupling the control and data of IoT devices. This is done by defining an SDN application layer that manages the data and two controllers (SDN and IoT) that convert the communication protocols in an understandable way for forwarding systems. As a complementary solution to SDN, network function virtualization (NFV) separates the physical network from the functions that run on them so that different service providers can create isolated virtual networks that share the physical network. Therefore, several communication protocols can be handled. Finally, fog computing can also be used to manage all the IoT devices in the edge, thus delegating on it the task of making all the communications compatible with each other.

4.3 Syntactical interoperability

Interoperability at syntactical level refers to the foundation for successfully transmitting messages from system A to system B. This is achieved by defining a structure and syntax that enables the message to be ascertainable by both systems. When data is exchanged, the data is serialized by the data publisher whereas the receiver deserializes it. To this extent, a set of syntactic rules are defined so that the message receiver uses the same rules as the message sender. The problem arises when the rules defined by the publisher and the receiver are not compatible with each other, leading to parse errors as the receiver has no idea about how to decode received messages. To enable interoperability at syntactical level, researchers use WSDL or RESTful APIs to access resources exposed by devices as services.

4.4 Semantic interoperability

Interoperability at semantic level refers to the ability to exchange data between different devices, services and applications in a meaningful way. To achieve this, information regarding the data (metadata) and the working environment is provided along with the data itself. However, the metadata can be provided using a wide range of formats such as JSON, XML, or CSV, hindering the interoperability as different data formats require different ways to process them. In this sense, syntactic and semantic interoperability seems to be similar although there are some dissimilarities. Furthermore, data might be represented in different measurement units or contain other information. The fact of having different data models and schemas might lead to not being able to dynamically inter-operate between devices as they have different descriptions or understandings of resources and operational procedures. In order to achieve semantic interoperability, typically web ontologies are used such as Resource Description Framework (RDF), SPARQL, or Web Ontology Language (OWL) to reach an agreement on the format and meaning of data by using shared vocabularies regarding the schema.

4.5 Platform interoperability

Interoperability at platform level refers to the ability to manage the information of the diverse IoT devices regardless of the used platform. Generally, each platform uses different operative systems, programming language, data structures, or even proprietary frameworks, functionalities and APIs. This fact hinders platform interoperability as it requires ad-hoc applications for each platform, which might not be compatible in other ones. To achieve platform interoperability, it is necessary to use a standardized API that works on top of any platform so that data can be easily accessed regardless of the used platform.

4.6 Security

Within IoT platforms, devices and data involved in the monitorization are exposed to multiple vulnerabilities such as physical harms, data theft, or hijacking, among others. This might occur as a consequence of many security issues such as unpatched vulnerabilities, weak authentication, or vulnerable APIs. Hence, the implementation of strong passwords, certificated or token-based authentications, digital signatures, or encryption is mandatory to make data safe. However, the implementation of this security services also hinders interoperability as they often require specific protocols or data formats to work. Hence, security must be taken into consideration at the time of designing a full interoperable platform.

5 Equipment Interworking and Interoperability on pilots

In this section, the interoperability degree of the pilots involved in this WP is detailed. Each pilot presents its current configuration in a table which indicates whether its platform satisfies interoperability in terms of device, network, and platform level. Within each of these levels, a brief description is introduced regarding the current interoperability degree at such level. Besides, the supported connectivity technology, application protocols, and data formats are specified. Note that syntactic and semantic perspectives are involved in the entire stack of the platform and it is required, therefore, to include them within the mentioned three levels of interoperability. Furthermore, the solution that is currently used to provide interoperability is specified, if any, which includes gateways, APIs, or services. Afterward, which security methods are currently implemented is indicated, if any. Finally, the openness of all the used frameworks and tools are identified.

This information is presented at 3 different stages (columns of the tables). First, the status prior to the QU4LITY project is presented, that is, it shows the original status of each pilot before starting the project. Second, the intermediate status of each pilot is detailed, which includes all the development made from the beginning of the project until M15. Third, the final status of each pilot is presented, which refers to the work done between M15 and M30.

Hence, these tables show the evolution of each of the pilots during the entire project in term of equipment interoperability at different levels of their digital platforms.

5.1 Machine Pilots

5.1.1 Pilot 1: Grinding Machine (DANOBAT)

The system to be monitored is an LG machine available at the prototypes laboratory of DANOBAT. It produces cylindrical parts. The function of the machine is to externally grind these cylindrical parts. The machine is already connected to the cloud, so some historical data sets are already available. As it can be seen in Figure 2, devices of different types (CNC/PLC, IC2/IC3, etc.) and providers (Siemens, Fanuc, Omron, etc.) are connected to the Edge and Cloud. On the other hand, Figure 3 shows the architecture to be implemented in this pilot, which will be focalized on providing an architecture that delivers integration solutions in IoT-Edge-Cloud, in the field of Condition based maintenance (CbM) and ZDM zero defect manufacturing.

As the Data Platform System is the point of entry and delivery of data for the digital management of the machine, the goal is to design and develop technological enablers to guarantee the interoperability between the components of the platform to transfer or share data through the entire vertical (device, Edge and Cloud), regardless of the connectivity technology or the communication protocol used.

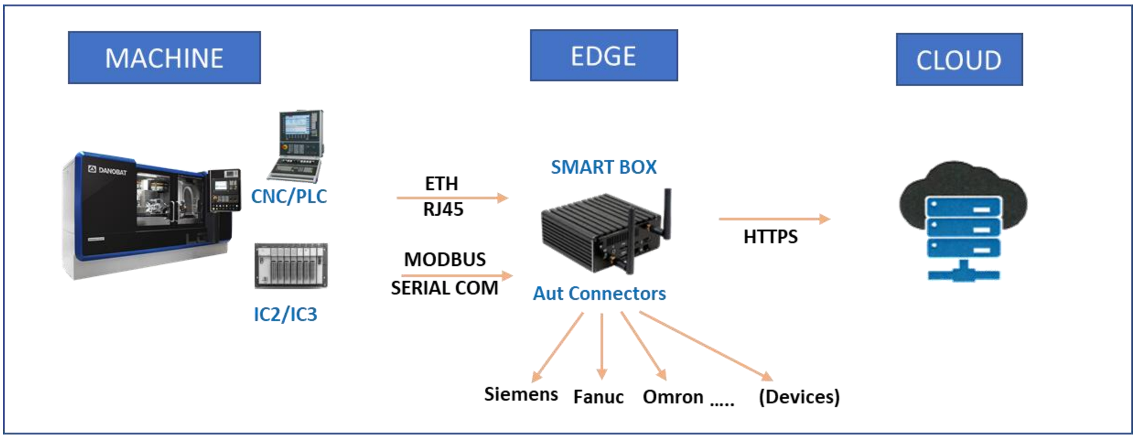

Figure 2 - Danobat grinding machine pilot with connectivity.

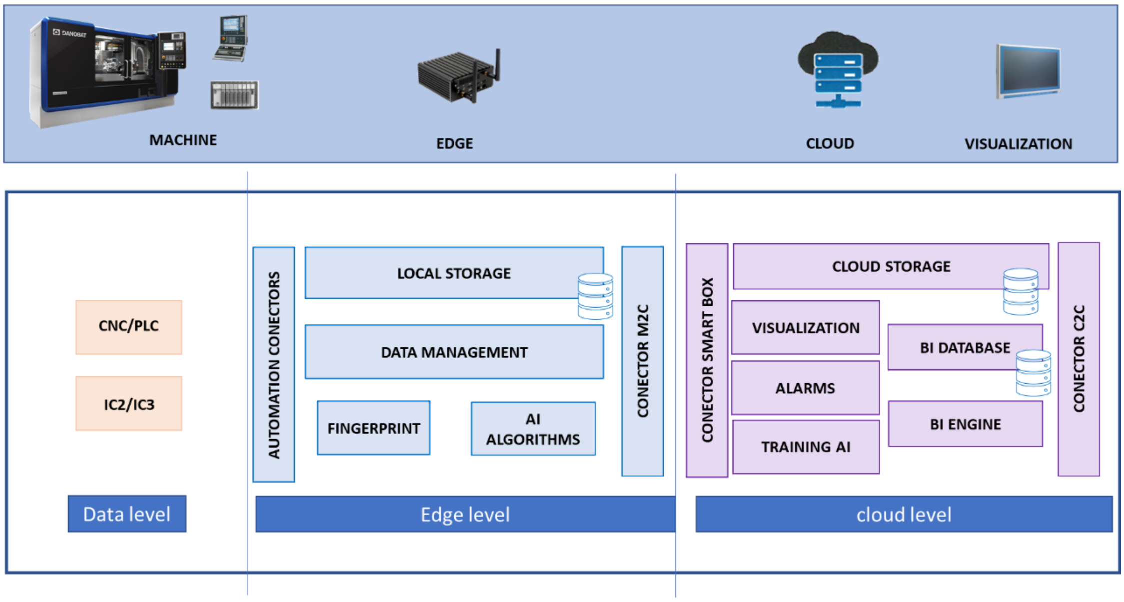

Figure 3 - Architecture to be implemented on the Danobat pilot.

Table 1 summarizes the original, intermediate, and final interoperability degree of the grinding machine pilot (Danobat) at device, network, and platform levels. As shown, this pilot does not work in equipment interoperability during this project, since they obtained the presented degree of interoperability before starting it.

		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Use case description		Digitally enhanced ZDM in grinding machine		
Device	Description	Danobat Machine tools and its components		

	QUALITY enabler/component	There are three main components of the solution at device level: the numerical control (CNC), the programable logic controller (PLC) and the real time analysis and actuation controller (ICX)		
	Connectivity	Ethernet	No updates	No updates
	Syntactic	Proprietary protocols of the device's suppliers	No updates	No updates
	Semantic	JSON	No updates	No updates
	Data Schema Standard	Proprietary	No updates	No updates
	Security	User password	No updates	No updates
	Solution	Proprietary protocols of devices suppliers	No updates	No updates
	License	Licensed by devices suppliers	No updates	No updates
Network	**Description**	The connection from the devices to the cloud is made through a gateway supplied by Savvy		
	QUALITY enabler/component	Gateway Danobat Box- supplied by savvy and customized by Danobat		
	Application protocols	HTTPS, MTConnect, Modbus TCP	No updates	No updates
	Syntactic	JSON	No updates	No updates
	Semantic	JSON	No updates	No updates
	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based TLS v1.2	No updates	No updates
	Solution	Savvy's proprietary	No updates	No updates
	License	License from Savvy	No updates	No updates
Platform	**Description**	Cloud for machine monitoring		
	QUALITY enabler/component	Proprietary cloud platform provided by Savvy and customized to DANOBAT (Danobat Data System)		

	Used platform	Proprietary	No updates	No updates
	Syntactic	N/A proprietary	No updates	No updates
	Semantic	N/A proprietary	No updates	No updates
	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based, user/pass based	No updates	No updates
	Solution	Proprietary API	No updates	No updates
	License	Savvy's License	No updates	No updates

Table 1 - Interoperability degree of the Grinding Machine pilot (DANOBAT)

As shown in Table 1, DANOBAT already had implemented interoperability mechanisms throughout the entire stack of their platform before the beginning of the project and thus, no advances have been made during it. In general terms, DANOBAT uses proprietary solutions for the communications and JSON as the predominant message format.

5.1.2 Pilot 2: Hot Stamping Press Machine (FAGOR)

The FAGOR pilot uses a hot stamping press machine (HHDD3-1200-3200-2500). Hot forming or press hardening is a process of metal forming, which allows forming high strength parts through quenching of boron steels heated above 950ºC. Figure 4 and Figure 5 show the current configuration and the Qu4lity ZDM architecture of this pilot. The objective of this project is to reach zero defects manufacturing process collecting press machine critical parameters and identifying exactly the process developed in the manufacturing of pieces based on data analytics of variables as well as new data analytics tools for predictive maintenance and to avoid defects (ZDM).

However, such process has a great complexity from the point of view of the acquisition, measurement and transmission of the parameters and variables. In addition to that, the integration of the data from other parts of the system at machine level should be valuable. To this end, interoperability between the equipment becomes critical to acquire data from several devices and sent it through the network to analyze it in the cloud.

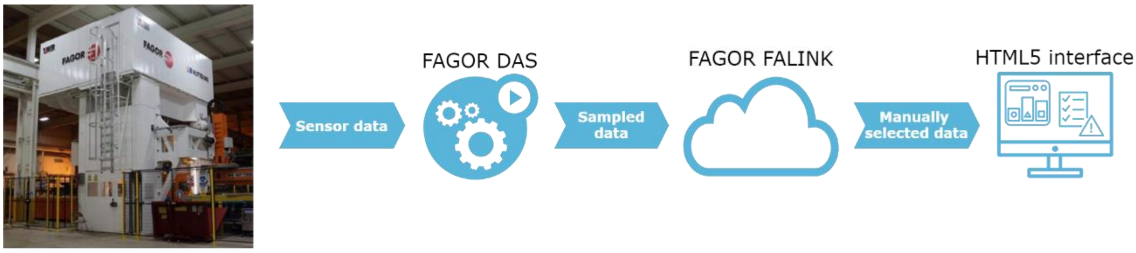

Figure 4 - Fagor hot stamping press machine pilot with connectivity.

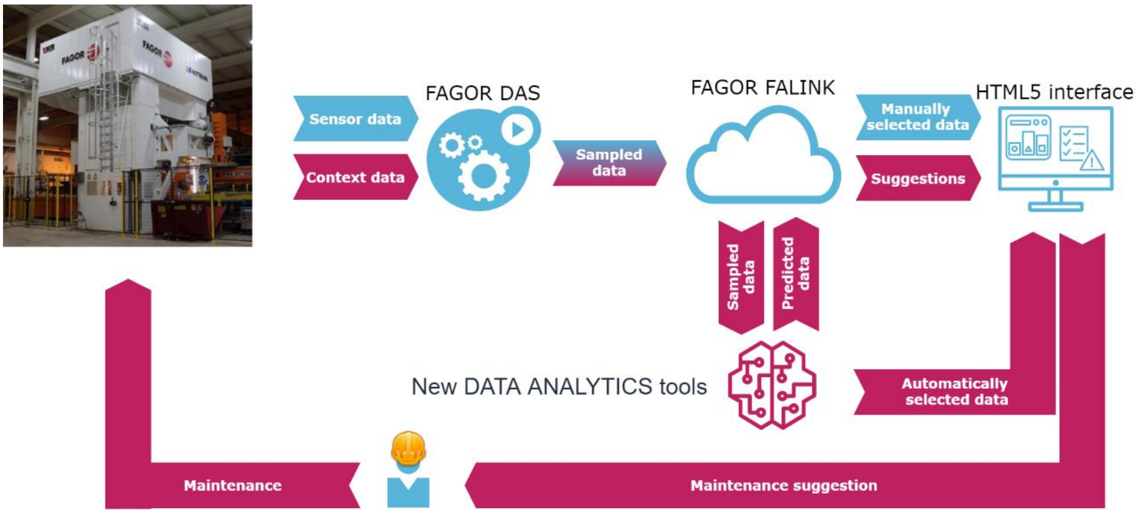

Figure 5 - Architecture to be implemented on the Fagor pilot.

		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Use case description		Hot stamping press machine		
Device	**Description**	At device level the use case will be able to deploy analytical models that describe the situation on the machine.		
	QUALITY enabler/component	-		
	Connectivity	Wired	No updates	No updates
	Syntactic	JSON, XML, CSV	JSON	No updates
	Semantic	JSON, XML, CSV	JSON	No updates

	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based	No updates	No updates
	Solution	Adapter/gateway	No updates	No updates
	License	Proprietary	No updates	No updates
Network	Description	Message Broker will use AMQP. Converters for OPC-UA to Messages in JSON format will be implemented in Node-RED Adapters for different programming languages (C#, Java …) to messages in JSON format will be implemented		
	QUALITY enabler/component	-		
	Application protocols	MQTT	No updates	No updates
	Syntactic	JSON	No updates	No updates
	Semantic	JSON	No updates	No updates
	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based	No updates	No updates
	Solution	-	-	-
	License	Proprietary	No updates	No updates
Platform	Description	The platform will be used to gather historical data and develop/deploy analytical models.		
	QUALITY enabler/component	-		
	Used platform	On-premise	Azure	No updates
	Syntactic	JSON, XML, CSV	JSON	JSON
	Semantic	JSON, XML, CSV	JSON	JSON
	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based; token based	No updates	No updates

	Solution	APIs	No updates	No updates
	License	Proprietary	No updates	No updates

Table 2 summarizes the original, intermediate, and final interoperability of the hot stamping press machine pilot (Fagor) at device, network, and platform levels.

		Initial State (Before QU4LITY project)	**Intermediate State (M15)**	**Final State (M30)**
Use case description		Hot stamping press machine		
Device	**Description**	At device level the use case will be able to deploy analytical models that describe the situation on the machine.		
	QUALITY enabler/component	-		
	Connectivity	Wired	No updates	No updates
	Syntactic	JSON, XML, CSV	JSON	No updates
	Semantic	JSON, XML, CSV	JSON	No updates
	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based	No updates	No updates
	Solution	Adapter/gateway	No updates	No updates
	License	Proprietary	No updates	No updates
Network	**Description**	Message Broker will use AMQP. Converters for OPC-UA to Messages in JSON format will be implemented in Node-RED Adapters for different programming languages (C#, Java …) to messages in JSON format will be implemented		
	QUALITY enabler/component	-		
	Application protocols	MQTT	No updates	No updates
	Syntactic	JSON	No updates	No updates
	Semantic	JSON	No updates	No updates

	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based	No updates	No updates
	Solution	-	-	-
	License	Proprietary	No updates	No updates
Platform	**Description**	The platform will be used to gather historical data and develop/deploy analytical models.		
	QUALITY enabler/component	-		
	Used platform	On-premise	Azure	No updates
	Syntactic	JSON, XML, CSV	JSON	JSON
	Semantic	JSON, XML, CSV	JSON	JSON
	Data Schema Standard	Proprietary	No updates	No updates
	Security	Cert based; token based	No updates	No updates
	Solution	APIs	No updates	No updates
	License	Proprietary	No updates	No updates

Table 2 - Interoperability of the Hot stamping Press Machine pilot (FAGOR)

As it can be seen in Table 2, Fagor had most of its interoperable infrastructure developed before the Qu4lity project, although some advances have been made in this sense. For instance, they migrated their platform from an on-premise to a managed one like Azure. On the other hand, they initially allowed several message formats (XML, CSV, and JSON), although they defined JSON as the de facto messaging format during the project.

5.1.3 Pilot 3: Milling Machine Tool (GF)

This pilot will focus on part of an automated cell and will be cantered in GF HPM milling series and FORM die sinking machines, which act in combination in applications in the mould and die but also aerospace and automotive segments. Other main components of the cells are the Workshop manager software, communicating with machines and FANUC robots for execution program implementation and monitoring.

The goal of this pilot is to set up a full process and product digital system for detecting, diagnosing, and fully compensating deviations on accuracy, quality, productivity and sustainability of a machining cell based on the aggregation of information from milling and EDM machinery health, process performance and geometrical part characterization, using a common data space for making possible a holistic data analytics and dynamic optimization in subsequent simulation and planning stages, making possible the integration of all information from different types of hardware & software coexisting at different end-users factories, and targeting fully automated, zero defect manufacturing.

Figure 6 shows the current status of the milling machine pilot, which production scenario requires highly skilled human expertise for tuning and maintaining accuracy in applications at different conditions depending on the factory infrastructure. On the other hand, Figure 7 shows the future architecture to develop an adaptive machining system in automated cells, integrated into an open cloud and data analytics infrastructure, taking into account actual information of machine condition and performance in accuracy, surface quality, productivity and sustainability. Here, interoperability will play an important role to allow the integration of data coming from different hardware and not bound to one single supplier but allowing an eco-system, seamless integration of all relevant data in a specific common data and analytics space allowing appropriate data access authorizations.

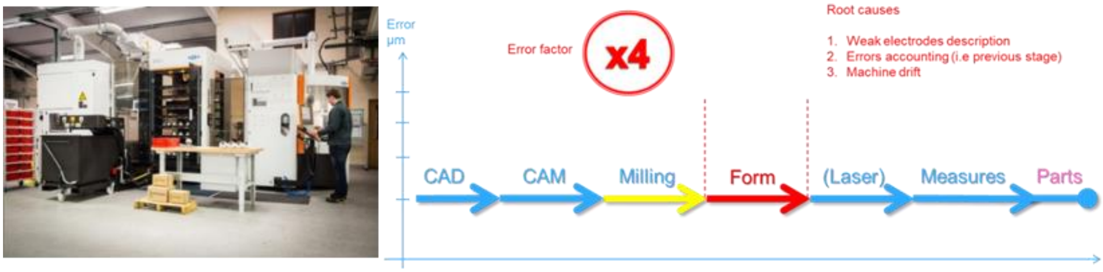

Figure 6 - GF milling machine pilot current status.

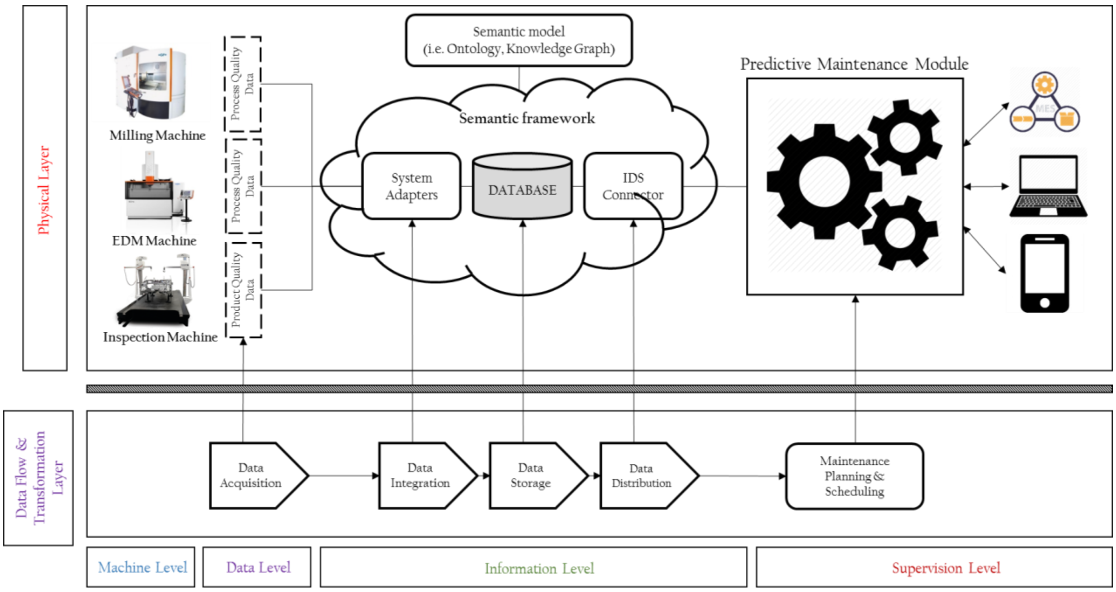

Figure 7 - GF milling machine pilot future implementation.

Table 3 summarizes the current interoperability degree of the milling machine pilot (GF) at device, network and platform levels.

		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Use case description		GF Digital Twin for Zero defect machines and automated lines. Intelligent application for high accuracy, data-driven adaptive automated manufacturing multi-stage processes.		
Device	Description	GF machines deliver data from sensors during machining processes to both GF cloud infrastructure and local server having applications for intelligent optimization of processes and predictive maintenance		
	QUALITY enabler/component	The GF QU4LITY enabler component for interoperability is the Module EDGE integrated to all GF machines and devices and serving as bridge to the GF cloud infrastructure.		
	Connectivity	Wi-Fi, RFID	5 G, Wi-Fi, RFID	No updates
	Syntactic	JSON, XML, CSV	No updates	No updates
	Semantic	JSON, XML, CSV	No updates	No updates
	Data Schema Standard	MT Connect	OPC UA	UMATI and OPC UA
	Security	user/pass based, token based	No updates	No updates
	Solution	Adapter	No updates	No updates
	License	Proprietary	No updates	No updates
Network	Description	-		
	QUALITY enabler/component	GF Machines are connected through Ethernet to EDGE gateways providing communication with GF cloud and to other machines at local level through Profinet with the Workshop Manager central station		
	Application protocols	MTConnect	Profinet, OPC UA	No updates
	Syntactic	JSON, XML, CSV	No updates	No updates
	Semantic	JSON, XML, CSV	No updates	No updates
	Data Schema Standard	MTConnect	OPC UA	UMATI and OPC UA

	Security	user/pass based, token based	No updates	No updates
	Solution	APIs	No updates	No updates
	License	Open source	No updates	No updates
Platform	**Description**	GF Digital infrastructure based on MS Azure, providing the framework for the implementation of business applications of predictive maintenance and intelligent automation with machine data		
	QUALITY enabler/component	GF Digital cloud based infrastructure, My rConnect, based on MS Azure		
	Used platform	Server	MS Azure	No updates
	Syntactic	JSON, XML, CSV	No updates	No updates
	Semantic	JSON, XML, CSV	No updates	No updates
	Data Schema Standard	MTConnect	OPC UA	UMATI and OPC UA
	Security	user/pass based, token based	No updates	No updates
	Solution	APIs	No updates	No updates
	License	Proprietary	License (MS Azure and GF)	No updates

Table 3 - Interoperability degree of the Milling Machine Tool pilot (GF)

Table 3 shows that GF had and advanced interoperable infrastructure before starting the Qu4lity project. Nonetheless, they have done some improvements over the platform. For instance, they added 5G connectivity by M15, in complement to what they already had. Furthermore, they changed the data schema in the entire stack, from MTConnect to OPC UA by M15, and extended in M30 to use the UMATI data schema standard. Finally, they have migrated the platform from an on-premise server to Azure.

5.1.4 Pilot 4: Hot Stamping Furnace (GHI)

This pilot will focus on a hot stamping furnace, which is a current process for the manufacture of structural parts in the automotive sector. Hot stamping is a process by which a sheet is subjected to a load between two dies, while the entrance temperature of the sheet is bigger than the automatization temperature of about 900-950 °C. This process takes advantage of the high ductility of the piece due to its high initial temperature and then proceeds to a rapid cooling to achieve the martensitic hardening of the piece. Figure 8 shows the current status of the furnace in production line, which has some limitations related to the geometry of the final part due to discrepancies regarding sheet thickness and the geometry in radial areas.

The goal of this pilot is to develop a ZDM solutions based on implemented improvements (sensor and data analysis) in the furnace that will provide a more accurate control of the temperature of the pieces and therefore, a more optimized quality for such critical parts. Moreover, Zero-defect manufacturing in these systems will be related to the development of smart connected furnaces with ability for real-time connected and smart closed loop monitoring & control. Figure 9 shows the future implementation of the hot stamping furnace, which must consider the interoperability between all the components of the platform to support data sharing and communication across the entire platform regardless of the data formats or protocols used.

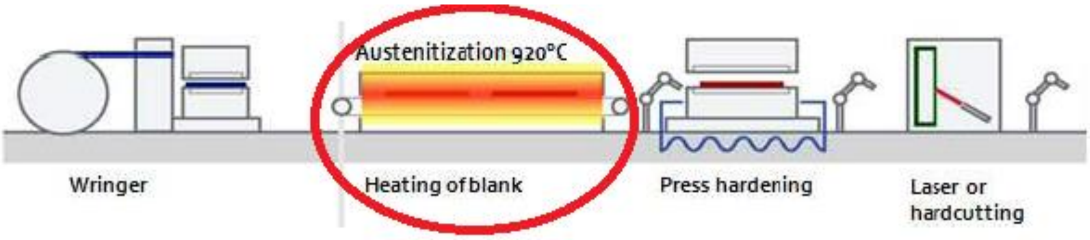

Figure 8 - Current status of the furnace in a production line.

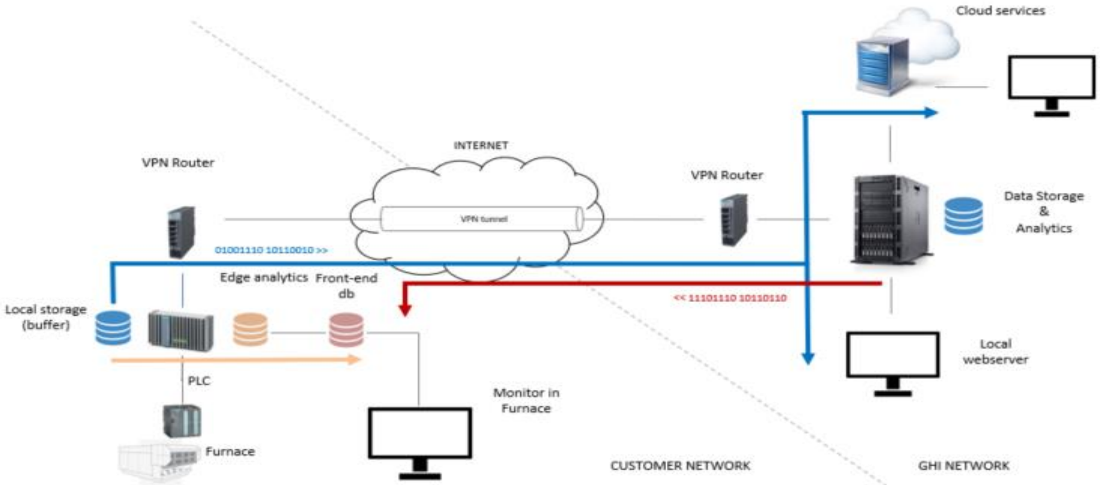

Figure 9 - Architecture of the future Hot Stamping Furnace scenario.

	Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Use case description	The real-time cognitive hot stamping furnace 4.0 pilot consists on the development of some enhancements on the rolling beam industrial		

		furnace that could guarantee an improved operation of the hot stamping line to reach the Zero-Defect Manufacturing target.		
Device	Description	Mainly from one of the 3 components that are linked to this pilot, there are four main hardware devices (the programable logic controller (PLC), the industrial PC, the local server & the VPN router) that compounds the Big Data infrastructure remaining the Beyond Platform component.		
	QUALITY enabler/component	-		
	Connectivity	Ethernet and VPN tunnel	No Updates	No Updates
	Syntactic	XML	No Updates	No Updates
	Semantic	XML	No Updates	No Updates
	Data Schema Standard	Proprietary	No Updates	No Updates
	Security	user/pass based	No Updates	No Updates
	Solution	Proprietary protocols of devices suppliers	No Updates	No Updates
	License	Licensed by devices suppliers	No Updates	No Updates
Network	Description	The connection from the devices located in-field with the GHI server will be made through VPN tunnel.		
	QUALITY enabler/component	-		
	Application protocols	MQTT	No Updates	No Updates
	Syntactic	XML	No Updates	No Updates
	Semantic	XML	No Updates	No Updates
	Data Schema Standard	Proprietary	No Updates	No Updates
	Security	User/pass based (IPSec)	No Updates	No Updates
	Solution	OpenVPN	No Updates	No Updates
	License	Open Source	No Updates	No Updates

Platform	Description	With Beyond Platform, GHI will be able to collect a large amount of data that will be monitored and analyzed with advanced Big data tools developed by the 4.0 engineering team, in order to improve the furnace operation and even to improve the whole process.		
	QUALITY enabler/component	-		
	Used platform	Own platform	No Updates	No Updates
	Syntactic	XML	No Updates	No Updates
	Semantic	XML	No Updates	No Updates
	Data Schema Standard	Proprietary	No Updates	No Updates
	Security	user/pass based	No Updates	No Updates
	Solution	Open Standard	No Updates	No Updates
	License	Own License	No Updates	No Updates

Table 4 summarizes the current interoperability degree of the hot stamping furnace pilot (GHI) at device, network and platform levels.

		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Use case description		The real-time cognitive hot stamping furnace 4.0 pilot consists on the development of some enhancements on the rolling beam industrial furnace that could guarantee an improved operation of the hot stamping line to reach the Zero-Defect Manufacturing target.		
Device	Description	Mainly from one of the 3 components that are linked to this pilot, there are four main hardware devices (the programable logic controller (PLC), the industrial PC, the local server & the VPN router) that compounds the Big Data infrastructure remaining the Beyond Platform component.		
	QUALITY enabler/component	-		
	Connectivity	Ethernet and VPN tunnel	No Updates	No Updates
	Syntactic	XML	No Updates	No Updates
	Semantic	XML	No Updates	No Updates

	Data Schema Standard	Proprietary	No Updates	No Updates
	Security	user/pass based	No Updates	No Updates
	Solution	Proprietary protocols of devices suppliers	No Updates	No Updates
	License	Licensed by devices suppliers	No Updates	No Updates
Network	**Description**	The connection from the devices located in-field with the GHI server will be made through VPN tunnel.		
	QUALITY enabler/component	-		
	Application protocols	MQTT	No Updates	No Updates
	Syntactic	XML	No Updates	No Updates
	Semantic	XML	No Updates	No Updates
	Data Schema Standard	Proprietary	No Updates	No Updates
	Security	User/pass based (IPSec)	No Updates	No Updates
	Solution	OpenVPN	No Updates	No Updates
	License	Open Source	No Updates	No Updates
Platform	**Description**	With Beyond Platform, GHI will be able to collect a large amount of data that will be monitored and analyzed with advanced Big data tools developed by the 4.0 engineering team, in order to improve the furnace operation and even to improve the whole process.		
	QUALITY enabler/component	-		
	Used platform	Own platform	No Updates	No Updates
	Syntactic	XML	No Updates	No Updates
	Semantic	XML	No Updates	No Updates
	Data Schema Standard	Proprietary	No Updates	No Updates
	Security	user/pass based	No Updates	No Updates

	Solution	Open Standard	No Updates	No Updates
	License	Own License	No Updates	No Updates

Table 4 - Interoperability degree of the Hot Stamping Furnace pilot (GHI)

As shown in Table 4, GHI had already developed the infrastructure before starting the project, so no updates have been done during it.

5.1.5 Pilot 5: Additive manufacturing (PRIMA)

The pilot will focus on an Additive Manufacturing (AM) machine for powder bed and direct deposition to enhance process control for producing metal components. In laser-based additive manufacturing, production time has a great influence on the economic efficiency of the production process. To increase the productivity but also reliability of such processes, a zero-defect AM strategy is targeted.

Nowadays, additive manufacturing is still very dependent from the operator (see Figure 10) on the machine and takes continuous tuning, also during the process, because this has a very high dependency on geometry and building strategies defined by the engineers. Figure 11 and Figure 12 show the Qu4lity ZDM architecture of this pilot.

The goal is to create a modular monitoring and control system that can be used with many different sensors and process models. The system will be also connected to a higher-level factory data interface which allows to exchange process information and reassign the production strategy based on additional factory conditions. Data can be further used to a management of higher level of the factory in order to act on different machines of the pilot line.

To exchange information at any level of the digital platform, the system must allow sharing data and communicating multiple devices and components with each other, which means that the system must be interoperable to support the communication between several connectivity and communication protocols.

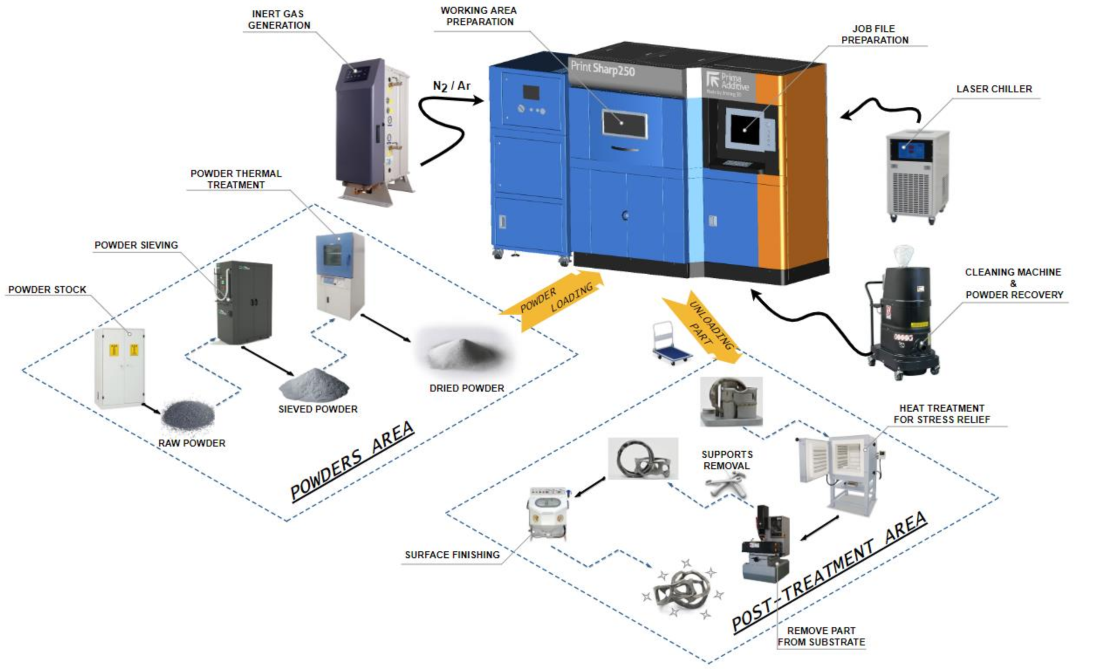

Figure 10 - Laser based additive manufacturing system.

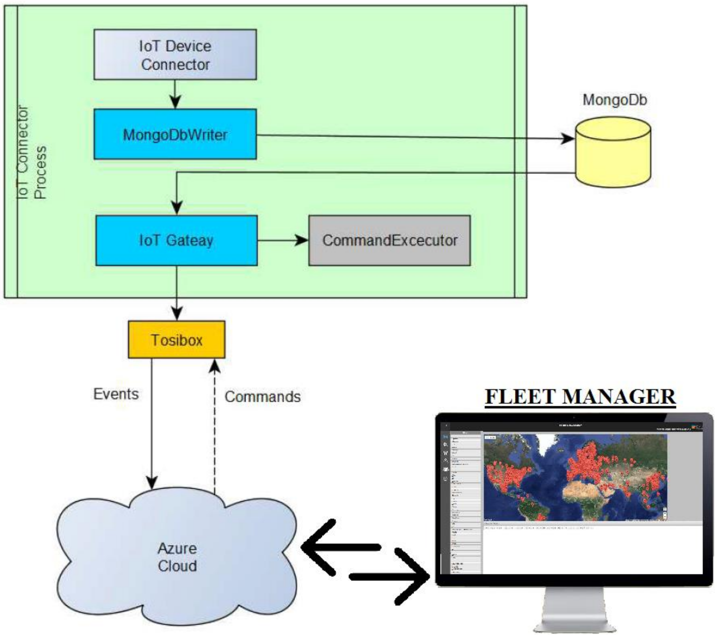

Figure 11 - Future pilot implementation with connection to fleet manager.

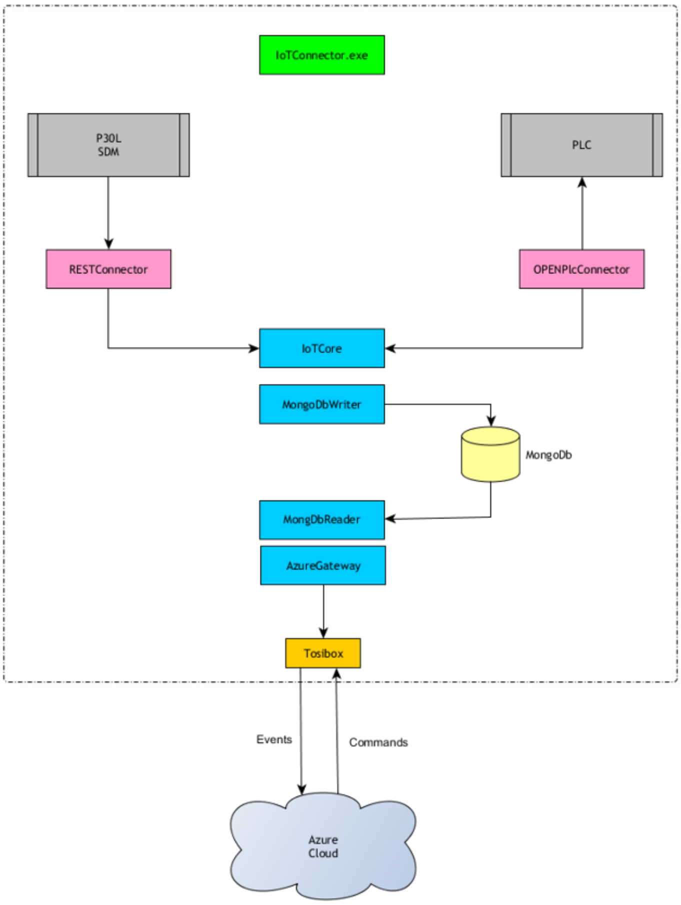

Figure 12 - On machine future pilot implementation.

Use case description		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Device	Description	The decision support tool for Additive Manufacturing is a software tool developed within the project activities that provides the end user support to the decision-making process with suggestions. They are based on the manufacturing procedure and the rules that apply to it. The tool also exploits the complex events happening on the shop floor during the manufacturing process and tries to extract results for better performance implementing a complex event processing for the suggested decisions.		
	QUALITY enabler/component	DSS for ZDM		
	Connectivity	Wi-Fi	No Updates	No Updates

	Syntactic	JSON	No Updates	No Updates
	Semantic	JSON	No Updates	No Updates
	Data Schema Standard	N/A proprietary	N/A	N/A
	Security	user/pass	No Updates	No Updates
	Solution	N/A	N/A	N/A
	License	Commercial software license	No Updates	No Updates
Network	**Description**	The decision support tool elaborates the information collected from the data analytics tool and the sensor data on the shop floor. The data is exploited to create decision rules based on complex event processing and the manufacturing processes to suggest new maintenance or manufacturing procedures which lead to zero defect manufacturing and maintenance quality. Considering the computational and connectivity requirements to collect the data from the factory's sensors and other QU4LITY components, the decision support tool operates at edge level, exploiting both the fast connectivity with the field and the distributed access to the cloud.		
	QUALITY enabler/component	Data analytics tool		
	Application protocols	MQTT, HTTP	No Updates	No Updates
	Syntactic	JSON	No Updates	No Updates
	Semantic	JSON	No Updates	No Updates
	Data Schema Standard	N/A	N/A	N/A
	Security	user/pass based; token based	No Updates	No Updates
	Solution	APIs, open API		
	License	N/A	N/A	N/A
Platform	**Description**	-		
	QUALITY enabler/component	Microsoft Azure server will be used as a cloud platform for the decision support tool.		
	Used platform	Azure	No Updates	Final update

	Syntactic	JSON	No Updates	Final update
	Semantic	JSON	No Updates	Final update
	Data Schema Standard	N/A proprietary	No Updates	Final update
	Security	User/pass based, token based	No Updates	Final update
	Solution	Open API	No Updates	Final update
	License	Atlantis' License	No Updates	Final update

Table 5 summarizes the current interoperability degree of the additive manufacturing pilot (PRIMA) at device, network, and platform levels.

Use case description		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Device	Description	The decision support tool for Additive Manufacturing is a software tool developed within the project activities that provides the end user support to the decision-making process with suggestions. They are based on the manufacturing procedure and the rules that apply to it. The tool also exploits the complex events happening on the shop floor during the manufacturing process and tries to extract results for better performance implementing a complex event processing for the suggested decisions.		
	QUALITY enabler/component	DSS for ZDM		
	Connectivity	Wi-Fi	No Updates	No Updates
	Syntactic	JSON	No Updates	No Updates
	Semantic	JSON	No Updates	No Updates
	Data Schema Standard	N/A proprietary	N/A	N/A
	Security	user/pass	No Updates	No Updates
	Solution	N/A	N/A	N/A
	License	Commercial software license	No Updates	No Updates
Network	Description	The decision support tool elaborates the information collected from the data analytics tool and the sensor data on the shop floor. The data is exploited to create decision rules based on complex event processing		

		and the manufacturing processes to suggest new maintenance or manufacturing procedures which lead to zero defect manufacturing and maintenance quality. Considering the computational and connectivity requirements to collect the data from the factory's sensors and other QU4LITY components, the decision support tool operates at edge level, exploiting both the fast connectivity with the field and the distributed access to the cloud.		
	QUALITY enabler/component	Data analytics tool		
	Application protocols	MQTT, HTTP	No Updates	No Updates
	Syntactic	JSON	No Updates	No Updates
	Semantic	JSON	No Updates	No Updates
	Data Schema Standard	N/A	N/A	N/A
	Security	user/pass based; token based	No Updates	No Updates
	Solution	APIs, open API		
	License	N/A	N/A	N/A
Platform	**Description**	-		
	QUALITY enabler/component	Microsoft Azure server will be used as a cloud platform for the decision support tool.		
	Used platform	Azure	No Updates	Final update
	Syntactic	JSON	No Updates	Final update
	Semantic	JSON	No Updates	Final update
	Data Schema Standard	N/A proprietary	No Updates	Final update
	Security	User/pass based, token based	No Updates	Final update
	Solution	Open API	No Updates	Final update
	License	Atlantis' License	No Updates	Final update

Table 5 - Interoperability degree of the Additive Manufacturing pilot (PRIMA)

Use case description		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Device	Description	The decision support tool for Additive Manufacturing is a software tool developed within the project activities that provides the end user support to the decision-making process with suggestions. They are based on the manufacturing procedure and the rules that apply to it. The tool also exploits the complex events happening on the shop floor during the manufacturing process and tries to extract results for better performance implementing a complex event processing for the suggested decisions.		
	QUALITY enabler/component	DSS for ZDM		
	Connectivity	Wi-Fi	No Updates	No Updates
	Syntactic	JSON	No Updates	No Updates
	Semantic	JSON	No Updates	No Updates
	Data Schema Standard	N/A proprietary	N/A	N/A
	Security	user/pass	No Updates	No Updates
	Solution	N/A	N/A	N/A
	License	Commercial software license	No Updates	No Updates
Network	Description	The decision support tool elaborates the information collected from the data analytics tool and the sensor data on the shop floor. The data is exploited to create decision rules based on complex event processing and the manufacturing processes to suggest new maintenance or manufacturing procedures which lead to zero defect manufacturing and maintenance quality. Considering the computational and connectivity requirements to collect the data from the factory's sensors and other QU4LITY components, the decision support tool operates at edge level, exploiting both the fast connectivity with the field and the distributed access to the cloud.		
	QUALITY enabler/component	Data analytics tool		
	Application protocols	MQTT, HTTP	No Updates	No Updates
	Syntactic	JSON	No Updates	No Updates

	Semantic	JSON	No Updates	No Updates
	Data Schema Standard	N/A	N/A	N/A
	Security	user/pass based; token based	No Updates	No Updates
	Solution	APIs, open API		
	License	N/A	N/A	N/A
Platform	**Description**	-		
	QUALITY enabler/component	Microsoft Azure server will be used as a cloud platform for the decision support tool.		
	Used platform	Azure	No Updates	Final update
	Syntactic	JSON	No Updates	Final update
	Semantic	JSON	No Updates	Final update
	Data Schema Standard	N/A proprietary	No Updates	Final update
	Security	User/pass based, token based	No Updates	Final update
	Solution	Open API	No Updates	Final update
	License	Atlantis' License	No Updates	Final update

Table 5 shows that PRIMA use case no advances have been made during the Qu4lity project, since the presented architecture in terms of interoperability was developed before the beginning of the project.

5.1.6 Pilot 6: Injection Moulding (KOLEKTOR)

Because the Pilot is based in real-world production, which needs to adapt to market demands and conditions for the company to stay afloat, the initial plan of Pilot deployment has been changed. It still deals with the prediction and detection of defects on objects that are produced with injection moulding, but on a different production line and with somewhat different parts. For example, the moulding tool is now automatized and separated from the Pilot and cannot be inspected anymore. However, it provides the partners with more moulding parameters and process data and is more interconnected into the Information infrastructure of the production plant. As such, it will provide more information for the process of predicting possible defects and positions of defects.

The new production line is depicted in the Figure 13. The goal is to detect, possibly predict, and remove the cause of the process failure as soon as possible, ideally in real-time based on the collected data and by applying advanced analytics and artificial intelligence methods to better understand the moulding process. Therefore, the goal is to improve on the feedback capabilities of an already existing moulding production line, through collecting moulding process parameters, monitoring environmental parameters, visually inspecting the moulding tool and visually inspecting the moulded parts. Production line consisting of assembly line, robot assisted manipulation for visual quality control and moulding machines.

To this extent, a digital platform will be implemented (Figure 14Figure 13) which allows to provide products and services supporting by intelligent IoT sensors, communications with other machines, devices, and services (including robots), and Big Data (based on AI). Therefore, the interoperability between these devices and services is a key aspect to enable communication between different communication protocols and data formats.

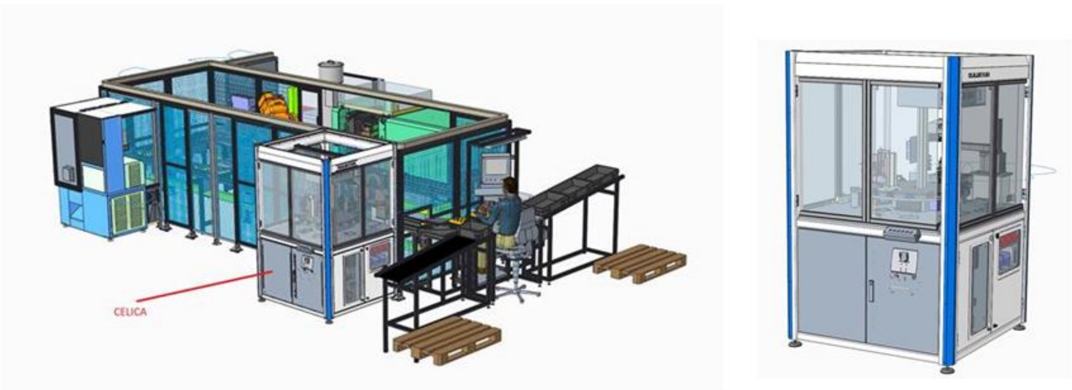

Figure 13 The complete production line on the left, with the inspection cell on the right.

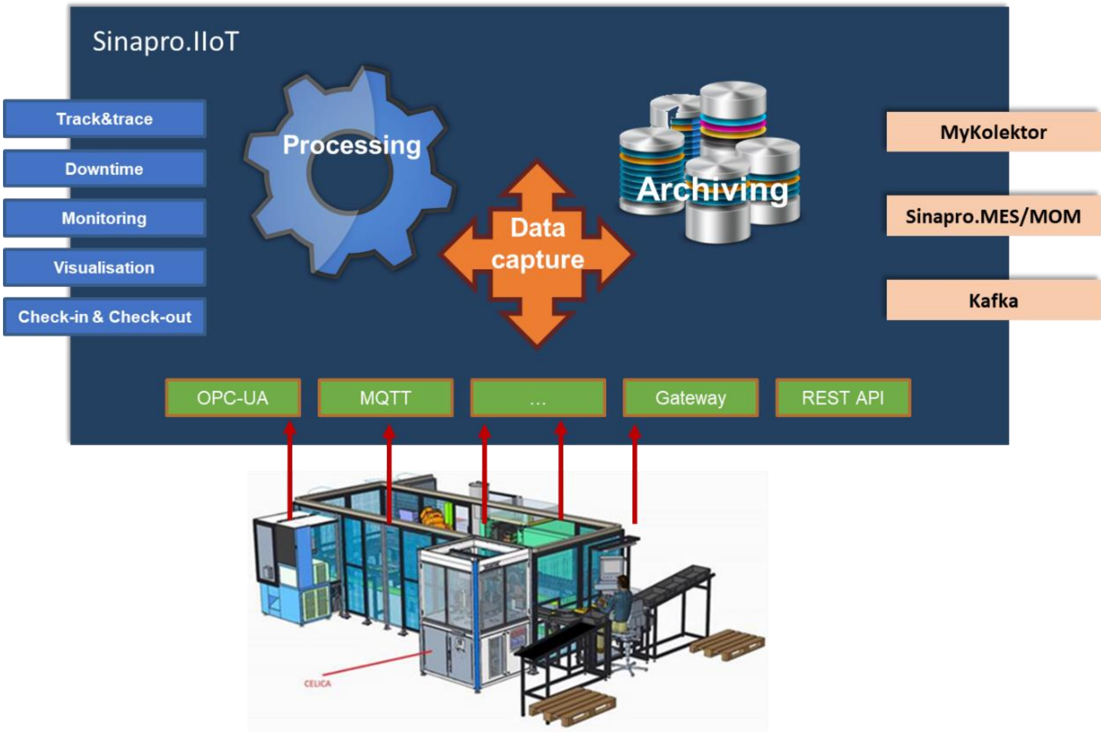

Figure 14 Digital platform Sinapro.IIoT.

Table 6 summarizes the original, intermediate, and final interoperability degree of the injection moulding pilot (KOLEKTOR) at device, network, and platform levels. As shown, this pilot has had a clear evolution in terms of equipment interoperability as they added new functionalities and interoperable mechanism to improve their degree of interoperability during the project.

Use case description		Initial State (Before QU4LITY project)	Intermediate State (M15)	Final State (M30)
Device	Description	Production line with plastic molding machine, robot, transport, vision control..		
	QUALITY enabler/component	There are three main components of the solution at device level: molding machine, the programable logic controller (PLC) for cell management and PC for vision system.		
	Connectivity	Ethernet	No updates	No updates
	Syntactic	Through proprietary IIoT platform	JSON, XML	No updates
	Semantic	Through proprietary IIoT platform	JSON, XML	No updates
	Data Schema Standard	-	OPC-UA	No updates
	Security	Cert based, user/pass based	No updates	No updates

	Solution	-	Through proprietary IIoT platform	Native, Adapter/gateway
	License	-	-	-
Network	Description	Devices are connected with Ethernet connectivity to proprietary IIoT platform.		
	QUALITY enabler/component			
	Application protocols	HTTPS	HTTPS, OPC-UA	HTTPS, OPC-UA, MQTT
	Syntactic	JSON	No updates	No updates
	Semantic	JSON	No updates	No updates
	Data Schema Standard	-	OPC-UA	No updates
	Security	Cert based, user/pass based	No updates	No updates
	Solution	Proprietary IIoT platform	API	No updates
	License	HTTPS	HTTPS, OPC-UA	HTTPS, OPC-UA, MQTT
Platform	Description	Proprietary IIoT platform Sinapro.IIoT for real-time calculation and store data.		
	QUALITY enabler/component			
	Used platform	Proprietary IIoT platform	No updates	No updates
	Syntactic	-	Rest API, KAFKA, MQTT	No updates
	Semantic	JSON	JSON	JSON, XML
	Data Schema Standard	-	OPC-UA	No updates
	Security	Cert based, user/pass based	No updates	No updates
	Solution	-	Rest API, KAFKA MQTT	No updates
	License	Used components with open source	No updates	No updates

Table 6 - Interoperability degree of the Injection Moulding (KOLEKTOR)

As it can be seen in Table 6, the KOLEKTOR use case has advanced in several parts of its infrastructure during the Qu4lity project, specially from the starting of the project until M15. At device level, they have improved their interoperability as they have added support for JSON and XML message formats, in contrast to the initial proprietary format. At network level, they have added MQTT and OPC-UA protocols in addition to the existing HHTPS. At platform level, they have developed a messaging system based on MQTT, Apache Kafka, and a REST API.

6 Conclusions

This document has reported the final status regarding the equipment interworking and interoperability of the machine pilots, which refers to the Grinding Machine pilot (DANOBAT), Hot Stamping Press Machine pilot (FAGOR), Milling Machine Tool pilot (GF), Hot Stamping Furnace pilot (GHI), Additive manufacturing pilot (PRIMA) and the Injection Moulding pilot (KOLEKTOR). Concretely, the interoperability of the pilots at device, network and platform levels within the entire digital platform has been described in terms of connectivity technologies, syntactics, semantics, security, solution and licenses.

Concretely, this document has presented the evolution of the machine use cases during the Qu4lity project, as the interoperability degree of the uses cases has been detailed at different phases of the project. First, the initial state of the uses cases has been presented, that is, the infrastructure developed before the beginning of the project. Second, the intermediate state has been detailed, which corresponds to the work done from the beginning of the project until M15. Finally, the final status of the of the uses cases has been presented, which corresponds to the improvements made from M15 to M30. In this way, this document has reflected the impact of the Qu4lity project in the improvement of equipment interworking and interoperability of the machine pilots.

In general terms, the analysis of all machine pilots has shown that most of them had already an infrastructure developed before starting the Qu4ity project. Nonetheless, this project has helped partners to improve some of their solutions in terms of interoperability at different levels of their infrastructure.

At device level, the Ethernet connectivity has been the most used for all the uses cases, although other technologies have also been used, such as Wi-Fi or RFID. Moreover, the upcoming 5G technology has been used in the GF use case. Therefore, even though wireless connectivity has become more popular in the last decade, the industry still relies on wired connections due to it robustness and reliability. On the other hand, most of the use cases have used proprietary solutions, with proprietary licenses, for communication and data exchange between the devices and the cloud platform.

At network level, MQTT and OPC-UA protocols have been the most used ones, which is in line with the industrial standards. However, other protocols such as HTTPS, Modbus or MTConnect have also be utilized on a smaller scale. With respect to the solution used for the communication between devices and the platform, a wide variety of solutions have been used, ranging from proprietary solutions with proprietary solutions to APIs or open-source solutions such as OpenVPN. To secure the communications, User/password based, and token based have been the most used techniques, following by Cert based ones.

Al platform level, most of the pilots have deployed their architecture on a proprietary server (on-premises), which indicates that most of have full control of their solutions and maintain their infrastructure. However, some of the pilots decided to migrate their platform to a managed infrastructure as Microsoft Azure during the Qu4lity project. In order to provide communication and data exchange services in the cloud (data ingestion), machine pilots have typically used custom APIs or distributed messaging systems like Apache Kafka.

Regarding the data formats and data schemas used throughout the entire stack of the infrastructures, JSON and XML have been the most used ones, being JSON the predominant for all uses cases. After analyzing the used message formats, it can be shown that almost all pilots have decided to use a single format, typically JSON, whereas only a few allows data exchanges in different formats (i. e., JSON and XML). With respect to data schemas, a OPC foundation standard or UMATI have ben used in a few pilots, although proprietary schemas have been used in general terms.

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8 List of figures

9 List of tables

10 List of Abbreviations

AI	Artificial Intelligence
AM	Additive Manufacturing
API	Application Program Interface
CbM	Condition based maintenance
CNC	Computer Numerical Control
CoAP	Constrained Application Protocol
CSV	Comma Separated Value
DAS	Direct Attached Storage
ETH	Ethernet
JSON	JavaScript Object Notation
HTTP	HyperText Transfer Protocol
HTTPS	HyperText Transfer Protocol Secure
IoT	Internet of Things
IP	Internet Protocol
M2M	Machien-to-machine
MQTT	MQ Telemetry Transport
NFC	Near Field Communication
NFV	Network Function Virtualization
OPC UA	Open Platform Communications Unified Architecture
OWL	Web Ontology Language
PLC	Programmable Logic Controller
RDF	Resource Description Framework
REST	Representational State Transfer
RFID	Radio Frequency Identification
SDN	Software-defined networking
TCP	Transmission Control Protocol

XML	Extensible Markup Language
XMPP	Extensible Messaging and Presence Protocol
WSDL	Web Services Description Language
ZDM	Zero Defect Manufacturing

11 Partners: