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QU4LITY

DIGITAL MANUFACTURING PLATFORMS FOR CONNECTED SMART FACTORIES

D2.4 Autonomous Quality Vision for Zero Defect Manufacturing and Quality Management Excellence (Version II)

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Abstract:
This Deliverable presents the Autonomous Quality (AQ) vision for Quality Management (QM) excellence and Zero Defect Manufacturing (ZDM) in terms of its critical processes and Key Performance Indicators (KPIs). As part of the vision of a digital platform the content contains a description of technological use of ZDM as a high-level concept illustrated as operations across multiple stages and supply chain processes. Proactive interactions, real-time operations and human factors are also detailed and associated with specific KPIs in a generic form. Technical KPIs and further internal information is added as an annex.

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Contents

HISTORY

Version	Date	Modification reason	Modified by
V0	28/01/2020	First draft QU4LITY D24_v0	SINTEF
V0.1	11/02/2020	Modification of Draft QU4LITY_D24_v1	SINTEF
V0.2	14/02/2020	Modification on Draft QU4LITY_D2.4_v1.1	Innovalia, SINTEF
V0.3	18/02/2020	FINAL Minor modification of D2.4_v1.1	SINTEF
V0.4	16/02/2020	FINAL, to review	SINTEF, ATOS
V1.0	28/02/2020	FINAL	SINTEF

Summary version II

This Deliverable (D2.4) is an extended and updated version of D2.3. D2.3 is a base which will give an overview of the different state of the art technologies and the KPIs is a more snapshot of the current KPI status at that point of time (M6).
D2.4 contains new information about the total idea of the project and has new information about the relations to different tasks and work packages. The architecture is extended and more information on the relevant standards are added. Some more about State of Art on the use of digital components and digital twins as platforms and at last some extension on the relations to new business models and marketplace for QU4LITY.

As a main improvement an appendix has been added to show the extent of the KPIs from Chapter 7 in a more technical manner. This document is added as appendix to this deliverable, since this information is a part of Background and IPR of the involved Pilots in the project. The appendix is however Project Internal.

Executive Summary

This Deliverable presents the Autonomous Quality (AQ) Vision for Quality Management (QM) Excellence and Zero Defect Manufacturing (ZDM), in terms of its critical processes and KPIs. It also defines the scope for a digital ZDM Platform, and the expectation of underlying components that ensure ZDM and QM excellence for manufacturing companies. The document gives a definition of AQ as Paradigm in the relation to building Digital Platforms as technology-enabled business models that create value for end-users and producers to transact with each other. We also present the State-of-the-Art (SOTA) for ZDM, Artificial Intelligence (AI) and other Information and Communication Technology (ICT) components in relation to Industry 4.0 standards and architecture.
The main aim of this document is to define ZDM Key Performance Indicators (KPIs) for each of the pilots utilizing the digital ZDM platform for connected, smart factories. This was pre-defined in the proposal phase, but further developed and prioritised in the pilot definition. Public generic KPI's status is presented in this version II and a more specific KPI's for each pilots is presented in an internal Annex.
Towards the end of this deliverable, the stakeholders' roles and the business interactions are refined, in the scope of the AQ Vision. This is important as a final objective in order to see the stakeholder's roles and business interactions as a complete ecosystem, for understanding the scope and vision since digital platforms can be accelerated by third parties' interaction by sharing data, applications, interfaces that can create new services and new business models. It is also an important objective that resources as a service and data ownership on such a digital platform need clear governance conditions that protect intellectual properties with clear rules and regulation.

To retain and expand Europe's leading position of excellence in manufacturing, it is imperative that the European manufacturing industry understands and prepares for the profound transformations that Industry 4.0 operations present for future production facilities. This will have significant implications on the nature of work in industry, as AQ will transform the way in which products are designed and manufactured in advanced production systems. However, knowledge of products, markets and technologies are disseminating across countries and regions with an increasing speed, not to mention how easy it is to gain insight of almost everything through the internet. Both knowledge of and access to technology are getting simpler and more commonplace. Technology is less expensive, and hence increasingly affordable due to economic growth. Together with increased possibilities of gaining knowledge of competitors, this creates many new ways for everyone to "copy" anyone. Summarized, this reduces the competitive leverage that has been embedded in technology and advanced manufacturing for decades.
Smart products allow for new product-service systems (PSSs) and business models to be developed. Traditionally, ownership of a product has been transferred from the product provider to the customer following a sale. However, during recent years, product providers have increased the focus on product-as-service business models, where the manufacturer retains ownership of the product and responsibility for maintenance and repairs, while the user is paying for use of the product or the product's functionality (e.g. through leasing and rental agreements). Altogether, smart products will both be the basis to internally reach AQ and simultaneously be the gateway to "collect" data and provide the manufacturer with

feedback about the products, how it is being used, its performance and under which conditions; and through this, also create the context for further new service systems and business models.

To reach ZDM in the different process steps by optimizing both equipment and production processes, a fuzzy area of how to tackle predictive and prescriptive interaction of cyber-physical production systems (CPPS) and full automation for production lines need be implemented and controlled. However, due to increased product mass customisation and the proliferation of global manufacturing networks, scalable first-time right manufacturing is becoming also increasingly complex. The vision of ZDM is also a mind-set and one feature that is almost impossible to copy in how companies train, build competence, structure and organize the division of labour, hence being able to build an agile, flexible organization with capabilities to utilize technology and advanced manufacturing systems. The workforce will need greater digital-literacy and to have high-tech and collaboration skills. It will also need to be able to work cross-functionally as well as with increasingly intelligent machines to bring higher levels of efficiency and productivity. Further this will require skilled and knowledgeable workers that know and understand integrated and complex manufacturing processes. Thus, this triggers a shift in the operator's workplace, towards less manual and more complex and advanced operations, requiring workers to continuously update their competence levels. This is an advanced socio-technical system and will be the core of future manufacturing competitiveness where AQ is combining ZDM with a zero-defect mindset.

1. Introduction

"Any European manufacturing company has a constant need to strive for excellence. This requires producing top quality goods, being highly efficient in terms of costs and resources, while being extremely responsive to market and customer needs, and using and offering creative and innovative solutions. Moreover, there is an increasingly pressure on European industry to build sustainable, green and circular processes and products that ensure not just business goals but also societal and environmental ones for future generations – see European Green Deal[1].
However, due to increased product mass customisation and the proliferation of global manufacturing networks, scalable first-time right manufacturing is becoming also increasingly complex. Products are increasingly complex, feature an increasing amount of electronics or micro-features and are increasing composed of advanced (multi-) materials - becoming stronger, lighter and smarter whilst remaining at least as safe or secure as previous versions. While a clear benefit for the end customer, such process variation is the enemy of competitiveness and profitability. It causes waste and inefficiency, leads to high quality costs and manning levels, and results in late deliveries and poor traceability. Hence, with new product features, new manufacturing processes and techniques will emerge, which in turns will call for evolution of quality control and quality assurance procedures capable to effectively deal with the inherent variability of Factory 4.0 manufacturing processes, ultimately reducing scrap levels and raising productivity".

In an industry 4.0 perspective, Autonomous Quality (AQ) in all steps in production can be a challenging task. The AQ vision for ZDM also encompasses a mind-set for ensuring that all employees are involved in addressing quality issues in the factory. The way of thinking needs to be openminded and visionary for change of cultural behaviour, to achieve outcomes "right first time".
AQ can be consider a neologism. In fact, both the academic literature and publicly available scientific documents not only lack a clear definition for AQ, but also lack the binomial “Autonomous Quality” as keyword. Therefore, a step back is needed in order to provide a definition of AQ and to understand how the concept of quality has been defined and how it has evolved in the industry over the years.

This report begins by exploring relevant AQ topics with specific reference to existing Quality Management (QM) systems, before providing a definition of AQ. The status of several standard approaches is given with focus on the Reference Architectural Model Industry 4.0 (RAMI 4.0) standardisation approach. It appears that much of the standardization efforts that also can support ZDM remain in an early phase of development for Autonomous Quality vision.
For a better navigation to the strategic vision Figure 1 will give an overview of the different Tasks and WP's related to the vision and strategy in the ZDM QU4LITY Platform.

[1] https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

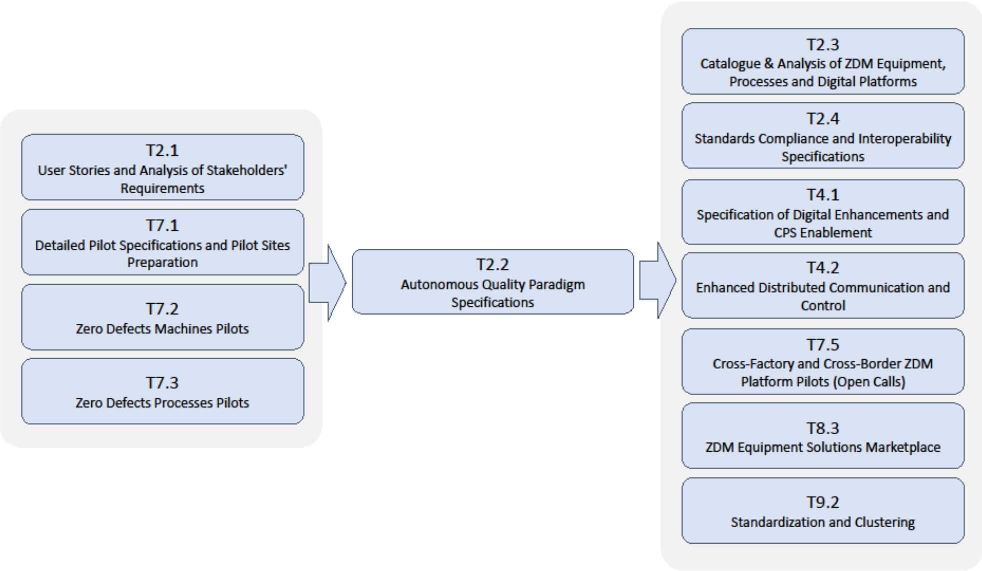


Figure 1 – WP inputs an output related to WP2 T2.2

1.1 Defining the Autonomous Quality Paradigm

Traditional QM approaches such as Total Quality Management (TQM), Statistical Quality Control (SQC) or in-line multi-stage statistical process control (SPC) solutions are not fully capable to deal with the dynamism of such new manufacturing scenarios, calling for effective support to control smart and connected excellent and responsive production processes that combine speed, precision, quality and reliability with flexibility and agility. Manufacturing companies need to produce an array of products, from very small lot-sizes to large volumes and there is a growing need for the ability to quickly scale up from small to large lot-sizes whilst retaining the required quality. Traditional quality methods are rigid and still do not deliver learning and adaptation capabilities. In such connected production environments to determine the root causes or sources of variance of bad quality in supply chains is usually more difficult because multiple parties are involved in the current global manufacturing environment.

In the manufacturing domain, “quality” is defined as a measure of excellence or a state of being free from defects, deficiencies and significant variations. ISO 9000:2015 defines quality as

"*the degree to which a set of inherent characteristics of an object (product, service, process, person, organization, system, resource) fulfils requirements (need or expectation that is stated, generally implied or obligatory)*"

The definition shows that the concept of quality in manufacturing can be declined according to the object of interest. In QU4LITY the objective is to demonstrate, in a realistic, measurable, and replicable way an open, certifiable and highly standardised, SME-friendly and transformative shared data-driven ZDM product and service model for Industry 4.0, leveraging five competitive advantages to foster new digital business models:

1. increase operational efficiency,
2. reduce scrap,
3. prescriptive quality management for defect propagation avoidance,
4. increase energy efficiency,
5. improved smart product customer experience.

For this reason, attention is focused both on the product, processes and machines. The definition of quality for the latter could be seen in both ways; product quality and process quality, since a machine can be considered as a product itself from the OEM point of view or as a component, that influences the quality of the production process if the point of view of the user is taken in consideration. Product quality can be defined as the overall conformity of a manufactured product to specifications and requirements from the end user. In other words, product quality looks at how much the product features and functionalities satisfy the end user's expectations. On the other hand, process quality focuses on the manufacturing activities required to manufacture a product and it is about ensuring that it is "fit for purpose". The concept of quality evolved over years from the mere consideration of the product to a broader concept of TQM.

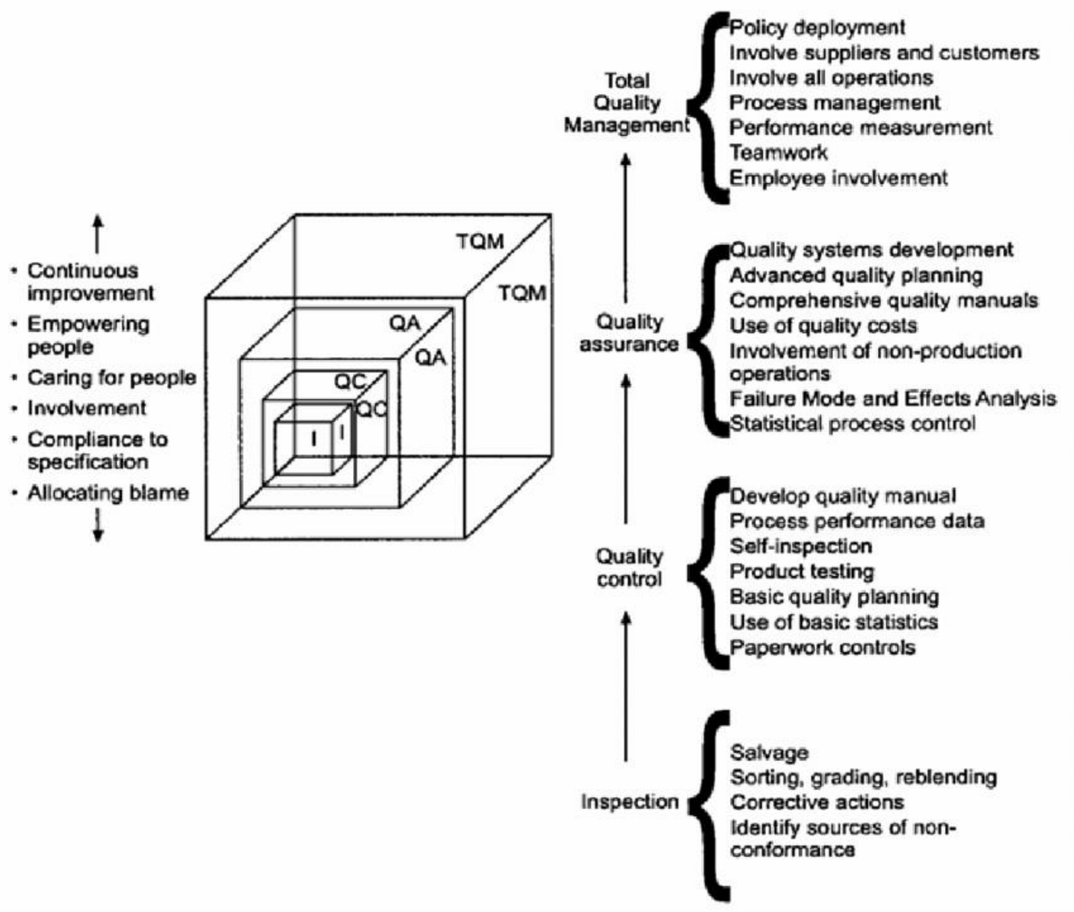


Figure 2 - Evolution of quality management ISO 9000[2]

The first step in the quality evolution was characterized by a simple inspection (I) performed by an operator at the end of the production process with a go/no-go approach and, if needed, some corrective actions were implemented. Then, quality control (QC) and quality assurance (QA) started to be performed. They consist in the development and use of quality manuals, quality planning and statistical approach, which implies the measuring, analysing and monitoring product quality parameters in a systematic way. Preventive actions to reduce costs, related to rework, waste, and mayor stop had to be determined. Following these objectives, quality management practices as Total Quality Management (TQM) were introduced. In the 21st century, starting from TQM, holistic frameworks aimed at helping organizations to achieve excellent performances especially in customer satisfaction and business betterments were developed. The main methodologies designed and adopted to put in place quality control practices are the TQM-, Lean Production-, Six Sigma- and Zero Defect Manufacturing paradigms.

Total Quality Management is a managerial approach, focused on quality and based on the participation of all members of an organization, to achieve long-term success through customer satisfaction and benefits that bring advantages to workers and society. Considering product quality, this means to monitor and assure quality of the product from ideation to use.

[2]https://www.researchgate.net/figure/The-four-levels-in-the-evolution-of-quality-management-18-35_fig2_313250893

In the design phase, before production, customers' needs must be identified and included in the product specifications. Then, during the production, quality must be monitor at different stages and finally after production quality controls must be performed to check conformity with design-specification.

Lean Production is an approach focused on waste minimization along the production process to increase the production capacity. It aims to achieve (i) quality improvement through a deep understanding of the customer's needs and the design of the processes devoted to meet customer's requirements and expectations; (ii) waste reduction that includes the elimination of all the activities that do not add value to the product/service from the customer's perspective; (iii) time reduction considering the whole production process; (iv) total cost reduction without negatively impacting customer satisfaction.

Six Sigma aims at improving the manufacturing process in terms of the quality of the process outputs. This is pursued through the identification and subsequent elimination of defects' causes and by minimizing the variability of the production and business processes. It is mainly based on a set of quality management practices that exploit empirical and statistical methods.

Zero Defect Manufacturing is a paradigm that aspires to develop methodologies, technologies and integrated tools for maintenance, quality control, and logistics of production that takes advantage of the knowledge of the process and the system. The most relevant aspects are: (i) predictive models of degradation machine states; (ii) condition-based maintenance approaches able to prevent deviations without interfering with the performances of the logistics system; (iii) models and methods for predicting the defects impact on subsequent production phases in order to identify proactive solutions (rework and repair online). Therefore, it aims to reduce defects as much as possible thanks to the implementation of preventive actions. Some of these actions include worker motivation in order to increase their consciousness and encourage them to do the job right the first time.

Quality control, as well as all the other manufacturing process, are subject to the Fourth Industrial Revolution that has being transforming how the manufacturing and industrial processes are performed by introducing a high degree of digitalization.

Advanced manufacturing systems are now changed into "Smart manufacturing" to define "a data intensive application of information technology at the shop floor level and above to enable intelligent, efficient and responsive operations" [1] by use of data analytics. "Autonomous" in manufacturing can be defined as the ability of a system to gain information about the environment in which it operates, learn and take decisions in order to adapt itself to a specific situation without the need of human intervention or working in a collaborative way with humans to augment or complement their activities.

In that light, Autonomous Quality (AQ) can be defined as a real-time quality control process supported by Industry 4.0 enabling technologies where, at the maximum level of system autonomy, the decisions (closing loop) are taken by software after a deep data analysis [2] [3].

On the other hand, it must be clear that we distinguish between AI and Machine Learning. AI means that machine can perform tasks in ways that are "intelligent" adapting to different situations.

Machine Learning is in this context based on the idea that can build machines to process data and learn on their own, without the constant supervision of humans.

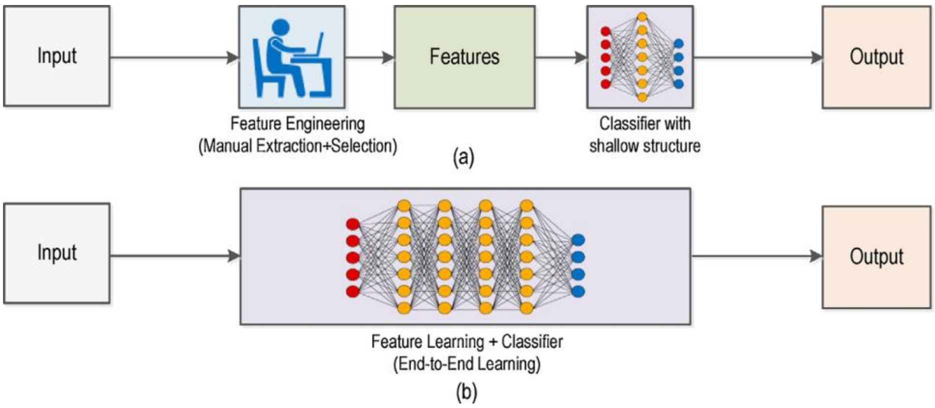


Figure 3 - Comparison between two techniques: a) traditional machine learning. b) deep learning [3]

In the QU4LITY project, Autonomous Quality is intended as a paradigm-shift for ZDM in connected smart factories, which requires the implementation of interrelated control loops for real-time adaptation, flexible composition, smart planning and continuous learning.

1.2 Autonomous Quality – The next evolution of ZDM

In the next 10 to 15 years, factories and plants across industry sectors will be high-tech engines of mass customization, able to respond quickly and effectively to changing customer and market demands. Highly automated and information-intensive, the factory of tomorrow will look like an integrated hardware and software system. This system will be fuelled by vast quantities of information from every corner of the enterprise and beyond, moderated by analytical systems that can identify and extract insights and opportunities from that information, and comprised of intelligent machines that learn, act, and work alongside highly skilled human beings in safe and collaborative environments.

Specifically, the key trends are digitalization, mass-customization, collaborative models, smart supply chains, new business models and cognitive computing[3]:

- **Digitization** is transforming how manufacturers need to think about human capital management. The workforce will need greater digital literacy and to have high-tech and collaboration skills. It will also need to be able to work cross functionally as well as with increasingly intelligent machines to bring higher levels of efficiency and productivity to the enterprise;
- Future factory designs and footprints will likely favour modularization, with micro factories capable of **mass customization** using such technologies as 3D printing as well as **digital manufacturing technologies**;

[3] https://www.intel.com/content/www/us/en/industrial-automation/factory-of-the-future-vision-2030-white-paper.html

- The manufacturing innovation process will evolve to be more open and extended, with **collaborative models** that span internal as well as external constituencies;
- **Supply chains** will become highly integrated, increasingly intelligent, and even self-managing;
- **New business models** incorporating outcome-based services will emerge, enabling manufacturers to diversify their revenue streams and provide greater value to customers;
- **Cognitive computing and analytic techniques** will enable production environments to self-configure, self- adjust, and self-optimize, leading to greater agility, flexibility, and cost effectiveness.

The EC has already started early in supporting the factories of the future by establishing already in 2008, the "Factories of the Future" PPP, understanding the necessity to support one of the main European areas in its transition into the digital world[4]. The EC is now also on the forefront in promoting the concepts of the AQ.

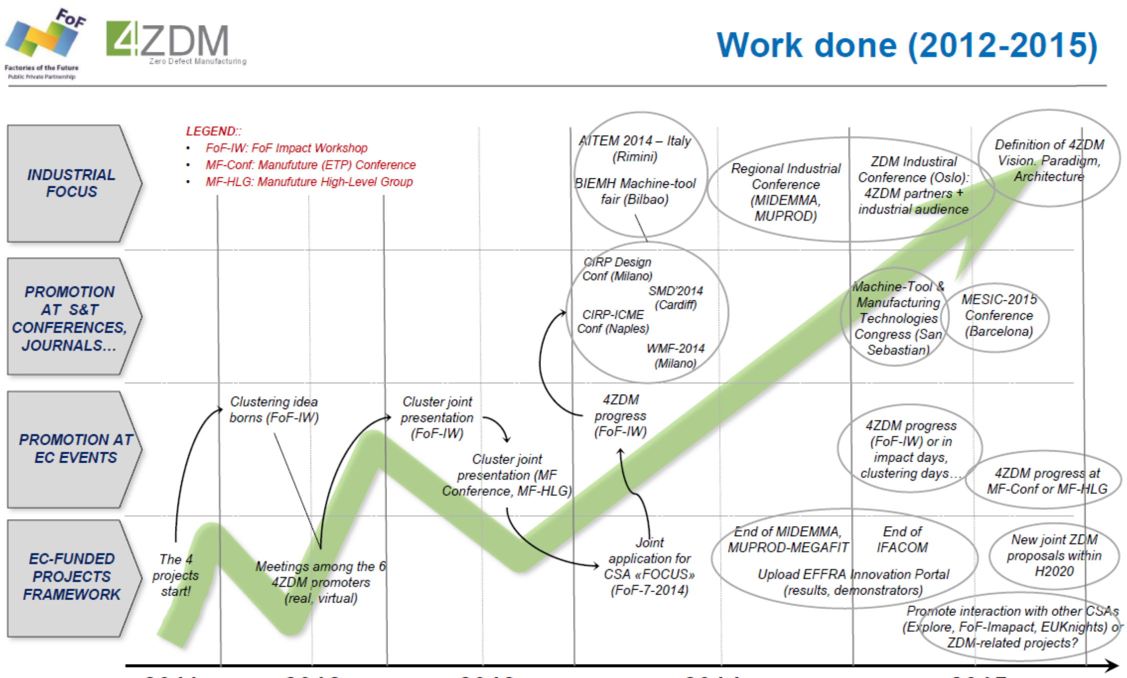


Figure 4 - The evolution of the concept of ZDM in the FoF-Community (4ZDM Cluster)

In the light of the FoF pathways or roadmap defined for ZDM by the 4ZDM Cluster and the CSA project FOCUS (Factory Of the future CLUsterS), the specification of the AQ concept will target the different aspects of the manufacturing, including products (smart products and machines) and processes both within the factory (connected factories) and across the supply chain (hyper-connected factories), aiming at creating value for both industry and the customers. From the FOCUS Roadmap, the future trends for ZDM are;

[4] http://ec.europa.eu/research/industrial_technologies/factories-of-the-future_en.html

- Market demand for mass-customization, personalized, and small lot products
- Pressure on efficiency in delivering complex multi-material products
- Pressure on zero-waste, social and environmental performance of EU industries
- New service-oriented businesses and globally efficient manufacturing ecosystems
- Integrated approach for quality control, production logistics and maintenance policies.

The QU4LITY ZDM strategies will use data to drive efficiencies and improve capabilities in three ways;

- Connected workforce, manufacturing assets, facilities and devices will enable use cases such as high precision manufacturing, plug & control solutions and smart in-process adaptation.
- Second, integration with non-production departments, such as engineering, planning and after-sales service, enables new business insights to drive simulation-based production and work-cell self-reconfiguration and multi-stage manufacturing process optimisation avoiding error propagation.
- Third, improved data visibility among companies enables implementation of outcome-based service models and collaborative and orchestrated digital twin service operation.

The evolution of ZDM in Industry 4.0 systems is characterized by a four-steps pathway [4].

1. Descriptive purpose: the goal is to describe the current status / what it is happening of the element under analysis
2. Diagnostic purpose: the goal is to understand why something is happening
3. Predictive purpose: the goal is to understand what likely will happen
4. Prescriptive purpose: the goal is to recommend what should be done, provide guidelines/improvement action to reach the desired status

In that light, the AQ aims at reducing the human input in the data analysis and process control to achieve the automation of the loops of information through improved use of more complex control systems. The goal is to achieve autonomous decision-making processes to assure the quality of production processes and related output in autonomous way. The figure below explains in a generic way the path to achieve AQ in Industry 4.0 systems provided by Philips and their approach to define the pilot[5].

[5] https://www.gartner.com/en/doc/344077-accelerating-digitalization-in-manufacturing-industries-primer-for-2018

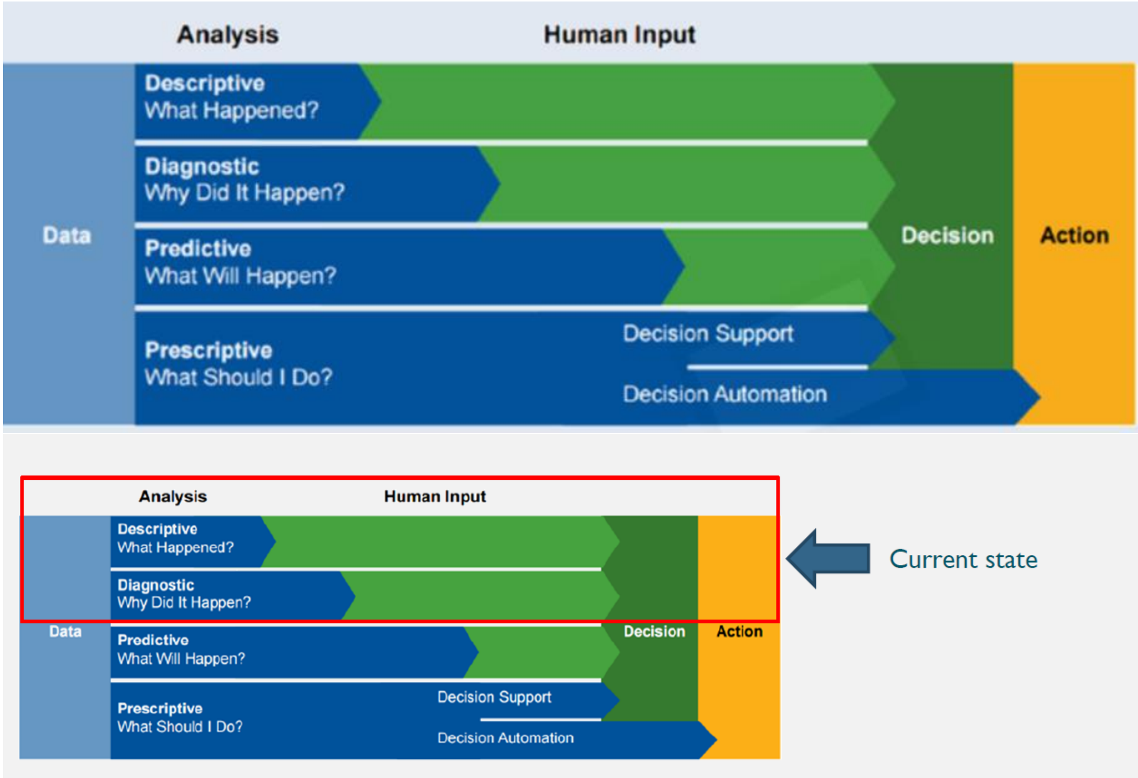


Figure 5 - Questionnaire for QU4LITY provided by Philips in D2.1 for all pilots

Therefore, in order to realise an AQ paradigm, four types of control loops are required [5]:

1. real-time control loop – it is a control system where the time window to collect and process data to then update the system is tight. If there is not a defined time window, the system stability is in danger.
2. composition & orchestration control loop – the data collected must be integrated to support the decision system, the orchestrator automates sequences of activities by implementing the necessary rules and policies in order to change the system state in response to an event.
3. deep control loop – the data mining infrastructure will support deep-learning as a means of providing AI capabilities in manufacturing analytics. Existing data analytics infrastructures that are already customized for manufacturing (i.e. listed in Section 1.3) will be used to accelerate the developments.
4. augmented human in the control loop – the availability of new technologies that allow data handling and visualization using mobile/wearable apps (mobile middleware) contribute to keeping the human in the loop while reducing errors [6].

1.3 Autonomous Quality

By 2030, European industry in general, and small- & medium enterprises (SMEs) in particular, will master an intensive and holistic (interoperable) use of data-driven AI

Figure 6 - Autonomous manufacturing processes

technologies in products of the future and in autonomous sustainable manufacturing processes and services enabled by augmented, human-centric, high performance, interoperable platforms and digital-twins.
In fact, we will see an evolution in the flexibility and modularity of factory processes (autonomous transportation & logistics, plug & produce modular assembly cells, human & robot collaboration, digital factory) that will be linked to an increased ability for manufacturing equipment and manufacturing processes to make autonomous decisions supervised and assisted by the expertise and knowledge of human workers. Those autonomous manufacturing processes will see and deploy different levels of human-AI collaboration. According to Industry 4.0 classification, QU4LITY will address the implementation of processes and manufacturing equipment up to Autonomy Level 4:

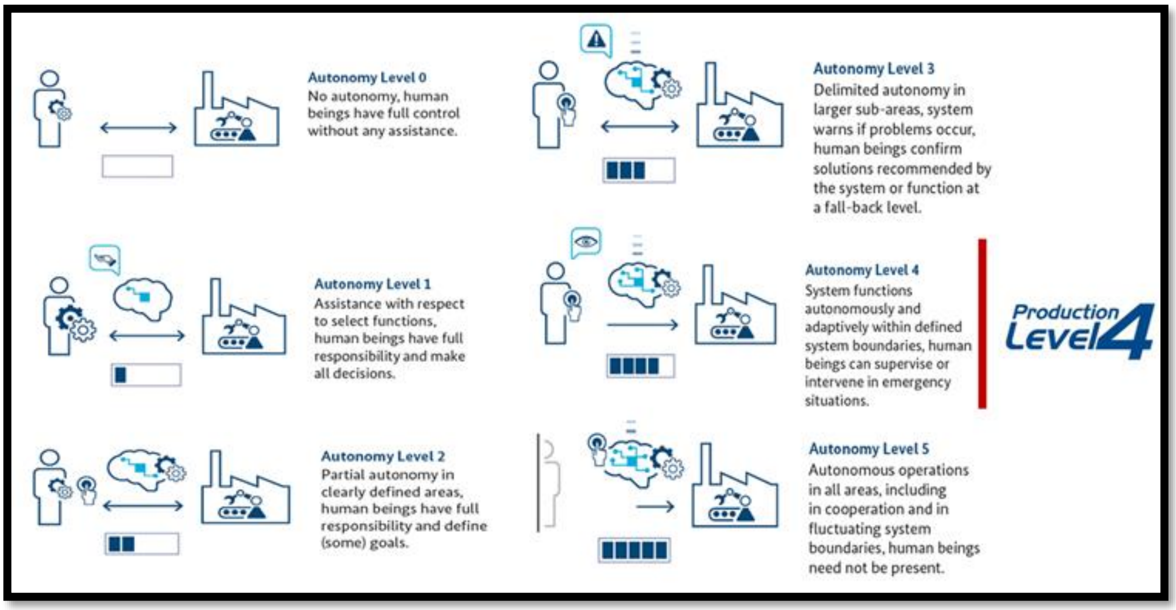


Figure 7 - Autonomous manufacturing processes autonomy levels.

While manufacturing process evolution is taking place, quality control methods are not yet evolving accordingly. Therefore, QU4LITY strategic, high-level objective is to establish:

- fully digitalized concept of human-centric
- collaborative self-learning
- proactive next generation autonomous ZDM,

This can in a Hybrid structure.

- recognize, forecast and communicate less optimal process behaviour well, before these occur and
- adjust itself with human supervision in order to keep the process continuously close to or at optimum.

Over the last five years, the European Digital Shop-floor Alliance (DSA) and EFFRA Connected Factories Cluster have been working on defining a reference model and transformation pathway towards the autonomous factory - see EFFRA digitisation pathways. Such pathway establishes the capabilities that need to be enabled at digital platform, manufacturing equipment and manufacturing process level to realise increased level of autonomy in the manufacturing strategies (see Figure below).

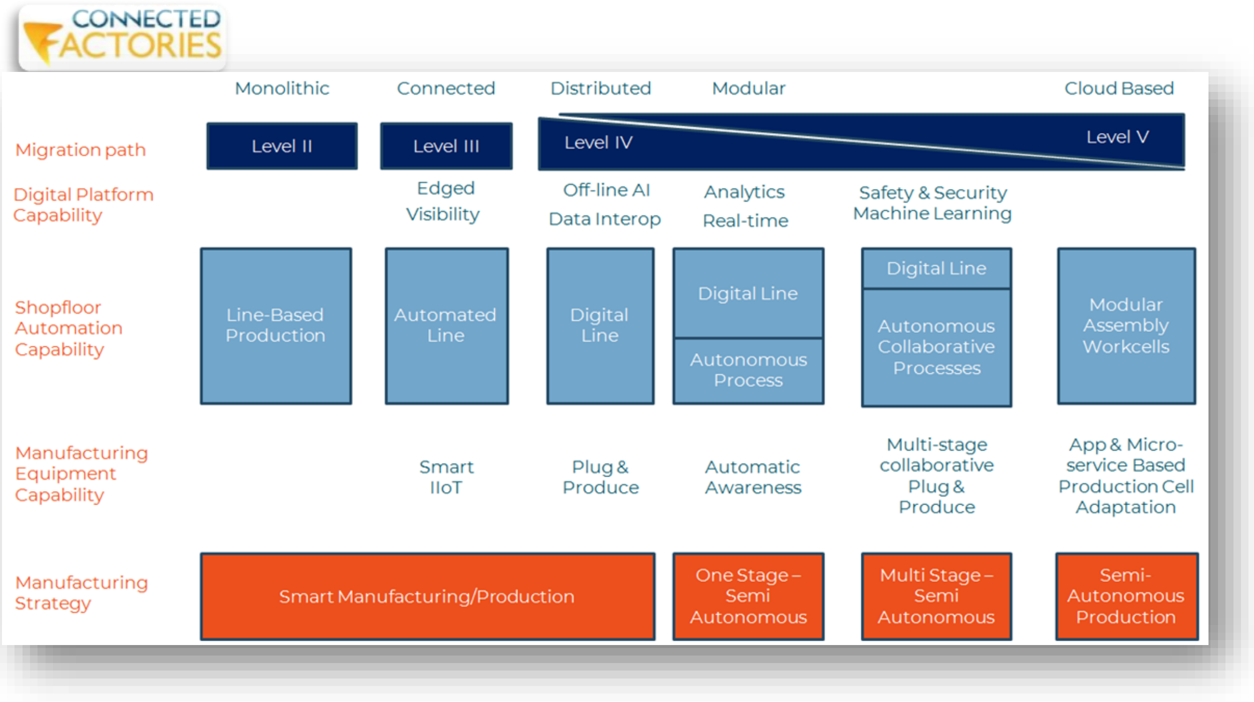


Figure 8 - EFFRA Autonomous Factory Pathway – EFFA Connected Factories

Consequently, autonomous ZDM equipment and factory operation is essentially conditioned by the ability of future cognitive systems to implement and interoperate feedforward and feedback quality control loops at multiple levels in a cost and time effective manner and to achieve the right balance among process automation and human interaction.

The ultimate autonomous factory transformation goals are:

1. to improve the quality of manufacturing decisions
2. to reduce the time to decision
3. to make things happen as plan and predicted

2. The Vision of a Quality Platform

It becomes apparent that cognition can improve the behaviour of a complex process system. However, cognition on its own is not sufficient to drive smart decision processes in Industry 4.0. Autonomous systems cognition should be seamlessly blended and combined with human intelligence; i.e. collaborative intelligence. Therefore, one of the main expectations of future autonomous factories is the use of digital twins with such cognitive capabilities in combination with human expertise to leverage the capability to observe and monitor with high fidelity the behaviour of their respective physical twins. In order to make it happen, QU4LITY will need to combine digital twins, which are driven by human expert and/or simulation-based domain models (i.e. knowledge), with the models derived from data (i.e. experience).

Currently, manufacturing and assembly systems need to be flexible to adapt quickly to a variety of material combinations and products. This new manufacturing model requires the development of flexible and high reconfigurable manufacturing systems capable to offer high reactivity and adaptivity to changes in market demand. The rising complexity of modern production systems have shown several handicaps like lack of knowledge about the different possible configurations, perception capacity of sensors or non-linear relationships between quality-related magnitudes and parameters involved.

This situation jeopardizes the perception-control-actuation loop productivity under the conventional automation approach. In this way, cognitive automation capable to react to unpredictable situations and/or process variations proposes a step forward for autonomous manufacturing systems[6]. The implementation of new autonomous manufacturing paradigm requires not only the development of flexible manufacturing systems, but also the development and *implementation of novel control systems with cognitive capabilities and new information flows capable to react to unpredictable situations*, to plan their further actions, and to learn and gain experience from previous manufacturing processes –i.e. Cognitive Automation[7]. This approach increases the operation range of the manufacturing system autonomously. This involves the implementation of perception, learning, reasoning and management abilities[8].

QU4LITY does not call for abandoning well established and sound quality control methods. On the contrary, QU4LITY calls for extending such methods with a multi-dimensional, multi-stage and systematic framework for cognitive collaborative quality assurance throughout an entire supply chain; i.e. autonomous quality control framework.

[6] Bannat, A., et al. Artificial cognition in production systems. IEEE Transactions on automation science and engineering, 2011, vol. 8, no 1.
[7] Zäh Michael F., et al. The cognitive factory, in Changeable and reconfigurable manufacturing systems. Springer London, 2009. p. 355-371.
[8] Zaeh M., et al., Towards the cognitive factory, in Int. Conf. Changeable, Agile, Reconfigurable and Virtual Production, Canada, 2007

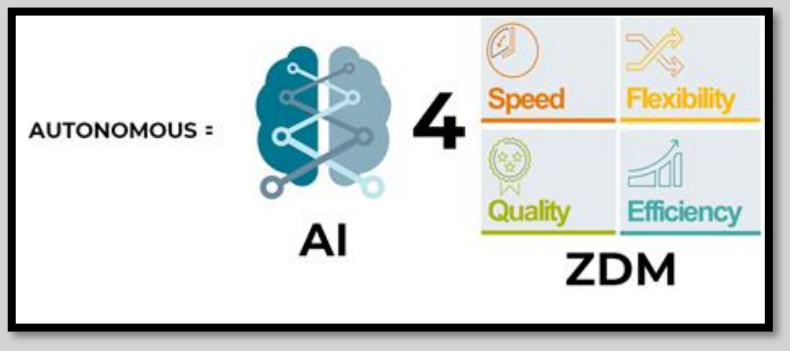


Figure 9 - Autonomous quality (AQ) concept

2.1 The Digital QU4LITY Platform for ZDM and QM Excellence

The secret to consistent, automated, and productive Factory 4.0 manufacturing is to understand *where process variation comes from and how to deal with it at source.* Over the past thirty years, considerable advances have been made in computational intelligence and our ability to deal with quality control in the digital domain has significantly improved; i.e. computational metrology.

Compared to traditional statistical control-based quality assurance, computational intelligence (AI, machine learning, deep learning, genetic algorithms, metaheuristics etc.) technologies have advantages for making intelligent decisions, such as quality prediction and pattern recognition for the situations with high complexity.

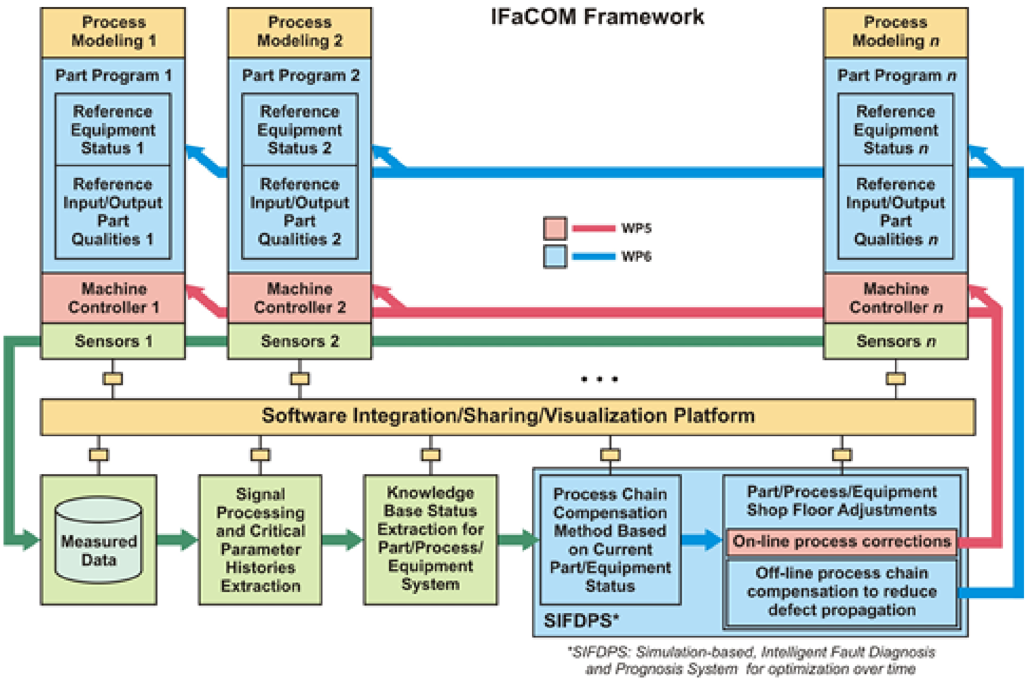


Figure 10 - Digital platforms (QU4LITY) and ZDM process (IFaCOM[9] coexistence)

[9] The IFaCOM Framework; published at the IFaCOM-end Conference Oslo, April 2015.

QU4LITY is leveraging modular and composable digital enablers, to support the implementation of a closed loop (feedback and feed-forward) quality assurance, and improvement framework to unlock the key to predictable, productive manufacturing.
As mentioned in the executive summary, it is an important success factor that the ecosystem for such a platform is built in a sustainable way. To enhance the data information, the collaboration of the companies in and around the QU4LITY Pilots, and the innovation of new products and services that will be created and made available at the ZDM Platform. AI in QU4LITY is used to learn complex behaviours as perception, self-reasoning or action from experience (data acquired and simulated) in federated and privacy-preserving distributed manufacturing environments, barrier that conventional AI used to overcome only with expert knowledge.
Ultimately, joint operation of cognitive hybrid twins' technologies with collaborative explainable Intelligence is driven to master the implementation of autonomous multi-level control and decision loops. It also controls the product-process-system and self-adaptation in multi-stage production systems.
However, the prevailing ISA95 function-oriented IT architecture lack of flexibility, composability, holistic data integration and cross-hierarchical information provisioning, which limit the cost-effective exploitation of big industrial data and fast replication of AI-powered autonomous strategies across processes, factories and sectors.

To address ISA-95 well known limitations and to enable a standardised implementation of the four types of control loops that are required to realise the QU4LITY Autonomous Factory paradigm, namely:

1. event-driven real-time control loop
2. autonomous multi-stage control loop
3. deep adaptive control loop
4. and 'human-in-the-loop' autonomous control loop

The QU4LITY Platform is proposing to spread intelligence across the various levels of the smart connected factory (field, edge, factory and cloud) with suitable networking, computing and analytic enablers (including visualization) that are able to meet volume, variety, velocity of decisions in the shop-floor.

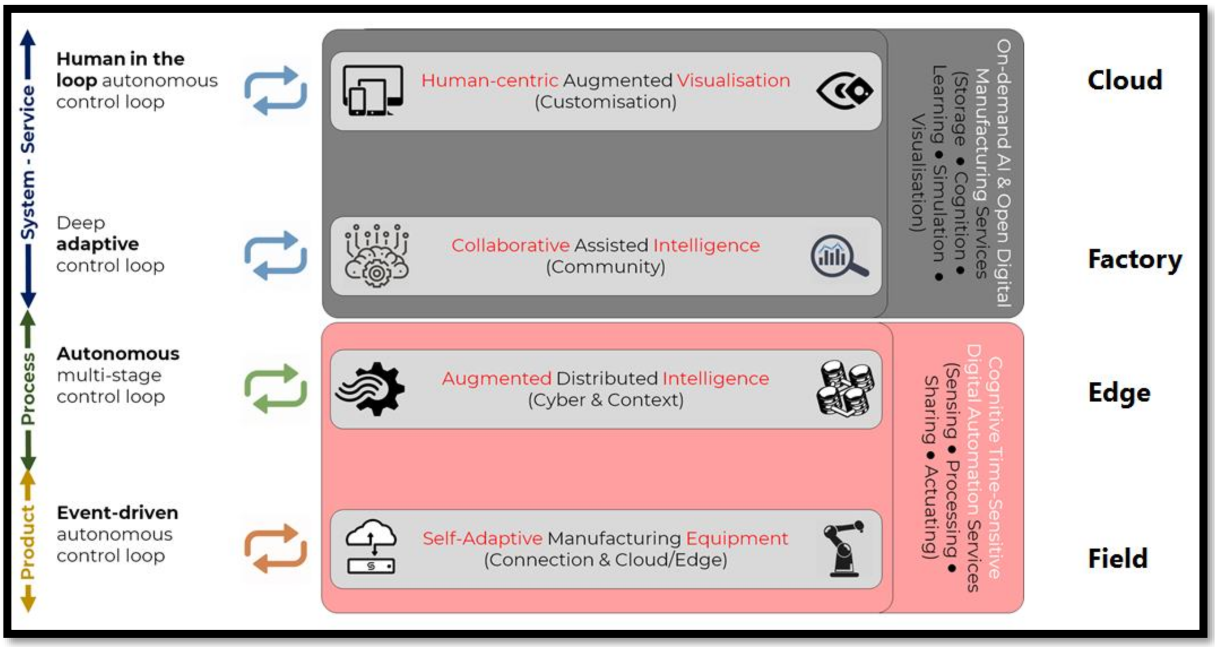


Figure 11 - QU4LITY AI distribution model and types of decision and control workflow (Innovalia)

QU4LITY brings quality control to new levels of automation, adaptation, actuation, cognition and collaboration. The goal is to get quick, comprehensive feedback about the whole production process, looking at both the production means, the part and all the elements contributing to manufacturing in that final workpiece.

3. State of the art of ZDM and Smart Manufacturing

Manufacturing has always sought a high-quality performance pursuing "near zero" perfection, aiming at quality improvements both of products and manufacturing processes. Over time, scientific methods supporting the reduction (or elimination) of defects in manufacturing processes and related outputs have been adopted to achieve quality objectives. Approaches such as TQM, lean manufacturing, six sigma and zero defect (described previously) have been flanked by statistical tools capable of analysing data from the field to generate indicators to support the decision-making activities according to the logics of quality management. However, technological progress makes more data available as the complexity of manufacturing systems increases.

3.1 ZDM in the era of Digitalization

Industry 4.0 is characterised by the automation and data exchange in manufacturing technologies. It connects and integrate digital environments throughout the value chain focusing on the end-to-end digitization of everything, everywhere. Industry 4.0 networks new technologies, platforms and data spaces to create value by generating, analysing and communicating data seamlessly. In light of this, for companies to achieve ZDM, operations and products must be smart and connected. The digitalization of manufacturing systems allows access to data by implementation of Cyber-physical Production Systems (CPSs) and generates connectivity and interoperability through the IIoT (Industrial Internet of Things). To this end, the interaction between hardware/software and data management makes the ZDM concept easier to be implemented due to the availability of the required amount of data for advanced technologies such as machine learning to work properly. Although a lot of effort is still need for better integration and coordination of the capabilities of each enabling technology, ZDM is expected to become the new standard for companies towards more efficient and eco-friendly production lines with zero defects.

Defects arise when a process or a product does not perform within its specification, resulting in a non-compliant condition. Defects cause failures and result in loss of resources and increased costs due to scrap or waste in production or customer return of products due to failures. Zero defect in Industry 4.0 requires obtaining anticipated information on the quality of the parts during the respective process steps and evaluating the influence of deviating process parameters.

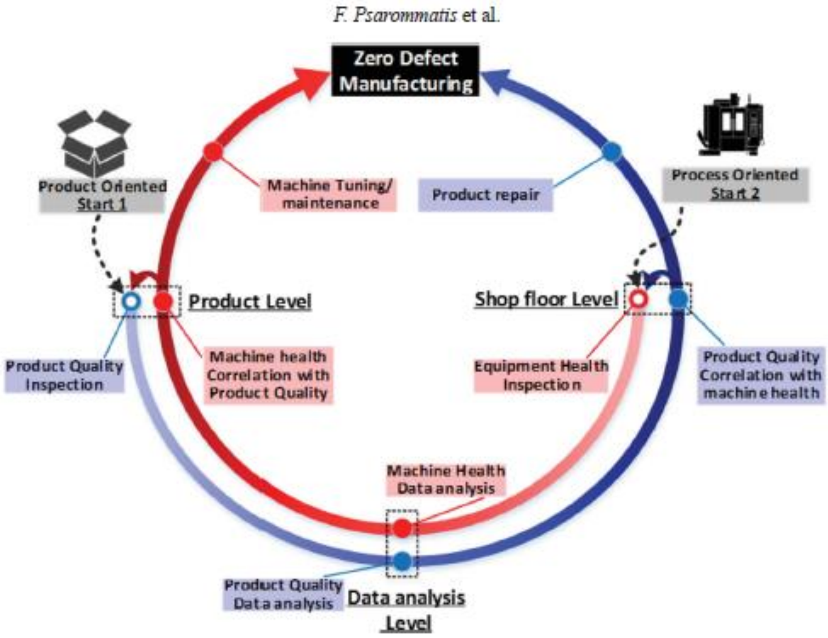


Figure 12 - Zero Defect manufacturing concept [4]

Many of the current methods and tools in the frame of quality control and management are not directly Industry 4.0 compatible, as they rely on fixed models of the processes, often tied to fixed devices, they are on-site focused, relying on a restricted set of smart capacity from the field, they consist of linear, fixed models of assets and processes, they have a high-touch integration to automation, and they rely on factory-context workflow.

3.2 The use of AI and Digital Twin Technology

- **Common Sensing**

Common-sense reasoning is a field of AI that aims to represent and reason about the world in close to the way how humans understand and structure the world. The research started in 1980s and was evolving slowly as part of general AI development. Recently the area got lots of attention through a large US DARPA programme 'Machine Common Sense' including most of the key US academic and industrial institutions solving a set of challenges with the common characteristic that humans are good in solving the tasks, while machine are not. The key element in the common sense reasoning is the representation of the world or broader context in which a machine is supposed to reason – we call this a 'world model' and is typically represented as an ontology or some form of a probabilistic structure (e.g. interlinked linguistic embeddings).

- **Anomaly Detection**

With dataset that cannot be structured in a proper way, it is possible to use a data mining method by looking at anomalies. Anomalies are classified as point anomalies, where a single data point does not conform to the dataset, and contextual anomalies, where a data point coupled is unexpected within the context of other points (e.g.: points close in time for a temporal dataset, points close in space for a spatial dataset, etc.). Techniques can also be categorized with respect to the availability of labelled data. Supervised methods deal with training sets annotated with labels corresponding to normal and one or more anomalous classes. Popular approaches include using Bayesian networks, Support Vector Machines, association rules and a semi-supervised approach dealing with datasets that has instances labelled as normal and another set that is unlabelled (consists of normal and anomalous instances).

- **Machine Learning**

In recent years, machine learning (ML) has made major advances in the field of image recognition mainly due to the success of convolutional neural network architectures (CNN[10]) and the availability of large annotated datasets together with increased computing capacity on graphics processing units to train CNNs with a large number of layers and parameters. Problems such as image classification as well as object recognition and segmentation have been tackled successfully in a broad range of settings without the need for manual feature engineering. With large computing capacity at disposal in cloud computing (e.g, Azure), efficient hardware-based realisation of neural network training, and transfer learning from models trained on large-scale datasets will be possible.

- **Digital Twins**

Digital Twin is a technical term which appeared after 2010 and got widely adopted after 2017, especially in the context of IoT technologies. Functionally, a digital twin is a "digital mirror" of some observed physical reality. Structurally, a digital twin is just a dynamical model which, given a current state of an observed system, is capable of a digital partial reconstruction of such a system. Depending on the technology used to build digital twins, it can offer various analytical operators which allow monitoring, controlling, prediction or some other type of reactive or proactive queries.

In its simple form, a digital twin can simply be a discrete event simulator, often outfitted with data collection functionality through recorded sensors. In more sophisticated scenarios a digital twin can perform operations like anomaly detection, optimization of parameters, prediction of future evolution, (re)scheduling of tasks, causality modelling, decision making and other more or less complex operations to manage the observed physical system. Technology to build industrial strength digital twins is typically classified in two major categories:

a. top-down design using human understandable formalisms (like differential equations, if-then rules), and
b. bottom-up data driven approach where the model is trained from the data using machine learning techniques. By combining both approaches we get hybrid digital

[10] Alex Krizhevsky, Ilya Sutskever, Geoffrey E. Hinton: ImageNet Classification with Deep Convolutional Neural Networks. NIPS 2012: 1106-1114

twins which are partially trained from data and partially tuned by human interventions.

In the current industrial practice, most of digital twins are designed in a top-down manner by experts understanding the underlying physical processes. Such an approach can lead towards very accurate and interpretable models but are not necessarily very robust in the case of out-of-norm situations and are typically costly and slow to develop. Data driven digital twins are still not in a general industrial practice due to the lack of AI know-how and possibly lack of relevant IoT data to reconstruct underlying physical processes.

- **Communication Technologies**

Cyber-physical systems (CPSs) are systems where real-time computing and physical systems interact tightly such as the distributed automation systems. For such systems, deterministic and reliable communication is crucial. As a way to ensure reliable real-time communications, CPSs rely largely on industrial Ethernet-based networks such as IEEE Ethernet Time Sensitive Networking (TSN). The IEEE Ethernet TSN standards specified the different mechanisms that allow having deterministic, reliable and efficient communications. On the other hand, the telecom industry developed 5G networks with the aim to make it possible different scenario use cases related to industry 4.0. For example, with a reliable wireless network such as 5G, Automated Guided Vehicles will be able to move around in the factory carrying products to different stages as programmed.

3.3 Smart Manufacturing and Industry 4.0

Changes are still needed before Industry 4.0 will be more directly compatible with all the new technologies that are available for a smart factory. According to Deloitte insights[11], there are five key characteristics of a smart factory:

1. **Connected**: assets of a smart factory, such as processes and materials, should be connected so that both traditional data sets and new sensor data can be updated constantly. It enables real-time decision support, supplier and customer collaboration, and inter-department collaboration in the factory.
2. **Optimized**: a smart factory should have optimized performance in terms of high yield, uptime and quality, with low cost and waste rate, enabled through automated workflows, synchronized assets, improved tracking and scheduling, and optimized energy consumption.
3. **Transparent**: the real-time data should be transformed actionable insights for both humans and autonomous decision-making systems supported by real-time data visualization solutions.
4. **Proactive**: based on historical and real-time data, a smart factory should have the ability to predict future outcomes enabling systems and humans to anticipate and act before quality or safety issues arise.

[11] https://www2.deloitte.com/insights/us/en/focus/industry-4-0/smart-factory-connected-manufacturing.html

5. **Agile**: advanced smart factories should allow self-configuration of the equipment and material flows to adapt to schedule and product changes with minimum intervention.

All these key issues play a vital role in understanding the ZDM concept and, more important, take action towards it. Smart factories are more responsive, proactive, and predictive, thus avoiding operational issues and other productivity challenges.

In that light, smart factories are empowered to be able to adjust to and learn from data in real time through:

- Connectivity/Sensing/Mobile
- Cloud/Advanced analysis
- Decentralization
- Vertical and Horizontal integration
- Interoperability

Thus, AQ practices and tools require incorporating existing classical quality control and management solutions, but also offering additional features and functionalities. AQ solutions allow capabilities like:

- Acceleration of IT operations
- Achieve accurate information on processes and product quality throughout each process step based on real-time data
- Continuous improvement capabilities due to integrated advanced analytics frameworks
- Greater visibility into process quality levels and greater accuracy in predicting performance over time both at plant level and at supply chain level
- Increase of efficiency, revenue, accuracy and yield of production
- Interoperability of IT infrastructure with other manufacturing and operational systems (ERP, MES, company own, etc.)
- Measuring compliance empowerment and traceability to the machine level
- Plant performance transparency and understanding across multiple metrics
- Quantify daily production impact in financial performance with visibility to the machine level
- Unite quality management and compliance systems.

The reason is that the many of classical IT solutions are standard systems and not agile enough to match specific company quality needs in an autonomous way. Smart software solutions can automate quality processes. This means that companies can adapt smart solutions to their specific needs, considering all their quality aspects lowering humans' intervention in the quality processes.

QU4LITY will provide an integrated framework that allows enterprises to adopt AI, digital technologies, and advanced quality control methods for active monitoring, autonomous diagnosis or self-adjustment, to maintain product quality under control. There are multiple factors (e.g. raw material factors, manufacturing environment factors, machine factors, assembly factors, delivery factors, etc) throughout smart factory and supply chain that may influence product quality in various ways and in dynamic situations. The individual and combined influence of multiple factors on quality is unclear. The rules of knowledge base will be obtained from the intensive study of the impact of multiple factors on product quality by the QU4LITY cognitive integrated quality system.

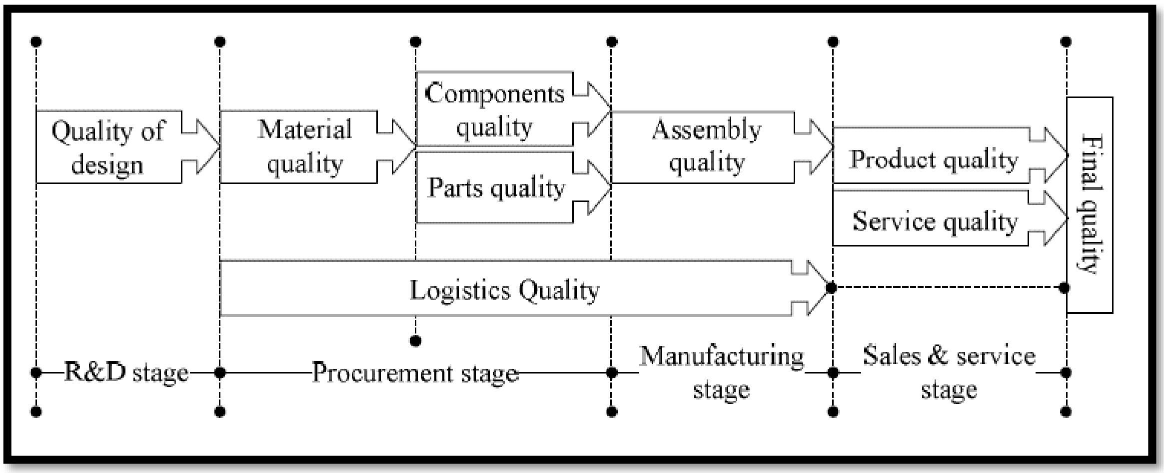


Figure 13 - Autonomous quality chain components

There is a risk that the implementation of autonomous ZDM control loops will derive in highly customized solutions, that lack a general approach and therefore suffer from lack of portability and do not exhibit economies of scales. Therefore, it is important that the QU4LITY framework allows such universal approach while at the same time enables the required level of customization that will leverage industrial competitive advantages.

In fact, industrial manufacturing environments are always different, always specific and always incorporate something new, since this is the actual essence of the factory capability, which differentiate one factory from its competitors. This uniqueness, while a clear manufacturing competitive advantage, represents a critical barrier for straight-forward, mass and cost-effective deployment of AI services and solutions at a scale. AI deployments are currently strictly tailored to highly individualised implementations. The QU4LITY platform will therefore deploy AQ to allow better performing processes and machines in order to lower the delivery of non-defective products.

AQ for processes. Quality assurance embraces process management control. Smart AQ control functionalities are challenging to obtain. They require continuous monitoring capabilities, which can be achieved through interconnected systems and processes. This is not an option with classical IT systems. Smart audit solutions empower to execute process qualifications and compares data constantly by monitoring real-time process deviations.

AQ for products. These are often executed by stand-alone solutions. The reason for this is that classical IT systems are not deeply embedded enough within the IT landscapes and production environment. Normally, data has to be captured manually. Smart solutions can relate to the overall ICT landscapes and production environments to process information in real-time. Operators are empowered with automatic assistance, enabling them to execute product qualification procedures, ensuring that all qualification requirements are within the predefined range.

In order to achieve the AQ goals, some key issues that constitute the framework necessary to achieve ZDM processes in an AQ perspective are presented below.

- Measurement Equipment. The lack of interoperability between IT systems and measurement equipment prevents the availability of real-time data, often linked to the machine or factory system. Otherwise, equipment connected to each other ensures comprehensive monitoring and provides up-to-date information thanks to interoperable functionalities that enable automatic real-time measurements. This allows smart systems not only to read data, but also to close the information loop in feedback, recalibrating the activities intelligently.

- Quality Reporting. To achieve perfect quality levels, smart and automatic reporting procedures must be in place. Smart means based on real-time data, generated instantaneously and correlating relevant information. Classical quality systems are not deep enough embedded into IT landscapes. This lack of automation limits the quality reporting and therefore efficiency. Smart quality reporting requires a new type of software with all-embracing interconnectivity. Smart software solutions automatically record quality data and provide any kind of configured / customized, quality reports. Interoperability capabilities, with multiple system, machine, station or process, enable to get instantly updated reports accessible from smart devices.

Smart quality reporting predefines relevant information and provides the right conclusions, in an intuitive and simple manner, relieving operators from manual work.

3.4 Standards for Industry 4.0 related to ZDM

IT standards for Industry 4.0 and the manufacturing disciplines covered within digitalisation has not been satisfactory developed yet. However, the development of the RAMI, Reference Architectures RAMI for Industry 4.0 covers both the framework and platform issues that can support ZDM.

- The “Life Cycle & Value Stream:” axis: The left horizontal axis represents the life cycle of facilities and products, based on IEC 62890 for life-cycle management.

- The “Hierarchy Levels” axis: Indicated on the right horizontal axis are hierarchy levels from IEC 62264, the international standards series for enterprise IT and control systems.

- The "Layers" axis: The six layers on the vertical axis serve to describe the decomposition of a machine into its properties structured layer by layer, i.e. the virtual mapping of a machine. Such representations originate from information and communication technology, where properties of complex systems are commonly broken down into layers.

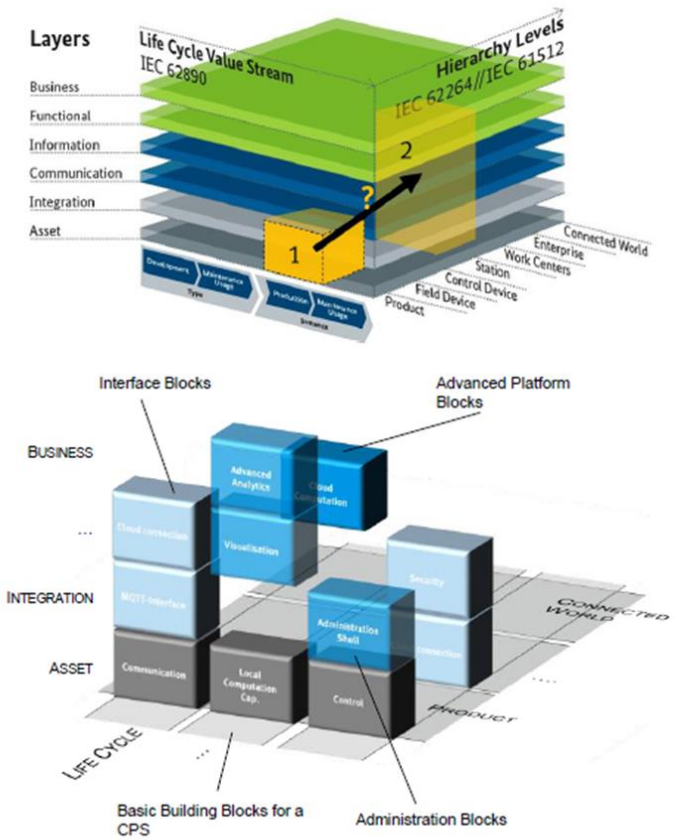


Figure 14 - Architectures RAMI for Industry 4.0[1]

- The "Hierarchy Levels" (with IEC62264) dimension is based on the classic ISA-95 which dates to the 1990s (but is still maintained). The interface between control functions and other enterprise function based upon the Purdue Reference model for CIP as published by ISA.

Within manufacturing standards there are quite a few that consider how existing standards can be modified an improved to meet the challenges of Industry 4.0 implementation. Interesting international and European standardization organizations are the International Electrotechnical Committee (IEC), the International Organization for Standardization (ISO), the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC). In particular, the technical committee ISO/TC 184 "Automation systems and integration", ISO/TC 108/SC 5 "Condition monitoring and diagnostics of machine systems", IEC/TC 65 "Industrial-process measurement, control and automation" and the CLC/TC 65X "Industrial-process measurement, control and automation". In addition, we have ISO 22400 which proposes a list of 34 KPIs for manufacturing operations management involving four information categories: production operations management, maintenance operations management, quality operations management, and inventory operations management (Appendix).

- **Data Analytics.** Smart software for statistical quality analyses are created by automatically monitoring production environments. Using real-time data empowers the creation of varieties of statistical quality analyses, which fulfil AQ needs and tailored requirements.

- **Data Security software vs hardware in Industrial IoT.** In a typical industrial IIoT area it will always arise a question for security, this is often the software versus hardware. Software-based security solutions encrypt the data to protect it from theft. However, a malicious program or a hacker could corrupt the data in order to make it unrecoverable, making the system unusable and unstable, in an industrial environment this can hamper the production. Hardware-based security solutions can prevent read and write access to data and hence offer very strong protection against tampering and unauthorized access, which can lead to slow asses for the operators and bad internal communication. It is also a security where hacker could thru software solutions i.e. take control over the machinery which can lead to a total brake shut down on a plant.

3.4.1 Autonomous Quality Management relation to Existing Standards

ISO/TC 176/SC 2 Quality systems, especially the handbook for SME of how to make a strategy and become compliant to fundamental quality requirements could be important for QU4LITY. Other interesting part like "quality in processes" as we can transfer this into AI and look whether we are compliant with our AI services form Q-LSP (QU4LITY Large Scale Pilots).

- ISO 9001:2015 Quality management systems–Requirements
- ISO 9000 family – Quality management and how to apply this as guidance from ISO/TC 176
- ISO/TS 9002:2016: Guidelines on the application of ISO 9001:2015
- ISO SME handbook:2016 ISO 9001:2015 for Small Enterprises-Advice from ISO/TC176
- ISO 9004:2018 Quality management - Quality of an organization, guidance to achieve sustained success
- ISO10005:2018 Quality management - Guidelines for quality plans
- ISO 10006:2017 Quality management - Guidelines for quality in projects, this can be used as a guideline on how to construct a QU4LITY strategy
- ISO 10007:2017 Quality management - Guidelines for configuration management

- ISO 9001:2015 How to use it Guidance on using ISO 9001:2015, Selection and use of the ISO 9000 family of standards the fundamentals of quality and the terminology used in ISO 9001:2015
- ISO 90000 Glossary – Guidance on selected words used in the ISO 9000 family of standards (vocabulary to check)
- Quality Management Principles

3.4.2. QMS Standards, other Management Systems and Excellence Models

The approaches to a QMS described in QMS standards developed by ISO/TC176, in other management system standards and in organizational excellence models are based on common principles. They all enable an organization to identify risks and opportunities and contain guidance for improvement. In the current context, many issues such as innovation, ethics, trust and reputation could be regarded as parameters within the QMS. Standards related to quality management (e.g. ISO9001), environmental management (e.g. ISO14001) and energy management (e.g. ISO50001), as well as other management standards and organizational excellence models, have addressed this.

The QMS standards developed by ISO/TC176 provide a comprehensive set of requirements and guidelines for a QMS. ISO9001specifies requirements for a QMS. ISO9004provides guidance on a wide range of objectives of a QMS for sustainable success and improved performance. Guidelines for components of a QMS include ISO10001, ISO10002, ISO10003, ISO10004, ISO10008, ISO10012and ISO19011. Guidelines for technical subjects in support of a QMS include ISO10005, ISO10006, ISO10007, ISO10014, ISO10015, ISO10018and ISO10019. Technical reports in support of a QMS include ISO/TR10013and ISO/TR10017. Requirements for a QMS are also provided in sector-specific standards, such as ISO/TS16949.

The various parts of an organization's management system, including its QMS, can be integrated as a single management system. The objectives, processes and resources related to quality, growth, funding, profitability, environment, occupational health and safety, energy, security and other aspects of the organization can be more effectively and efficiently achieved and used when the QMS is integrated with other management systems. The organization can perform an integrated audit of its management system against the requirements of multiple International Standards, such as ISO9001, ISO14001, ISO/ IEC27001and ISO50001.

4. QU4LITY ZDM Model

The QU4LITY ZDM model proposed relies on 3 main flows:
(1) **Integrated planning, design, production and service quality flows** that establish the internal and collective quality strategies across the product lifecycle.

(2) **Holistic quality control flows** which establish the individual and collective control mechanisms to ensure the effective operation of the designed quality control strategies.

(3) **Cognitive quality improvement flows** that respond to the dynamic and changing environment that quality control systems will have to deal with, in particular the individual and collective learning and model development mechanisms developed to optimise operations at local and global level for overall product performance.

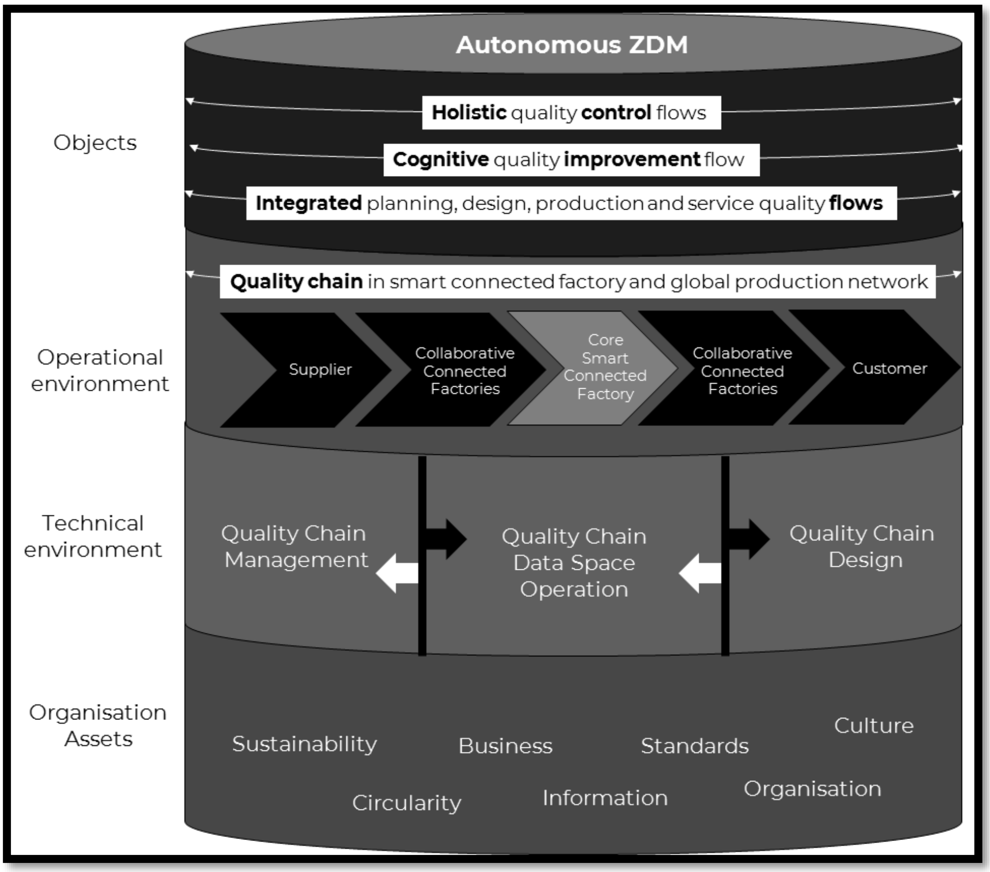


Figure 15 - QU4LITY autonomous quality reference model (ref: Innovalia)

These flows need to be operated across the quality chain in a traceable, trusted and cooperative manner enabled by a technical layer responsible for the management of the network organisation, quality process services and quality information integration and sharing. This multi-dimensional model for autonomous ZDM should therefore be rooted in the development of sovereign and trusted distributed industrial data spaces and effective design and management of quality chains. The development of such data space and quality chains is central to the development of internal as well as external quality information integration and exploitation.

The internal quality information chain (see figure below) is generated in every step of operation, and managed by the relative information systems, such as ERP/MRPII, CAD, CAE, CAPP, and PDM, etc. Integrated quality information systems need data collection for analysis of the quality control parameters.

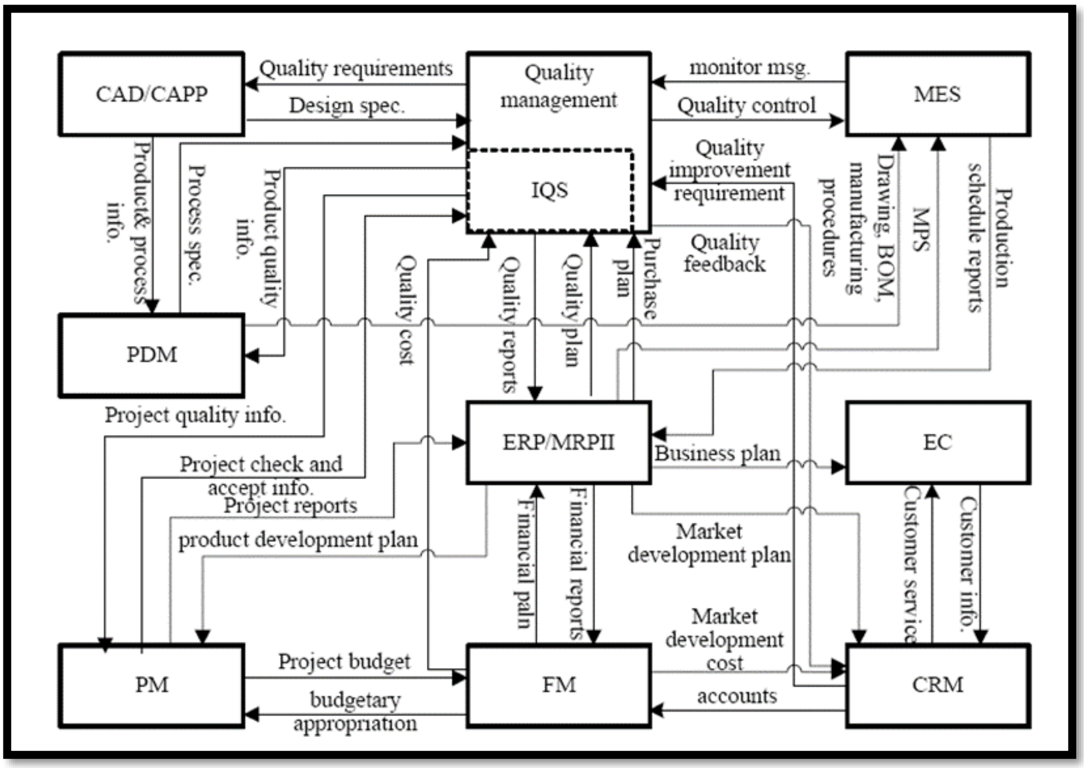


Figure 16 - QU4LITY integrated quality system (IQS) information flow model

Such IQS information chains articulated via federated industrial data spaces (intra. and inter-factory systems) are the foundations to the development of more elaborated **holistic quality control and decision workflows** (see figure below)**,** which can then exhibit cognitive features and expand across the process and product lifecycle.

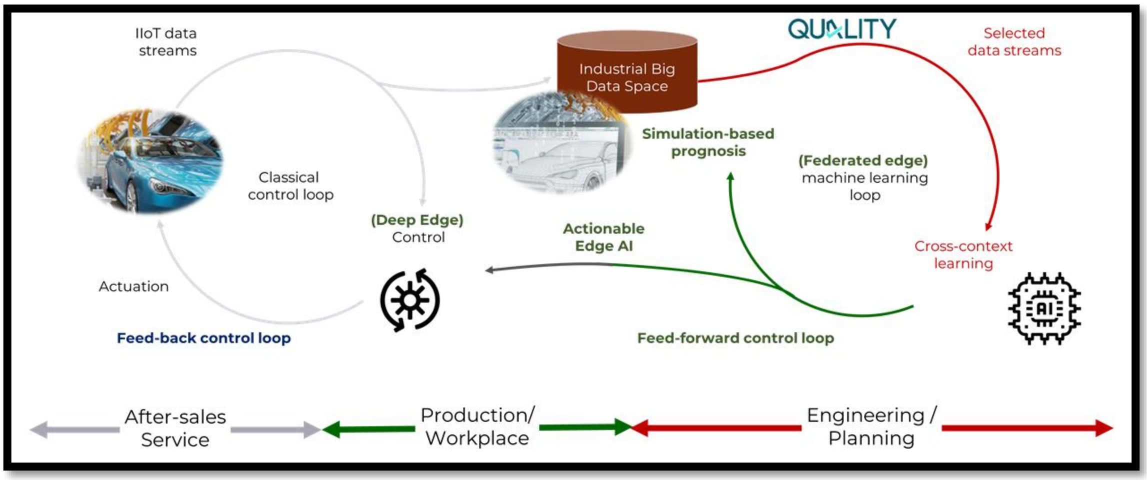


Figure 17 - QU4LITY holistic quality control and decision flow model

4.1 Autonomous Quality Opportunities and Challenges

AQ relies on Industry 4.0 technology and devices, autonomously communicating with each other along value chains. The integration of process and parts monitoring and control along the value chain can enhance traceability and earlier detection enabling quality improvements and defect reductions. Quality management in digitized systems does not only mean avoiding defective products delivered to the customer but acting in advance along the value chain to guarantee quality performance by making all the processes of an organization efficient [7].

Typically, there are two ways to improve the products' quality: optimal process design for quality improvement and statistical process control. Now, in the industrial big data era, a lot of data is available, including sensor readings, inspection measurements, optical images as well as structured/unstructured data sources. This multi-source data is becoming an indispensable resource for production managements and quality improvement. Complexity of the quality control rises also since there is a need to go beyond one manufacturing process quality control. In a value chain there may be multiple manufacturing and assembly stations, each contributing to the product quality.

The measurement data contains a large amount of manufacturing process and product information. Technological means to control quality of the manufacturing process include also perception of the environment (i.e. tracking operator movements), feedback from the operators or machines, and external information collected from web, customers, product use phase and supply chains.

At the same time, the modelling technology of multi-station manufacturing system is being improved continuously. Together with the different data sources available, the manufacturing process modelling techniques provide great potential for root cause identification of manufacturing process failures. However, it requires that new data analysis methods are applied, such as methods based on the combination of principal component analysis (PCA) and pattern recognition.

Therefore, Industry 4.0 offers opportunities in quality management: reduction in complexities, costs, risks, waste, dependency, vagueness and increase simplicity, convenience, interconnectivity, flexibility, productivity human-machine collaboration.

Nevertheless, it also challenges to overcome technological complexity, the need for new skills as well as the adoption of new technologies.

4.2 Efficiency & Productivity

The development of high-efficiency production systems allows to minimize production costs, improve the productivity and quality of the product and the manufacturing process. High production efficiency is in fact a necessary condition for the competitiveness of all companies.

Opportunities	Challenges
Higher Quality, less defects	Quality control systems
Improved timing and scheduling	ERP communication
In-line measurement	Data analysis
Data analytics, Visual analytics, Artificial intelligence	Access to data, data quality, heterogeneous data sources, data storage infrastructures
Virtual product design	Real basis for digital twin systems
Better operator support (AR/VT)	Process predictions and simulations

4.3 Competitiveness (on cost-basis)

It has become much more important for manufacturing companies to clearly understand the competitive capabilities they need to develop in order to attain superior performance.

Opportunities	Challenges
Flexibility/customizing	Logistics and stock control
New business models for the products	Implementation
Improved vendor control	Open systems

4.4 "TO BE" AQ Framework

Manufacturing has always sought a high-quality performance pursuing "near zero" perfection, aiming at quality improvements both of products and manufacturing processes. Over time, scientific methods supporting the reduction (or elimination) of defects in manufacturing processes and related outputs have been adopted to achieve quality objectives.

4.5 Business

Product service systems

Product-Service solutions are becoming increasingly necessary in the manufacturing context. This leads to the evolution from Product (manufacturing) Systems to Product-Service Systems (PSS). Development of such systems is a complex process which requires efforts to decrease the risks.

Digital Innovation Hubs

The Digitising EU Industry Communication of April 19th, 2016 aims "to reinforce EU's competitiveness in digital technologies and to ensure that every industry in Europe, in whichever sector, wherever situated, and no matter of what size can fully benefit from digital innovation". The former objective is being addressed by its Working Group (WG) No. 2 concerning the EU Digital Platforms, while the latter objective is being addressed by Working Group (WG) 1 and is strongly related to Digital Innovation Hubs (DIHs).
In its final report, WG1 "Digital Innovation Hubs: mainstreaming digital innovations across all sectors" defines a 6-steps approach (Figure 7) to build and develop a successful regional DIH.

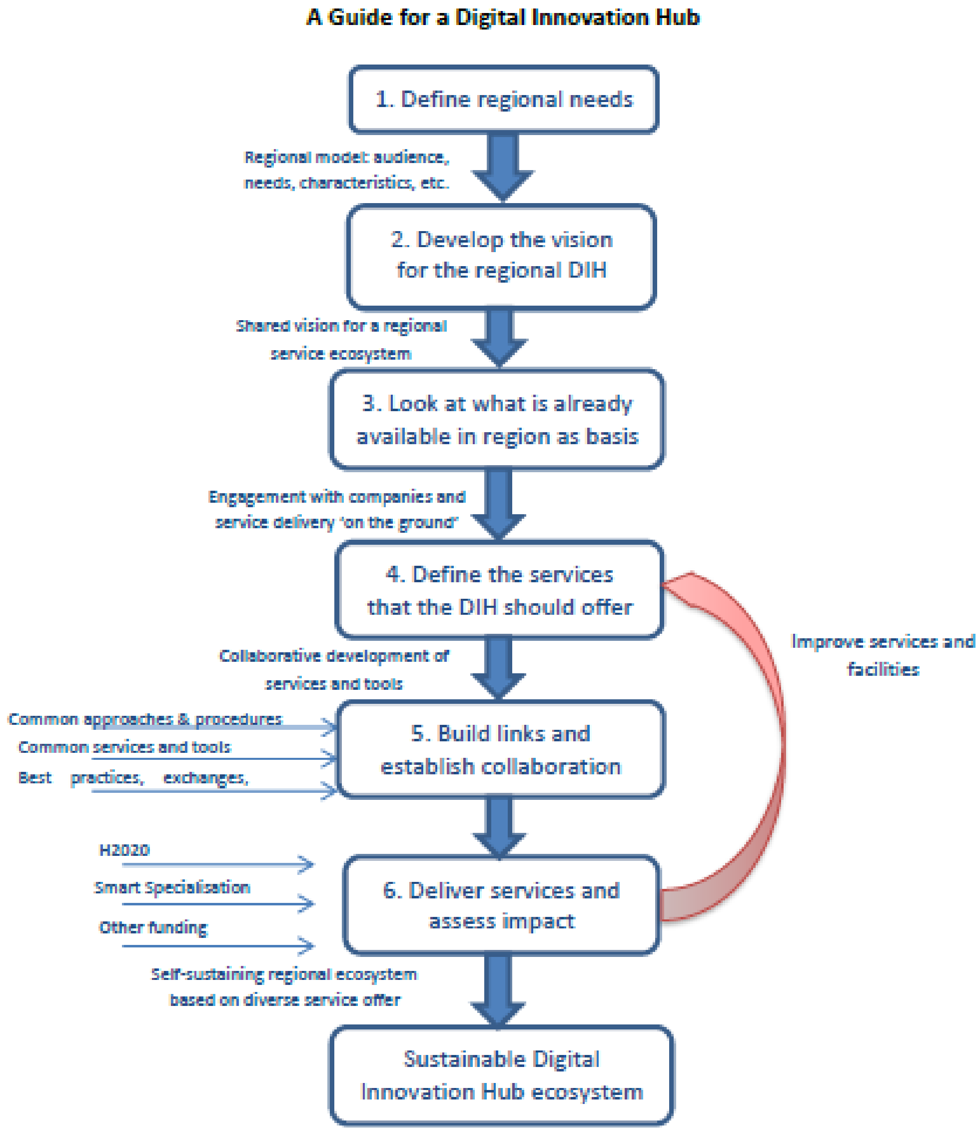


Figure 18 - The Manufacturing interpretation of such a guideline in the AQ domain[12]

4.6 Technology

Cyber-physical Systems of Systems (CPSoS)

The current needs of the markets require the so-called "Smart factories": due to products and services with ever shorter life cycles and an ever-higher level of customization, it is necessary to keep in mind some keywords that support a good design; responsiveness, flexibility, reconfigurability and modularity.

Complexity has reached such a point that we can speak of Cyber-physical Systems of Systems; as defined in the literature of the state of the art [8] “A SoS is a system which results from the coupling of a number of constituent systems at some point in their life cycles”.

The complexity of CPSoS lies in the interoperability of subsystems that are not necessarily designed to cooperate and work together. It is therefore necessary to work in order to minimize the risks of unforeseen and highly undesirable behaviour.

4.7 Data in the Value Chain

Data and information technology are more than just computers, during the last decade there has been a large transformation of how and what type of data the value chain creates. However, the logistic activity is only a small piece of data capturing picture. In an industrial site where smart components and business activities can be analysed and optimized; by use of data structured data management [10].

Data management:

- Data acquisition and sensing: Data acquisition (Data in Motion Models and Services for Industrial Internet of Things), data protection (Data anonymization, confidentiality, encryption and privacy preservation services)
- Data processing and analysis: data storage (Data Spaces, Data Lake, Linked Data, Distributed Storage, Knowledge representation services), data analytics (Semantic analysis, Data discovery, Advanced Data Analytics (Edge Analytics, Cloud Analytics) services)
- Decision support: Cognition, Prediction and prescription, Simulation, Machine Learning, Reinforcement

Trusted Data Spaces (data sharing)

The growing importance of data to the efficient running of organisations is driving increased interest in best practices for data management and data governance. Data Management Association (DAMA) defines Data Management (DM) as the development and execution of architectures, policies, practices and procedures that properly manage the full data lifecycle needs of an enterprise. a trusted data space should consider different aspects, such as Security, Safety, Privacy, Trust and Resilience. For these purposes, the International Data

[12] https://ec.europa.eu/digital-single-market/en/digital-innovation-hubs

Spaces Association (IDSA) offers a Security Architecture with means to identify participants, protect communication and data exchange transactions between them, and to control the use of data after it has been sent, and the Trusted Connector to ensure that the specifications and requirements of the Security Architecture materialize in everyday interactions and operations of the IDSA.

Human, Skills and maturity

How to use the human skills maturity is an innovation challenge in future industries (Smart Factories). Nearly five times as many survey respondents from maturing companies as from early-stage companies report that their organizations provide them enough resources to innovate. This year's research also finds a strong relationship between a company's rate of digital innovation and its staffers' confidence that the organization will be stronger in the future, thanks to digital trends.

Organisation and workers add more complexity to a company than technology probably ever will. Moreover, industrial companies are managed by engineers and economists, who tend to look for single-right solutions in order to simplify and justify the decisions made. As a paradox, when the technology is given and implemented (e.g. an IT-system, a CNC-machine etc) and workers are allocated to an organisation map, the workers seem to treat the technology as black boxes [11].

This issue only increases in importance as companies evolve into high-tech, mass-customised industries, where technology is considerably more complex than in traditional industries. Operators are not operators anymore, but still far from redundant; the industry of the future has clearly a growing need for knowledge-intensive jobs in maintenance and in planning and control functions. Operations management aims at building better manufacturing systems that are more productive (efficient) and profitable (effective) than what we have today, whereas social research on work practice generally aims at building better work places that are more humane, attractive, educational, and that bring along Quality of Work Life workers. However, in modern high-tech industry we do not need better systems; we need new systems that are better. Collaborative intelligence within a Human-Machine Interface setting e.g. Human-Robot Interaction, Human-Data Interaction, Multi-lingual AI, combined Machine and human learning are all interaction areas which will influence ZDM approaches.

5. Description of KPI's for ZDM and QM Excellence

5.1 Building a Framework for KPIs in the domain of AQ

This chapter presents the logic to build the reference conceptual model to be used when defining key performance indicators (KPIs) to quantify the performance of quality in smart manufacturing systems. According to this objective, it is important to define a framework that will support the development of indicators intended to evaluate the AQ performance of products and processes. KPIs are the most traditional tools used to track factors deemed crucial to the success of operations, organizations, value chains, products, industries and manufacturing systems at large. Some authors, such as Rosemann & de Bruin [12], [13], [14], [15],etc., suggest methods intended to guide researchers and practitioners in developing models and frameworks to evaluate the level of satisfaction of an intended improvement in a specific domain of reference.
Even though different authors have provided different guidelines and methods to build such framework, five recurrent features are identified as from: inception, elaboration, construction, deployment and maintenance. According to Rosemann & de Bruin [12] also testing the built model is vital to guarantee the robustness of the model itself. The figure below represents [12] development framework and recalls its core phases.

Figure 19 - Model development phases retrieved from Rosemann & de Bruin [12]

Scope. Scoping involves the definition of the focus of the domain the framework would be targeted, and then applied to.

Design. Design the framework's architecture to support its development and application. Frameworks are preferred to address complex realities, and this choice pertains this phase, as it influences the way in which the model is developed.

Populate. This phase defines the framework structure by identifying what needs to be represented by the framework, which are the components of the domain.

Test. The testing is intended to verify and validate the framework's construct. The construct must be verified in terms of completeness and accuracy with respect to the predefined objective and purpose.

Deploy. The framework is made available for use, which allows determining the framework's criticalities or can lead to the general acceptance of the framework.

Maintain. After the framework is validated, it has to be maintained in growth (if the domain evolves and innovates) and use.

Therefore, it is appropriate to consider methods specifically intended to design instruments for performance evaluation; KPIs are the most traditional and consolidated tools in the field of performance assessment.

KPIs address the problem of obtaining real values from analytics, interpreting and extracting meaningful information from real data. They are intended to inform how business is performing, which in turn should suggest what actions need to be taken for further performance improvement.

Among the existing KPIs development frameworks, the KARTA framework is of particular interest because it suggests building KPIs following a logical process, aiming at facilitating the alignment between real issues and theoretical constructs to analyse and solve them. According to the KARTA framework, the goals of the analysis are derived from real problems and guide the definition of KPIs constructed from the identification of measures related to the objectives to be achieved. Objectives are broken down into critical success factors (CSFs), and metrics (theoretical constructs) are built from the available measures of CSFs. CSFs and metrics meet intersect in the design of PIs.

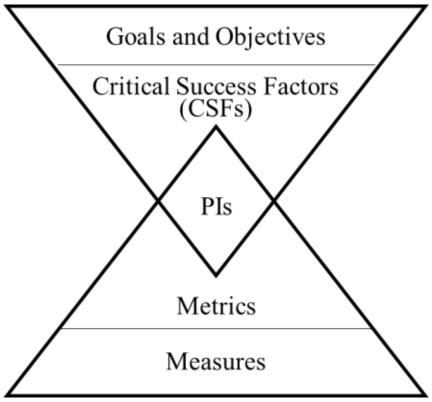


Figure 20 - KARTA framework to develop KPIs

The KARTA framework is composed of five steps characterized as follows.

Establish goals and objectives. Understanding the purpose of the assessment allows getting the right measures and improving the intended performance. The aim is to set goals that can be met by measures of success (performance) related to the specific objectives.

Establish CSF from the goals & objectives. CSFs are key elements that are intended to be successful. They represent the factors that the assessment would focus on.

Identify measures. Measures are raw values (usually numbers) that have limited communication capacity by themselves and must be correlated with each other to obtain meaningful information. Measures are related to the CSFs and goals. They represent the starting point to evaluate the current performance and success.

Establish PIs from CSFs. PIs are calculated measures to quantify the success of the specific performance according to the CSFs, while CSFs are factors that drive the success.

Design and calculate PIs. Metrics are the way to convert measures in meaningful information according to the identified goals and by inclusion of the CSFs related to success. In fact, metrics are calculations of measures and are usually expressed as ratios, percentages, etc. To be considered a PI, a metric must be designed to provide relevant information on the

success of a specific performance. By combining the development framework as from Rosemann & de Bruin [12] and the KARTA framework guiding the design of KPIs with respect to real world issues, it derives on the definition of a method intended to the evaluation of the AQ performance of products and processes.
Nevertheless, this deliverable is intended to specify a conceptual framework for the definition of KPIs in the domain of AQ in manufacturing. The instantiation of the framework and the development of specific metrics to assess performances of quality in smart manufacturing systems at operative level will be done on WP7.

5.2 QU4LITY Framework of AQ KPIs

According to the methodology explained in chapter 4.1, this chapter is intended to present the framework developed in the project QU4LITY to support the definition of KPIs, for the achievement of improved performances in the AQ domain of smart products and processes. Therefore, taking as reference Rosemann & de Bruin [12], the sequence of steps to build a conceptual framework includes: (i) scope, (ii) design, (iii) populate, (iv) test, (v) deploy, (vi) maintain.

Figure 21 - Model development phases retrieved from Rosemann & de Bruin (2005)

The deployment of the framework is connected with the activities of WP7 “Large Scale ZDM Pilots Deployment, Validation and Evaluation” and WP9 “Dissemination, Exploitation and Standardization”. The maintenance of the framework is in charge of the whole AQ community represented by the 4ZDM cluster, considered as the first reference framework to support the European Manufacturing in addressing the performance of products and processes in the domain of AQ.
The whole process to build the first version of the AQ framework for KPIs followed a bottom-up approach starting from the KPIs defined by the 14 industrial pilots. The final version of the AQ framework for KPIs foresees the integration with a top-down approach. This will help to overtake the limitations brought by the bottom-up approach, which is tied to the products and processes of the 14 industrial experiments. In that light, the 14 industrial experiments of the project are listed in the table in Chapter 5.3.

5.3 The 14 Industrial Pilots

Table 1 - Industrial pilots with type of processes and possible improvement

No	Industrial Pilot	Type of process	Improvement scenario
#I.1	Philips	Improvement of factory line	Process optimization Human interaction Robot precision
#I.2	SIEMENS	Improvement of electronic production Circuit boards	Process
#I.3	Continental	Improvement of factory line for electronic production. Platform for data integration of different sites	Process Data lake Data acquisition Big Data
#I.4	Whirlpool	A holistic quality platform for dryer factory	Process
#I.5	Mondragon	Two scenarios on process and product: Danobat and Fagor	Product & Process
#I.6	Kolektor	Injection moulding of parts. Detection and removal of defects on Injection tool.	Product
#I.7	Thyssenkrupp	Acoustic control system on Steering Gear	Control system in the end of process line
#I.8	Airbus	Trade space framework, Autonomous design	Process improvement Human interaction Engineering processes
#I.9	GHI	Hot stamping furnace	Hot stamping line
#I.10	RiaStone	Assembly line for ceramic tableware	Process line
#I.11	PRIMA	Adaptive control technology on additive control process	Additive manufacturing process
#I.12	Danobat	Improvement on railway axles production lines	Product Process
#I.13	Fagor	Improvement of Digital press machine	Product
#I.14	GF	Digital EDM Machine	Product

5.4 Structure of the AQ Framework

The design of the AQ framework is thought in a hierarchical structure composed of three layers:

1. The *first layer* specifies the areas of impact that practices of zero-defect manufacturing in the domain of the CPS/IoT can affect.
2. The *second layer* specifies the impact areas according to

   a. the different business objectives that manufacturing companies would like to achieve by developing an improved approach to quality management
   b. control according to the AQ paradigm.
3. The *third layer* details the critical success factors to achieve the objectives of AQ.

The two main areas of impact affected by practices of ZDM in the CPS/IoT domain identified are:

1. the Operational area and
2. the Business area.

Operational. It includes all the technical indicators strictly related to production. It is further divided according to the main elements that characterise it: the assets involved in the production process, the process itself and the products. Therefore, the three categories identified as second layer, keeping in mind the objectives that manufacturing companies would like to achieve are:

- Asset value (A). It has the objective to group all the indicators focused on productive resource monitoring.
- Product Conformity (PD). It groups all the indicators related to the physical characteristics of the product monitored during the production process or related to the final test performed on the finished product.
- Process efficiency (PR). It includes all the indicators focused on the monitoring of the production process efficiency.

In order to achieve the business objectives presented above, as a third level, some critical success factors, that drive company through the achievement of its goals, have been identified.

Table 2 - Operational category - third layer description

#	Name	Description
A1	Raw material usage	It aims to group parameters that monitor the amount of raw material used during the production process.
A2	Energy consumption	It aims to group parameters that monitor the energy used by a specific activity on a machine, a machinery or by a production system during the production process.
A3	HR productivity	It aims to group parameters that monitor the effort put in place by human resources involved in the production process.
PD1	Dimensional	It includes all the product physical parameters (in terms of length, weight and so on) measured during the production process or at the end, in order to verify to meet the design requirements.
PD2	Acoustic emission	Non
PD3	Shocks/vibrations	It aims to group parameters that monitor the robustness of the product after some test have been performed.

PD4	Temperature	It aims to group parameters that monitor the product temperature in a specific moment of the production process.
PR1	Time	It groups the parameters that monitor the relevant time in the production process (e.g. cycle time).
PR2	Inspection	It groups the parameters related to the volume of WIP/products that are tested/inspected in a specific phase/station.
PR3	Detection	It groups the parameters related to the volume of WIP/products that, after a test, result to be defective.
PR4	Wastage	It groups the parameters related to the volume of WIP/products that need to be discarded after the production process due to the identification of severe defects.
PR5	Repair/Reuse	It groups the parameters related to the volume of WIP/products that need to be repaired or that can be reused after the production process due to the identification of some defects.
PR6	Line Backlog	Non

Business. It is an essential area, that must be monitored in order to understand if the introduction of new technologies is bringing benefits and effective improvements to the company and the ecosystem in which it operates. In this area, two main classes of objective have been identified:

Strategic (S). It groups the indicators devoted to the monitoring of the impact that the introduction of zero-defect manufacturing practices brings at high level in terms of people and environment.

Economic/financial (E). It groups the indicators devoted to the monitoring of the impact that the introduction of zero-defect manufacturing practices brings at economic and financial level in order to control their sustainability on the long term.

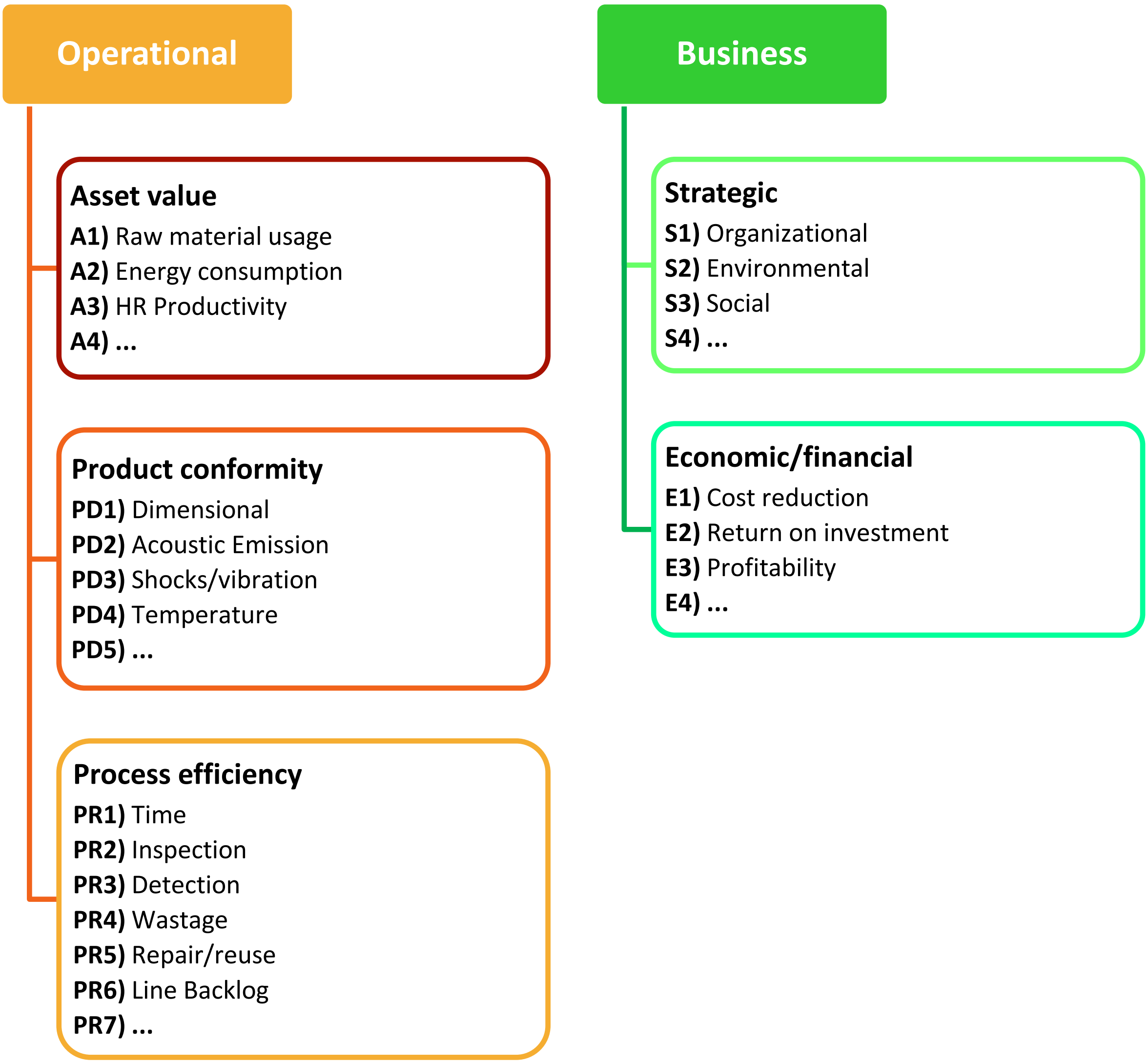
In order to achieve the business objectives presented above, as a third level, the following critical success factors, that drive company through the achievement of its goals, have been identified.

Table 3 - Business category - third layer description

#	Name	Description
S1	Organizational	It includes the indicators focused on the monitoring of organizational changes registered in a company after the introduction of new practices.
S2	Environmental	It includes the indicators focused on the monitoring of environmental parameters in order to verify to have a positive impact on the overall environment (e.g. CO_2 emission).

S3	Social	It includes the indicators focused on the monitoring of the effect that the introduction of new practices brings to the overall society that is affected by company activities (e.g. creation of new jobs).
E1	Cost reduction	It includes the economic indicators which monitor the improvement obtained in terms of cost reduction along the whole process (e.g. rework costs, non-quality costs).
E2	Return on investment	It includes the financial indicators that allow verifying the benefits gained thanks to an investment devoted to the introduction of zero-defect manufacturing practices.
E3	Profitability	It includes the indicators that allow monitoring the variation of company profitability.

Figure 22 - KPIs Framework



6. Adoption of the QU4LITY AQ Model by QU4LITY Pilots

The adoption of the QU4LITY AQ Model by the QU4LITY pilots demands that pilots need to reconcile and design pilot activities under a unified framework that supports an AQ control workflow. The diagram below depicts the QU4LITY AQ Model operation. The model is enabling the implementation of joint quality optimisation procedures at quality chain level and at component integrated quality system (IQS) level. The procedure for conducting Quality Chain Level Quality Assurance starts by setting and identifying the global production network and specific supply chain of the product (or system).

The criteria for what constitute quality chain-level quality, such as reliability, based on the customer requirements, are then defined. Component level quality assurance (factory integrated quality system level) is one important step for guaranteeing system level quality assurance. Theoretically speaking, quality assurance for each component will ensure the optimal result, in terms of quality, for the overall product. However, in reality it is not necessary to research each component, and it would be costly to do so. Thus, it becomes essential to balance the costs versus the benefit first. For the situation in which it is not cost effective to do quality assurance for each component, the critical component analysis and selection needs to be conducted. Subsequently, it is vital to define component-level quality for the chosen critical component(s) in order to conduct component-level quality assurance.

The factors of the component that are most indicative of quality will be selected for studying their impact on the defined component-level quality. With this information, the integrated quality system can be constructed adopting First Time Quality (FTQ) World Manufacturing Class (WCM) methods. The comparison of component quality performance before and after applying the proposed system will be used for evaluation and to determine if improvements to the system quality can and should be made. Such analysis is driven by highly automated collective intelligence services and human-centric assisted analytic platforms that are integrated as part of the quality control process.
In order to set and operate the QU4LITY holistic integrated quality system (IQS) based on the component-level quality model,

1. The integrated planning, design, production and service quality information flow needs to be defined. Thus, QU4LITY sets the data sources required to support the information model capable of delivering the required component-level quality control outputs.
2. Such information flow is also crucial to support the development and deployment of selected AI/ML techniques in the QU4LITY infrastructure to build the cognitive dimension of the autonomous quality (AQ) operations. Therefore, this is step in the development of the holistic integrated IQS considers the design and deployment of the QU4LITY federated and distributed cognitive quality improvement flow under an augmented intelligence and continuous learning model.
3. The final step in the development of the IQS considers the set-up and configuration of the QU4LITY self-adaptive plug & control manufacturing equipment. Such self-adaptation is supported both by the embedded intelligence (in-machine & edge-

powered AI) but also by coordination functions that enable equipment to coordinate multi-stage quality control strategies through feedforward and feedback control and decision support loops.

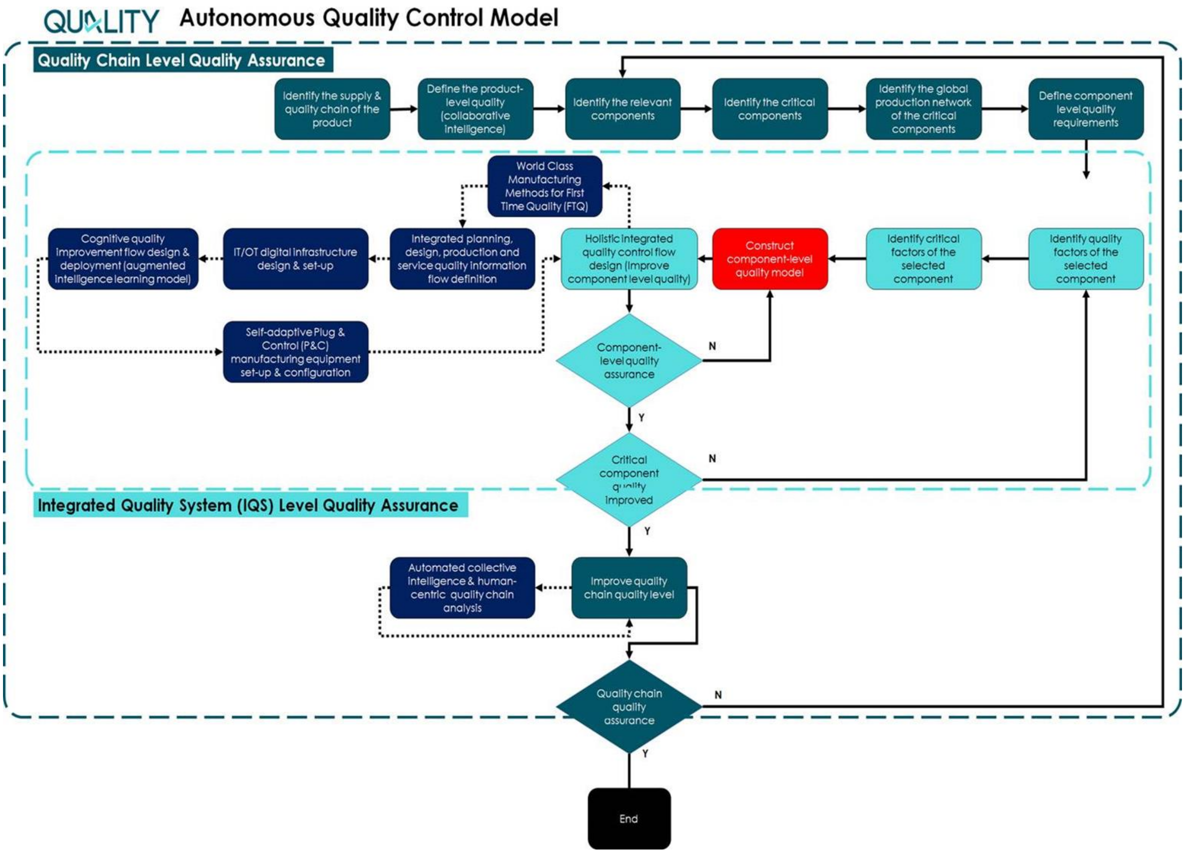


Figure 23 - QU4LITY autonomous quality model (ref. Innovalia)

In parallel to the development, the above figure shows deployment and set-up of information flows, cognitive services and self-adaptive manufacturing equipment.

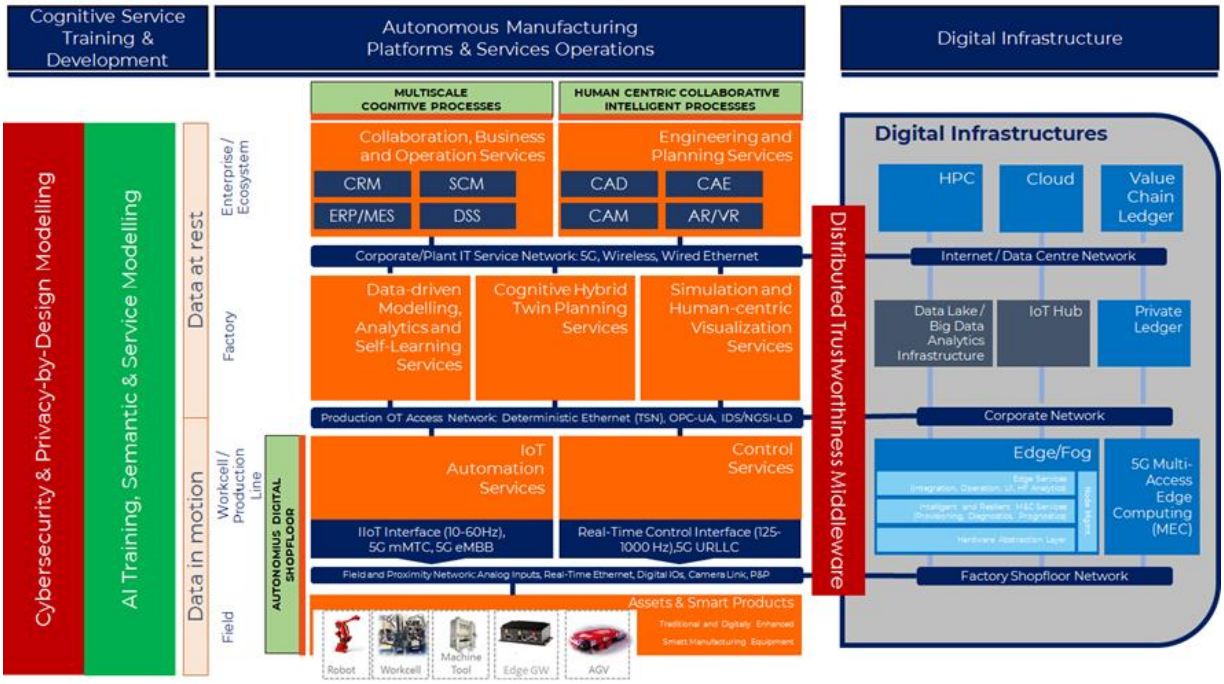


Figure 24 - The QU4LITY reference architecture (RA) (ref. Innovalia)

The QU4LITY AQ Model considers the design and implementation of the IT and OT integrated digital infrastructure leveraging the reliable and high-performance networking, storage, computing & processing required by autonomous ZDM operation. Such IT/OT deployment should adhere to the QU4LITY reference architecture (RA) which Innovalia has proposed and is mentioned in the proposal phase of the project.

7. A General Table of KPIs for AQ in ZDM from Existing Documentation

From the QU4LITY work we have harvested a list of KPIs that are identified as important for AQ in manufacturing processes. As stated earlier, AQ has been defined in chapter 2 and the table below will give an overview of KPI's attached to the AQ vision of the QU4LITY Project. Each pilot has described their target KPIs found in section 4-5 of the proposal. Furthermore, the pilots have developed updated KPIs related to possible improvement scenarios during the first period of the project. However, this has been and shall continue to be an ongoing activity.

In addition, an annex has been added to show the extent of the KPIs in a more technical manner. However, this is for internal use only (for project participants and the Commission), since this information is a part of documented background and IPR for the Pilots in the project.

The table below shows a generic picture of the current situation with prioritized KPIs directed to the projects target areas.

The KPIs in *Italic* are from the first project work to define KPIs, those with normal font are from the initial phase.

Table 4 - Snapshot table of Autonomous Quality parameters for the QU4LITY pilot

Autonomous Quality Control loops	Engineering		Planning and Management		Operations		Connected Production	
	Plug & produce Equipment	ZDM Production Facility	Plug & produce Equipment	ZDM Production Facility	Plug & produce Equipment	ZDM Production Facility	Plug & produce Equipment	ZDM Production Facility
Augmented human centred decision control loop services		Savings to investment ratio. Amount of savings divided by initial investment	*Critical Process Monitoring Process analysis and root cause- spiralling marks*	*Visually inspection of tools and parts*	System operating within specification without requiring worker learning	*Smart solution and improved tools for operators Operator knowledge, mindset, culture increase*		*Predictive Quality Predictive Maintenance on-line*
Multistage ZDM deep analysis control loop services		*Architecture Cost reduction Time reduction from concept to selection Maturity in operation increase Flexibility for late customisation*	*Reduction of: Production cost Defective parts Rework time Waste Lead time*	Number of defects and repaired manufactured per total volume manufactured Frequency of system or component failure	*Fast detection of root causes Increased decision-making efficiency for process control and maintenance OEE increase*	The number of correct products without rework divided by the number of units entering a manufacturing process Number of defective products that can be reused divided by total number of defective products	Number of times a specific part of a machine has failed Total cost of maintenance on the manufacturing line	Number of scraps per volume manufactured *Scrap reduction Rework reduction*

ZDM orchestration & simulation-based composition control loops		Quantified measured severity of defects divided by number of products sampled	*Production optimization with aggressive machine configuration*	Costs of tests performed in connection to the manufacturing line *Digital Twin that can simulate the whole production in Realtime closing the loop*	*Cognitive digital twin whit deep streaming analytics framework* *Big data simulation-based framework* *Sematic data models for part quality information*	*Autonomous removing defective products from production processes*	*Digital twin of the machine in Realtime Simulation at planning stages*	*Holistic system that builds on real-time data mining in production, by Big Data and ZDM over the whole value chain.*
ZDM embedded intelligence and real time control loop services	*Increase of Machine availability* *Reduction in down time* *Reduction and control of all on-line energy consumption*		*Reduction of:* *Defective parts* *Rework time* *Waste*	Number of scraps per volume of multiple times inspected components		*Detect, predict and remove causes of process failures, ideally in real time*	*Adaptive machining system.* *Integrated in an open cloud and data analytics solution*	

8. Relevant business models

In recent years, digital platforms have been transforming market competition in industries all over the world. However, the concept is not new, and the availability of affordable digital technologies that enables companies in all sizes to embrace mobile and data analytics while adopting a cloud solution to redesign their business model is growing. Digital platforms have some features that speed up the added value for selling products in different ways, and the models will be different from company to company in the manner they are selling their product to the customers.

8.1 Smart Products and Components

Smart systems and products create a need for knowledge and competence but also provides opportunities for new services and business models. Digitalization of production, value chains can facilitate services in the B2B relations and towards B2C. New business models based on outcome-based services (i.e. customers pays for the result of the product or service, rather than the product or service itself) is outlined as one of the key emerging trends for business models future factories [16]. This might go either way, new business models might change processes, and optimized processes might lead to opportunities for new services/business models. In the field of business models and industry 4.0, there are several trends emerging. Of relevance in this context are business models for autonomous systems and value -based services enabled by industry 4.0 [17] [5]

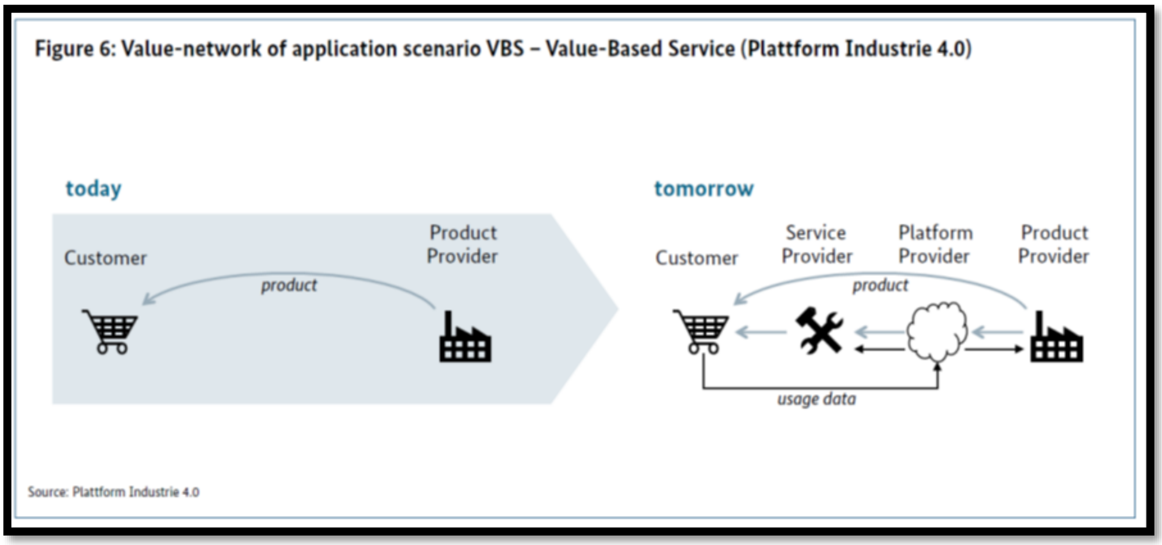


Figure 25 - Value Network of application scenario Value-Based-Service [18]

Additionally, by introducing smart, connected products the number of hybrid business models increases, "product sales bundled with warranty or service contracts, or product sales bundled with performance-based contracts" [19]. These business models take point of departure in

- Ownership
- Services
- Maintenance and repair.

Further, smart connected products can change the user experience of the product. Smart connected products can support shared ownership business models, subscriptions, car-pooling etc. Finally, Smart connected products allow for iterative improvements. Manufacturers can release product updates through firmware updates; known for years in computers and smart phones, and more recently from cars like Tesla [19].
Industry 4.0 redefines the business boundaries – or the industry boundaries – by drastically increasing the amount of information about the product (and its use context). A product can be part of a product system, consisting of a range of related products in an entire factory floor of producers. In the long run, the smart product can be part of the system of systems, as Porter [19] illustrates by a smart tractor, connected to other farm equipment, farm management system, seed optimization system, irrigation system, the weather forecast, etc. [19]. Thus, business value can be increased by for example cross-disciplinary collaboration – providing data between plant systems or product systems [19].

ZDM is an enabling factor for extending the lifespan of products. Either in the traditional point of view - where the duration of a washing machine can be twenty years, or by extending the product horizon through multiple user cycles, in order to make a product that was designed for remanufacturing really work, obsolete products need to be consistently returned to the OEM to be remanufactured. This requires arrangements for reverse logistics and a transactional model that allows the (re)manufacturers to retain economic control of their product over time"[13].

Traditionally, a producer has received little or no feedback on the usage of their products from the consumer. In the future, products will be connected to a service platform, where data is harvested and utilized, which again can open up for new data-driven value-added services to the consumer (and associated business models). Porters article provides three examples of value-based services, condition monitoring services, machine and process optimization services and production scheduling services, which is important in a ZDM relation in addition to software optimizing.

- **Condition Monitoring Services**

Condition Monitoring Services (platforms) are provided by the supplier to the operator of the machine. Those are services that includes the stakeholders, operator of the machine, the supplier of the machine and a new stakeholder, namely the operator of the service platform. The key objective is to increase efficiency due to detect faults earlier. Value for the operator is early fault detection, higher availability of the machine, which deal to reduce costs of maintenance. Possible also lower investment costs because of pay-per-use. Value for the supplier of the machine is prediction of failures and downtime, possibilities to offer new availability and warranty models. Transparency on his/her own fleet, knowledge that can be used for design and engineering. Possibilities for billing for manufacturing services based on usage. The key objective of **Machine and process Optimization Services** is to operate the individual machine at their optimum operating point. Involves no new stakeholders, realized within the company and the value chain does not change. Benefit and values generated within the company.

[13] den Hollander, 2017 #487 Podkast

- **Production Scheduling services**

Production Scheduling Services are concerned with the entire set of machines of a given production site. It introduces two new stakeholders, a provider of production scheduling services, and an operator of a service platform. It creates value for the operator of the machine since it can increase efficiency by optimal use of all machines. The provider of the production scheduling services can offer a service on a pay-per use model, which lowers entry barriers and opens up a new market. The operator of the service platform can be positioned as a broker between the operator of the machine and the provider of the product scheduling services. "Various business models are possible including arcuate gain and risk sharing models." [5]

- **Market Space**

The Market Space will, in addition to the partners involved and the fourteen Pilots in the QU4LITY project, be the Digital Innovation Hub (DIH) ecosystems. The DHIs will also be organized around the following main business targets in QU4LITY:

1. DIH and Marketplace Establishment: To establish a marketplace for ZDM innovation management technologies and services, which will facilitate enterprises to access innovation management services and IPR, as means of accelerating their ZDM innovation cycles, improving the quality of their relevant products and shortening time to market.
2. Business Modelling and Monetization: To detail, validate and pursue three complementary business models and associated monetization strategies for its marketplace including: (i) Membership fees to be paid by its members; (ii) Pay-per-use for the services of the DIH/marketplace; (iii) Acquisition of equity on companies that participate in the marketplace, with an outlook of benefitting from future profits and possible investment exits.
3. Strong Relationships with Industry4.0 Innovators across the EU: To establish a strong relationship with ZDM/Industry4.0 innovators in Europe, through appropriate activities for disseminating and communicating information about the marketplace to enterprises building Industry4.0 products. All these targets will be pursued based on an appropriate clustering of services and products of the virtualized DIH as it is proposed in WP8.

- **Business Canvas Modelling**

Related to all this, the project aims to enable manufacturers and solution providers (from big organizations to SMEs) to develop, validate, deploy and adopt innovative Cognitive Manufacturing solutions for ZDM. This is to provide digital enhancements to ZDM processes & equipment, providing a reference architecture and also blueprints in order to facilitate the integration within the factories.

WP9 will focus on transferring the project results to the market. This will cover the full range of results, from the individual exploitation approach of each of the beneficiary partners (i.e. business model generated by each pilot considering the project development impacts and how they will obtain a benefit from them) to the joint exploitation of the ZDM platform and the project results (i.e. how from a bilateral or a multilateral approach, project partners will agree to exploit a commercial opportunity in the future).

The methodology used for this purpose is the Business Model Canvas (BMC) which allows a flexible approach to the specific need of each of the stakeholders, a clear definition of the value proposition and a flexible segmentation of the potential customers for each case [20]. In the picture below, a BMC is shown, describing visually the 9 building blocks of the model.

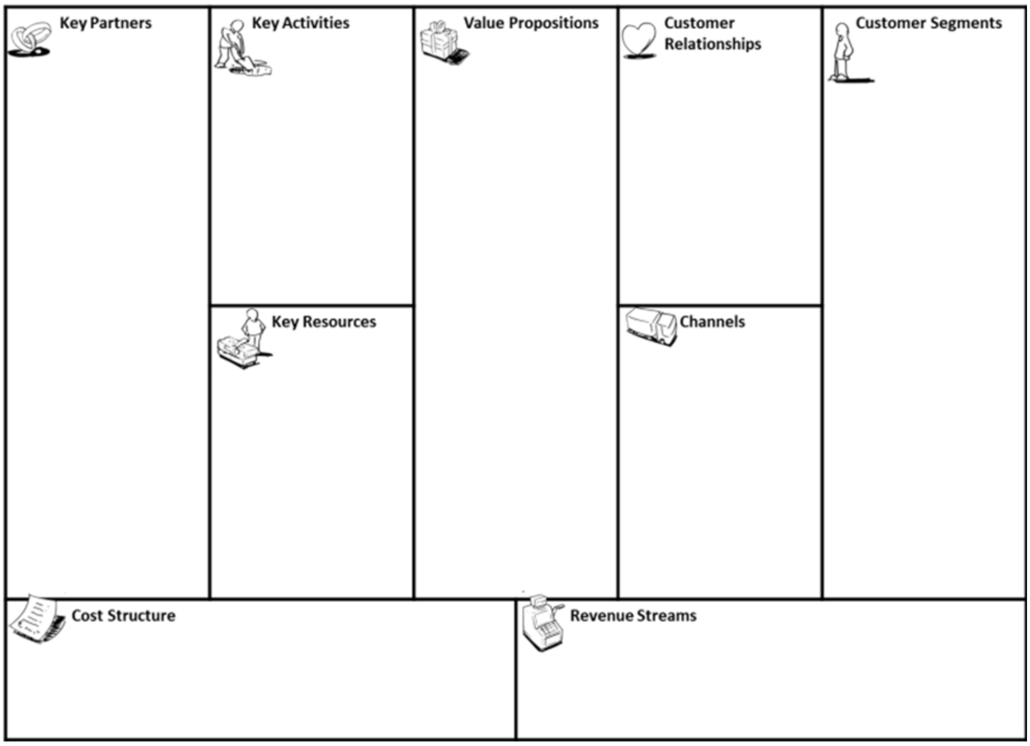


Figure 26 – Business Model Canvas (BMC) [20]

8.2 Stakeholder's roles and Business Interaction in the Scope of the AQ Vision

The representative for the stakeholder has in QU4LITY project, been earlier identified as the pilots. However, the whole ecosystem of suppliers, customers and regulatory governance on a Digital Platform should also be considered. In an earlier chapter, KPIs were collected and presented for the fourteen pilots as an important criterion to identify the success of each stakeholder.

As an exercise in QU4LITY, this will be on a dissemination level in WP 8 & 9. However, external stakeholders that can have interests in the outcome of the QU4LITY platform should also be identified, since the market space, landscape and ecosystem for each of the fourteen QU4LITY Pilots is huge if we include their suppliers. Mapping of how sustainable such a platform will be, depends on the exploitation of data whole the ecosystem is willing to share and the revenue stream in the marketplace of the QU4LITY platform.

8.2.1 Universal, Multi-dimensional model for AQ and ZDM

In connected smart factories and global production networks, product quality characteristics and their impact factors and control measures along with the interaction of product realization, make the final quality performance-related processes and elements constitute an organic network, which is called the quality chain. Quality chains as a new form of product quality formation is established on supply chain and value chain theories. Quality chain is also a quality processes aggregation by enterprises intra- and inter-organizational participation and realization, which extends and enhances internal quality control practices. In the quality chain, product quality implementation process breaks the boundaries of individual enterprise and extends into enterprise group completely; being characterised by wide integration, wide synergies agility and openness.

Member enterprises in manufacturing network act differently according to their roles which constitute the quality chain structure. Product quality based on the above constitution flows from the material supplier to the end user. Because of the difference and interest conflict between enterprises, the construction of quality chain environment needs all enterprises to participate, and then achieve the ultimate goal of quality control by synthetically implement modern management methods in the product realization process.

In quality chains, quality processes pass through enterprises, and eventually make up the final quality of product. Thus, quality control in smart connected factories go well beyond the optimisation of individual multi-stage manufacturing strategies and take an innovative collaborative approach. Collaborative quality control is a set of organized activities, which is participated by all members to achieve their desired product quality.

In a generic system interface, it is important to define and to determine the stakeholder's requirements. Some stakeholders are experts in their fields and will identify their expectations easily. Other stakeholders do not identify the need of flexible tools for businesses before they need to get a visualized picture of a platform or a business architecture that support their needs. In this respect, this chapter just briefly mention the way software technology looks at quality as a critical success factor for a shared architecture for product families [21].

An often-used standard is the TOGAF content framework[14], which differentiates between the functions of a business and the services of a business. Business services are specific functions that have explicit, defined boundaries that are explicitly governed. The following diagrams should be considered for further architecture development:

- Business Model diagram
- Business Capability Map
- Value Stream Map
- Organization Map
- Business Footprint diagram
- Business Service/Information diagram
- Functional Decomposition diagram
- Goal/Objective/Service diagram

[14] http://pubs.opengroup.org/architecture/togaf9-doc/arch/

- Business Use-Case diagram
- Organization Decomposition diagram
- Process Flow diagram
- Event diagram

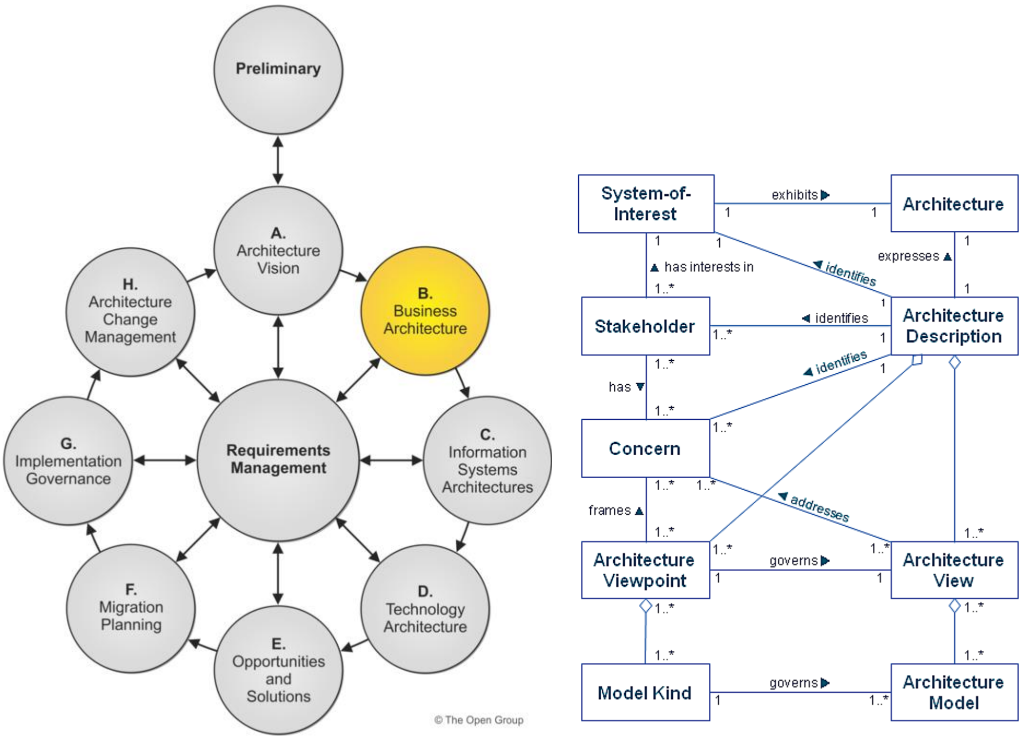


Figure 27 - TOGAF® Framework to Define and Governance Service-Oriented Architectures

A possible table of problems with existing solution as the stakeholders perceives them, can also be created:

- What is the reason for this problem?
- How is the problem solved now?
- What solutions does the stakeholder want?

Or a table with needs and priorities for the different solutions that will be described, the figure and table is just an example.

Need	Priority	Concerns	Current solutions	Proposed solutions
Control system	Scrap in line	40% scrap rate, non- re-circular able materials	Manual labour check point	Change in product design or material. Digital software, simulation, VR/AR.

In the manufacturing area there is also certain risk, with reference to each of the Pilot's in the manufacturing area on requirement in the quality of product and processes. This will best be solved by listing different questions answered by each of the stakeholders to receive the most relevant information. Depending on the relevant key partners needed to carry out the business, some agreement should be made among the different partners to guarantee there will be not an issue that could make the business unviable (i.e. issues related to intellectual property rights). Investment is also needed to carry out the business activity that will be determined by the key resources and possible users of the platform. In the proposal phase, QU4LITY has proposed that the project will provide a one-shop-stop marketplace for autonomous quality ZDM solutions, which will provide a single-entry point to the project's intellectual property (IP) and results.

The project's marketplace will support the AQ services development processes end-to-end, through access to digital technologies, ZDM equipment and other related IP, but also through access to required complementary assets such as training, technical support and consulting. The QU4LITY marketplace will be empowered by a unique multi-side market platform that will enable the participation of both supply-side and demand-side stakeholders with DIH (Digital Innovation Hub) as partner. The QU4LITY marketplace will be distributed and fully virtualized, as it will be based on pooling of resources from the DIHs of the consortium. The consortium brings together some of Europe's leading DIH structures in manufacturing and ICT, which will pool resources and expertise to the QU4LITY virtualized DIHs. With respect to the QU4LITY partners and further work, it will be explained further in WP8.

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9. Conclusions

This deliverable describes the first concept and specification of an Autonomous Quality Paradigm for ZDM and QM excellence. The concept has its roots in state-of-the-art technology, and the report also documents how the AQ paradigm promises to influence business concepts, in addition to presenting the vision for the QU4LITY AQ Model as well as the proposal for an approach for adopting the model by the fourteen QU4LITY pilots.

Based on the composition framework and the Open APIs, QU4LITY will be implemented and shall demonstrate a fully digital shop-floor, which will provide exceptional flexibility and intelligence towards supporting AQ. To this end, elements from a variety of digital platforms (such as simulation, augmented reality, industrial data spaces, digital twins and more) will have to be composed into AQ solutions in-line with the requirements of the ZDM deployment. Human aspects like training, remote support and visualization will be also addressed.

The main section covers the industrial ZDM-related KPIs from the fourteen pilots that will be important for realizing the AQ approach. This version of the deliverable is written during an early stage of the project and there is uncertainty of the direct relevance from the needed theories and state of the art to the pilots. However, D2.4 gives a general description of autonomous quality KPI's and a more technical description that will be added as an internal Annex as a refined and prioritized version on the industries and a more complete descriptions of their pilots. Most of quantitative measures of the KPI's are in the project internal annes.

The AQ approach includes a business concept in both manufacturing and ICT domains and will be an extended version of earlier work adapted into a ZDM platform. Aspects of human interaction will be closer elaborated, and efforts will be made to find more relevant standards and proposals for how QU4LITY can eventually contribute to them.

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List of Abbreviations

AI	Artificial Intelligence
AQ	Autonomous Quality
AR	Augmented Reality
B2B	Business to Business
B2C	Business to Consumer
CFS	Critical Success Factors
CNN	Conventional Neural Networks
CPSS	Cyber Physical Systems of Systems
CPPS	Cyber Physical Production Systems
CQ	Critical to Quality
DM	Data Management
EC	European Commission
IIOT	Industrial Internet of Things
IT	Information Technology
KPI	Key Performance Indicators
MES	Manufacturing Execution System
ML	Machine Learning
OEM	Original equipment manufacturer (producer of parts and equipment)
PCA	Principal component analysis
PI	Performance Indicators
PSS	Production Service System
QA	Quality Assurance
QLSP	Quality Large Scale Pilots
QM	Quality Management
SME	Small and Medium Size Organizations
TQM	Total Quality Management
TOGAF	The Open Group Architecture Framework
VR	Virtual Reality
VT	Virtual Technology
ZDM	Zero Defect Manufacturing

Partners