DIGITAL MANUFACTURING PLATFORMS FOR CONNECTED SMART FACTORIES

D4.2 Specification of Digital Enhancement of ZDM Equipment

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Abstract: The task will focus on the specification of the ways various types of ZDM equipment will be enhanced. A list of machine equipment entailed in the pilots are available, as well as the experimentation activities for all pilots and their current capabilities and performance. The first version contained expectations, and this second version will show requirement for all types of enhancements of the real-life pilots.

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Contents

HISTORY

Version	Date	Modification reason	Modified by
0.1	25/03/2020	First draft based on 4.1	SINTEF
0.2	16/06/2020	Inclusion of technical information and comments from partners	SINTEF
1.0	30/06/2020	Final version after review and final additions	SINTEF

1. Executive Summary

This deliverable focuses on the specification of the various types of Zero-Defect Manufacturing (ZDM) equipment that will be digitally enhanced. ZDM equipment entailed in the QU4LITY pilots and experimentation activities are described in a generic way for this public deliverable. The D4.2 deliverable is an extension of D4.1 and has some new information of the development of the enhancement that is in progress in the Pilots. The deliverable also describes requirements for the digital enhancements for 12 of the 14 pilots in the project.

For some pilots, the digital enhancement can include quite complex operations. Especially the innovation and development of complex manufacturing equipment and the enhancement of multiple process lines functionalities and in-line communication.

Section 3 includes information on the current situation of innovation potential and strategies including an overview of performance and capabilities of the pilot manufacturing cases in digital transformation.

Each of the machine tool pilots have completed a matrix in section 3.3 with their current capabilities, and performance needed to bridge the gaps that were observed in the early phase of the project. Further, WP4 has also completed an internal matrix that describes technical characteristics of the machine equipment, ZDM activities, capabilities & performances, quality issues, remaining useful life (RUL) and machine failures to be optimized. Technical information from the pilots have been updated in line with their documentation status, and most pilots have updated their Trial Handbooks with documentation on the requirements needed for ZDM Digital Enhancements in their respective pilot.

WP4 has investigated and documented the ZDM digital enhancements that are planned or in progress for equipment in the Machine Pilots. We also realized that some of the process pilots will have interesting quality issues containing improvements on existing equipment in the direction of digital enhancement.

The process pilot innovation steps are described in section 3.4.2 and is updated with the latest available documented information from the pilots.

The documentation of the work on ZDM Digital Enhancements for the machine pilots have evolved significantly through thorough documentation in these pilots Trial Handbooks, and in large part with the work done in D4.7, we feel that the state of documentation for these pilots give a fairly comprehensive insight into the status of ZDM enhancement work.

The situation is very different for the process pilots, where the documentation is less comprehensive or missing altogether. This means that there is some ambiguity concerning the completeness of documentation for the process pilots and also uncertainty about how updated the documentation is.

2. Introduction

Industry and academic leaders have a common understanding that digital manufacturing technologies will affect every step in a manufacturing value chain, from research and development, supply chain, and operations to marketing, sales, and services. Connectivity is the key word for *industrial assets* for creating value in this landscape and will make significant changes to the manufacturing area[1] [2].

ZDM is a key driver to quality of industrial assets or digital enhancements of products and equipment for elimination of faults. The ZDM methodology is part of a disruptive shift to reduce scrap and propagation of equipment and products, and to make the product more adaptive, self-learning, and autonomous. These are some of the ZDM benefits for customers as well as companies[3].

Product developers of manufacturing equipment and assets have for several decades been using digital control systems, statistical process control and AI and machine learning systems. However, if we look at the process optimization, the use of digital equipment and control systems in multiple stages have previously been difficult to implement due to data availability, bandwidth and data storing capacity.

The digital technologies have even made small companies more capable in manufacturing complex parts and product systems, previously unachievable or only possible with manual work by highly skilled professionals.

Connected smart assets make possible the development of quality management several steps further. This is achieved by enabling continuous monitoring of real-word data, identifying and addressing design problems, test failures with diagnostic tools and making predictive maintenance in assets and inventory of factories. All this can be done by using smart, connected technologies that unite digital and physical assets. However, in the quality area it is still necessary to incorporate instrumentation, data collection capability and pre-designed software. Predictive maintenance is not a new concept, but the massive investments in technology typically needed to handle the massive volumes of data required for making this autonomously is often limited in deployment to only the largest organizations. In these new production development (NPD) of connected machine systems, new products and production lines with self-learning systems that can provide new services to customers, we will see a shift in how they work, sell and develop new products.

These new smart factories can in the long run be able to predict e.g. learning loops, which can lead to better design, new services to customers, reduce quality faults and

[1] https://www2.deloitte.com/insights/us/en/legal/about-deloitte-insights.html

[2] Successful Asset management strategy implementation of Cyber Physical systems, Rødseth & Eleftheriadis, Conference Paper to WECAM 2018 (World Congress on Engineering Asset Management)

[3] Zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research, Psarommatis, May, G., Dreyfus, P., Kiritsis, D. 2019, International Journal of Production Reserach, p. 20

improve control systems and maintenance operations real-time in early process stages. The quality of historical and real time data can help to improve design and business models. These data used in a right way will provide a more sustainable product with reduced scrap and cost of material, reduce workload due to re-manufacturing of products, labour cost and organizational strategies by offering other business models. All these opportunities will accelerate in the NPD by including a ZDM philosophy in products, production processes and the value chain of smart products, mentioned as the use of exponential technologies in manufacturing[4].

2.1 Objectives and Approach

The main objective for this deliverable is to present a report on the enhancements to be carried out over the ZDM equipment in the project. To do that the work focuses on collecting a list of ZDM equipment entailed in the project's pilots and experimentation activities along with their current capabilities and performance. The deliverable also specifies the digital enhancements to be carried out in each one of them, including the expected results and the requirements needed.

The specifications address enhancements to adaptive hot stamping machines, to self-learning autonomous systems, to high precision machining, to quality controlled additive Manufacturing, to self-reconfigurable flexible cells, to augmented reality and mixed reality platforms, to human centred manufacturing systems, as well as to predictive maintenance and autonomous field service engineering. As these machines and equipment are used in the pilots, the specifications are also driven by the requirements and needs of the real-life pilots.

The information necessary to produce this deliverable has been obtained by means of interviews and surveys with each pilot responsible and researchers. Matrixes have been used to collect that information in a standardized manner. Documentation has also been gathered through communication with other relevant WP4 tasks and from the various pilot Trial Handbooks.

Thus, the deliverable has evolved in time and has been updated according to two milestones (M9 and M18). The first version of the deliverable gathered the initial proposals and digital enhancements vision in the project. This second and final version will present a more detailed description of all the digital enhancements that can be implemented in the pilots, in addition to the requirements identified in the pilots (partly collected from T4.7, T7.1 and pilot Trial Handbooks) and interoperability needs.

2.2 Relation to other deliverables and WP

This deliverable has relations to other deliverables and WPs. On the one hand, some deliverables have been used as sources of information to identify the digital

[4] Deloitte, Singularity University report; Exponential technologies in manufacturing, https://www.compete.org/storage/reports/exponential_technologies_2018_study.pdf

enhancements to implement in the project. The following deliverables have contributed in this aspect, some of the developed in parallel:

- D2.1 Analysis of User Stories and Stakeholders' Requirements (version 1): Initial report on the outcomes of T2.1 on User Stories and Stakeholders' Requirements. This information is necessary for understanding the needs for digital enhancements, to fulfil the requirements.
- D2.3 Autonomous Quality Paradigm Specifications (Version 1) interlink with KPI's for processes and operations.
- D2.5 Catalogue of ZDM Assets, an on-line catalogue of ZDM equipment platforms, digital automation platforms, simulation components, predictive maintenance platforms and various other digital enablers.
- D2.11 Reference Architecture and Blueprints (Version 1): A report on the QU4LITY-RA (based on T2.6), including blueprint examples for using it in different contexts. The architecture needs to be considered when planning the digital enhancements of the ZDM equipment and their relation to the QU4LITY components.
- D4.7 Equipment Digital Enhancement Assessment and Assurance Report: A formative and summative evaluation of technological production and application.
- D7.1 Detailed Pilot Specification and Report on Pilot Sites Preparation: Report reflecting the outcomes in terms of pilot specifications and sites preparation. The pilot descriptions hold information about the ZDM equipment to be used in the project and the gaps that need to be covered.

The methodology of ZDM with the use of a Six Sigma approach and IEC/ISO Standards will be a deliverable later in WP4. KPIs are also part of QU4LITY D2.3, and section 4 "Description of KPI's for ZDM and excellence in quality management" gives further instructions on goals and KPI's structure for further work of Scenarios and Use-cases in QU4LITY Pilots.

On the other hand, there are pilots that will collect results for implementing, deploying and testing digital enhancements. In WP6, ZDM developments will be validated, verified and certified against standards and benchmarks for the equipment, process, platform levels. In WP7 the enhancements will be tested and validated in the realization of the pilots.

3. The innovation potential in ZDM equipment included in Qu4lity pilots and experimentation activities

3.1 Digital Capabilities

The Organization for Economic Co-operation and Development (OECD) has often highlighted the performance of firms in regional innovation. Strategist like Grant[5], Porter[6] and Deming[7] outline the importance of knowledge sharing for a centre of creation and for maintenance innovation in a firm. When Porter talks about Competitive Advantages, he means that innovation plays a critical role in predicting the long-term survival and sustaining economic development for building products in today´s digital development[8]. The introduction of more and open innovation, data sharing on the Internet of Things, the way of working, collaborating and exchanging information is changing our insight in how to enhance products and innovation processes[9] [10].

Change processes often start by discovering that there is an issue in the organization (awareness), and there are many ways to address those issues. Knowledge and technology are the key drivers to competitiveness, both regionally and at a firm level. Absorptive capacity refers to a firms' ability to create and arrange the knowledge for developing operation capabilities to achieve a competitive advantage. Value chains are changing the way we store and deliver products. New business models for selling products and maintaining equipment give machine builders new channels of insight[11]. The entire manufacturing area is increasing the focus on performance and capabilities.

Digital capabilities as Artificial Intelligence (AI), including cognitive perception and learning with autonomous decision-making, are still immature within manufacturing. The use of AI, meaning algorithm-based, data driven computer systems that enhance machines and people with digital capabilities, are from an industrial point of view applications used as tools. Production data to feed the algorithms is needed. Manufacturing domain knowhow structured in data sets is crucial for optimal machine innovation or refurbishment to digital transformation to product, production and processes in manufacturing.

A ZDM Platform is consequently a step further to achieve these innovation processes that will digitalize the manufacturing domain. Innovation of assets and equipment is only one side of this change. The knowledge of harvesting data, the quality of data

[5] Grant, R. M., Prospering in Dynamically competitive Environments; Organizational Capability as knowledge integration. 1996 Organ. Science.
[6] Porter, M.; Millar, V., 1985, How information gives you competitive advantage, Harvard Business review.
[7] Deming, Edward, Out of the Crisis, 1982, Quality, Productivity and Competitive Position, MIT Press.
[8] Porter, M., Heppelmann, J. How smart connected product are transforming Competition, Harvard Business Review, 2014.
[9] Chesbrough, H., The Era of Open Innovation, MIT Sloan Management Review, 2003.
[10] Rao, J., Weintraub, J., 2013. How Innovative is Your Company's Culture? MIT Sloan Management Review.
[11] How smart connected products are transforming companies, Harvard Business Review, Porter, M.; Heppelmann, J., 2015

and using data analytics together with machine learning, AI or deep Neural Network as tools in a descriptive, diagnostic or predictive way to specify what actions to take is complex and needs collaboration between the silos in several domains. A new cultural mindset of collaboration, data sharing and learning systems is needed and will provide workers with the ability to focus on skills and learning loops in a different way.

3.2 ZDM Digital enhancements to be carried out in each equipment

In the QU4LITY proposal phase the project has initialized some of the following enhancements of:

- **adaptive hot stamping machines;** Today this is a technology that allows ultra-high strength steel to be formed into complex shapes by heating the metal at a furnace or formed in hot condition. A total adaptivity of quality and maintenance monitoring are a goal for two of the machine tool builders in the project.
- **self-learning autonomous systems;** Self-learning algorithms develop successful solutions for highly complex tasks without any human guidance or prior expert knowledge. In the manufacturing domain this will be a huge step towards AI. Challenging situations can become very simple. The machine needs to know which the objectives are to be achieved in order to autonomously find out how to do it.
- **high precision machining**; will work on equipped CNC and connection boxes that are able to extract machining data (milling, drilling…) from the processes. This is existing digital platforms that will be the base for data acquisition, standardisation, and interface with common Data Space. In the future, the machine builder will be able to recover information from such Data Space to a centralised cloud for analytics and application development.
- **augmented reality (AR) and mixed reality platforms:** AR refer to "augmenting natural feedback to the operator with simulated cues". In a more restricted way, it is a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world where rich information is added. Simulation of factories, digital twins and mixed reality platforms are growing fast and give a future vision of excellent learning tool for management, operation, quality and maintenance.
- **human centred manufacturing systems;** The change in manufacturing will require new skills and expertise in application engineering, user interface development, system integration and data scientists capable to build and run automated analytics for human-machine collaboration.
- **predictive maintenance and autonomous field service engineering**; We can apply AI to robotic, automatic programming, tasks and processes for enabling predictive control functions. In the future, the field of machine learning and AI is a promising area for argument advanced quality, safety and maintenance features and services i.e. new business models, blockchain and distributed ledger?

- **quality controlled additive Manufacturing, to self-reconfigurable flexible cells:** In order to reach the goals of high-quality standards in metal-based additive manufacturing, additive manufacturing machines can be equipped with a high-speed sensor system that allows the retrieval of information from the powder bed surface and the process zone, during and after the build process. The information could be processed on an edge device, where relevant information about the part quality are extracted using machine-learning techniques. As a result, the system will recommend further actions and supports the decisions to be made by the operator in case of detected surface faults and anomalies and can also adapt to new process situations easily. Additionally, process simulation and real time digital twin will be designed for the powder bed fusion process.

3.3 Expected results from the real-life pilots in QU4LITY

In a generic way we have harvested possible enhancements at the starting point for all the pilots in QU4LITY. More quantitative and technical measures of each enhancement will be included in section 3.4. The current functionalities of the equipment are briefly described in the table below. This part of the document gives some headword about planned enhancement of equipment and an outlook for expected result from each of the machine builders in the project.

The following table shows a generic overview of machines and equipment in use, current functionalities, planned enhancement and expected results for the pilots involved.

Table 1: Machine tool builders planned and expected enhancement

Machine/Equipment	Business Processes	Current functions	Planned Enhancement	Potential type of enhancements (sensors SW etc.)	Expected result
Hot Stamping press machine.	Elimination of defect root and downtime (Smart services) Availability and machine condition optimization in Press Machine	Has an existing data acquisition system from PLC and sensors. Miss routing of variables, unproductive downtime and condition monitoring. Reactive and corrective actions after quality or machine condition problems	Process Prediction and data analytics on variables. New data analytics tools for predictive maintenance and avoid defects (ZDM)	Sensors; Temperature, vibration, press Data analytics for measure stamped part with CAD geometry.	Data analytics for condition monitoring of variables in the PLC and sensor systems. Reduction in defective parts Production optimization - Reduction of unscheduled down times - Reduction of equipment downtime on customers - Reduction of intervention time on customer - Reduction of intervention costs
High precision machining Heavy-duty cylindrical horizontal grinding machine LG grinding machine	Elimination of root and downtime for value proposition and revenue streams (Smart Services) Availability and machine condition optimization in Grinding of cylindrical parts	Designed on modular basis, on customer's specification and needs. (made to order) This flexibility can increase unpredicted quality issues and machine failures in different ways. Reactive and corrective actions after quality or machine condition problems	Condition monitoring to increase the Remaining Useful Life (RUL) of the components, tool wear, geometry tolerances control. Sensorized machines and analytics for ZDM	In-line/real time geometric measurement of critical parts, data feedback functions to control system Surface measuring, sensors, (Glossy, roughness, curves etc.)	Reduction of Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR). Predictive functions to avoid unplanned machine stoppage and quality problems - Reduction of unscheduled downtimes - Reduction of equipment downtime on customers - Reduction of intervention time on customer - Reduction of intervention costs

Powder Bed Fusion Additive Manufacturing machine; Enhanced sensors system	**BP1** Data Acquisition and Control. **BP2** Data analysis and support in decision making	Simple monitoring system are not present.	Sensors system	Fusion control system Machine learning systems Inline sensors/vison-based system for measure current layers deviations	Defects identification and possible extinction; AI for decision support AR for training and set up.
Digital milling machine. High precision machining.	Connected, intelligent automated Mould Manufacturing line	High accuracy, consistent automated solution.	Big Data acquisition, and intelligent integration.	In-line/real time geometric measurement of critical parts, data feedback functions to control system	Smart Decision Services through machining simulation. Planning based on zero defect data space analytics
Automated Mould manufacturing line Digital milling machine Automated component manufacturing line	Connected, intelligent automated components in the manufacturing line Accuracy, quality, productivity and sustainability optimization in milling and EDM machining cell	High accuracy, repeatable manufacturing solutions. Highly skilled human experts' intervention for tuning and maintaining accuracy in applications	With use of Big Data acquisition and intelligent integration. Process and product digital system for detecting, diagnosing and compensating deviations on accuracy, quality, productivity of a machining cell	Sensors; Temperature, vibration, mold Data analytics for measure molded part with CAD geometry. In-line/real time geometric measurement of critical parts, data feedback functions to control system. Sensors for tool wear. Measurement according to tolerances and positioning in the different processes in the manufacturing line, e.g. in-line measurement according to robot and fixture	Smart decision Services for optimum, consistent surface integrity based on zero defect data space analytics. - Improved accuracy in mould and die applications - Improvement of OEE in component manufacturing - Improved predictive models for component degradation and failure and quality risk - Improved quality in milling through intelligent mould trajectory definition - Improve maintenance planning

				positions, both equipment and part measurement	- Improved process through new cognitive system for real time process adaption
Hot Stamping furnace. Hot stamping line	**BP1:** Real-time cognitive hot stamping furnace 4.0. Data acquisition and control by sensor and data analysis in the furnace. Hot stamping process optimization	Parameters are isolated monitored on HDMI. Process parameters are controlled by operator. Data and variables to be collected. Problems in the geometry of the final part related to cracks and geometry variations caused by difficulty to adjust heating parameters	Big data simulation-based framework, semantic data models, cognitive digital twin, high-speed edge-powered furnace control platform. Reduce defective parts manufacturing, crack formation.	Sensor and data analytics technologies for accurate control of temperature and optimized quality in critical parts. Sensors; Temperature, vibration, stamping Data analytics for measure stamped part with CAD geometry In-line/Realtime measurement with control feedback AI based control systems (Machine learning, Neural Networks, batch compare)	Obtain optimized and efficient hot stamping process. Obtain a modular, extensible, scalable and customizable solution, transferable to other sectors. - Reduction of defective parts in manufacturing - Sustainable production through production optimization Modular system transferable to other process industries

3.4 Reference to proposed ZDM scenarios from the proposal and feasible demo results from the PILOTS

In the following section we have picked a list of scenarios from the proposal as a part of expected outcome. These scenarios are innovation steps by using ZDM strategies and methods on products but also on processes.

In the first version of this deliverable, the focus was on the machine tool builders and their equipment. In this second version we have included some more technical information from all the involved pilots, to show the complexity and disparity of enhancement in each of the pilots. We have given an introduction to identify the scenario and what kind of machine or ZDM method and last the expected results that can enhance their machine and processes by adding Autonomous Quality to the equipment for better quality functionalities and control loops.

One issue for the QU4LITY Project is to discuss if the future expected results can give the QU4LITY Platform a lead to new business models and market opportunities. Interoperability between machines and platforms are essential aspects to improve the usage of digital enhancement in the different use cases. This is further addressed in QU4LITY WP4 Task 4.5.

3.4.1 Proposed Autonomous Quality (AQ) on Machine solutions

The tables in this section is based on the WP4 deliverable 4.7, the Trial Handbooks chapter 3 for the respective pilots, in addition to updated documentation received from individual pilots. The tables contain the specific ZDM Digital Enhancement components involved, specific requirements with a type and identification number, for clear cross-referencing and relations where this has been documented. This is also for any future such actions using the documentation. Planned enhancements and related requirements have been documented where the information is available.

- **The ZDM on a Digital Press Machine for Fagor**

The objective is to reach ZDM process collecting press machine critical parameters and identifying exactly the process developed in the manufacturing of pieces. Traditional zero defects approaches propose the analysis of such parameters isolated from the rest of the process where the machine is integrated. Whereas these approaches try to maximize the efficiency of the process by maximizing the efficiency of the parts, it fails to maximize the efficiency of the overall system. In order to go a step further, cognitive manufacturing proposes the utilization of data across systems to derive actionable insight through the entire value chain. The pilot envisions the usage of data analysis not only at the press machine but to have a holistic view of the production. This responds to an existing market demand that no other agent is currently covering.

ZDM Equipment: Digital press machine including control unit, power pack, control valve, feeding system, cooling system control.

Table 2: Digital ZDM Enhancement and technical information on Pilot Fagor Digital Press-machine

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
FAGOR Zero Defect Manufacturing Digital Press Machine	FAGOR DAS, FaLink-MAP (Ingestion and cloud), FaLink-MAP (Web Interface), IKCLOUD, IKSEC, VTT OpenVA, Industrial Data Space	0.1	System must ensure data is transferred satisfying defined security standards.	General technical	Must	Process Prediction and data analytic on variables. New data analytics tools for predictive maintenance and avoid defects	1.1 It must be able to read from all sensors 1.2 It must be able to send analytics results to the machine 2.4 It must be able to analyze measures and relate results to working conditions.
		0.2	System must ensure data is confined satisfying defined security standards.	General technical	Must		
		0.3	System must ensure sensible data is managed accordingly to pre-set user privileges	General technical	Must		
		0.4	System must ensure scalability, reliability and latency on communication between components.	General business	Should		
		0.5	System must store data regarding machine behavior for performance testing	General technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		0.6	The system should be capable of sending feedback to user from analysis results	General technical	Should		
		0.7	System must be able to capture data from different sensors and transfer it to cloud components.	General technical	Must		
		0.8	System should be able to take autonomous actions from analysis results.	General business	Should		
		0.9	System acquisition latency, processing latency and response latency are such that permit real time analysis.	General technical	Must		
		0.10	System must provide predefined product on an acceptable standard of quality	General technical	Must		
		1.1	Component must ensure data is transferred satisfying defined security standards.	FAGOR DAS technical	Must		
		1.2	Component connections should enable transferring data in different formats and communication protocols	FAGOR DAS technical	Should		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.3	Data quality should be controlled.	FAGOR DAS technical	Should		
		2.1	Component must ensure data is transferred satisfying defined security standards.	FaLink-MAP (Ingestion and cloud) technical	Must		
		2.2	Component connections should enable transferring data in different formats and communication protocols	FaLink-MAP (Ingestion and cloud) technical	Should		
		2.3	Cloud platform must ensure either no data loses or process interruptions are faced.	FaLink-MAP (Ingestion and cloud) technical	Should		
		2.4	Process Latency must meet response time established requirements.	FaLink-MAP (Ingestion and cloud) technical	Must		
		3.1	Component must ensure data is transferred satisfying defined security standards.	FaLink-MAP (Web Interface) technical	Must		
		3.2	Component must ensure sensible data is managed accordingly to pre-set user privileges	FaLink-MAP (Web Interface) technical	Must		
		3.3	Latency on consulting	FaLink-MAP (Web Interface) technical	Should		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		4.1	Component must ensure data is transferred satisfying defined security standards.	IKCLOUD technical	Must		
		4.2	Cloud platform must ensure a fast, scalable and fault tolerant data processing	IKCLOUD technical	Should		
		5.1	Component must ensure data remaining components meet security standards	IKSEC technical	Must		
		5.2	Component must ensure data remaining components meet privacy standards	IKSEC technical	Should		

Expected results

Reduction in defective parts.

- Monitoring the transformation made by the press, to sensor e.g. temperature, vibrations, pressure etc. and tracing with the final product/part geometry to enable the possibility of selecting which variables directly affect the final quality of the product. This approach is one step further compared with traditional quality processes.

Production optimization.

- Aggressive machine configurations (ultrafast movement of dies, increment in the pressure made by dies) can lead to an improvement on the production at expenses of low-quality pieces and reduction in the machine lifetime.

Conservative machine configurations (slow movement of dies) can lead to an improvement of the quality of the pieces at the expenses of a slower production. Searching for a balance between the quality and performance will lead to a sustainable production.

- **DANOBAT Pilot on High precision machining–cutting and grinding machine-tools**

The DANOBAT machine level trial has the goal to build enhanced DANOBAT AQ Precision Grinding machines by means of incorporating hardware (a Cyber-Physical System) and software (AI fingerprints) to the machine, taking advantage and integrating QU4LITY technology modules. In this sense DANOBAT pilot will mainly be supported by Savvy Data System Digital Manufacturing Platform.

ZDM Equipment: LG external cylindrical horizontal grinding machine. Manufacturing process: external grinding of specific areas of cylindrical parts.

Table 3: ZDM Digital Enhancement table for Danobat Pilot on Precision Machining-cutting and grinding machine tool

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
Danobat Digital Machine for Zero-Defects at high precision cutting/grinding	Operation Technologies System, Danobat Box, Danobat Data System	1.3	The different components of the system should be able to connect to each other to transfer data in different formats and directions	General technical	Must	Big Data acquisition and intelligent integration	1.10, 1,11, 2.4, 2.7, 2.8, 4.4
		1.5	Diagnosis and prediction of machine failure and misfunction	General business	Must		
		1.6	Periodic reports from the system so the user doesn't have to actively go to the platform	General business	Should		
		1.7	Possibility to connect to the cloud punctually not in a constant connection	General technical	Should		
		1.8	Improvement of machine availability and decrease of defective products	General business	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.9	The system should be able to monitor analyze and extract features that allow to act avoiding problems in real time	General business	Must		
		1.10	The system should be able to send results to the machine so, the machine or the operator can take actions to avoid defects	General business	Must		
		1.11	The system should not be expert dependent it should be intuitive and easy to use	General business	Should		
		2.8	Embed Intelligent autonomous quality functions on the machines.	OTS technical	Must		
		2.9	Gather quality data from the real behavior of the machines for later analysis to be able to use it for further improvement of the machines to the market	OTS technical	Should		
		2.10	The system will incorporate computational capacity for machine dynamics information so different types of analysis can be performed	OTS technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		3.1	Reduce and process the data on the Edge/IoT side before they reach a central location such as the Cloud	Edge technical	Must		
		4.3	Other software should be able to communicate with the system through an API to read data and use it for purposes like analytics.	Cloud business	Must		
		4.4	The cloud should be able to store big quantities of data	Cloud technical	Must		

Expected results

- Interoperable, useful and friendly ZDM-oriented digital platform to build more reliable grinding machines.
- AQ approach in the grinding machines will decrease scrap and reworks.
- Prediction of how the deterioration rate of equipment to plan maintenance actions before it affects the quality of the produced products.

In addition, it is expected that the Remaining Useful Life (RUL) of the components and grinding wheels will increase. It is also important to achieve an increase Mean Time Between Failures (MTBF) and reduction of Mean Time to Repair (MTTR).

- **Prima AM Pilot on Adaptive Control Technology**

The AM pilot will focus on acquisition, tracking and analysis of data to enhance process robustness of powder bed Additive Manufacturing. The ambition is to create a modular monitoring and control system that can be used with many different sensors and process models, in order to increase process robustness and reach the ZDM target. Real-time process and machine signals need to be analyzed by machine-learning algorithms to find structures and pattern related to the required key quality indicators (critical defects per track, distortion, keeping of dimensions). The system will be also connected to a higher-level factory data interface which allows to exchange process information and reassign the production strategy based on additional factory conditions.

ZDM Equipment: Additive Manufacturing pilot including AM lab equipment, AM new concept Directed Energy Deposition and AM machines Powder Bed

Table 4: ZDM Digital Enhancement table for Prima AM Pilot

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
PRIMA Additive Manufacturing Pilot Adaptive Control Technology	Process Texture Analysis, Correlation of process Data, Analysis Tools in cloud; Decision Support System, Augmented Reality, Digital Twin	1.1	Respect privacy requirements (such as GDPR compliance)	General business	Must	Raise early warning signals based on cognitive quality diagnosis, including anomaly detection and equipment condition reporting, control laser - based AM processes on the basis of data-driven process models.	2.1-2.12

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.2	The platform should be easy to maintain with adequate version updating mechanisms, version control and document sharing systems amongst developers	General technical	Must	AR for human error reduction: thanks to new and advanced AR applications,	4.11
		1.3	The different components of the system should be able to connect to each other to transfer data in different formats and directions	General technical	Must	The Data Storage System is combined with and triggers the activation of semantically defined ZDM Strategies to control the propagation of defects and manage their occurrence in multi stage production	4.5, 4.6
		1.4	Software quality should be tested	General technical	Should	The information flow provided by the designed architecture and digital enhancement will be used to apply production strategies for ZDM.	4.12, 4.13, 4.14, 4.15, 4.16
		1.9	The system should be able to monitor analyze and extract features that allow to act avoiding problems in real time	General business	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.11	The system should not be expert dependent it should be intuitive and easy to use	General business	Should		
		1.12	Data quality	General technical	Must		
		1.13	The future implementation is based on IEC-61499, OPC-UA, VDMA, and edge node	General technical	Must		
		2.1	Modular adaptable signal processing system that can operate to RAMI standards on the edge for data-driven online quality assessment	Process Texture Analysis technical	Must		
		2.2	Connectivity to MES and control systems	Process Texture Analysis technical	Must		
		2.3	Interaction with data space and simulation tools through the platform	Process Texture Analysis technical	Must		
		2.4	High level decision support and overview of the AM equipment.	Process Texture Analysis technical	Must		
		2.5	Conversion of sensor data into a compact representation utilizing data processing methods	Process Texture Analysis technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		2.6	Volumetric visualization of sensor data	Process Texture Analysis technical	Must		
		2.7	Interactive graphical interface. The model should show an approximation of the complete sensor data set. The user should be able to navigate this scenery	Process Texture Analysis technical	Must		
		2.8	user selected areas from the overview should be visualized with a finer resolution of the selected section	Process Texture Analysis technical	Must		
		2.9	The user should be able to select further cutouts from the intermediate view that should be rendered using the exact data set.	Process Texture Analysis technical	Must		
		2.10	Intuitive user selection and visualization of data sections	Process Texture Analysis technical	Must		
		2.11	Human friendly interaction with optical sensor data	Process Texture Analysis technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		2.12	the system must be able to read data from optical sensors volumetrically distributed and show them together with a CAD model of the printed object	Process Texture Analysis technical	Must		
		3.1	The data analytics tool must be able to collect data form the automation level and the cloud to use them in analytics algorithms	Correlation of Process Data technical	Must		
		3.2	The tool must be implementable at edge level	Correlation of Process Data technical	Must		
		3.3	the data will be collected through automatic and semiautomatic procedures	Correlation of Process Data technical	Must		
		3.4	The exploitation of the data must result in cause effect patterns	Correlation of Process Data technical	Must		
		3.5	The data should also be able to be used and leveraged with the DSS tools	Correlation of Process Data technical	Must		
		3.6	the system must be able to use OPC UA and MQTT standards.	Correlation of Process Data technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		3.7	The system should be able to read continuous or batches based data and transform them for analytics purposes	Correlation of Process Data technical	Must		
		3.8	the system should be able to communicate a t a higher level with the DSS tool	Correlation of Process Data technical	Must		
		3.9	The data analytics solution running on a PC at the Edge should be able to connect to other virtual and /or real machines hosting data storage/ processing tools.	Correlation of Process Data technical	Must		
		4.1	The additive simulator should be displayable in an external cloud or on premises	Analysis tools in the cloud technical	Must		
		4.2	Data about process and product should be obtained through the cloud as well as on premises	Analysis tools in the cloud technical	Must		
		4.3	No constraints on response time, latency or robustness in the wireless network	Analysis tools in the cloud technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		4.4	The system should be secure. Communications will use VPN an SSL certificates used to guarantee data transport security	Analysis tools in the cloud technical	Must		
		4.5	The system developed should be able to be deployed in the cloud	Analysis tools in the cloud technical	Must		
		4.6	The DSS system should be able to communicate with the Edge node via OPC UA or MQTT protocol	Analysis tools in the cloud technical	Must		
		4.7	The system in the cloud should be able to process data, filter , aggregate telemetry and route to other systems	Analysis tools in the cloud technical	Must		
		4.8	The cloud to device communication should be tested in terms of quality and completeness of transferred data	Analysis tools in the cloud technical	Must		
		4.9	Authentication methods will be deployed in the cloud	Analysis tools in the cloud technical	Must		
		4.10	There should be a data transmission API to make the data available to other service providers	Analysis tools in the cloud technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		4.11	The AR tool to support the user in the set up phase must be easy to use and understand	Analysis tools in the cloud technical	Must		
		4.12	ZDM Strategies must be able to predict defective production and trigger actions to avoid them	Analysis tools in the cloud business	Must		
		4.13	ZDM Strategies must be able to prevent propagation of defective production downstream in the production line	Analysis tools in the cloud business	Must		
		4.14	ZDM Strategies must be able to Repair proposing rework options for defective parts	Analysis tools in the cloud business	Must		
		4.15	ZDM Strategies must be able to reverse supply chain. Deciding process flow for improvement of production in case of defective items	Analysis tools in the cloud business	Must		
		4.16	ZDM Strategies must be able to manage strategies through event modelling, KPI monitoring and real time decision support	Analysis tools in the cloud business	Must		

Expected results

- Modular adaptable signal processing system that can operate to RAMI standards on the edge.
- Connectivity to the Manufacturing Execution System and control systems
- Interaction with data space and simulation tools through the platform.
- High level decision support and overview of the AM equipment.

Possible results: Raise early warning signals based on cognitive quality diagnosis, including anomaly detection and equipment condition reporting, control laser - based AM processes on the basis of data-driven process models, increase Overall Equipment Effectiveness by recommending process adjustments to the operator, reduce reject rate by application of data-driven process model that has been derived by AI algorithms and enable mode.

AR for human error reduction: thanks to new and advanced AR applications, it will be possible to mitigate human errors and increase the quality of the process because of a better machine setup.

- **Digital machine and part twins for ZDM by Georg Fischer (GF)**

Current barriers to high accuracy in manufacturing in multi-technology and automated cells are related to limitations in data aggregation and exploitation in either the optimization of machining processes or machine health scopes. ZDM in these systems will be therefore possible by taking into account in the planning stage how the machine mechanics evolve towards states where deviations are more likely to occur, where failures might damage the part or the machine, or where uncertainties are introduced by calibration defects, maintenance, repairing or any other uncontrolled factor in the chain.

The pilot will address this challenge by setting up a first digital system for detecting, diagnosing, and fully compensating deviations on accuracy, productivity and sustainability of a robotized machining cell based on the aggregation of information from milling and EDM machinery health, process performance and geometrical part characterization, using a common data space for making possible a realistic information integration from different types of hardware & software coexisting at different end-users factories, and targeting fully automated, ZDM across the full chain.

The system will demonstrate ZDM in mold and die and aerospace applications, where most critical challenges are found regarding accuracy, surface quality and machine productivity. The outcomes will be measured in terms of KPI's for geometrical accuracy, surface quality, scrap rate, OEE, depending on the application, and targeting full automated assembly processes for mold and die manufacturing and zero defect for aerospace component manufacturing.

All GF devices will be equipped with rConnect interfaces which standardize data by using the OPC UA framework. Coordinate-Measuring Machine systems from Zeiss and Hexagon can be integrated in the cell by using their standard communication interfaces. Inspection software from Innovalia will be used for generating and managing information from these measurement machines. The Workshop Manager is able to interface with ERP and MES systems as well as CAD CAM modules. Current interfaces are implemented for SAP, Siemens NX and Autodesk. A digital twin planning system will be implemented for delivering machining codes with simulation tools taking into account given process parameters and machine configuration, in an initial optimized set-up. Data from machine sensors, monitoring process, components and environment will be collected during machining and aggregated in a common, standardized data space to be associated with data from dimensional measurements. A cognitive zero defect framework will be developed by EPFL which will correlate product dimensional and surface quality measurements with machine component data predicting aging of machinery and process parameters drift, so to update the process simulation model and return the optimum parameters for generating the numerical control (NC) codes based on KPI indicators on dimensional accuracy, surface quality, productivity and sustainability.

ZDM Equipment: Part of an automated cell cantered in milling series and die sinking machines. Other main components are Workshop manager software, communicating with machines and robots for execution program implementation and monitoring.

Table 5: ZDM Digital Enhancements table for GF Machine Solutions

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
GF Digital machine and part twins for Zero Defect Manufacturing	rConnect, M3MH, Pace lab TWIN, T.R.U.E; Power Shape, Powel Mill, Power Inspect, MPP, Workshop Manager, Azure Cloud/ML environment	1.1	Ensuring data transfer by satisfying the defined security standards.	General technical	Must	Create Data storage space	1.1, 1.2, 1.9, 2.1, 2.2, 2.3, 3.1, 3.2, 3.3
		1.2	Ensure scalability, reliability, and latency on communication between components.	General business	Should	Implement Cloud infrastructure	1.1, 1.2, 1.4, 1.9, 2.1, 2.2, 2.3, 3.1, 3.2, 3.3, 6.1, 6.2
		1.3	Communication between components regarding the data transfer in different formats and directions.	General technical	Must	Perform Data analytics in different authorized environments	1.5, 6.3
		1.4	Acquiring data from different sensors and transfer it to cloud components.	General technical	Must	Set up a Digital Twin for error compensation, KPI prediction and control	1.6
		1.5	Send analysis results back to user for further optimization actions.	General technical	Should	Create a simulation-based framework to update NC codes and maintenance plans	1.8, 5.5
		1.6	Diagnosis and prediction of machine status	General business	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.7	Improvement of machine availability and decrease of defective products	General business	Must		
		1.8	Optimize manufacturing process to reduce time and cost	General business	Must		
		1.9	Data quality	General technical	Must		
		2.1	Ensuring data transfer by satisfying the defined security standards.	rConnect technical	Must		
		2.2	Ensure scalability, reliability and latency on communication between components.	rConnect business	Should		
		2.3	Data quality	rConnect technical	Must		
		3.1	Ensuring data transfer by satisfying the defined security standards.	M3MH technical	Must		
		3.2	Ensure scalability, reliability and latency on communication between components.	M3MH business	Should		
		3.3	Data quality	M3MH technical	Must		
		3.4	Send analysis results back to user for further optimization actions.	M3MH technical	Should		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		4.1	Ensure visualization of 3D model of the part and mapping process data on the model.	Pacelab TWIN technical	Must		
		4.2	Cloud connection by using diverse communication protocols for data analysis, visualization, and simulation modules.	Pacelab TWIN technical	Must		
		4.3	Ensure robust scalability on cloud.	Pacelab TWIN technical	Must		
		5.1	Communication between components regarding the data transfer in different formats and directions.	T.R.U.E technical	Must		
		5.2	Send analysis results back to user for further optimization actions.	T.R.U.E technical	Should		
		5.3	Improvement of part accuracy and surface quality.	T.R.U.E business	Must		
		5.4	Manufacturing program optimization	T.R.U.E technical	Must		
		5.5	Optimize manufacturing process to reduce time and cost	T.R.U.E business	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		6.1	Ensuring data transfer by satisfying the defined security standards.	Azure Cloud/ML environment technical	Must		
		6.2	Ensure scalability, reliability and latency on communication between components.	Azure Cloud/ML environment business	Should		
		6.3	Ensure of cloud module availabilities.	Azure Cloud/ML environment technical	Must		

Expected results

- An automated cell achieving 5μm accuracy and Cpk levels higher than 1.66 for mould and die applications, involving Milling and EDM technologies as well as automation systems.
- An automated milling cell for ZDM of aerospace component manufacturing and improving OEE above 95% from current 85% of actual systems implemented in the field and reducing scrap and rework rate from current 5% to below 1% only due to identified rework.
- A coupled predictive maintenance/quality optimisation analytic application delivering improved predictive models for component degradation and failure as well as quality risk at level of accuracy and surface integrity of parts.
- A Machining analytical model able to consider the tool deformation surface roughness depending on the working conditions (chip load, feed rate).

This model would be integrated in the CAM system that would modify the tool trajectory depending on the expected cutting forces. An integrated continuous inspection system of the manufactured workpieces providing Cpk trend in several parameters: roughness, dimensional tolerances, geometrical tolerances.

- A common data space integrating inspection data with information coming from the Machine CNC (process and components) and workspace (room temperature) so to adapt (i) the working conditions (ii) the tool trajectory (iii) the cutting tool (iv) the maintenance planning.
- A cognitive system where the adaptation decisions taken during the manufacturing process, whether machine maintenance or process parameters, will be considered to

improve the model in next manufacturing parts, e.g., if cutting forces are higher or lower to the predicted ones, material parameters will be corrected, or if an aging component produces more vibrations, check whether they remain within acceptable limits.

- **GHI solution on Real-time cognitive hot stamping furnace 4.0**

The ZDM Digital Enhancements in this pilot will consist of two phases. The first phase will aim to reduce defective parts manufacturing, especially crack formation on parts. This is achieved through increased control and monitoring of the industrial furnace operating parameters. The system will demonstrate ZDM in automotive hot stamping of safety critical parts in automotive, where quality is at the highest standards in the sectors in terms dimensional, surface, and structural characteristics of the manufactured part.

In the second phase, another objective will be related with the production optimization. The holistic approach given by this performed control platform will provide a balance between the different elements' interaction. These performances will lead to a sustainable production. Finally, another objective will be the possibility to obtain a modular solution: extensible, scalable, customizable and, replicable system that could be transferable to other process industries, e.g. steel industry.

ZDM Equipment: Smart Furnace 4.0 in the context of a hot stamping line. The furnace itself will become the main Cyber-Physical Production System component but the use case will also consider the data coming from transfers and the stamping press for the smart monitoring and the cognitive control loops.

Table 6: GHI ZDM Digital Enhancements table for hot stamping furnace

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
GHI Real time cognitive hot stamping furnace 4.0	Furnace Data gathering system, Furnace data analysis, Beyond Monitor, Beyond Report, Edge-powered quality control system, GD&T parts digitization, Quality Control Data Analysis, Quality Control Data Space, IDSA components validation services	1.1	Deploy a common data space, for furnace and press installations to allow to correlate secured, standardized and referenced information from both machines.	General technical	Should	Data access, data will be contextualized and uploaded to Orion context Broker. Dashboard for data visualization. Data sent from QCS through the IDS connector to Orion Context Broker	1.6, 2.1, 2.3

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.2	To provide a high-speed (real-time) edge-powered furnace control platform.	General technical	Should	Store and manage the data. Provide local processing capabilities in isolated domains. Remota access and centralized control. Multi-service gateway via virtualization.	1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.all
		1.3	A deep streaming analytics framework for real-time analysis and smart learning engines for correlation of part defects, press parameters and optimum furnace parameter selection.	General technical	Must	Algorithms may be developed using different regression models in order to find correlations.	1.all, 2.all, 3.all
		1.4	A big data simulation-based framework to optimize part heating profiles in the furnace and temporal temperature variations in the hot stamping process.	General technical	Should	Simulation program should take into account the multiple temperature sensors installed along different sections of the furnace, also considering parts real position.	
		1.5	Transform semantic data models for the furnace operation into learning algorithms for the furnace control.	General technical	Should	First simulation models may be developed to correlate part temp necessities with sectional furnace temperatures . Correlation of temp with burner's usage requirement.	

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.6	Correlate furnace heating with part real temperature.	General technical	Must		
		1.7	Improve decision making efficiency thanks to the analysis & visualization tools.	General technical	Must		
		1.8	Fast detection of root cause of quality problem.	General technical	Must		
		1.9	To obtain an extensible, scalable and customizable system that could be adapted to other processes.	General business	Must		
		2.1	The data volume should be not that large so that the data ingestion system does not crash.	Beyond Platform technical	Must		
		2.2	Remote data access should be achievable in order to be able to analyze and manipulate it from the GHI 4.0 Engineering service headquarters.	Beyond Platform technical	Must		
		2.3	Latency for the data acquisition system should permit analysis near real time.	Beyond Platform technical	Must		
		2.4	Ensure that no noise or incoherent data is introduced in the system.	Beyond Platform technical	Should		
		2.5	Ensure that no data is lost when transferring data to the GHI server, if there is a loss of network connection.	Beyond Platform technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		2.6	Testing and validation of the algorithms developed	Beyond Platform technical	Must		
		3.1	There is a need of availability of furnace and press data to test the component	Cognitive Digital Twin Service for ZDM technical	Must		
		3.2	Two different data sources that should be stored and contextualized in a common data space.	Cognitive Digital Twin Service for ZDM technical	Must		
		3.3	There should be a management system to control the data published on the OCB.	Cognitive Digital Twin Service for ZDM technical	Must		
		3.4	The data sharing process must provide the guarantee of being reliable and secure.	Cognitive Digital Twin Service for ZDM technical	Must		
		3.5	As data sources come from different machines operated by different stakeholder, the ownership of the data should be clarified.	Cognitive Digital Twin Service for ZDM technical	Must		
		4.1	Ensuring both transmission and quality of data	Composable Digital Shopfloor V&V technical	Must		
		4.2	With the introduction of some IoT sensors on the furnace, it should become a plug & produce enhanced equipment	Composable Digital Shopfloor V&V technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		4.3	Beyond platform services, as visualization tools, must be optimally operational to be functional for users	Composable Digital Shopfloor V&V technical	Should		
		4.4	Proper operation of the M3BOX to ensure data sharing.	Composable Digital Shopfloor V&V technical	Should		
		4.5	Ensure that only the desire part of the dataset is shared on the Orion Context Broker	Composable Digital Shopfloor V&V technical	Must		

Expected results

First phase: reduce defective parts manufacturing.

- The system will demonstrate ZDM hot stamping of safety critical parts in automotive.

Second phase: Production optimization.

- Using a holistic approach given by the ZDM control platform, will provide a balance between the different elements' interaction, leading to a sustainable production.

Finally: Obtain a modular solution.

- Extensible, scalable, customizable, and replicable system that could be transferable to other process industries.

3.4.2 ZDM Autonomous Quality on process lines

Quality control on process lines is a more complex process than doing enhancement on a single equipment. Here we have different variants of product, equipment and solutions that needs to cooperate in a smooth process. The work on digitally enhancing process lines for ZDM involves numerous adapted and new tools from both pilot owners and technical providers, that have to communicate and extract data from existing lines: This data is then used for various purposes that are described in each pilot description, in order to ensure optimal ZDM Digital Enhancement. The pilot descriptions also include requirements for the digital enhancement for all but two pilots.

The tables in this section is based on the Trial Handbooks chapter 3 for the respective pilots, in addition to updated documentation received from individual pilots. The tables contain the specific ZDM Digital Enhancement components involved, specific requirements with a type and identification number, for clear cross-referencing and relations where this has been documented. This is also for any future such actions using the documentation. Planned enhancements and related requirements have been documented where the information is available.

- **Application of autonomous quality on a production line at Philips**

The main goal of the pilot is to improve the Padprint process for the OneBlade shaving unit. This is achieved by knowledge building through better use of data and organizational interaction, a more stable process, longer ink-pot life, less rejects, better process control and less use of cleaning chemicals, storing real-time data and finding a correlation between stored data and rejects. Other important priorities are to enable better operator decisions and deliver better data to the system. The system must be able to act as a support and controlling stable production, early triggering and information sharing.

ZDM Equipment: Production line with moulding, cold forming, assembly, welding, printing, functional testing, and packaging processes.

Table 7: Philips ZDM Digital Enhancements table for process at production line

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
OneBlade shaving unit production line	Functional requirements, user interfaces, hardware interfaces, software interfaces, communications interfaces, performance requirements		Functional requirements	General technical		Prescriptive functionality on the line that automates current manual settings and reduces number of errors, reducing scrap, manual inspections, reduces costs and optimizes the assembly of parts in the production process to avoid high torque and related errors.	
			Functional requirements	General technical		Analytics that aid in production within tolerances, predictive maintenance.	
			Functional requirements	General technical		Automated quality inspections, near full automation of production line	
			Functional requirements	General technical		Scalable platform fed by real-time data to enable prescriptive models.	
			User interfaces	General technical		Dashboard KPIs, digital logbooks, SPC, HMI interface, KPI screen, raw data access all depending on user level.	
			Hardware interfaces	General technical		Beckhoff PLC ethernet	
			Software interfaces	General technical		TwinCAT 3	
			Communications interfaces	General technical		OPC/UA over ethernet	

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
			Other requirements	General technical		Factory is not directly connected to internet or external computers/ pc's, any hardware must be installed on production site.	
			Performance requirements	General technical		Analyze early indicators and trends from process signals and CTQs of components to predict quality of product. Early warning based on early indicators and trends from signals. Suggest feed-forward or feed-backward controls. Operator process adjustment support. Increase data interactions to predict quality.	

Expected results

- Realization of a holistic system that can raise early warning signals based on early indicators and trends from process signals and dimensional CTQ's that are still acceptable on component level but will lead to Fall Off Rate on the finished goods in the current quality framework.
- Suggest feed-forward or feed-backward controls to neighbouring process stations which might have an influence on the dimensional CTQ under observation, increase OEE Availability and Performance by helping the operator to take correct process adjustment decisions, to reduce Fall Off Rate by learning from unknown data interactions

- **Whirlpool Pilot on a Dryer Factory Holistic Quality Platform**

The ZDM Digital Enhancements in the pilot involves data processing according to an ontological structure, the data refer to the following process areas: heat pump testing, functional testing, aesthetic testing, repair area, drum production. The information collected is the inputs to the process of elaboration of the MPFQ model. Through this model it is possible to process the quality data according to the following scheme: Visualization System, Analytic, CpK forecast, and Automatic Feedback.

The main objective of the SW applications is to give an instrument capable of acting on two different levels: the first one to generate the information (Cpk, KPI or similar) which represents the company standard for quality and productivity measurements; the second level is to understand what is the impact of the elements: Material, Process, Function on the specific KPIs connected to product and process quality. This is in order to quickly and precisely identify which processes are deviating from their optimal performance.

The main actions performed by the system can be summarized through these steps:

1. Data collection: Heat Pump (testing and verification of vacuum and charge parameters), Production Scheduling, Production Drum, Functional Test, Aesthetic control, Final Gate, Repair area.
2. Ontological processing of the data in order to harmonize its structure and meaning
3. MPFQ processing in order to integrate processes and data in a single model
4. Develop the process and performance indicators as defined in point 3
5. Develop an interface capable of displaying the data processed as in point 4 according to the factory organizational model of the factory

ZDM Equipment: Complete production line with drum line, heat pump, side fabrication, main assembly, functional test, ZHQ area and reliability test. In addition, a quality gate for gauge testing, fail/pass testing and process monitoring

Table 8: ZDM Digital Enhancements table on a Dryer Factory Holistic Quality Platform at Pilot Whirlpool

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
Dryer Factory Holistic Quality Platform	User interface, Hardware interface, software interface, communication interface		Configurable software tool	General technical		Configured with information processed in real time. User access levels for access to various levels. PC and tablet access.	

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
			Hardware interfaces	General technical		No specificity required to be used in the processing and collection of information	
			Software interfaces	General technical		Under evaluation between project partners	
			Other required software components	General technical		Under evaluation between project partners	
			Communication interfaces	General technical		System must be able to show the data elaborated in real time	

Expected results

- Common and holistic semantic model able to represent concepts at different stages of product lifecycle.
- Standard methods and tool to gather, store and share data, flexible and user-friendly.
- Analytical tools and a comprehensive way to share results to different management roles

- **Data analytics for ZDM efficiency increase in electronics production for Siemens**

The system contains the following ZDM Digital Enhancements components.

MFC – module for failure classification to reduce "false positives".
MFP – module for failure prediction to allow for partial testing instead of 100% testing.
MSPC – module for simulation-based definition of different process control strategies to optimize the overall process chain. Based on results from Based on results from data analytics, the simulation framework can improve handling of defective parts or derive strategies for bottleneck relief.
MFPA – module for Failure Propagation Analysis on Process Chain Level. The aim of this module is a characterization of intermediate product properties (IPP) at every process step by applying suitable data analytics models. As a result, an analysis of IPP behavior over the entire process chain can be conducted and used for the process control to reduce (pseudo) failures and improve the efficiency and availability of the equipment.

ZDM Equipment: Complete production line with solder printing, solder paste inspection, pick and place, AIO, reflow and ICT & X-Ray testing

Table 9: ZDM Digital Enhancements on data analytics to increase efficiency in electronic production at SIEMENS

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
Simatic Products Quality Improvements	MFC, MFP, MSPC, MFPA	1.1	The test station has to be directly connected to be able to retrieve live data	MFC technical			
		1.2	The system shall classify the state of the products	MFC technical			
		1.3	The system shall identify a pseudo error	MFC technical			
		1.4	The system shall provide feedback that a pseudo error is detected.	MFC technical			
		1.5	Shall be executable on a Simatic Edge Device	MFC technical			
		2.1	The system shall classify the	MFP technical			

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
			state of the products				
		2.2	The system shall calculate the probability of an error	MFP technical			
		2.3	The system shall provide recommendation if 100% testing is necessary	MFP technical			
		2.4	The system has to be connected to the database.	MFP technical			
		3.1	The system shall simulate the complete process chain	MSPC technical			
		3.2	The system shall provide insight into the process	MSPC technical			
		3.3	The system shall assist in handling defective parts	MSPC technical			
		3.4	The system must be able to retrieve live process information	MSPC technical			
		3.5	The system shall be able to be executed on an edge device	MSPC technical			
		4.1	The system shall characterize intermediate product properties at every process step.	MFPA technical			
		4.2	The system shall provide insight into the products state in every process step	MFPA technical			

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		4.3	The system shall provide insight into the potential error propagation	MFPA technical			
		4.4	The system must be able to retrieve live process information	MFPA technical			

Expected results

- Identification and valuation of possible data sources for predictive quality control.
- Realization of data access and acquisition, data mining / analytics algorithms, data analytics tools implemented and up and running, improved throughput / bottleneck-reduction for production lines, systematic failure root cause
- Detection supported by data analytics, improved knowledge on machine states / maintenance requirements for neuralgic points
- Improved production execution on organization / logistic level and estimation of benefits and possible development of availability of machinery (predictive maintenance)

- **AQ in PCB Production Continental's Pilot for Future Mobility**

The purpose of the ZDM Digital Enhancements in the Continental Pilot is to detect abnormalities in process operation data from ASM Pick and Place machines by collecting data from IoT devices in the manufacturing domain, that are not entirely covered by existing proprietary solutions.

ZDM Equipment: Complete SMD production line with laser marking, paste printing, placement, reflow oven. Solder Paste Inspection, Automatic optical inspection and In-circuit testing.

Table 10: ZDM and Autonomous Quality in PCB Production, Digital Enhancement on Continental future mobility

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
Autonomous Quality in PCB Production for Future Mobility	User interfaces, Hardware interfaces, software interfaces, communication interfaces, performance requirements		Functional requirements	General technical		Ensure that the data obtained in the IoT world is pre-filtered and formatted before being passed to a consumer, reducing the flow or the quantity of inaccurate data	
			User interfaces	General technical		To be defined during pilot.	
			Hardware interfaces	General technical		Standard supplier equipment interfaces.	
			Software interfaces	General technical		IPC/CFX. ASM equipment specific interface: OIB.	
			Communications interfaces	General technical		Near realtime.	

Expected results

- Realization of a holistic system. Build on real-time Data Mining in Production systems and communication (via Bluetooth 4.0 for Autonomous Quality).
- Provide early indicators and trends from process signals, enables "Big Data in Zero Defect Production".
- Facilitates creation of new applications. Span over the whole value chain, i.e. data acquisition and extraction, data analysis, data storage, data visualization and usage in a safe "Cloud storage" environment.
- Allows Digital Modelling & Zero-Defect Strategies an suggest feed-forward or feed-backward of quality data along the supply chain.
- Enacts the physical interpretation and initiation of real-time reaction plans via innovative shop floor visualization management increasing OEE by helping the operator to take correct process adjustment decisions

- **ZD & AQ in Machinery Building for Capital Goods sector two scenarios at Mondragon Pilot**

The pilot will use hybrid edge+ technology and a Big Data Analytics Infrastructures DA-IA for ZDM Digital Enhancement of cutting/grinding machinery. The goal is to develop new system level ZDM solutions in order to satisfy customer quality requirements by systematizing quality control and lowering costs.

ZDM Equipment:
Scenario 1: Complete production line with upstream processes influencing the machining, centring, part assignment, adaptive machining, critical process monitoring, data engineering, root cause analysis, data analytics, NDT optimization and system optimization
Scenario 2: Complete hot forming in manufacturing line for boron steels

Table 11: ZDM Digital Enhancement and AQ in Machinery Building and capital goods at Mondragon's Pilot

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
Zero Defect and Autonomous Quality in Machinery Building for Capital Goods sector		1.1	Enable big data collection	Hybrid edge+ technical	Must		
		1.2	Analysis of these applied algorithms will trigger alarms to the machine, that can also be sent to the cloud.	Hybrid edge+ technical	Must	Connect the remaining useful life (RUL) of the components with the quality of parts	

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		1.3	These warnings help operators in making decisions or to recommend maintenance actions	Hybrid edge+ technical	Should	Decision support for enhanced operator support	
		2.1	Processed data must feedback sensors	DA-IA technical	Must	Helps improve the assessment of RUL	
		2.2	Verify input data is correct and accurate (data type, value range…)	DA-IA technical	Must		
		2.3	Check clusters, volumes and agents are deployed and have enough resources.	DA-IA technical	Must		
		2.4	System must be able to extract KPI features form production data	DA-IA technical	Must		
		2.5	System must be able to learn from press produced data	DA-IA technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		2.6	DA-IA conclusion on threshold and metrics must be consistent with inputs.	DA-IA technical	Must		
		2.7	System shall feedback production control subsystem (sensors, PLCs...).	DA-IA technical	Should		
		2.8	Data must be stored and updated as data lake keeps growing up.	DA-IA technical	Should		
		2.9	Results must be accessible by users	DA-IA technical	Must		
		2.10	System must be able to interact with press control subsystem.	DA-IA technical	Should		
		2.11	Feedback should be double check. If control is performed over any observable (stop of press, heat of oil...), it must be consistent with press capacities.	DA-IA technical			
		2.13	DA-IA outputs must be accessible on HMI. Data models must be accessible just by the data engineer.	DA-IA technical	Must		

Pilot	Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
		2.14	Latency on feedback might be crucial, as production will be control on real-time	DA-IA technical	Should		
		3.1	Translation between data formats and protocols should be possible by building converters over the Digital Enabler (Converter	Digital Enabler (Converter/Message Broker)	Must		
		3.2	Events on process and devices must be communicated by means of messages using the Digital Converter (message brokers)	Digital Enabler (Converter/Message Broker)	Must		

Expected results

- **Scenario 1**: apply new ZDM integrated solutions to demonstrate sensible reduction of defective, waste, work time and product prices, consolidating wheelset business unit market share.
- **Scenario 2:** Reduction in defective parts, monitoring input material properties, measuring during the transformation process and output piece properties; It will be possible to detect which processes are critical and should be prioritised to be controlled.
- Reduction in set-up time. Using ZDM algorithms, this process should be shortened leading also to a reduction in waste and scrap.
- Reduction in difficulties during assembly of parts. The quality of the product is the sum of their parts. Accumulated deviations can produce defective products even when their parts meet their quality parameters. Data sharing between the producers of the different parts should favour the reduction of waste and improvement of the quality of the overall product leading to a better final customer satisfaction and branding engaging.

Target ZDM through prediction of defects based on asset's deterioration rate and its impact on the quality of products.

- **AQ Detection and removal of defects in injection moulding at Kolektor the Pilot**

The aim of the pilot is to detect, possibly predict and remove the cause of the process failure as soon as possible, ideally in real-time. Real-time capability is a requirement in order to allow for process correction and optimization.

ZDM Equipment: Production line consisting of assembly line, robot assisted manipulation for visual quality control and moulding machines.

Table 12: ZDM Digital Enhancement for AQ detection and removal of defect in Kolektor's Pilot on Injection Moulding

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
Real-time injection moulding process monitoring control	Acoustic parameter monitoring, Visual quality inspection control, Thermo vision control, Universal Robots UR-10 robot (potentially UR-5), Industrial Data Space, Visual Components 4.0		Specify the numerical requirements placed on the software. Amount and type of information to be handled	General technical			
			Data analysis and support in decision making	General business			
			Database and data analysis	General technical			

Expected results

- Better understanding of moulding process, real-time detection and possibly prediction of failures based on advanced analytics and AI, implementation of feedback loop for troubleshooting
- Monitoring of machine parameters such as temperature, pressure, flow speed.
- Introduction of novel acoustic sensors for improved flow monitoring.
- Visual inspection of the moulded parts and the injection tools.
- Analysis of data and furniture of process markers to the decision-making system
- Automated adaptation of process parameters to reduce scrap rate.

- **Quality Management of Steering Gear based on Acoustic control at Pilot Thyssenkrupp**

The aim of the pilot is to solve acoustic quality problems in steering columns. By analyzing the deviations, the pilot wants to adjust the production parameters in order to stay within the allowed acoustic tolerances. The system is part of the control loop of the production line.

ZDM Equipment: Steering gears production lines, electric steering columns production lines and all workstations of the production line which possibly can be involved in the acoustic measure by changing some process parameters

Table 13: ZDM Digital Enhancement and Quality control on Steering Gear at Pilot Thyssenkrupp

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
Quality Management of Steering Gear based on Acoustic control	Functional requirements, user interfaces, hardware interfaces, software interfaces, communications interfaces, performance requirements.		Functional requirements	General technical		A system that defines trends in the acoustic results from the measurements made on the different assembly processes of a steering column.	
			Functional requirements	General technical		A system that corrects the instructions of the assembly processes to reach an acoustic level within the tolerances required by the standard.	

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
			User interfaces	General technical		User able to access product trends by activating and deactivating process parameters.	
			Hardware interfaces	General technical		New acoustic sensors will be integrated into the different modules as part of the pilot.	
			Software interfaces	General technical		Software able to read quality files without altering them on internal network from production line control computer.	
			Communications interfaces	General technical		An interface with the Beckhoff PLCs that control the production line is necessary.	
			Performance requirements	General technical		The data will be analogue and will have to be captured in a real-time system.	

Expected results

- Solution must be implemented as a step-in current production line.
- It must give root cause probabilities for each component of the assembly, machine can interfere with the measure, deviations have to be detected as clamping or tightening forces.
- Assembly process can also influence the acoustic of the part, upstream deviations can be detected and corrected by the measure

- **Trade space framework for AQ Manufacturing Systems' Design in Airbus Pilot**

ZDM Equipment: Aerostructure design use case with composite or metallic machining and assembly process using robots or humans

There is no updated documentation on ZDM Digital Enhancements or requirements for the Airbus pilot.

Expected results
• Process, methods and tools supporting Industrial System development process dans especially trade analysis. • Meta model standard. • Performance Indicators standards like OEE or OPE

- **AQ ZDM implementation for "Ceramic tableware Single-firing" at Riastone**

ZDM Equipment: Complete production line with Iso-Static pressing, abrasive trimming, finishing and edging, pre-cure warehousing, glaze preparation, tableware glazing, pre-firing product grouping, oven single firing, quality control inspection, sorting and packaging, warehousing and logistic dispatching

The goal of the RiaStone AQ ZDM Loop is the early detection of greenware defects that will originate recyclable product scrap. This includes automated fault detection, product inspection, removal of non-conformant products, information feed-forward for calculation of the line adjustments, translating instructions to machine language and automated adjustment of the production.

Table 14. ZDM Digital Enhancements for Ceramic tableware Single-firing.

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
Autonomous Quality ZDM for Ceramic tableware Single-firing	Functional requirements, user interfaces, performance requirements, other non-functional requirements		Functional requirements	General technical		System shall perform visual submillimetre inspection of newly pressed greenware.	
			Functional requirements	General technical		System shall compare the acquired digitalized image parameters.	
			Functional requirements	General technical		System shall compare the acquired data against a standard points matrix for conformity check.	
			Functional requirements	General technical		With positive matrix confirmation, the system shall confirm positive conformity and take no further action.	

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
			Functional requirements	General technical		With negative conformity, the system shall issue instructions for product removal from the production flow.	
			Functional requirements	General technical		System shall compare non-conformity with a standard data bank of non-conformity matrices and issue a judgement regarding needed machine adjustment.	
			Functional requirements	General technical		System local fog node shall issue an M2M instruction for production machine adjustment.	
			Functional requirements	General technical		System shall retake production cycle.	
			User interfaces	General technical		System has M2M interfaces with the production systems SS7 based.	
			Performance requirements	General technical		The system will have a 1 second cycle time for the full AQ measurement.	
			Performance requirements	General technical		Image acquisition of 20Mb/Image	

Pilot	Components	ID nr	Requirement	Type	Priority	Planned enhancement	Related requirements
						will be done in 1/10th second.	
			Performance requirements	General technical		Image processing will be done in 3/10th second.	
			Performance requirements	General technical		Machine instruction will be issued in 1/10th second.	
			Performance requirements	General technical		The remaining 6/10th second of the cycle time will be used for product positioning inside the inspection camera.	
			Other non-functional requirements	General technical		The system shall transmit to an external service server all collected images, which originate from non-conformant greenware for later defect root cause analyses.	

Expected results

- Implement a set of ZDM enabling systems that:
  - can raise early detection warning signals of production factors that will originate product defects
  - can suggest feed-forward or feed-backward controls and adjustments to neighbouring process areas which might have correction capability over the future course of overall production and will effectively increase OPE by helping the factory operator take correct process adjustment decisions and will increase FPY overall in the complete production lines

3.5.3 Other ZDM Autonomous Quality solutions

Quality control digital enhancements in Experimental Facilities intends to be a showroom of new technologies, not implemented at first place in any of the 14 pilots but while also being inside the scope of the QU4LITY project, thus, related to ZDM and Automated Quality. These technologies could be implemented to improve performance indicators of either a machine or a process, for any company in the path of digital transformation.

The description of the technology here is more generic than in most of the above cases, where specific end users require improvements on OEE, scrap reduction, etc. However, it is useful in the sense of constituting a solution for some of end users which are indeed QU4LITY beneficiaries, as well as for other companies from their very same industrial sector.

- Machine tool Quality Control operations

The Quality Control in machine tools is a process that has been traditionally performed off-line, outside the machining equipment. Currently, indeed, there is a lack of in-line solutions, and this means that the quality inspection with a CMM may only be performed at a laboratory outside of the production premises, with the impossibility to measure all the parts produced; thus, quality data becomes a mere statistical figure per batch. This is especially critical, having the biggest impact, for the machining of parts that will afterwards be utilised at demanding industrial sectors in terms of GD&T, such as Aeronautics or Automotive.

Furthermore, most of the times, the machined part is only able to be measured at the end of the process, where all the added value has been provided to the physical product, and, thus, resulting in a waste of time and energy if there is any error at the programming of the CAM, for instance.

This kind of solution consists in a digital enhancement of the machine tool, with the capability to act as a quality control equipment for dimensional inspection. Through this solution, the machine tool is allowed to feed back the information captured in real time to dynamically update the manufacturing process of mechanical components, thereby improving its direct control as well as the dimensional accuracy of the products obtained.

Therefore, additionally to the connector that enables the communication between the CNC and the Coordinate Measuring Machine, or CMM, a software solution for machine tool measurement is also presented. This software allows actions in order to verify the state of the machine, set it up and perform the measurement operations for 3-axes machines, with controls that incorporate open communication protocols, in semi-connectivity mode and for simple geometries.

This enhancement will be deployed at the AIC Experimental Facility, and its requirements are described below as if the case was the need of implementing this solution at a 3-axes machine pilot. However, it could also be implemented at scenarios inside QU4LITY, for example the +GF+ pilot, but, for that purpose, the

connectors and software should be adapted to operate at 5-axes machines to fulfil the necessity of the manufacturing of more complex geometries.

Table 15: Machine tool Quality Control operations

Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
M3MH. Functionalities: 1. CNC communication enhancement; 2. Part Data acquisition and GD&T parts digitization; 3. GD&T quality data storage and traceability; 4. GD&T statistical data analysis	1.1	Ensure the communication and interoperability with the machine tool control	C&C technical	Must	Developing a series of connectors that generate the conversion of instructions between DMIS code, typical of CMM machines, and the different CNC communication protocols	all
	1.2	Enable the manufacturing process reconfiguration to complete the vision of ZDM and Automated Quality	C&C technical	Must	Feed back the information captured in real time in order to dynamically update the machining process of mechanical components, establishing an active control loop between the CMM results and the CAM process	1.1, 5.all
	2.1	Capture of dimensional data from the part inside the manufacturing process	CPPS-related technical	Must	The sensor (touch probe) is connected mechanically with a piezoelectric that sends electric signals to the analogical input. Each of the electric signals is transformed into 3D coordinates and a normal vector	1.1

Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
	2.2	Digital reconstruction of the part from the point cloud (creation of the Digital Twin)	CPPS-related technical	Must	For the meshing of the point cloud, Poisson Algorithms are used to infer the topology of the surface and eliminate noise and discontinuities	1.1, 2.1, 3.all, 4.1
	2.3	Comparison of the meshed digitally reconstructed part (Digital Twin) with the CAD of the part	CPPS-related technical	Must	Implementation of OCC reverse engineering algorithms	2.1 and 2.2
	2.4	Visualization of the difference between measured part and	CPPS-related technical	Should	Some "colour mappings" could be developed in order for the user to quickly spot the difference of the manufactured part with respect to design tolerances	2.1, 2,2 and 2.3
	2.5	Automatization of the Quality Inspection process	CPPS-related technical	Must	Developing measurement plans via the calculation of probing paths	1.1, 2.all, 5.all
	3.1	Store the measured parts in the cloud	IoT-related technical	Must	Ensuring that the quality GD&T results are stored in an own module of the software, called M3 Server, which will be available to the customer	-
	3.2	Ensure traceability of the GD&T measurements	IoT-related technical	Must	QIF standard will be implemented, an information framework which is all-over interoperable and offers a unique code for the identification of parts	1.1, 2.all, 3.1, 5.all

Components	ID nr.	Requirement	Type	Priority	Planned enhancement	Related requirements
	4.1	Possibility to generate SPC reports of the part dimensions, in order to observe tendencies and enable decision-making	IoT-related technical	Should	-	1.1, 2.all, 3.all
	5.1	Adapt the M3MH software by UNIMETRIK for machines of 3- and 5-axes	Validation technical	Should	-	1.1
	5.2	In-line integration of the solution in a machine tool	Validation technical	Must	-	1.1, (5.1)
	5.3	Ensure the possibility of GD&T measurement in the middle of the manufacturing process	Validation technical	Should	-	1.all

Expected results

If implemented in a pilot machine, the expected results would be the following ones, qualitatively speaking:

Reduce the measurement time for the manufactured parts

- The system will need a lower time to align and prepare the part for the measurement process, and this will also result in a reduction on the overall time to inspect the part dimensions.

Adopt a fully Automated Quality ZDM approach

- The measuring software, integrated in the machine, offers the possibility to incorporate the dimensional inspection as part of the very same manufacturing process.

Decrease the time to manufacture the first correct machined part

- Thanks to the feature that is able to feed back the machining process for its reconfiguration after each measurement, less time will be needed to produce the first part of a new CAM design.

4. Conclusions

This deliverable is the second version of a description of the Specification of Digital Enhancement of ZDM Equipment. The deliverable gives a quite detailed enhancement description of the machine or manufacturing equipment covered in the project, like hot stamping machines, high precision machining and additive manufacturing. The focus on the process pilots is increased, in order to bring descriptions, digital enhancements and requirements closer to the machine pilots.

Enhancement of ZDM Equipment is for a machine or other manufacturing device a product improvement and in this way a product development issue. For a process pilot digital enhancement will focus on the manufacturing line and be specific for the pilot factory installation.

There is a disparity in the amount of documentation available for the process pilots compared to the machine pilots, and this also includes documentation concerning ZDM Digital Enhancements and requirements. All process pilots include complex additions to the current process lines, and a further emphasis on documenting these changes properly would bring the documentation for the process pilots more in line with the machine pilots. This would increase the ability to document and evaluate the progress in all pilots in a more thorough manner for the remainder of the project.

List of tables

List of Abbreviations

AI	-	Artificial Intelligence
AM	-	Additive Manufacturing
AQ	-	Autonomous Quality
BP	-	Business process
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CNC	-	Computer Numerical Control
Cpk	-	Process Capability Index
CPPS	-	Cyber Physical Production systems
CTQ	-	Critical to Quality (measuring metrics)
EDM	-	Electrical Discharge Machining
MTBF	-	Mean Time Between Failures
MTTR	-	Mean Time to Repair
NDT	-	Non-Destructive Testing
NPD	-	New product development
OEE	-	Overall Equipment Effectiveness
QM	-	Quality Management
RAMI	-	Reference Architectural Model Industrie 4.0
RUL	-	Remaining Useful Life
ZDM	-	Zero Defect Manufacturing

Partners: