DIGITAL MANUFACTURING PLATFORMS FOR CONNECTED SMART FACTORIES

D4.8 Equipment Digital Enhancement Assessment and Assurance Report

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Abstract:

This deliverable proposes a methodology for the assessment and assurance of the quality of the digital enhancements developed in the ZDM equipment in WP4 pilots. It gathers in a standardized manner the detailed technical verification and validation of the digital components for each machine pilot.

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History

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0.1	07/06/2021	Document creation	DAN
0.2	26/07/2021	First Version of Deliverable	DAN, SQS, GHI, FAGOR, UNIM
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1 Executive Summary

This deliverable is dedicated to the assessment and assurance of the quality of the digital enhancements developed in the ZDM equipment in WP4's pilots. Quality Assurance in the area of software engineering, encompasses two main processes: defining quality and assessing quality. Defining quality refers to the challenge of specifying the requirements, while assessing quality refers to the challenge of measuring the satisfaction of the requirements.

These processes will be supported in the QUALITY project through an "Enhancement Assessment and Assurance plan or Validation Plan". The purpose of this evaluation is to conduct a formative and summative evaluation of technological production and application. The deliverable starts describing the pilots and the implementation plan that have been worked in T 4.1. Then, the process and methodology proposed for the quality assessment and assurance is proposed. Finally, it includes the validation plan matrices for every use case. They describe the requirements for the enhancements and the acceptance criteria that has been used for each of them.

This is the final version of the deliverable. The document presents the completed validation matrices for each of the software components on the different machine pilots, gathering the results of the validation for the requirements that were defined in D4.7.

2 Introduction

2.1 Machine- Equipment Pilots within QU4LITY

The QU4LITY project demonstrates its data-driven ZDM product and related services in a combination of five strategic ZDM plug & control lighthouse equipment pilots (green) as well as nine production lighthouse facility pilots (orange). An overview of the pilots is presented in figure X, followed by a short description of each pilot.

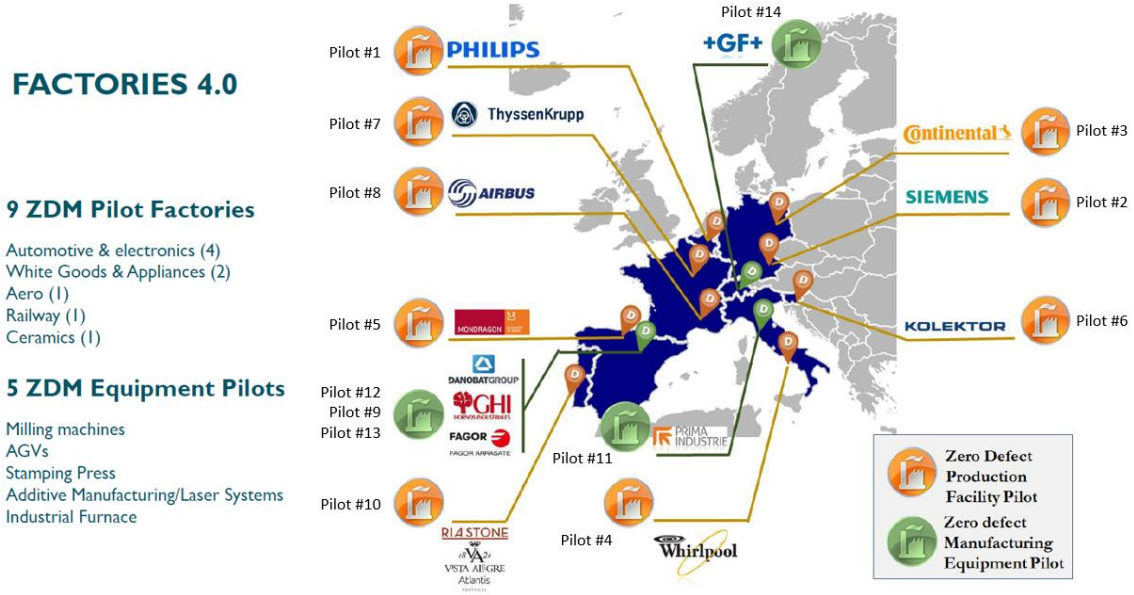

Fig 1: An overview of pilots part of the QU4LITY project

Pilot #1: PHILIPS OneBlade shaving unit production line
Pilot #2: SIEMENS SIMATIC Products Quality Improvements
Pilot #3: CONTI Autonomous Quality in PCB Production for Future Mobility
Pilot #4: WHR Dryer Factory Holistic Quality Platform
Pilot #5: Zero defect and Autonomous Quality in Machinery Building for Capital Goods sector
Pilot #6: KOL's Real-time injection moulding process monitoring-control
Pilot #7: THYS Quality Management of Steering Gear based on Acoustic control
Pilot #8: AIRBUS Trade space framework for Autonomous Quality Manufacturing Systems' Design
Pilot #9: GHI Real-time cognitive hot stamping furnace 4.0
Pilot #10: RiaStone Autonomous Quality ZDM for "Ceramic tableware Single-firing
Pilot #11: PRIMA Additive Manufacturing Pilot Adaptive Control Technology
Pilot #12: Danobat Digital Machine for zero-defects at high precision cutting/grinding
Pilot #13: FAGOR Zero-Defects Manufacturing Digital Press Machine
Pilot #14: GF Digital machine and part twins for zero defect manufacturing

The present deliverable is part of the Work Package 4, titled "ZDM Equipment Digital Enhancement for Autonomous Quality Operations", and is related to the lighthouse equipment pilots which are described in the following lines according to what has already been included in deliverable *D4.5 Implementation of Digital Enhancements of ZDM Equipment (Version 1).*

Pilot #9: GHI Real-time cognitive hot stamping furnace 4.0

Hot stamping is a current process for the manufacture of structural parts in the automotive sector. Hot stamping is a process by which a sheet is subjected to a load between two dies, while the entrance temperature of the sheet is bigger than the austenitisation temperature of about 900-950°C. This process takes advantage of the high ductility of the piece due to its high initial temperature and then proceeds to a rapid cooling to achieve the martensitic hardening of the piece. In the QU4LITY project the furnace (Rolling Beam Furnace "L Type") is of interest.

The furnace itself will become the main CPPS 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.

Pilot #11: PRIMA Additive Manufacturing Pilot Adaptive Control Technology

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

The goal is to implement new sensors into the machine and combine multimodal process data and machine data to deduce complex relationships between product quality and its influencing factors. This information will then be transferred to the fleet manager as well as in an augmented form to the operator.

Pilot #12: Danobat Digital Machine for zero-defects at high precision cutting/grinding

The system to be monitored is an LG machine available at the prototypes laboratory of DANOBAT used for the production of cylindrical parts. The function of the machine is to externally grind these cylindrical parts. The goal is to implement an architecture that delivers integration solutions in IoT-Edge-Cloud for condition-based maintenance and zero defect manufacturing based on vibration analysis and other continuous machine data.

Pilot #13: FAGOR Zero-Defects Manufacturing Digital Press Machine

The FAGOR pilot uses a hot stamping press machine (HHDD3-1200-3200-2500). Hot forming or press hardening is a process of metal forming, which allows forming high strength parts through quenching of boron steels heated above 950ºC. The goal of the enhancement is to get a process prediction based on data analytics of variables as well as new data analytics tools for predictive maintenance.

Pilot #14: GF Digital machine and part twins for zero defect manufacturing

The pilot will focus on a part of an automated cell and will be cantered in GF HPM milling series and FORM die sinking machines, which act in combination in applications in the mold and die production but also aerospace and automotive segments. Other main components of the cells are the Workshop manager software,

communicating with machines and FANUC robots for execution program implementation and monitoring. The goal of the enhancement is to set up a first digital system for detecting, diagnosing, and fully compensating deviations on accuracy, productivity and sustainability of a robotized machining cell. It is 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, zero defect manufacturing across the full chain.

2.2 Relation to other tasks and deliverables

The following figure shows the relations amongst the different work packages in the project:

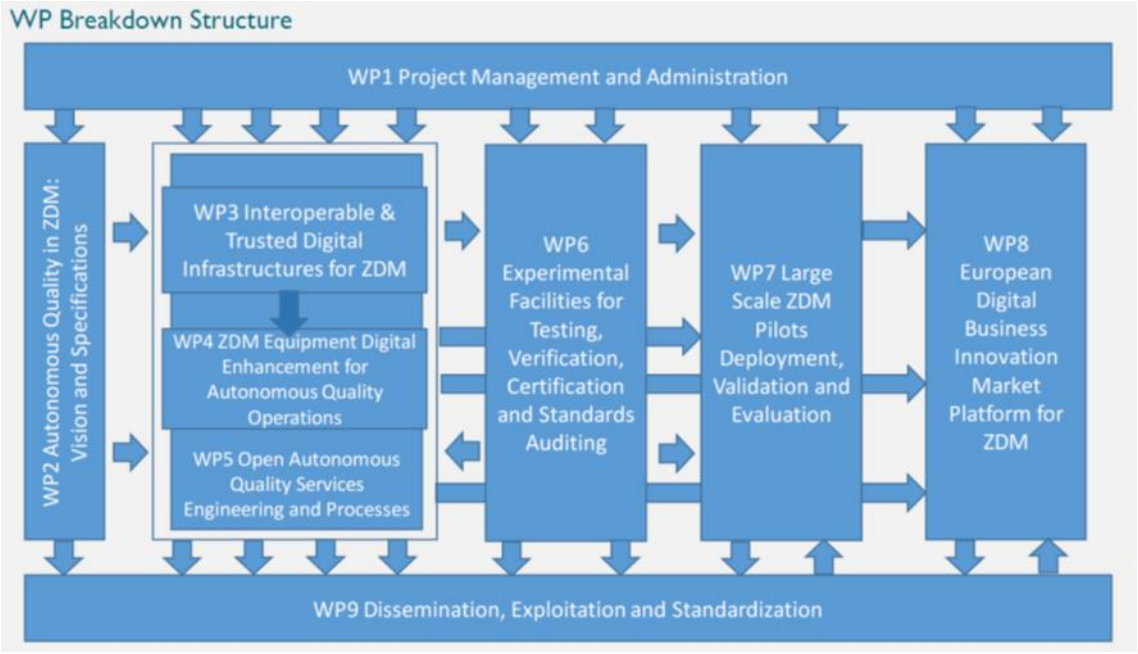

Fig 2: Visualization of the relation between the tasks

This deliverable is part of WP4 which main goal is to enhance state of the art ZDM equipment and machinery with digital capabilities. It is related to, and makes use of, several concepts also considered in other work packages and deliverables. The main relations are detailed below.

Following deliverables of the same work package that have already been submitted:

- **D4.1: Specifications of Digital Enhancements of ZDM equipment** focuses on the specification of the various types of Zero Defect Manufacturing (ZDM) equipment that can be digitally enhanced. ZDM equipment entailed in the QU4LITY pilots and experimentation activities are described in a generic way. For some pilots the digital enhancement can be quite complex operations. Especially innovation and development of complex manufacturing

equipment and enhancement of multiple process lines functionalities and in-line communication.

- **D4.3 Distributed Communication and Control Infrastructure** provides description of the Distributed Communication and Control Infrastructure of ZDM Equipment. It is the first version of the deliverable and the next version, the demonstrator, in relation to the further development of the QU4LITY project, will be presented in M21.

Other project tasks in other work packages that are listed below:

Task 2.1 User Stories and Analysis of Stakeholders' Requirements: This task will collect, document and analyze requirements regarding the excellence in ZDM. The requirements will be collected and analyzed based on a variety of different modalities, including direct interactions with stakeholders (i.e. manufacturers and their employees, quality management experts, providers of ZDM solutions, digital manufacturing solutions integrator), focus groups, collection of questionnaire-based feedback, documentation of user stories reflecting the viewpoints of different users (e.g., maintenance workers & engineers, production quality managers), as well as review of relevant project's and initiatives (e.g., projects of the 4ZDM cluster, H2020 FoF-09 projects on maintenance etc.). Interactions with stakeholders will be facilitated by the partners business networks, including clusters, associations (e.g., EFFRA) and DIHs where the consortium partners play a leading role (**D2.1 User Stories and Analysis of Stakeholders Requirements -** already submitted)

Task 6.3 Digitally enhanced ZDM Equipment Verification and Certification: "Proper processes for the testing of the digital features of each ZDM platform will be specified, including benchmarks against performance (i.e. latency) and scalability targets. Where appropriate, test datasets will be created and used.

Task 7.7 Business and Techno-Economic Evaluation: To perform business and techno-economic evaluation will define and track relevant manufacturing / DM indicators such as OEE, RUL (remaining useful life), equipment end of life (EOL), number of defects, order fill rate, manufacturing cycle time and more. Along with business indicators such as ROI (Return on Investment), IPR (Internal Rate of Return), NVP (Net Present Value), Payback and more.

Specially the following deliverables:

D4.5 Implementation of Digital Enhancements of ZDM

D6.3 ZDM Technologies and Equipment Testing and Experimentation (Version 1)

D6.4 ZDM Technologies and Equipment Testing and Experimentation (final Version)

D 7.3 Zero Defects Machines Pilots (Version 1)

D 7.4 Zero Defects Machine Pilots (Final Version)

D 7.9 Report on Stakeholders' Feedback and evaluation (Version 1)

D 7.10 Report on Stakeholders' Feedback and evaluation (Final version)

D7.11 Pilots' Techno-economic Evaluation (Version 1)

D7.12 Pilots' Techno-economic Evaluation (Final version)

3 Digital Enhancement Assessment and Assurance

Quality assurance in the area of software engineering, encompasses the two main processes of defining quality and assessing quality. Defining quality refers to the challenge of specifying the requirements, while assessing quality refers to the challenge of measuring the satisfaction of the requirements.

This processes will be supported in the QUALITY project through an "Enhancement Assessment and Assurance plan or Validation Plan. The purpose of this evaluation is to conduct a formative and summative evaluation of technological production and application. This deliverable is dedicated to defining the validation plan for the technological solutions that the work package 4 involves.

ESA Guide to software verification and validation [ESA, 1995][1] provides some other definitions for verification, such as:

- Act of reviewing, inspecting, testing, checking, auditing, or otherwise establishing and documenting whether items, processes, services or documents conform to specified requirements [ANSI/ASQC A3-1978][2].
- Process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of the phase [IEEE, 1990][3].
- Formal proof of program correctness [IEEE, 1990].

In addition, the guide includes tasks like: technical reviews, walkthroughs and software inspections; checking that software requirements are traceable to user requirements; checking that design components are traceable to software requirements; unit testing; integration testing; system testing; acceptance testing; audit.

Validation is, according to its ANSI/IEEE definition, 'the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements'. Validation is therefore, 'end-to-end' verification.

In summary, software verification and validation should show that the product conforms to all the requirements. The process of validation can be represented in the steps shown in Fig 3:Process of validation the present deliverable D4.8 corresponds to the final three steps.

[1] ESA PSS-05-10. Guide to software verification and validation
[2] ANSI/ASQC A3- 1978 Quality Systems Terminology
[3] IEEE 1990 IEEE Standard Glossary of Software Engineering Terminology

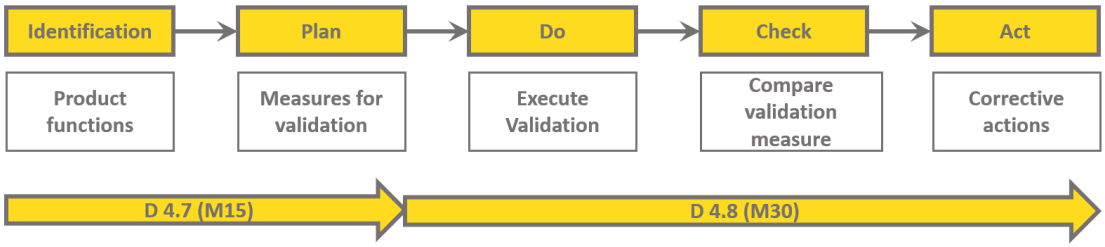

Fig 3:Process of validation

The following is a detailed technical verification and validation approach that the consortium members have performed during the project. The first deliverable **D4.7 *Equipment Assessment and Assurance Report (Version 1)*** gathered the general methodology and the specifications set by each of the pilots . The present deliverable ***D4.8 Equipment Assessment and Assurance Report (Final Version)*** shows the results of the verification and validation processes.

4 Requirements tracking and methodology

Methodology and general recommendations for the partners:

4.1 Requirements tracking

Tracking requirements is an important aspect of the software development process as it ensures that all of the requirements have been correctly considered and updated during each stage of the project. It's a decisive part, as it guarantees that the development team has covered every need and no functionality is missed out or left untouched, giving with this the stability and consistency to the final product and to each of its components.

Is the first part of the methodology and has been developed among the partners of the different use cases. The requirements will be classified by type and the source of it, the partner who defines it will be identified.

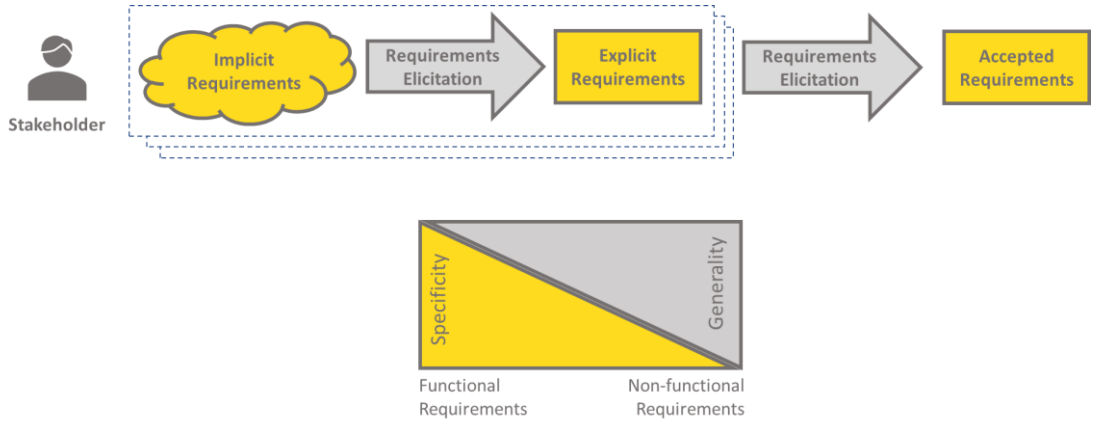

Fig 4. Process of defining requirements

The most common way of ensuring that there's a proper and full traceability is using a "Requirements Traceability Matrix". For the QUALITY project, we have integrated the requirements traceability in the "Verification Plan Matrix".

This matrix gives us a fast view and a total traceability of each requirements with the component that has to fulfill it and which test case we have to run in order to validate it.

Moreover, we include a traceability matrix of the digital enhancements of each equipment as defined in ***D4.1 Specifications of Digital Enhancements of ZDM Equipment.***

4.2 Requirements as user stories

In Agile[4] development, user stories are a brief and simple definition of a feature faced from the perspective of the one who desires a new capability, which is usually a user or a customer of the system. They have the following from:

> As a <type of user>, I want <some goal> so that <some reason>.

For example, a user story for searching on a website can be as follows:

> As a website user, I want to able to search on the webpage, so that I can find necessary information.

For the project, the consortium members are encouraged to employ user stories to define the requirements on a user-friendly way, and they are written on the "*Description*" column of the Validation Plan Matrix.

4.3 Acceptance criteria

For the QUALITY project, as well as with the user stories, the consortium members are encouraged to use acceptance criteria in order to describe the way to test and fulfill the requirements, that is, to specify conditions under which a user story (a requirement) is fulfilled. The acceptance criteria sentences are written on the "*Test case / Acceptance criteria*" column of the "Validation Plan Matrix".

For example, and following the example of the previous section, the acceptance criteria for searching on a website can be as follows.

> Given that I'm in a role of registered or guest user
>
> When I open the "Products" page
>
> Then the system shows me the list of all products
>
> And the system shows the "Search" section in the right top corner of the screen
>
> When I fill in the "Search" field with the name of existing item in the product list
>
> And I click the "Apply" button OR press the Enter key on keyboard
>
> Then the system shows the matching products in the Search Results section

The acceptance criteria will drive the verification of the requirements, as it enables individual requirement verification. Moreover, when possible acceptance criteria will be automated in continuous delivery pipelines. When not possible, manual inspection will be used to track the fulfillment of the requirements.

[4] https://en.wikipedia.org/wiki/Agile_software_development

4.4 Working methodology

As stated on 5.1 *Requirements traceabilit*y section, each Work Package has its own Requirements Traceability Matrix. The initial requirements are the ones that were described on **D4.1 Specification of Digital Enhancement of ZDM Equipment.** Hereafter, the way of updating the Requirements in the Validation Plan Matrix for each role is as follows:

- Every **pilot case partners** are in charge of updating, removing or adding the internal requirements. The internal requirements should be written using the User Stories style described above.
- Every **pilot case leaders** are also responsible for updating the *Test Case / Acceptance Criteria.*

5 Verification and validation

It is convenient to recall the difference between the verification (technical) and the validation (user):

- Verification (technical): to establish the truth of the correspondence between a software product and its specification. "Am I building the product right?" → The software should adjust its specification
- Validation (user): to establish the fitness or worth of a software product for its operation al mission. "Am I building the right product?" → The software should do what the customer requires

5.1 Verification methodology

Software verification is required to ensure the software quality and is a key phase in the software development life cycle. For ease of understanding we can summarize it with the question, "*Am I building the right product?*"; that is to say, "*does the software satisfy its specification*"?

The software verification for the QUALITY project is focused on the development of the components that are described on the following subsections. Every pilot case should decide how to run these test . There are several tools that can be used in these verifications we cite as an example the Jenkins tool[5] for executing pipelines .

The flow for the software verification is as follows:

Fig 5: Software verification tests

5.1.1 Unit tests

A unit test is a way of testing a unit, the smallest piece of code that can be logically isolated in a system ensuring that the units are individually and independently scrutinized for proper operation.

The main pillars of unit testing in QU4LITY are the following:

- Developers are encouraged to develop as many unit tests as possible to cover as much code as possible.
- Write tests before the code is written, after, or a combination of both strategies, is a choice that is left of each development team.
- Code coverage metric should be used in order to track the amount of covered code. This will be measured using automatic code coverage reports from specific add-ons of our CI system.

[5] Pipeline development tools. https://jenkins.io/doc/book/pipeline/development/

The unit tests will provide the completeness metric. In software quality assessment this can be measured using code coverage. Said that, completeness should be measured using an automated code coverage plugin integrated into de CI server.

These tests are performed, for example, on the "*Build - Test stage*" of the Jenkins Pipeline.

The following example shows a unit test performed by a Virtual Data Container (VDC) Repository Engine, a Java-based developed component. It uses Maven as a build automation tool for building and running all the unit test classes.

```
stage('Build - test') {

    agent {

         dockerfile {

                filename 'Dockerfile.build'

         }

    }

    steps {

         // Build and store artifact

         sh 'mvn -B -DskipTests clean package'

         archiveArtifacts 'target/*.jar'


         // Run unit tests

         sh 'mvn test'

    }

}
```

If any of the unit tests fails, the Jenkins pipeline stops, and the developer gets instantly notified via email, so he can fix its code errors as soon as possible.

5.1.2 API validation test

In case the solution uses an architecture that requires it, APIs should be tested.

In order to check that the API is implemented according to its definition file, tools like Dredd[6], a language agnostic command-line tool can be used. *Dredd* reads the API description from the definition file and step by step validates whether the API implementation replies with responses as they are described in the documentation.

[6] https://dredd.org/en/latest/

Using this tool enforces the developer to have the API documentation up to date, ensuring also and up-to-date API documentation for the users.

The following example shows a API validation test performed by a VDC Repository Engine, using Dredd as explained above. The VDC Repository Engine component container is running on the Staging machine (31.171.247.162) and it serves on the port 50009. The validation of the API definition happens against this endpoint.

```
stage('API validation') {

    agent any

    steps {

         sh 'dredd VDC_Repository_Engine_Swagger_v2.yaml.yaml http://31.171.247.162:50009'

    }

}
```

If the API validation fails, the Jenkins pipeline stops and the developer gets instantly notified via email, so he can fix its API definition as soon as possible.

5.1.3 Integration Tests

Within the integration tests, multiple and bigger units in interaction are tested to ensure the consistency and interoperability between integrated components. This level of testing exposes faults in the interaction between integrated units.

To plan de integration test of each component, components diagrams can be used as starting point in order to see dependencies between components

The following example shows an integration test performed by VDC Repository Engine component, which uses, as it is Java-based component, the Maven Failsafe plugin to simplify the action and to fire the corresponding integration tests.

```
stage('Integration tests') {

    agent any

    steps {

         sh 'mvn verify'

    }

}
```

If the integration tests fail, the Jenkins pipeline stops, and the developer gets instantly notified via email, so he can fix its dependency problems as soon as possible. The failed component is not deployed downstream so will never reach the Staging or Production servers.

5.2 Validation methodology

The validation methodology for the QUALITY project, which leads us to meet the project requirements in the most efficient and effective way, contains three different levels:

- *General validation:* Validation of requirements that are common for the whole architecture or solution.
- *Component level requirements validation: For each of the components in which the solution can be divided.*
- *Validation against project objectives:* How we validate the project objectives set in D4.1.

5.2.1 Validation Matrix

As stated on the previous sections, using the matrix we have requirements written on the "*Description"* column for each Work Package. These requirements are fulfilled by one component, which is declared on the "*Component that fulfills it*" column of the same matrix. Finally, this component is tested using a concrete acceptance test. If the test passes, the component gets validated. We can summarize the components validation with the following figure.

Fig 6: Component Validation Flow

Each acceptance test provides enough information to run the test. Depending on the nature of the test, it will be run automatically or manually. All the information regarding acceptance tests is detailed on the present deliverable.

5.2.2 Validation criteria

Validation criteria are set by each partner and should consider system tests and user acceptance tests

5.2.2.1 *System Tests*

System tests are performed from a functional perspective to check the system against requirements. System test are crucial for validating the behavior of the components when critical actions are required from framework.

Systems tests must be designed and executed following these rules:

- Each requirement for each component must have at least one system test.
- To speed up systems testing design, a test could cover more than one requirement whenever possible.
- Traceability Matrix must be updated when a system test is designed.

Performance requirements could contain quantitative statements about system performance. They may be specified by stating the:

- worst case that is acceptable;
- nominal value, to be used for design;
- best case value, to show where growth potential is needed.

Performance tests will derive in the assessment of a main metric, scalability. Scalability is about how system performance grows with adding more re-sources or the ability to accommodate rising resource demand gracefully. Scalability can be measured in response time, throughput or resource usage levels.

Developers will make its own acceptance testing along the whole lifecycle, ensuring that the product that reaches the end users for definitive testing is fully functioning. Some of the most relevant capabilities tested should be reliability and security. Reliability can be defined as a set of attributes that bear on the capability of software to maintain its level of performance under stated conditions for a stated period of time [ISO/IEC 9126][7]. The system or software should be able to maintain its performance level under given conditions.

On the other hand, in QU4LITY, security is clearly focused on ensuring confidentiality, integrity, availability and authenticity of stored data. Scenarios where violations of security policies are enforced should be used to check framework behaviour in these situations.

5.2.2.2 *User acceptance tests*

The User acceptance tests, as the name suggest, are processes for verifying that a solution works for the user. Each use case defines a set of business requirements, that is, what they need from the software. These requirements cover different types of categories, such as performance or availability. Furthermore, they define test cases or acceptance criteria in order to validate these requirements. We consider that if this happens, the user acceptance tests are successfully passed, as they requirements are met.

User Acceptance Tests consist of a set of test steps, which verify if specific requirements are working for the user. In QU4LITY, User Acceptance Tests should be driven by the real world case studies that will demonstrate the usefulness of the outcomes.

We can summarize the user acceptance tests with the next figure, where the application of the use cases (which is using the QUALITY framework) have some requirements. These requirements get fulfilled if the acceptance test gets accomplished, therefore, the application using QUALITY meets the user requirements, so the user acceptance tests are passed.

[7] https://es.wikipedia.org/wiki/ISO/IEC_9126

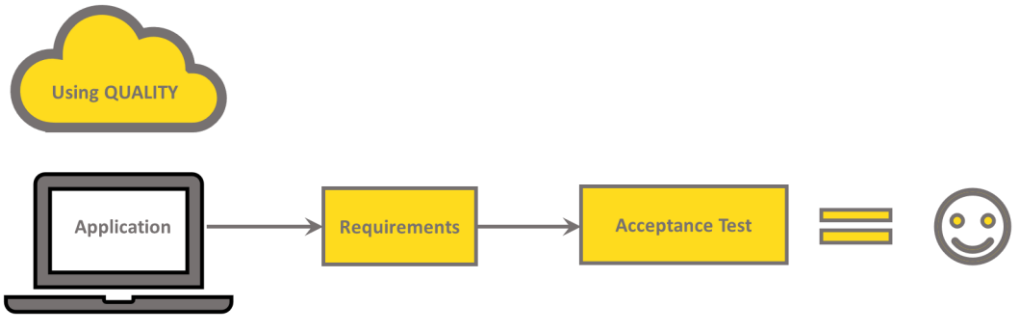

Fig 7: Validation against use cases flow

6 Pilot Use Cases Requirements Validation

6.1 Pilot Case #9: GHI Real time cognitive hot stamping furnace 4.0

6.1.1 Software Components

This is the structure followed to represent the digital enhancement's: Pilot/component/subcomponent. In the case of GHI the system is just divided into components.

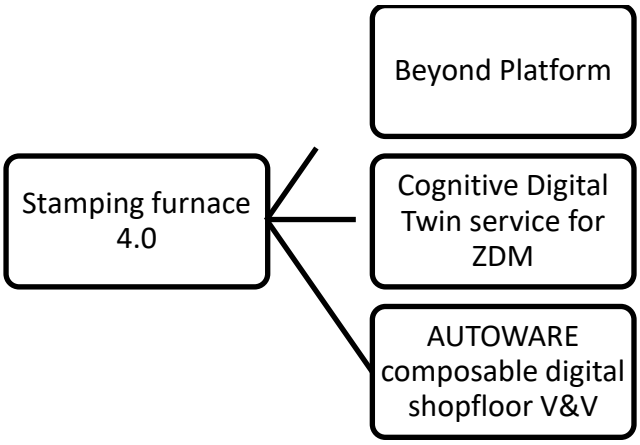

Fig 8: Components in GHI machine

COMPONENT	SUBCOMPONENT	MAIN STAKEHOLDER	INVOLVED PARTNERS	DESCRIPTION
Beyond Platform		GHI	GHI	Through the implementation and integration of the Beyond Platform on the rolling beam furnace, GHI will be able to collect a large amount of data that will be monitored and analyzed with advanced Big data tools developed by the 4.0 engineering team. Knowing the behavior of the equipment and through the development of algorithms, it will be able to control the process and plan the preventive and predictive maintenance interventions.
Cognitive Digital Twin Service for ZDM		INNO	GHI, SQS	Cognitive Digital Twin (CDT) augmentation and intelligent companion of the physical twin as whole including sub-systems and across life-cycles and evolution phases of ZDM. These means the connection of furnace DT with the stamping machine DT through a Cloud based IOT (brokering, interoperability & complex event processing), Data analysis (data storage, data analysis) and Data visualization system.
Autoware composable digital shopfloor V&V		SQS	INNO, GHI	It's a solution for composable digital automation shop-floor verification & validation doing the integration and seamless interworking of the digital enablers of the autonomous quality paradigm. It will be used in this context of the GHI pilot, to ensure the trustworthiness of the interoperability of the Beyond4.0 Platform.

6.1.2 Validation Plan Matrices

6.1.2.1 ***General requirements of the system***

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Should	Technical	Functional/ Infrastructural/ Interoperability	INNO	Deploy a common data space, for furnace and press installations to allow to correlate secured, standardised and referenced information from both machines.	Some tests will be performed using Orion Context Broker as the space to share industrial data from the press and the furnace in order to find correlations.	NO	This test will be carried out at the end of the project and reported in WP7.
R1.2	Should	Technical	Functional/ Infrastructural/ Performance	INNO	To provide a high-speed (real-time) edge-powered furnace control platform.	Some tests will be performed with M3BOX (Edge Device), regarding connectivity and data gathering speed.	YES	The tests proved that thanks to M3BOX, communication between different modules benefit in terms of flexibility and latency. M3BOX allows you to use data in three ways: at the edge, on the local server of the company or remotely on the server in the cloud. It also provides centralized management to the system. Machine software updates have proven to be possible without the need to be on site. The communication and integration of pressure or flow sensors, has also been tested.
R1.3	Must	Technical	Functional/ Performance	GHI	A deep streaming analytics framework for real-time analysis and smart learning engines for correlation of part defects, press	Some algorithms will be developed and trained with the data gathered from both equipment.	YES	Through the Data Gathering System, all the data collected from the IoT elements integrated both in the furnace and in the press are processed, incorporating a series of

					parameters and optimum furnace parameter selection.			connectors that manage to ingest all the relevant data.
R1.4	Should	Technical	Functional/ Performance	GHI	A big data simulation-based framework to optimize part heating profiles in the furnace and temporal temperature variations in the hot stamping process.	Some algorithms will be developed and trained with all the new data that will be gathered through the IoT devices integrated on the furnace.	YES	Advanced algorithms for control and data processing and analysis have been developed, both at PLC signals and at higher levels, implementing them in the Software. In this way, in this validation advanced signalling algorithms for PLCs have been integrated and tested, both at the isolated programmable control system level and at the SCADA level, as well as advanced calculation algorithms capable of supporting big-data and data mining processes, thus contributing to the optimization at machine level and the discrimination of defective parts.
R1.5	Should	Technical	Functional/ Performance	GHI	Transform semantic data models for the furnace operation into learning algorithms for the furnace control.	New algorithms will be trained in order to have the capability to generate orders to the furnace control operation in order to make it more autonomous.	NO	This test will be carried out at the end of the project and reported in WP7.
R1.6	Must	Technical	Functional/ Performance	GHI	The implementation of the control platform requires the hot stamping process to be optimized, and therefore, the manufacture of defective parts should be greatly reduced.	Due to the implementation of more IOT sensors on the furnace, simulation-based models and data analytics, efficiency on the furnace regulation system will be improved.	NO	On behalf of GHI, coming from the data analysis they have been working on, valuable information for improvements and optimizations of the hot stamping process has been gained and seen at the testing activities, as for example: A lack of heating power in the first areas of the furnace.

								There's some heterogeneity on the furnace temperature. The high impact produced by small stops on the line. Inability to maintain the dew point on the furnace.
R1.7	Must	Technical	Functional/ Performance	GHI	Improve decision making efficiency thanks to the analysis & visualization tools.	Different kind of end user roles will test the visualization tools and measures will be registered about decision making.	YES	The visualization of the raw data is done through tools based on Visual Basic where the complete list of variables is available, selecting up to five plotting environments and a single time range.
R1.8	Must	Technical	Functional/ Performance	GHI	Fast detection of root cause of quality problem.	Different kind of end user roles will test the visualization tools and measures will be registered about the time to find and solve operational problems.	YES	A series of pilot plants have been agreed in which to carry out the different tests to verify that the results of the implementation of the platform are really effective and that the objectives set are being met. Once full implementation in the pilot plants has been achieved, the study will be extended to as many lines as possible.
R1.9	Must	Business	Functional/ Performance	GHI	To obtain an extensible, scalable and customizable system that could be adapted to other processes.	By the end of the project, it will be checked if the platform solution can be replicated on other kind of furnaces.	NO	This test will be carried out at the end of the project and reported in WP7.

6.1.2.2 ***Requirements for Component #1 Beyond Platform***

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R2.1	Must	Technical	Functional/ Performance	GHI	The data volume should be not that large so that the data ingestion system does not crash, taking into account the hardware processing capacities.	Approximately, 30 floating-point values per unique timestamp will be registered from the different IoT sensors integrated on the industrial furnace, which do not form such a large volume.	YES	The synchronisation system was activated, achieving synchronisation speeds of less than one record per second, so that the data acquisition rate is slower than the sync rate. Initial estimates suggest that the system would be capable of updating in the event of a desynchronisation at a rate of 30 records/second.
R2.2	Must	Technical	Functional / Infrastructural	GHI	Remote data access should be achievable in order to be able to analyse and manipulate it from the GHI 4.0 Engineering service headquarters.	Agents will be deployed locally permitting remote access to the data via VPN tunnels.	YES	To generate an "internal cloud" of capture equipment with the server, a VPN tunnel concentrator solution has been chosen. The connection equipment architecture requires a hub connected to the data server that listens. Each of the client routers establishes the connection through the internet, addressing the public IP where the server is hosted. IPSec and OpenVPN are used to establish the tunnel, generating the private and public keys that are loaded on the devices. Once the connection is established, the data capture PC and the server are able to see each other and, therefore,

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								synchronization between both databases is possible.
R2.3	Must	Technical	Functional / Performance	GHI	Low latency on data transmission in order to be able to monitor data near real-time.	The PLC located in the industrial furnace will gather data every second.	YES	The study interval selector algorithm defines, based on the input data, the study time interval that will make up the calculation dataset. It is not particular for each oven, since the criteria are shared. The information is synchronized in real time with the server through the VPN connection established with the server. The objective of the test is to verify that the latency of the RT algorithms does not exceed a logical time value for the time-stamps analysed, that is, that there is not excessive difference between the moment analysed and the moment in which it occurs. the result. For this, the algorithms have been started in RT in such a way that they overload the microprocessor of the central computing unit to the maximum. The algorithms run making the microprocessor at no time exceed 30% capacity (indicate that the microprocessor used is very high-end, from 14 cores to more than

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								3.8 Ghz). With this workload, the computation time does not exceed 5 seconds at any time, being more than acceptable for the current utility that is being given to the system. The systems were activated and it was checked that the latency was acceptable, storing all the variables in less than a second, an acceptable resolution for the studies to be carried out. The storage of the data locally was also carried out without problems, with a buffer capacity of more than 5 days.
R2.4	Should	Technical	Functional / Performance	GHI	Ensure that no noise or incoherent data is introduced in the system.	Some filters will be applied according to the GHI expertise (values out of range, manipulation of data according to other data sources value combination…)	YES	The objective of this test is to verify that the algorithms that run in real time on the collected data do not have an abrupt stop due to a failure or anomaly in the received data. For this, incoherent data have been entered and data gaps have been generated that prevent the algorithms from obtaining reliable results. Faced with the appearance of anomalies that induce errors in the algorithms, the system writes the events that have produced the

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								failure on a log and automatically restarts. This cycle repeats until the data is consistent and no error occurs. The results that are extracted are the last with consistency. The algorithms do not stop and absorb the error, they continue their operation until there are coherent values that allow to emit information in the same coherent way.
R2.5	Must	Technical	Functional / Performance	GHI	Ensure that no data is lost when transferring data to the GHI server, if there is a loss of network connection.	The industrial PC will also act as a temporal repository and will be synchronize as a temporal BBDD.	YES	There is an industrial PC connected via ethernet to the PLC, where the data connection, capture and storage software is housed. Standard libraries are used for the connection with the PLC and the frequency, starting pointer and length of the data frame to be acquired are programmed, as well as the database where that frame will be stored. The capture database is structured with a single table with four columns, containing the timestamp, analogue frame, digital frame and synchronization indicator.

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								A synchronization of databases is also programmed, because the present one acts as a buffer and temporary repository of the same against loss of connection with the server. The information is synchronized in real time with the server through the VPN connection established with the server.
R2.6	Must	Technical	Functional / Performance	GHI	Testing and validation of the algorithms developed	Intermediate visualizations of the results provided by the algorithms will be carried out in the Shiny environment, within R. The evolution of the data obtained will be contrasted with that of the raw data by an expert.	YES	The code validation phase involved the development of intermediate visualizations in the Shiny environment, within R. The evolution of the data obtained was contrasted with that of the raw data by an expert in the machine and process, who is the one who declares the validity or not of the results obtained, leading to a new iteration or standardization of the generated code.

6.1.2.3 *Requirements for Component #2 Cognitive Digital Twin Service for ZDM*

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULT
R3.1	Must	Technical	Functional/ Privacy/ Interoperability	INNO	There is a need of availability of furnace and press data to test the component	For firstly develop the system adapters and test the whole data flow process until its publication in the Orion Context Broker.	YES	The data obtained through the sensors for process and machine control are collected under the OPC-UA standard. In this way, these data sources reach you, which to carry out the sharing of the same safely through the IDS connector, this is based on the Fiware technology of the Orion Context Broker through a publication / subscription system.
R3.2	Must	Technical	Functional/ Privacy/ Interoperability	INNO	Two different data sources that should be stored and contextualized in a common data space.	With the development of an IDSConnector, it will be possible to feed data from both equipment, using system adapters from OPC-UA to NGSI in order to allow the contextualization of both data sources through Orion Context Broker.	YES	In order to properly contextualize all data sources, Orion Context Broker works based on a single standard (NGSI). For this reason, this IDS connector developed includes an adapter, which allows transforming this data in OPC-UA formats into NGSI formats.
R3.3	Must	Technical	Security/ Privacy/ Interoperability	INNO	There should be a management system to control the data published on the OCB.	IDS connectors are based on the LUCON framework for Logic Based Usage Control. These means that IDS connectors may have the ability to document and control data usage.	YES	The usage control of the system enables Data Providers to attach usage policies to data sources or items in order to define how a Data Consumer may use the data. The usage control model declaratively states the restrictions on processing and exploitation of transferred data

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULT
								enforced on the side of the Data Consumer. In line with the central aspect of ensuring data sovereignty, a data owner in the IDS may attach usage restriction information to its data before it is transmitted to a data consumer. The data consumer may use this data only if it fully agrees to that usage policy.
R3.4	Must	Technical	Security/ Privacy/ Interoperability	INNO	The data sharing process must provide the guarantee of being reliable and secure.	IDS connector presents the guarantee of a trustworthy data exchange, as each component is certified, verifying the implementation of generally accepted safety standards and mechanisms and also can be identified.	YES	The enabler has been developed following strategic requirement of the IDS to provide secure data supply chains (i.e., to ensure a high level of protection and confidence when exchanging data between participants). The Security Architecture of the provides means to identify participants, protect data communication, and control the usage of data, even after the data has been transmitted to a Data Consumer. For these purposes, the IDS offers a Trusted Connector on top of the Base Connector. The Trusted Connector ensures the validity of the Security Architecture and its related concepts. To ensure confidentiality and authenticity of the data transmitted, communication between Connectors must be protected. When using the

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULT
								Trusted Connector, two layers of security are in place: point-to-point encryption (between Connectors), using an encrypted tunnel, and end-to-end authorization: authenticity and authorization based on actual communication endpoints
R3.5	Must	Business	Security/ Privacy/ Interoperability	INNO	As data sources come from different machines operated by different stakeholder, the ownership of the data should be clarified.	Previous to the exploitation of this data, all stakeholders must agree with the idea that the metadata created can be freely used between them, but that the ownership belongs to the shopfloor.	YES	The IDS covers the topic of data ownership by providing a secure and trusted approach for authorization and authentication within a decentralized architecture, where Data Providers as well as Service Providers can be identified and controlled by an Identity Provider. Decentralized data exchange through Connectors, in contrast to other architectures of data networks (e.g., data lakes), ensures full sovereignty over the configuration of data offerings on the part of IDS participants. In addition to these self-control mechanisms, the architecture considers clearing and logging of data transfers through a Clearing House.

6.1.2.4 *Requirements for Component #3 AUTOWARE Composable Digital Shopfloor V&V*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R4.1	Must	Technical	Functional /Interoperability/ Reliability /……	SQS	Ensuring both transmission and quality of data	Interoperability between the data sources, components and devices must be ensured.	YES	This requirement is fulfilled through the use of IDS. The IDS promotes interoperability between all participants based on the premise that full self-determination with regard to one's data goods is crucial in such a business ecosystem, and that misuse on the customer side has to be restricted. The Governance Perspective of the Industrial Data Space defines the roles, functions, and processes from a governance and compliance point of view. It defines the requirements to be met by an innovative data ecosystem to achieve corporate interoperability.
R4.2	Must	Technical	Functional /Interoperability/ Reliability /……	SQS	With the introduction of some IoT sensors on the furnace, it should become a plug & produce enhanced equipment	All these functionalities will be tested and certified	YES	The Certification Scheme of the Industrial Data Space defines the processes, roles, objects, and criteria involved in the certification of hardware and software artifacts as well as organizations in the IDS. Certification or components evaluates compliance with other requirements defined in the Reference Architecture Model. This section provides an overview of how the central entities and roles defined for the Reference Architecture Model are linked with the Certification Scheme. After a

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								general description of how certification affects the different layers of the Reference Architecture Model, this section discusses which roles are in charge of carrying out the certification process, which entities and components are targets of the certification process, and how both sides interact with each other.
R4.3	Should	Technical	Functional / Performance	SQS	Beyond platform services, as visualization tools, must be optimally operational to be functional for users	The definition of tasks and the development of both functional and acceptance tests will be coordinated.	NO	This test will be carried out at the end of the project and reported in WP7.
R4.4	Should	Technical	Functional / Performance	SQS	Proper operation of the M3BOX to ensure data sharing.	The definition of tasks and the development of both functional and acceptance tests will be coordinated.	NO	This test will be carried out at the end of the project and reported in WP7.
R4.5	Must	Technical	Functional / Privacy / Security	SQS	Ensure that only the desired part of the dataset is shared on the Orion Context Broker	Code will be checked and tested in order to ensure that only the chosen data is shared on the Orion Context Broker.	NO	This test will be carried out at the end of the project and reported in WP7.

6.1.3 **Project Objectives validation plan**

(For Traceability with D4.1)

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
PO 1.1	Integration of advanced IoT sensors	To convert an isolated machine into a plug and produce equipment to be connected with the whole process.	Plug and Produce equipment.	Beyond Platform	R1.6, R2.1, R2.3,
PO 1.2	Deployment of a Big Data solution platform around the industrial furnace.	Plug and Produce equipment. Equipped with an intelligence system for	Data Analytics for condition monitoring of the furnace operation.	Beyond Platform	R1.4, R1.5, R1.6, R1.7, R1.8, R1.9 + R2.(all)

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
		autonomous control to optimize its operation	Reduction of defective parts production.		
PO 1.3	Connect and correlate furnace data with press data for a smart closed loop monitoring & control.	Data gathering from both equipment. Data sharing and contextualization of data. Correlate furnace and press operational data.	Data Analytics for condition monitoring of the hot stamping process. Reduction of defective parts production. ZDM target.	Beyond Platform	R1.(all) & R2.(all)
				Cognitive Digital Twin Service for ZDM	R1.1, R1.2, R1.3 & R3.(all)
				AUTOWARE composable digital shopfloor V&V	R1.1, R1.2, R1.3 & R4.(all)

6.2 Pilot Case #11: PRIMA Additive Manufacturing Pilot Adaptive Control Technology

6.2.1 Software Components

Digital enhancements: Pilot/ component/subcomponent

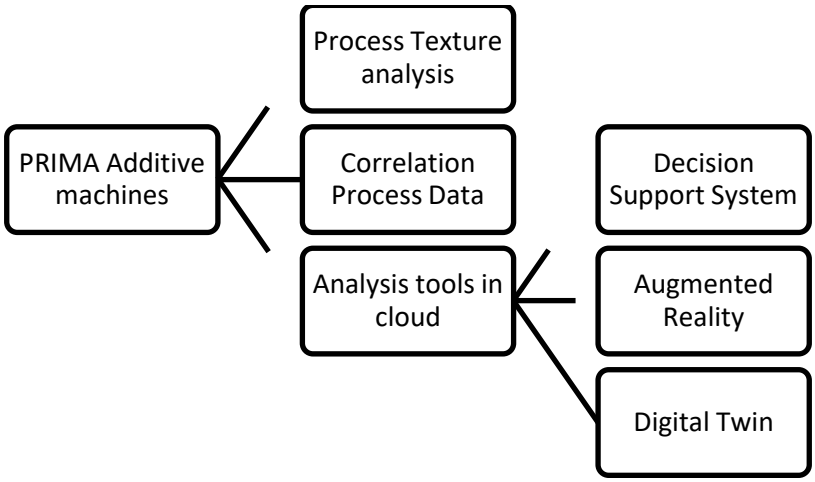

Fig 9: Components in PRIMA machine

COMPONENT	SUBCOMPONENT	MAIN STAKEHOLDER	INVOLVED PARTNERS	DESCRIPTION
Process Texture Analysis	----	PRIMA	Fraunhofer ILT Fraunhofer LTD	Fraunhofer ILT will take care of the sensors integration and online image processing for surface roughness estimation on the edge as well as the control of the machine at field level while Fraunhofer IGD provides interactive visualization of the sensors data
Correlation of process Data	----		Synesis	The data relating to the machine and status of process will be collected and analysed in first instance by Synesis at the edge level, in order to extract useful information from first rough data, such as energy consumption, status of the optics, filter, powder bed
Analysis Tools in cloud	Decision Support System		Atlantis	The DSS element manages zero-defect processes, by filtering out false alarms originated from predictive analytics; incorporating semantic rules and rule-based engine to cope with detected/predicted defects; providing recommendations for performance improvements, based on KPI assessment and dashboards
	Augmented Reality		VTT	Augmented Reality for training, work assistance, maintenance and other info
	Digital Twin		Technology Transfer System	Simulation framework for process simulation and integrated virtual commissioning. This QU4LITY's Pilot envisions both specific AM process simulation, in terms of material deposition mock-up, and system simulation, based on a discrete event engine, towards zero-defect manufacturing.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Business	Security	Prima	Respect privacy requirements (such as GDPR compliance)	Check there are mechanism in place to fulfil GDPR demands	YES	No sensitive data collected from the operator
R1.2	Must	Technical	Reliability	Prima	The platform should be easy to maintain with adequate version updating mechanisms, version control and document sharing systems amongst developers	Use mechanisms for version control and documenting . .	NO	This test will be carried out at the end of the project and reported in WP7..
R1.3	Must	Technical	Interoperability	Prima	The different components of the system should be able to connect to each other to transfer data in different formats and directions	Experimental testing through testing examples of data flows amongst components	NO	This test will be carried out at the end of the project and reported in WP7.
R1.4	Should	Technical	Reliability	Prima	Software quality should be tested	Unit test, API validation tests and integration tests will be implemented in the different stages of software development.	OFFLINE ONLY	The AR instructions APP, Time Estimation, DSS and Qu4lity Visualizer have been developed and tested offline, with real case studies and very good results in terms of time prediction in particular for the Time estimation App
R1.9	Must	Business	Functional	Prima	The system should be able to monitor analyze and extract features that allow to act avoiding problems in real time	The validity of the extracted data for avoiding problems will be checked through the validation of reports and diagnosis results provided to the user.	LAB ONLY	First evaluation of the vision-based in-line surface inspection tool has been carried out using LPBF machines at ILT. Next step is to integrate the system into PRIMA machines and evaluate it in the final use case including interoperability tests. Due to the Covid-19 situation and the resulting travel restrictions, on-site integration work at PRIMA was not possible. We expect to resume this work in fall/winter 2021.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.11	Should	Business	Functional	Prima	The system should not be expert dependent it should be intuitive and easy to use	This will be checked through qualitative evaluation of the received information by the end user. Usability tests by end user	YES	First demo using AR application with expert and not expert operator
R1.12	Must	Technical	Reliability	Prima	Data quality	During the project lifetime, test the data against different data quality dimensions, such as, accuracy, completeness, consistency, integrity, timeliness, etc.	YES	Testing data reading and accuracy within the TTS time estimation app

6.2.2 Validation Plan Matrices

6.2.2.1 *General requirements of the system*

6.2.2.2 ***Requirements for Component #*** Process Texture Analysis

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R2.1	Must	Technical	Functional	IGD	Modular adaptable signal processing system that can operate to RAMI standards on the edge for data-driven online quality assessment	The complementation of the standard will be doubled check though specifications an real implementation comparison	YES	The visualization tool is capable to interface with MQTT broker systems wherever they are deployed (either cloud or edge nodes are supported).
R2.2	Must	Technical	Functional	IGD	Connectivity to MES and control systems	The connection will be tested during the demonstrator implementation period	ONLY OFFLINE	The visualization tool embeds an MQTT client managing message exchange with

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								the other tools and systems of the Prima pilot.
R2.3	Must	Technical	Functional	IGD	Interaction with data space and simulation tools through the platform	the interaction will be tested during the demonstrator implementation period	NO	This test will be carried out at the end of the project and reported in WP7.
R2.4	Must	Technical	Functional	IGD	High level decision support and overview of the AM equipment.	The user will approve the level of the information provided	YES	Based on visual inspection and expert knowledge the user can derive insights on manufacturing quality. These insights are communicated to external analysis tools for further analysis and decision making.
R2.5	Must	Technical	Functional	IGD	Conversion of sensor data into a compact representation utilizing data processing methods	In an experiment data processing an representation will be double checked with data and representations obtained in more manual methods.	YES	Received sensor data is compressed to automatically fit into provided memory capacity on the graphical processing unit.
R2.6	Must	Technical	Functional	IGD	Volumetric visualization of sensor data	The user will verify that, the visualization is correct and it will be doubled checked in an experiment with sensor data	YES	The sensor data can be visualized via a direct volume rendering solution and through different filtering stages.
R2.7	Must	Technical	Functional	IGD	Interactive graphical interface. The model should show an approximation of the complete sensor data set. The user should be able to navigate this scenery	Check vs client requirements about interactive visualization needs	YES	The user can interactively explore the data set in 3D. Real-time performance is achieved by compact data representation.
R2.8	Must	Technical	Functional	IGD	user selected areas from the overview should be visualized with a finer resolution of the selected section	The user will verify that, the visualization is enough fine an accurate for their needs	YES	User-selected areas can be reloaded with finer resolution providing a more accurate representation of the data.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R2.9	Must	Technical	Functional	IGD	The user should be able to select further cutouts from the intermediate view that should be rendered using the exact data set.	The user will verify that, the visualization is enough fine an accurate for their needs	YES	The user can select further areas for a more detailed view.
R2.10	Must	Technical	Functional	IGD	Intuitive user selection and visualization of data sections	Usability test with users	YES	Sensor data can be easily and intuitively selected in the visualization tool.
R2.11	Must	Technical	Functional	IGD	Human friendly interaction with optical sensor data	Usability test with users	YES	We implemented a user-friendly interaction scheme allowing an intuitive investigation of optical sensor data.
R2.12	Must	Technical	Functional	IGD	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	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	Sensor data can be visualized together with the CAD model of the printed object.

6.2.2.3 ***Requirements for Component #*** Correlation of Process Data

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R3.1	Must	Technical	Interoperability	Synesis	The data analytics tool must be able to collect data form the automation level and the cloud to use them in analytics algorithms	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The tool is capable to interface with MQTT broker systems wherever they are deployed (either cloud or edge nodes are supported)
R3.2	Must	Technical	Functional	Synesis	The tool must be implementable at edge level	The capability of the system for providing this requirement will be checked	YES	The tool is based on modules running in virtualized machines managed by an Hypervisor implementable at edge level.

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
						against experimental data during the testing period.		
R3.3	Must	Technical	Functional	Synesis	the data will be collected through automatic and semiautomatic procedures	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The data will be collected from other systems running in the PRIMA pilot via MQTT messaging system.
R3.4	Must	Technical	Functional	Synesis	The exploitation of the data must result in cause effect patterns	The validity of the extracted data for extract conclusions will be checked through the validation provided by the user during the testing period.	YES	The KPI evaluated by the tool enable the additive manufacturing process expert to identify criticalities and to address them.
R3.5	Must	Technical	Functional	Synesis	The data should also be able to be used and leveraged with the DSS tools	The validity of the extracted data for extract conclusions will be checked through the validation provided by the user during the testing period.	YES	The data collected by the analysis tool will be semantically grouped and the most relevant ones will be made available to the DSS tool, possibly highlighting critical KPI thresholds.
R3.6	Must	Technical	Interoperability	Synesis	the system must be able to use OPC UA or MQTT standards.	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The analysis tool embeds an MQTT broker and an MQTT client dedicated to manage the exchange of messaging with the other tools and systems of the Prima pilot.
R3.7	Must	Technical	Functional	Synesis	The system should be able to read continuous or batches based data and transform them for analytics purposes	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The data generated by other tools, both as batches and continuous data, is collected and processed to elaborate the agreed KPIs.
R3.8	Must	Technical	Functional	Synesis	the system should be able to communicate a t a	The capability of the system for providing this requirement will be checked	YES	The analysis tool can deliver messages to the DSS system via MQTT interfacing.

ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
					higher level with the DSS tool	against experimental data during the testing period.		
R3.9	Must	Technical	Functional	Synesis	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.	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The main modules of the analysis tool can be deployed on different virtual machines and can interact each other via network communications.

6.2.2.4 *Requirements for Component # Analysis tools in the cloud*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R4.1	Must	Technical	Functional	TTS	The additive simulator should be displayable in an external cloud or on premises	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The additive simulator is displayable on premises
R4.2	Must	Technical	Functional	TTS	Data about process and product should be obtained through the cloud as well as on premises	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	Data about additive manufacturing process are sent to the cloud by MQTT protocol
R4.3	Must	Technical	Functional	TTS	No constraints on response time, latency or robustness in the wireless network	Test at lab level	NO	The additive simulator is run before working a job on a real machine in a technical office and it can work with no machine connection. It does not need any particular requirement on the wirless network performances.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R4.4	Must	Technical	Security	TTS	The system should be secure. Communications will use VPN an SSL certificates used to guarantee data transport security	Data transmission and security tests	NO	The simualtion results will be transmitted via MQTT protocol to a local server, without using a VPN.
R4.5	Must	Technical	Functional	Atlantis	The system developed should be able to be deployed in the cloud	The capability of the system for providing this requirement will be checked against different server application	YES	The system was developed in .NET framework and was deployed on a Microsoft server. The public URL was available to the end user for accessing the system
R4.6	Must	Technical	Functional	Atlantis	The DSS system should be able to communicate with the Edge node via OPC UA or MQTT protocol	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	An MQTT client was developed in the DSS in order to connect to the Edge node system and subscribe to the necessary topics to receive data from it.
R4.7	Must	Technical	Functional	Atlantis	The DSS system should be able to stream data in the QU4LITY solution	The capability of the system for providing this requirement will be checked against experimental data during the testing period	YES	The DSS is also equipped with an MQTT broker and publishes the analysis data in certain topics for other QU4LITY components.
R4.8	Must	Technical	Functional	Atlantis	There should be APIs for incoming and outcoming data from the DSS system	The capability of the system for providing this requirement will be checked against experimental data during the testing period	YES	APIs were created in order to receive and send data to the QU4LITY system. RESTful API endpoints cater the POST and GET functions for data retrieval and send. The APIs implement an authorization type with Bearer Token which allows only certified services to connect to the DSS

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R4.9	Must	Technical	Functional	Atlantis	The system implements an authentication and authorization mechanism for both data and users that connect to it	Security of the authentication method will be tested in specific security tests	YES	Along with the authorization type in the RESTful API, there also is a authentication mechanism in the DSS which allows users to access the system with their username and password. Only verified users have access to the system
R4.10	Must	Technical	Interoperability	Prima	There should be a data transmission API to make the data available to other service providers	The other partners and Prima will double check the capability of the system to provide the data through this method in experimental tests.	OFFLINE ONLY	For the surface inspection tool (ILT) as well as the visualization tool (IGD), an MQTT interface has been implemented that allows to share information regarding the inspection results and the storage path of the raw image data that relate to the layer-wise inspection result. The system is tested offline.
R4.11	Must	Technical	Interoperability	VTT	The AR tool to support the user in the set up phase must be easy to use and understand	Usability test will be developed with test users	YES	The AR tool has been testes although in early phases, the feedback was taken into account. More tests to be done until the end of the project
R4.12	Must	Business	Interoperability	Prima	ZDM Strategies must be able to predict defective production and trigger actions to avoid them	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	LAB ONLY	The visual inspection tool is able to recognize surface defects and deviations (in roughness) during the build process. As shown on ILT machines, another software subsystem uses this information to trigger subsequent actions in the form of adapting process parameters (laser power and scan velocity) for the upcoming layer to be built. More information can be found here: https://ieeexplore.ieee.org/document/9381862
R4.13	Must	Business	Interoperability	Prima	ZDM Strategies must be able to prevent propagation of defective production downstream in the production line	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The visual inspection tool will be able to detect defects in the powder bed area and react immediately with powder Dose factor adjustment, but if the defect propagation cannot be avoided the production will be

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								stopped in order to save powder, energy and gas
R4.14	Must	Business	Interoperability	Prima	ZDM Strategies must be able to Repair proposing rework options for defective parts	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	Repairing not possible for powder bed technology
R4.15	Must	Business	Interoperability	Prima	ZDM Strategies must be able to reverse supply chain. Deciding process flow for improvement of production in case of defective items	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	These functionalities will be taken in consideration in the final phase of the project, if could be processed by the DSS
R4.16	Must	Business	Interoperability	Prima	ZDM Strategies must be able to manage strategies through event modelling, KPI monitoring and real time decision support	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The Decision Support system will monitor the main parameters related to the hourly cost of the machine, in terms of energy, powder and gas consumption and optimise them in relation to the production needs.

6.2.3 Project Objectives validation plan

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
BR 1	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,	Monitoring systems and image processing tools	Increase OEE 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.	Process texture analysis	R2.1 to R2.12
BR 2	AR for human error reduction: thanks to new and advanced AR applications,	Augmented Reality based support system for operator	It will be possible to mitigate human errors and increase the quality of the process because	Analysis tools in the cloud	R4.11

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
			of a better machine setup		
BR 3	The DSS 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	Analytics applied to Decision Support System	Strategies will be set up that will avoid defects and their propagation	Analysis tools in the cloud	R4.5; R4.6
BR 4	The information flow provided by the designed architecture an digital enhancements will be used to apply production strategies for ZDM.	Zero Defect Manufacturing Strategies	The implemented ZDM Strategies will reduce defective and improve productivity in the line through the actions of: predict, prevent, repair, reverse supply chain, manage	All	R4.12, R4.13, R4.14;R4.15, R4.16

6.3 Pilot Case #12: Danobat Digital Machine for zero-defects at high precision cutting / grinding

6.3.1 Software Components

Digital enhancements: Pilot/ component/subcomponent

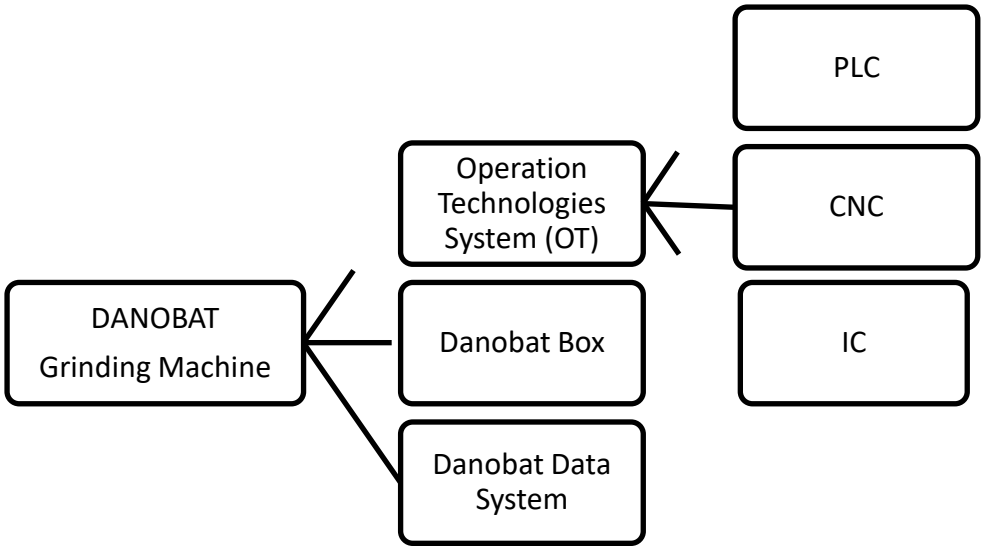

Fig 10: Components in Danobat machine

COMPONENT	SUBCOMPONENT	MAIN STAKEHOLDER	INVOLVED PARTNERS	DESCRIPTION
Operation Technologies System (OTS)	PLC CNC ICX	DANOBAT	IDEKO	Machine level software
Danobat Box (EDGE)		DANOBAT	IDEKO	Edge level software
Danobat Data System (CLOUD)		DANOBAT	IDEKO	Cloud level software

6.3.2 Validation Plan Matrices

6.3.2.1 *General requirements of the system*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Business	Security	Danobat	Respect privacy requirements (such as GDPR compliance)	Check there are mechanism in place to fulfil GDPR demands	YES	The user management of the system complies with GDPR
R1.2	Must	Technical	Reliability	Danobat	The platform should be easy to maintain with adequate version updating mechanisms, version control and document sharing systems amongst developers	Use of GitHub for version control and documenting . Qualitative evaluation of the methodology will be conducted by an independent test team.	YES	A private Gitlab is being used. Each software development is saved in the repositories and pipelines of the Gitlab of the project.
R1.3	Must	Technical	Interoperability	Danobat	The different components of the system should be able to connect to each other to transfer data in different formats and directions	Experimental testing through testing examples of data flows amongst components	YES	The system was installed in the pilot machine in the Danobat shopfloor data gathering, transmission and coherence were tested in experimental and then in continuous working conditions.
R1.4	Should	Technical	Reliability	Danobat	Software quality should be tested	Unit test, API validation tests and integration tests will be implemented in the different stages of software development.	YES	Automated quality tests are executed for each pipeline and programming language in the Gitlab DevOps platform.
R1.5	Must	Business	Functional	Danobat	Diagnosis and prediction of machine failure and misfunction	The user will evaluate the diagnosis capabilities of the system by comparing	YES	The data gathered and analyzed in the Quality pilot was checked against real working conditions and expert analysis

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
						results with real data of the machine retrieved from other information sources or by comparing with expert experience.		conclusions in the different steps of the implementation.
R1.6	Should	Business	Functional	Danobat	Periodic reports from the system so the user doesn't have to actively go to the platform	The user will verify that, after receiving reports during the testing phase of the project	YES	The system has sent periodical reports by email to several designated technicians during the project implementation, who have checked the periodicity and coherence of the data.
R1.7	Should	Technical	Interoperability	Danobat	Possibility to connect to the cloud punctually not in a constant connection	The system will be tested by interrupting the connection to the cloud. Data retrieval after disconnection can be easily checked visually through different screens available a t the cloud system	YES	System interruption test have been put in place, the detected errors have been corrected and good results have been attained in the final tests.
R1.8	Must	Business	Functional	Danobat	Improvement of machine availability and decrease of defective products	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The system has been able to detect indicators of malfunction in the machine. Predictive warning systems have been put in place
R1.9	Must	Business	Functional	Danobat	The system should be able to monitor analyze and extract features that allow to act avoiding problems in real time	The validity of the extracted data for avoiding problems will be checked through the validation of reports and diagnosis results provided to the user.	YES	The predictive warning system is installed in the demonstration pilots. The alarms are being sent to technicians and experts in the project. The number of alarms that are not related to a future machine failure has been reduced to a minimum. Reducing the expert time for predictive maintenance.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.10	Must	Business	Functional	Danobat	The system should be able to send results to the machine so , the machine or the operator can take actions to avoid defects	This requirement will be checked through experimentation in an example case.	YES	The system can send emails to the machine or maintenance operator.
R1.11	Should	Business	Functional	Danobat	The system should not be expert dependent it should be intuitive and easy to use	"This will be checked through qualitative evaluation of the received information by the end user. Usability tests by end user	YES	The information sent by the systems is intuitive although an expert is still needed sometimes to discard a possible machine conditions when some of the machine indicators surpass a limit.
R1.12	Must	Technical	Reliability	Danobat	Data quality	During the project lifetime, test the data against different data quality dimensions, such as, accuracy, completeness, consistency, integrity, timeliness, etc.	YES	Quality test have been put in place against different sets of data with good results.

6.3.2.2 *Requirements for Component #1 - OTS*

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R2.1	Must	Technical	Functional	Danobat	CNC and PLC data should be readable to the system	Read the data from different CNC's, sensors and PLC using libraries developed by DANOBAT and IDEKO.	YES	The Edge Clous system is able to read data from all the hardware and software that has been specified for the purposes of the project.
R2.2	Must	Technical	Functional	Danobat	The system must receive result analysis from the machine and use it for	The capability of the system for providing this requirement will be	YES	The system is able to send messages to the machine operator. The system

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
					improvement through messages to the user and writing information in the OTS	checked against experimental data during the testing period.		is able to write in a parameter in the memory of the CNC
R2.3	Must	Technical	Performance	Danobat	"The latency to the data will permit analysis near real time	Check that data acquisition latency is so low (milliseconds) that it allows different analysis in real time	YES	The data is sent to the cloud every second. Data files can be sent with information gathered at millisecond frequency, which is later on analyzed. The frequency of data gathering and analysis has proved to be adequate for the purposes of the project.
R2.4	Must	Technical	Functional	Danobat	The system will incorporate computational capacity for machine dynamics information so different types of analysis can be performed	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The information about dynamics behavior of the machines is gathered by special sensors at the machine and gathered with millisecond frequency. The processing functionalities developed in the project have also proved to deliver correct results
R2.5	Must	Technical	Functional	Danobat	High speed signal processing. The system should be able to launch high speed data colleting functions and send to the box	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	The system is able to automatically trigger high frequency data gathering and analysis processes.
R2.6	Must	Technical	Performance	Danobat	The OT system should be able to collect and communicate relevant data with seconds frequency and milliseconds where necessary	Check that the libraries are able to reed different values from the PLC at a frequency of seconds and milliseconds during a predetermined amount of time without date loses or coupling.	YES	The data sent every second by the machine is ubiquitous can be seen in different devices in web format. The millisecond data is also processed and can be seen in the screens and reports

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R2.7	Must	Technical	Functional	Danobat	The OT systems should be able to read and process data from the additional sensors and send it to the edge/cloud components	Check that the libraries are able to reed data form PLC and through the POST method, send them to edge / cloud components.	YES	The data is correctly gathered from all the sensors and hardware in the machine.
R2.8	Must	Technical	Functional	Danobat	"Embed Intelligent autonomous quality functions on the machines.	Check that the system is able to read analysis results and launch according actions for autonomous quality	YES	The system is able to lauch actions in the machine although this functionality is limited due to security actions and they always need to be confirmed by a user.
R2.9	Should	Technical	Functional	Danobat	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	Check that the libraries capture information from the CNC and this is stored in a Data Base for later analysis and exploitation.	YES	Historical data of the machines is stored in the cloud and can be used for later analysis of the machine builders design experts.
R2.4	Must	Technical	Functional	Danobat	The system will incorporate computational capacity for machine dynamics information so different types of analysis can be performed	The capability of the system for providing this requirement will be checked against experimental data during the testing period.	YES	Machine dynamic behavior is stored so it can be analyzed in further detail by the experts in DANOBAT

6.3.2.3 *Requirements for Component #2 - Edge*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R3.1	Must	Technical	Functional	Danobat	Reduce and process the data on the Edge/IoT side before they reach a central location such as the Cloud	The Edge offers an environment where data acquisition and treatment is possible and enables to latter send them to the cloud	YES	Data gathered from the machine is preprocessed so the quality of data sent to the cloud can be reduced.
R3.2	Should	Technical	Functional	Danobat	Harmonize the data coming from different data sources (data heterogeneity)	The edge will be able to harmonize data from different data bases in the edge like MySQL o API's REST. Therefore it will offer a programming environment, like for example container where data will be unified and heterogenized .	YES	The data gathers information from different sources of the machine, the coherence of the data has been double checked by different profiles in the organization during the project
R3.5	Must	Technical	Functional	Danobat	The gateway should be able to log the data if there is a failure in communication	Kill the process taking place in a container while it is performing a certain commutation and check if Savvy is showing log of errors.	YES	The data is logged at the edge in the gateway hardware. It is sent when the connection is available. The quality of the data has been checked and proved to be correct
R3.7	Should	Business	Functional	Danobat	Capabilities of the gateway to prioritize some capture groups when sending	Check that the Edge is prepared to configure a set of data or capture groups to be able to serve the data the user wants in the edge	YES	A user connected to the edge device can directly unload some data from the machine. The system gives the user options to choose the data of interest to be downloaded.
R3.8	Must	Technical	Functional	Danobat	Possibility of hosting containers and allowing access and management of them.	The system should offer a platform for container deployment at the Edge	YES	The system is able to host containers . Different functionalities have been developed in the project based on this data architecture.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R3.9	Should	Technical	Interoperability	Danobat	The gateway should be able to read various machine protocols	"The interoperability of data in the edge should at least permit the use of three protocols as for example Modbus, MTConnect and OPC UA	YES	The system is prepared to use the three protocols
R3.12	Must	Technical	Functional	Danobat	Results of analytics should be able to trigger alarms	The Edge is able to process data, analyze them and create triggers accordingly, like for example e-mails, to notify the user in the event of any incident.	YES	The system is able to trigger alarms and send them by email
R3.1	Must	Technical	Functional	Danobat	Reduce and process the data on the Edge/IoT side before they reach a central location such as the Cloud	The Edge offers an environment where data acquisition and treatment is possible and enables to latter send them to the cloud	YES	Data processing functionalities have been developed using the containers at the edge. Some of these functionalities do preprocess the data an send the results to the cloud
R3.2	Should	Technical	Functional	Danobat	Harmonize the data coming from different data sources (data heterogeneity)	The edge will be able to harmonize data from different data bases in the edge like MySQL o API's REST. Therefore it will offer a programming environment, like for example container where data will be unified and heterogenized .	YES	The data in the edge is harmonized and the results that the user received have proved to be coherent
R3.5	Must	Technical	Functional	Danobat	The gateway should be able to log the data if there is a failure in communication	Kill the process taking place in a container while it is performing a certain commutation and check if	YES	A data log is available at the edge.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
						Savvy is showing log of errors.		

6.3.2.4 *Requirements for Component #3 - Cloud*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R4.2	Should	Business	Functional	Danobat	The cloud should be able to send notifications as i.e. e-mails	Test that when a particular parameter is above a value the cloud is able to send an e-mail to a user.	YES	The cloud sends reports and notifications by email to selected users.
R4.3	Must	Business	Interoperability	Danobat	Other software should be able to communicate with the system through an API to read data and use it for purposes like analytics.	Check that the application offers an API that exposes and JSON REST interface with authentication .	YES	All requests sent by the client must include a header with its identification - the APIKEY - as well as a signature calculated by applying a HMAC-SHA1 signature mechanism to the content and headers of the request, using the private key - the APISECRET."
R4.4	Must	Technical	Performance	Danobat	The cloud should be able to store big quantities of data	The difference of storage capacity between the cloud and the edge should at least be of 60% (bigger in the cloud)	YES	The cloud storage has been sized to respond to the demands of the project
R4.5	Should	Business	Performance	Danobat	In order to avoid unnecessary increase of data storage size in the cloud, eldest data will be aggregated .	There will be a data retention policy defined by the user where the data will be whether retained with a temporal criterion (save high granularity data from one	YES	The data can be aggregated reducing the frequency of the stored data. The limit date for aggregation of older data can be chosen by the administrator

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
						year) or under a storage size criteria.		
R4.6	Should	Business	Functional	Danobat	Data Visualization should be flexible and customizable for different profiles of users	Check there is a permissioned section for the user where each of them can configure screens in a comfortable an agile manner.	YES	The system is flexible and custom screens can be developed in the cloud in a flexible and intuitive way.
R4.7	Must	Technical	Security	Danobat	The system should be secured with a series of criteria to ensure it.	The access to the platform will be served under HTTPS and will also be secured through user login. Furthermore the APIs accesses will be authenticated. Access to the data managed by authentication process on the API that possess a pair of keys, one public (APIKEY) and another private (APISECRET). There is also a signature calculated by applying a HMAC- SHA1	YES	The criteria of securitization described in the specifications have been fulfilled
R4.8	Must	Technical	Functional	Danobat	Capabilities to update containers installed in the edge through the cloud	Check a container can be updated through the cloud	YES	Functionalities for easy and secure update of the deployed containers have been developed

6.3.3 **Project Objectives validation plan**

Traceability with D4.1

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
BR 1	New data analytics tools for predictive maintenance and avoid defects (ZDM) Sensorized machines and analytics for ZDM	Monitoring systems and data analytics functionalities	Data analytics for condition monitoring of variables in the PLC and sensor systems. Reduction in defective parts Production optimization - Reduction of unscheduled downtimes - Reduction of equipment downtime on customers - Reduction of intervention time on customer - Reduction of intervention costs	General	R1.5 / R1.8 /R1.9 / R4.3
BR 2	Condition monitoring to increase the remaining useful life (RUL) of the components, tool wear, geometry tolerances control	In line/ real time geometric measurement of critical parts, data feedback functions to control system	Reduction of mean Time Between Failures (MTBF)	OTS, Edge, Cloud	R2.1 / R2.2 / R3.12

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
BR 3	Big Data acquisition and intelligent integration	Connection to the cloud	Smart Decision systems through engineering knowledge application and automation Improvement in OEE in Component manufacturing Improved predictive models for component degradation and failure and quality risk Improved maintenance planning Improved process through new cognitive system for real time process adaption	Cloud	R1.10 / R1.11/ R2.4 / R2.7/R 2.8/ R4.4

6.4 Pilot Case #13: FAGOR Zero Defect Manufacturing Digital Press Machine

6.4.1 Software Components

Digital enhancements: Pilot/ component/subcomponent

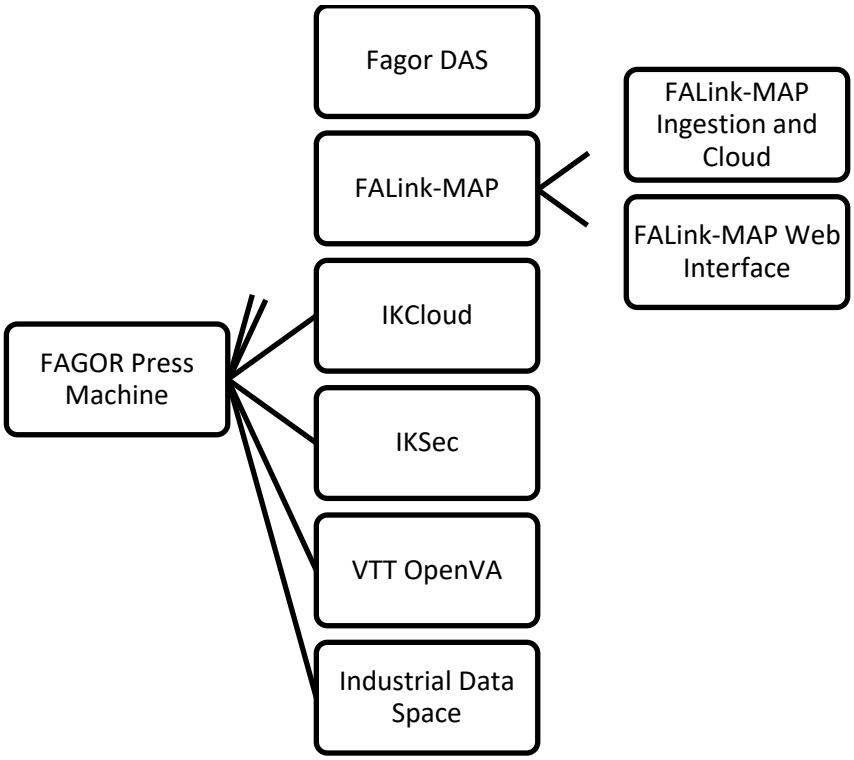

Fig 11: Components in Fagor machine

These could be components on TH·3

COMPONENT	SUB-COMPONENT	MAIN STAKEHOLDER	INVOLVED PARTNERS	DESCRIPTION
BC-IKE-1	Fagor DAS	IKERLAN	FAGOR	Fagor DAS (Data Acquisition System) is responsible of sampling data from the sensors via PLCs. This component handles direct-attached storage.
BC-IKE-2	FaLink-MAP (Ingestion and Cloud)	IKERLAN	FAGOR	Fagor's monitoring platform, FALink-MAP, is composed by two systems, the former that is executed in the

COMPONENT	SUB-COMPONENT	MAIN STAKEHOLDER	INVOLVED PARTNERS	DESCRIPTION
				manufacturing plant (on premise) and the latter that is executed in the cloud.
BC-IKE-3	FaLink-MAP Web Interface	IKERLAN	FAGOR	FaLink-MAP Web Interface is a Front-end where the user can interact with the processed data by the cloud subsystem and monitor a branch of parameters
BC-IKE-4	IKCLOUD	IKERLAN	FAGOR	IKCLOUD infrastructure allows the reception, processing and visualization of large amounts of information that is provided by the manufacturing entities.
BC-IKE-5	IKSEC	IKERLAN	FAGOR	IKSEC gathers all the modern competences in the cybersecurity domain and eases the application in an industrial domain.
BC-VTT-1	VTT OpenVA	VTT	FAGOR	Open Visual Analytics
BC-FHG-ISST-1	Industrial Data Space	FHG-ISST, IDSA	FAGOR	The Industrial Data Space is one of several initiatives of the Industrial Data Spaces Association and provides a reference architecture for supporting data exchanges in an industrial context.

6.4.2 Validation Plan Matrices

6.4.2.1 *General requirements of the system*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R0.1	Must	Technical	Security	IKE	System must ensure data is transferred satisfying defined security standards.	Transfer protocol meets security requirements.	YES	Data is transferred from the machine to the platform using FAGOR DAS, and ensuring that the data is sent using the protocols and standards defined by FAGOR ARRASATE
R0.2	Must	Technical	Security	IKE	System must ensure data is confined satisfying defined security standards.	Data is just accessible from pre-established endpoints.	YES	Obtaining data using API endpoints requires permissions and authentication to the user/machine.
R0.3	Must	Technical	Privacy	IKE	System must ensure sensible data is managed accordingly to pre-set user privileges	Assigned user privileges are coherent with sensibility of the data.	YES	The system provides support to define which data is accessible and available for each stakeholder. This way, the system ensures that the data is only transferred to stakeholders that have permissions.
R0.4	Should	Business	Performance	IKE	System must ensure scalability, reliability and latency on communication between components.	Communication protocols meet R0.1, R0.2, R0.3, enable scalability and allow stream as batch process with established latency.	YES	The system has been designed with scalability in mind (scalability in terms of resources and data). It provides support to increase the system computing power.

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R0.5	Must	Technical	Functional/Performance	IKE	System must store data regarding machine behaviour for performance testing	System can store raw metrics for standalone analysis.	YES	FALINK ingest data from Fagor DAS and persist it in the cloud platform. It provides support to query historic data and perform standalone analysis of this data.
R0.6	Should	Technical	Functional	IKE	The system should be capable of sending feedback to user from analysis results	System can provide feedback from analysis results in term of messages, alerts and warnings, enhancing system performance through user communication.	YES	FALINK platform provides support to show automatically alarms, alerts and warnings based on data analysis. It also provides a set of views with advanced and customizable charts to facilitate understanding of the performed data analysis.
R0.7	Must	Technical	Functional	IKE	System must be able to capture data from different sensors and transfer it to cloud components.	System can ensure sensor topics are correctly published and subscripted from cloud components. The capability of communications must be check with experimental data during testing period.	YES	The system has a testing case to check that the data is obtained using Fagor DAS and transferred to FALINK and IKCLOUD platforms correctly from different sensors and machines. The code also contains text (e.g. FALINK API), that automatically check that the data is correctly obtained and managed during incremental updates of the system.
R0.8	Should	Business	Functional	IKE	System should be able to take autonomous actions from analysis results.	Check that analysis results are accessible and performed actions are coherent with	YES	The system provides support to perform data analytics tasks, show the results and

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
						obtained results and expected reactions.		persist them using the platform. However, the system does not provide for now the ability to perform autonomous actions.
R0.9	Must	Technical	Performance	IKE	System acquisition latency, processing latency and response latency are such that permit real time analysis.	Check system acquisition, processing, storing and responding allow stable real time computation.	YES	The system uses CI, DEVOPS and MLOPS for automating lifecycle of itself and also to check that the latency, availability and performance of different parts of the system meet the requirements of FAGOR ARRASATE.
R0.10	Must	Technical	Performance	IKE	System must provide predefined product on an acceptable standard of quality	System can provide expected product, is said, satisfies R0.1 to R0.9, and quality of performance meets established standards.	YES	The system is able to provide data analytics and data monitoring of the different sensors and machines of the use case meeting the requirements previously defined by FAGOR ARRASATE for the QU4LITY project. The system integrates different components that have been developed during the project providing extended support for more advanced analysis of the data, anomaly detection and improvement of the system that follow the main goal of reducing defectives towards ZDM and

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								increasing the quality of the production process.

6.4.2.2 *Requirements for Component # (One table for each component)*

1. BC-IKE-1:

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Technical	Security	FAGOR	Component must ensure data is transferred satisfying defined security standards.	Data is properly confined and inaccessible from foreign components. Security transfer protocols are deployed.	YES	FAGOR DAS is able to obtain data from sensors and machines (PLC, sensors) and transfer to the cloud component (FALINK-MAP) using standards such as OPC-UA and MQTT and in a secure way. FAGOR DAS sends the data to FALINK, and the data is confined and inaccessible from the

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								components that have not permission.
R1.2	Should	Technical	Interoperability	FAGOR	Component connections should enable transferring data in different formats and communication protocols	Input points can be easily escalated without violating R1.1	YES	FAGOR DAS uses different formats and protocols to transfer data: OPC-UA, MQTT, TCP-IP
R1.3	Should	Technical	Reliability	FAGOR	Data quality should be controlled.	Data models' standards are ensured by logic laws.	YES	The data meets the specific data models and standards that have been previously adopted and designed by FAGOR.

2. BC-IKE-2:

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R2.1	Must	Technical	Security	IKE	Component must ensure data is transferred satisfying defined security standards.	Security transfer protocols are deployed.	YES	FALINK-MAP is connected to IKSEC component of the system, and this way the data is transferred and managed in a secure way.
R2.2	Should	Technical	Interoperability	IKE	Component connections should enable transferring data in different formats and communication protocols	Component is able to transfer data in different formats (JSON, XML,…) and using appropriate protocols (OPC-UA, 3/4/5G,…) one each case.	YES	FALINK-MAP provides a set of elements for interacting with data and using the protocols specified for the pilot by FAGOR. FALINK-MAP inputs data from FAGOR DAS and using cutting edge technologies such as Apache NIFI and KAFKA. The data then can be transferred to other elements using different scripts for each operative systems (windows, linux), a REST-API for WEB-based solutions.
R2.3	Should	Technical	Reliability/Interoperability	IKE	Cloud platform must ensure either no data loses or process interruptions are faced.	Data is not lost even if connection losses occur or some nodes of the cluster fail	YES	The data that is obtained from the FAGOR DAS and is processed using Apache Storm and persisted in a Elastisearch cluster. The data is replicated in different instances in order to prevent data loses. The cluster can be easily enhanced if the target scenario requires it.
R2.4	Must	Technical	Performance	IKE	Process Latency must meet response time established requirements.	Alerts feedback might generate an active response under stabilised threshold parameters.	YES	FALINK provides different solutions to detect anomalies or events, and also to monitor and analyze DA results. This facilitates to the stakeholders to adopt decisions that will help to reduce anomalous

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
								situations, prevent plant stops and in consequence reduce defectives (ZDM) and increase quality.

3. BC-IKE-3:

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R3.1	Must	Technical	Security	IKE	Component must ensure data is transferred satisfying defined security standards.	Transfer protocols meet security requirements.	YES	FALINK-MAP Web Interfaces component provides a set of views that allow users to monitor machines and sensors, show results of DA/IA tasks performed by IKCLOUD, check indicators, analyse anomalous scenarios, etc. Views and data shown in views, are only available to stakeholders that have access permissions to the views. These permissions are managed using IKSEC component.
R3.2	Must	Technical	Privacy	IKE	Component must ensure sensible data is managed accordingly to pre-set user privileges	Component must ensure user privileges must be controlled reliably	YES	As is previously described, the data that is shown on each of the views and to each stakeholder is managed by FALINK + IKSEC.
R3.3	Should	Technical	Performance	IKE	Latency on consulting	Response time should be human bearable.	YES	The system, and FALINK Web Interfaces specifically, are continuously being improved in to provide the best user experience.

4. BC-IKE-4:

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R4.1	Must	Technical	Security	IKE	Component must ensure data is transferred satisfying defined security standards.	Transfer protocols meet security requirements.	YES	IK-CLOUD is integrated within FALINK and using IKSEC in order to ensure that the data is transferred in a secure way.
R4.2	Should	Technical	Reliability	IKE	Cloud platform must ensure a fast, scalable and fault tolerant data processing	Cloud platform allows processing data in an efficient way although the data volume increases	YES	IKCLOUD has been developed using a set of MLOPS, BIG DATA, DEEP LEARNING and AI solutions that provide native support for scalability in terms of data volume. The system has been designed and implemented targeting use cases with a large amount of data.

5. BC-IKE-5:

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R5.1	Must	Technical	Security	IKE	Component must ensure data remaining components meet security standards	R1.1, R2.1, R3.1 and R4.1 must be satisfied.	YES	IKSEC is the component that is responsible to manage authentication and authorization of data and components of the system. Different components of the system use and interact with IKSEC to obtain credentials and security related data (e.g.) tokens, and to obtain the data according to permissions of each stakeholder/component.
R5.2	Should	Technical	Privacy	IKE	Component must ensure data remaining components meet privacy standards	Transfer protocols meet privacy requirements.	YES	IKSEC is responsible to provide access to the data only to the stakeholders and users that are allowed for it. The permissions of the data can be managed using different views that are only available for system administrators.

6.4.3 Project Objectives validation plan

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
PO 1.1	Process Prediction and data analytic on variables. New data analytics tools for predictive maintenance and avoid defects	Sensor temperatures vibration, press Data analytics for measure stamped part with CAD geometry	Data Analytics for condition monitoring of variables in the PLC and sensor system. Reduction of defective parts production optimization	Data acquisition software	R1.1 It must be able to read from all sensors R1.2 It must be able to send analytics results to the machine
				Cloud analytics software	R2.4 It must be able to analyze measures and relate results to working conditions…..

6.5 Pilot Case #14: GF Digital machine and part twins for zero defect manufacturing

6.5.1 Software Components

Digital enhancements: Pilot/ component/subcomponent

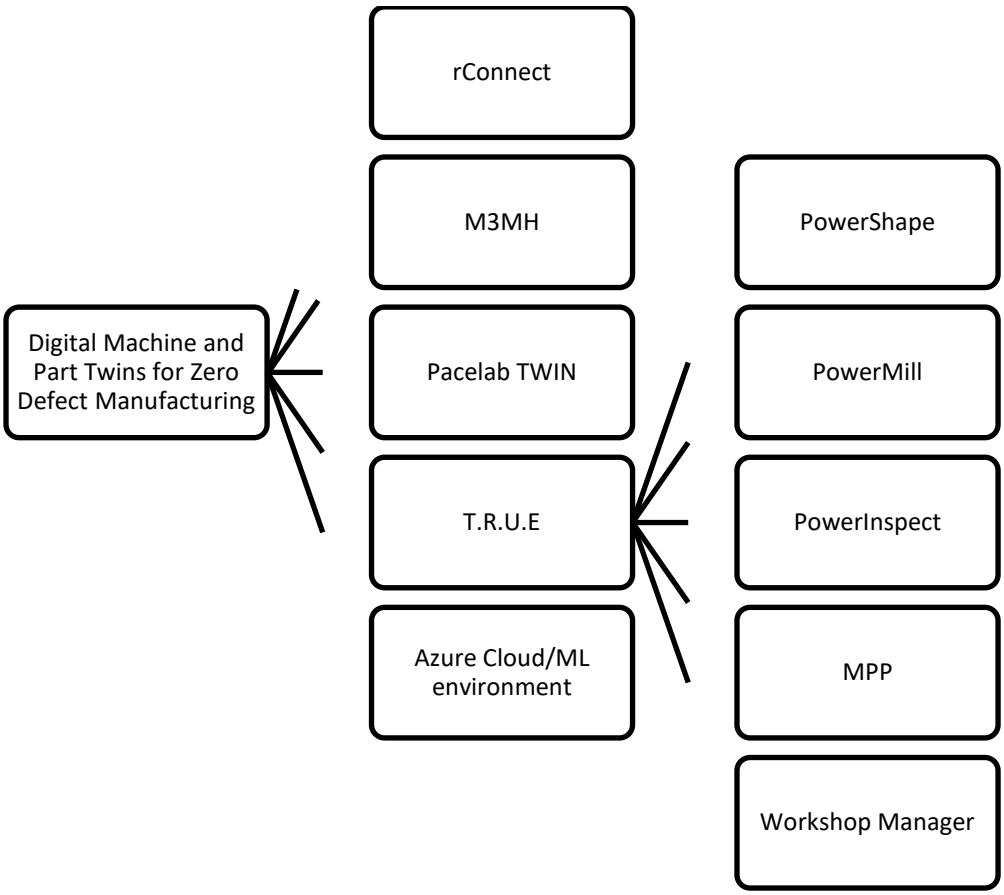

Fig 12: Components in GF machine

COMPONENT	SUBCOMPONENT	MAIN STAKEHOLDER	INVOLVED PARTNERS	DESCRIPTION
rConnect – Digital HUB		GF	MGEP Unimetrik EPFL	Allow to access GF Machining Solutions machines to acquire machine data and delivers web based business applications
M3MH		Unimetrik	GF	Full measurement software functionality within machine tool; Reference accurately during job set-up; Real-time tool monitoring; In-cycle gauging, automatic tool offset updates and reduced rework
Pacelab TWIN		Pace	GF MGEP	Powerful software toolbox and web application to streamline the design and development of digital twin with Artificial intelligence, supporting the entire production process with predictive quality and maintenance algorithms
T.R.U.E	PowerShape	GF	EPFL	CAD system with integrated electrode creation wizard.
T.R.U.E	PowerMill	GF	EPFL	CAM system for Milling
T.R.U.E	PowerInspect	GF	EPFL	CAM system for inspection with integrated GF wizard to obtain real electrode offset and undersize values.
T.R.U.E	MPP – Cockpit Optimiser	GF	EPFL	Multi-process preparation platform to define the manufacturing sequence with integrated CAM EDM DS module for optimized EDM settings.
T.R.U.E	Workshop Manager	GF	MGEP Unimetrik EPFL	It ensures process security and simplifies preparation of jobs, masters the workshop complexity and manages and controls the processes.
Azure Cloud/ML environment		GF	EPFL	Gives an interactive, visual workspace to easily build, test, and iterate on a predictive analysis model.

6.5.2 Validation Plan Matrices

6.5.2.1 *General requirements of the system*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Technical	Security	GF	Ensuring data transfer by satisfying the defined security standards.	Transfer protocol meets security requirements.	YES	OPC UA standard compliant
R1.2	Should	Business	Performance	GF	Ensure scalability, reliability and latency on communication between components.	Communication protocols meet R1.1.	YES	Reliable latency of 1 ms
R1.3	Must	Technical	Interoperability	GF	Communication between components regarding the data transfer in different formats and directions.	Experimental of data flows between components.	YES	Validated main M2M communication
R1.4	Must	Technical	Functional	GF	Acquiring data from different sensors and transfer it to cloud components.	The transfer capacity must be verified experimentally.	YES	Stable transfer of all machine variables
R1.5	Should	Technical	Functional	GF	Send analysis results back to user for further optimization actions.	Experimental testing to check the analysis feedback.	YES	Access verified
R1.6	Must	Business	Functional	GF	Diagnosis and prediction of machine status	Compare the prediction results with real data of the machine retrieved from other information sources or by comparing with expert experience.	NO	Validation ongoing
R1.7	Must	Business	Functional	GF	Improvement of machine availability and decrease of defective products	Experimental tests to verify the capacity of the system predicting machine and process status.	NO	Validation ongoing
R1.8	Must	Business	Functional	GF	Optimize manufacturing process to reduce time and cost	Experimental tests to validate the algorithm.	YES	Improvements validated

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.9	Must	Technical	Reliability	GF	Data quality	During the project lifetime, test the data against different data quality dimensions, such as, accuracy, completeness, consistency, integrity, timeliness, etc.	YES	Performance validated in test environments

6.5.2.2 *Requirements for Component # (One table for each component)*

1. rConnect

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Technical	Security	GF	Ensuring data transfer by satisfying the defined security standards.	Transfer protocol meets security requirements.	YES	OPC UA security compliant
R1.2	Should	Business	Performance	GF	Ensure scalability, reliability and latency on communication between components.	Communication protocols meet R1.1.	YES	Reliable latency of 1 ms
R1.3	Must	Technical	Reliability	GF	Data quality	During the project lifetime, test the data against different data quality dimensions, such as, accuracy, completeness, consistency, integrity, timeliness, etc.	YES	Validated in test environment conditions

2. *M3MH*

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Technical	Security	GF	Ensuring data transfer by satisfying the defined security standards.	Transfer protocol meets security requirements.	YES	Encripted transfer validated
R1.2	Should	Business	Performance	GF	Ensure scalability, reliability and latency on communication between components.	Communication protocols meet R1.1.		Reliable communication validated
R1.3	Must	Technical	Reliability	GF	Data quality	During the project lifetime, test the data against different data quality dimensions, such as, accuracy, completeness, consistency, integrity, timeliness, etc.	YES	Validated with part references and quality control at operations
R1.4	Should	Technical	Functional	GF	Send analysis results back to user for further optimization actions.	Experimental testing to check the analysis feedback.	YES	Validation at operational level (factory)

3. *Pacelab* TWIN

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Technical	Security	GF	Ensure visualization of 3D model of the part and mapping process data on the model and on machine	Performance testing for a given example with process data as a big point cloud.	YES	Embedded in new CAM module
R1.2	Must	Technical	Functional	GF	Cloud connection by using diverse communication protocols for data analysis, visualization and predictive modules.	The transfer capacity must be verified experimentally as well as predictive accuracy.	NO	Data capacity verified on Milling and EDM machines. Predictive accuracy validation ongoing.
R1.3	Must	Technical	Function	GF	Ensure robust scalability on cloud.	Experimental testing with predefined test cases.	YES	Validated on machines at production site

4. T.R.U.E

ID	PRIORITY	TYPE	CATEGORY	PARTNER	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Technical	Interoperability	GF	Communication between components regarding the data transfer in different formats and directions.	Experimental of data flows between components.	YES	Validated on full automated cell
R1.2	Should	Technical	Functional	GF	Send analysis results back to user for further optimization actions.	Experimental testing to check the analysis feedback.	YES	Field tests achieved with customers and feedback incorporated in new release
R1.3	Must	Business	Functional	GF	Improvement of part accuracy and surface quality.	Experimental tests to verify the capacity of the system predicting machine and process status.	YES	Accuracy improved for automated mold manufacturing
R1.4	Must	Technical	Functional	GF	Manufacturing program optimization	Experimental verification of machined part quality with and without the modules.	YES	Customer improvement validated
R1.5	Must	Business	Functional	GF	Optimize manufacturing process to reduce time and cost	Experimental tests to validate the algorithm.	YES	Cockpit optimizer algorithms validated

5. Azure Cloud/ML environment

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.1	Must	Technical	Security	GF	Ensuring data transfer by satisfying the defined security standards.	Transfer protocol meets security requirements.	YES	OPC UA compliant
R1.2	Should	Business	Performance	GF	Ensure scalability, reliability and latency on communication between components.	Communication protocols meet R1.1.	YES	Reliable processing of data validated with applications in operations

REQU. ID	PRIORITY	TYPE	CATEGORY	PARTNER ADDING THIS	DESCRIPTION	TEST CASE/ ACCEPTANCE CRITERIA	DONE	RESULTS
R1.3	Must	Technical	Interoperability	GF	Ensure of cloud module availabilities.	Experimental tests (long term).	NO	Validation ongoing

6.5.3 Project Objectives validation plan

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
PO 1.1	Create Data storage space	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	Common data space integrating inspection data with information coming from the Machine CNC (process and components) and workspace (room temperature)	rConnect M3MH	R1.1 Satisfy defined security standards R1.2 Ensure scalability, reliability and latency R1.8 Data quality
PO 1.2	Implement Cloud infrastructure	Cloud environment	Data storage and data analytics	rConnect M3MH Azure Cloud/ML environment	R1.1 Satisfy defined security standards R1.2 Ensure scalability, reliability and latency

OBJECTIVE ID	PLANNED ENHANCEMENT	TYPE OF ENHANCEMENT	EXPECTED RESULT	RELATED COMPONENT	RELATED REQUIREMENT
					R1.4 Acquire data and store in cloud environment R1.8 Data quality
PO 1.3	Perform Data analytics in different authorized environments	Data analytics to develop prediction algorithm for machine and process status	Download algorithm to local edge module	Azure Cloud/ML environment	R1.5 Send analysis results back to user
PO 1.4	Set up a Digital Twin for error compensation, KPI prediction and control	Prediction of machine and process status	Adapt working conditions, tool trajectory, cutting tool and maintenance planning	Azure Cloud/ML environment rConnect T.R.U.E (PowerMill, MPP)	R1.6 Diagnosis and prediction of machine and process status
PO 1.5	Create a simulation-based framework to update NC codes and maintenance plans	Simulation of different multi-process scenarios to optimize the manufacturing process planning regarding time and cost	Reduce manufacturing time and cost	T.R.U.E MPP	R1.8 Optimize manufacturing process planning to reduce time and cost

7 Conclusions and Key Technical Indicators

In Section 6 – Pilot Cases Requirements Validation, the complete overview of the validation by the relevant pilot cases and experimental cases is presented, following the Methodology introduced in D4.7. This includes the list of software components deployed by each pilot or experimental case, the validation plan for each component and the validation plan for all project objectives is presented for each use case considered in WP4.

Apart from this, and, also, as part of the verification and validation process, the technology developers from within WP4 have measured a set of technical KPIs set by themselves, apart from the validation ones from the point of view of the final end user.

Examples of both types of KPIs are provided below, just to provide an idea to the types of indicators which have been set and evaluated by the technology providers (left-hand-side of Table 1):

Table 1 – Examples of KPIs defined and evaluated in QU4LITY, from different stakeholders

Technology Providers' KPIs	Technology End Users' KPIs
Accuracy of a predictive/RUL model: How many times there was a failure that was not predicted (false negative)? How many times the RUL tool was not able to rise the flag early enough?	Overall Equipment Effectiveness
Accuracy of a defect detection tool	Decrease on Non-Conforming Parts
Impact on the quality of the parts due to the optimization of the machine operation and control parameters	Rework Rate
Performance tracking Capacity: ability to compute Key Performance Indicators based on monitored data	Productivity Increase
Reduction of unnecessary inspection points for visual inspection of the final product, and visual inspection speed increase	Mean Time Between Failures
Time reduction in measurement operation / defect identification	Return on Investment

Time reduction in decision-making, due to the deployment of quality inspection and data analysis components	Cost Reduction (whether related to maintenance, operation, rework, testing, etc.)

In order to maintain a coherent approach, and although the technology developers in WP4 have agreed that these KPIs are to be reported at M39 of the Project on D7.12 – Pilots' Techno-Economic Evaluation (Final version), including the ones from those technology providers which are actually participating in Demonstration experiments (whether Pilots and/or Experimental Facilities) but make the technological development as part of other technical Work Packages apart from WP4.

8 Conclusions

The pilots included in the deliverable, GHI, PRIMA, DANOBAT, FAGOR and GF, enhance their machines towards ZDM, through digital developments in collaboration with several partners of the project. The aim of the work described and collected in this deliverable, is to assess and assure the quality of such developments. In order to achieve this objective a process and methodology has been proposed and several examples of tools and methods have been included.

In order to ensure traceability of the process and a common format for all the pilots, Requirements Traceability Matrices have been proposed and then fulfilled by the concerned partners. For each pilot the digital enhancements have been divided in its components, which are described in detail. Then the requirements and its validation criteria have been specified in one matrix for the general specifications and independent matrices for each of the components of the pilot. Furthermore a final matrix for the traceability of the business and the related technical requirements has been elaborated.

The work carried out in this task will be very helpful as it ensures that the requirements have been correctly considered and also establishes an clear method for the validation clearly stating the responsibilities of the involved partners.

9 List of figures

10 List of Abbreviations

ZDM	Zero Defect Manufacturing
CbM	Condition based Maintenance
DSS	Decision Support System
RUL	Remaining Useful Life
MTBF	Medium Time Between Failures
MTTR	Medium Time To Repair
KPI	Key Performance Indicators
IDSA	International Data Spaces Association
PLC	Programable Logic Controller
CMM	Condition Monitoring System
OPC UA	Open Platform Communications Unified Architecture
ERP	Enterprise Resources Planning
MES	Manufacturing Execution System
ESA	European Space Agency
ANSI	American National Standards Institute
IEEE	Institute of Electrical and Electronics Engineers Standards Association
CDT	Cognitive Digital Twin
VPN	Virtual Private Network
SSL	Secure Sockets Layer
API	Application Programming Interface

11 Partners