D1.3 – Demonstration Scenarios and Monitoring KPIs Definition

WP1 – Industrial Scenarios and Requirements Analysis

European Commission

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	Further iterations of D1.3.
	• D1.3. has a second iteration:
	  ○ D1.3. is focused on the definition of AS-IS and TO-BE scenarios for all the pilots involved in the application and demonstration of the i4Q solutions. Moreover, D1.3 includes the mapping between TO-BE scenarios and the i4Q solutions.
	  ○ D1.8 is focused on KPIs definition, the KPI dashboard, and the baseline KPI values establishment.
	
	D1.3 provide inputs for:
	• D2.3 Report on Business Viewpoint
	• D2.4 Report on Usage Viewpoint
	• D2.5 Functional Specifications
	• D2.6 Technical Specifications
	• D6.1 Pilot 1: FIDIA - Smart Quality in CNC Machining
	• D6.2 Pilot 2: BIESSE - Diagnostics and IoT Services
	• D6.3 Pilot 3: WHIRLPOOL - White Goods Product Quality
	• D6.4 Pilot 4: FACTOR - Aeronautics and Aerospace Metal Parts Quality		

	• D6.5 Pilot 5: RIASTONE - Advanced In-line Inspection for incoming Prime Matter Quality Control • D6.6 Pilot 6: FARPLAS - Automatic Advanced Inspection of Automotive Plastic Parts
EXTERNAL ANNEXES/ SUPPORTING DOCUMENTS	Annex I. Business Process Modelling Notation
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ABSTRACT	This Deliverable 1.3 reports the first part of results obtained in the development of Task 1.3 "Use cases scenarios and KPIs", during M1-M4. Deliverable 1.3 sees the in-depth analysis of all the current business processes for the demonstration scenarios, to establish the starting point of the i4Q solutions (Reliable Industrial Data Services, RIDS) development and further implementation on the industrial use cases. Thanks to this passage, the detailed specification for the development of all composing elements of the use cases will be laid down, establishing the boundaries for the integration of i4Q technologies. The Deliverable 1.3 is a reference document focused on defining the current situation, and AS-IS scenarios, of the pilots participating in i4Q project. For doing this, the current business processes are described and represented. Based on the AS-IS scenarios, the top-level problems and improvements associated to the industrial pilots will be defined. Then, the TO-BE scenarios are determined of each use case. In this regard, the companies determine the improvements that are expected in the business processes after the implementation of i4Q based solutions. The use cases scenarios will be identified for their improvement, and will be matched with the i4Q solutions. Therefore, D1.3 serves as the reference for guidance of which i4Q solutions will be developed for project pilots.

Document History

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ABBREVIATIONS/ACRONYMS

AS9000	Aerospace Basic Quality System Standard
AsIs_PxBPy	AS-IS Pilot x Business Process y
AVC	Advanced Video Coding
BDA	Big Data Analytics
BPMN	Business Process Modelling Notation
CAEX	Computer Aided Engineering Exchange
CDC	Conference on Decision and Control
CFT	Cross Functional Team
CNC	Computer Numerical Control
CPM	Continuous Process Monitoring
D1.4	Deliverable - Requirements Analysis and Functional Specification
D1.8	Deliverable - Demonstration Scenarios and Monitoring KPIs Definition v2
D1.9	Deliverable - Requirements Analysis and Functional Specification v2
D2.3	Deliverable - Report on Business Viewpoint
DLT	Distributed Ledger Technologies
EoL	End of Line
FFT	Fast Fourier Transform
GPD	Global Product Development
GPO	Global Product Organization
IDSA	International Data Spaces Association
IEC	International Electrotechnical Commission
IIRA	Industrial Internet Reference Architecture
IOT	Internet of Things
i4Q^{DQG}	Data Quality Guidelines
i4Q^{QE}	QualiExplore for Data Quality Factor Knowledge
i4Q^{BC}	Blockchain Traceability of Data
i4Q^{TN}	Trusted Networks with Wireless & Wired Industrial Interfaces
i4Q^{CSG}	Cybersecurity Guidelines
i4Q^{SH}	IIoT Security Handler
i4Q^{DRG}	Guidelines for building Data Repositories for Industry 4.0
i4Q^{DR}	Data Repository
i4Q^{DIT}	Data Integration and Transformation Services
i4Q^{DA}	Services for Data Analytics
i4Q^{BDA}	Big Data Analytics Suite
i4Q^{AD}	Analytics Dashboard
i4Q^{AI}	AI Models Distribution to the Edge
i4Q^{EW}	Edge Workloads Placement and Deployment

i4Q^{IM}	Infrastructure Monitoring
i4Q^{DT}	Digital Twin simulation services
i4Q^{PQ}	Data-driven Continuous Process Qualification
i4Q^{QD}	Rapid Quality Diagnosis
i4Q^{PA}	Prescriptive Analysis Tools
i4Q^{LRG}	Manufacturing Line Reconfiguration Guidelines
i4Q^{LRT}	Manufacturing Line Reconfiguration Toolkit
i4Q^{LCP}	Manufacturing Line Data Certification Procedure
KER	Key Exploitable Results
KPI	Key Performance Indicator
LEIT	Leadership in Enabling and Industrial Technologies
MDA	Manufacturing Data Analytics
MDC	Manufacturing Data Consistency
MDI	Manufacturing Data Integrity
MDV	Manufacturing Devices & Virtualisation
MES	Manufacturing Execution System
ML	Machine Learning
MQA	Manufacturing Quality Assurance
MQR	Manufacturing Line Qualification and Reconfiguration
NMBP	Nanotechnologies, Advanced Materials, Biotechnology, and Advanced Manufacturing and Processing
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OPC	Object Linking and Embedding for Process Control
OPC UA	Open Platform Communications Unified Architecture
OPEX	Operating Expenses
OT	Operational Technology
PEDR	Plan for the Exploitation and Dissemination of Results
PLC	Programmable Logic Controller
PPM	Parts per million
PQM	Plant Quality Manager
PQL	Product Quality Leader
QC	Quality Control
RAMI4.0	Reference Architectural Model Industry 4.0
RIDS	Reliable Industrial Data Services
RMS	Root Rean Square
SAP	Systems, Applications & Products in Data Processing
SAS	Statistical Analysis System
SDN	Software Defined Networking

SMC	System Man and Cybernetics
SPC	Statistical process control
SQL	Structured Query Language
SSL	Secure Sockets Layer
SSP	System Structure and Parameterization
SWOT	Strengths, Weaknesses, Opportunities, Threats
TCP	Transmission Control Protocol
TCQ	Total Cost of Quality
TEE	Trusted Execution Environment
ToBe_PxBPy	TO-BE Pilot x Business Process y
TRL	Technology Readiness Level
TSN	Time-Sensitive Networking
WSN	Wireless Sensor Network
ZDM	Zero-Defects Manufacturing

Executive summary

The deliverable D1.3 "Demonstration scenarios and monitoring KPIS definition" summarises the main business processes of the industrial pilots involved in the i4Q project. It represents the current processes of the following industrial pilot scenarios:

- **Pilot 1**: Smart Quality in CNC Machining
- **Pilot 2**: Diagnostics and IoT Services
- **Pilot 3**: White Goods Product Quality
- **Pilot 4**: Aeronautics and Aerospace Metal Parts Quality
- **Pilot 5**: Advanced In-line Inspection for incoming Prime Matter Quality Control
- **Pilot 6**: Automatic Advanced Inspection of Automotive Plastic Parts

The purpose of this document is to describe and characterize i4Q pilots' descriptions. The use cases described in the i4Q Description of Action (DOA) document acts as the foundation of this document. The deliverable D1.3 reflects the approach taken to help the industrial pilots become aware of the i4Q technical capabilities and potentiality, and at the same time express their needs and future expectations from the project. Hence, it includes:

- The description of the industrial pilots processes according to their different scenarios and manufacturing processes;
- The pilot's analysis of their present state and forecasting towards the future, using i4Q project as the foundation to reach that state.

The D1.3 main actions are:

- Characterise the industrial scenarios
  - Describe the current manufacturing domain
  - Identify and describe the technical advancement derived from the i4Q project, considering the manufacturing data quality and manufacturing process quality
  - Map the technical advancements with the i4Q solutions
- Describe and analyse the current situation of each use case (AS-IS scenario)
  - Introduce the company involved
  - Define the current company business processes
  - Describe the main facing problematics
  - Describe the desired improvements
- Describe and analyse the future situation of each use case (TO-BE scenario) by considering the implementation of the i4Q solutions:
  - Define the company business processes expected after the implementation of i4Q based solutions
  - Map the TO-BE business processes with the i4Q solutions

In summary, the main results from deliverable D1.3 are grouped in 4 categories:

- The list of business processes identified in each i4Q pilot (AS-IS scenario);
- The steps identified from the AS-IS situations to the desired TO-BE cases;
- The mapping between the TO-BE business processes and the potential i4Q solutions applicable to achieve such TO-BE scenarios; and

- The mapping between i4Q project technical advancement and the i4Q solutions.

D1.3 is focused on the definition of AS-IS and TO-BE scenarios for all the pilots involved in the application and demonstration of the i4Q solutions. Moreover, D1.3 includes the mapping between TO-BE scenarios and the i4Q solutions. Further iterations of D1.3 will result on D1.8, which is focused on KPIs definition, the KPI dashboard, and the baseline KPI values. Finally, D1.3 provides inputs for D2.3 Report on Business Viewpoint, D2.4 Report on Usage Viewpoint, D2.5 Functional Specifications and D2.6 Technical Specifications.

Document structure

This deliverable is broken down into the following sections:

Section 1: Introduction: Provides an introduction to deliverable D1.3 Demonstration Scenarios and Monitoring KPIs Definition.

Section 2: Industrial Scenarios Characterization: Describes the current industrial situation and the technological advances beneficial of i4Q.

Section 3: User Scenarios Description: Provides a detailed description of each i4Q pilot, describing the:

- "AS-IS" scenario business processes to be improved, which are currently ongoing within the enterprises, are modelled. Moreover, the main facing problematics and the desired improvements are determined;
- "TO-BE" scenario and every application that will be developed in i4Q for improving the "AS-IS" situation of the industrial pilot partners. Finally, the company business processes expected after the implementation of i4Q based solutions are modelled.

Section 4: User Scenarios Classification and Analysis: Provides an analysis of the user scenarios and a list of i4Q solutions that address a set of problems identified within the presented industrial sectors. Provides a mapping to identify how the i4Q solutions deal with each specific technical advancement.

Section 5: Conclusions: Provides a summary of the document, emphasising the most important aspects of user scenario characterisation, and future actions to be carried out from the results in the Task 3.1 (M1-9).

1. Introduction

Deliverable D1.3, Demonstration Scenarios and Monitoring KPIs Definition, aims at creating the starting point of i4Q project towards the pilot-driven implementations, providing direct input from the use cases. It is inserted in Work Package 1 that aims at establishing main features of industrial scenarios to be addressed in the i4Q project, by implementing the IoT-based Reliable Industrial Data Services (RIDS).

The use cases compound a representative sample of the industry requiring manufacturing data quality and manufacturing process quality; moreover, a set of needs and problems that are common on each of the sectors to which the use cases belong have been identified. In order to deal with the problems and needs found in each use case, the set of 22 i4Q solutions (17 software tools and 5 guidelines) have been considered. The 22 i4Q solutions have been mapped to meet the use cases' needs, with the aim of managing huge amount of industrial data coming from cheap cost-effective, smart, and small size interconnected factory devices for supporting manufacturing online monitoring and control.

In particular, this deliverable identifies and classifies industrial scenarios to be targeted by i4Q RIDS. With the participation of most project partners (Universities and Research Centres, IT developers, and Industrial partners), this task seeks to achieve a well-known and agreed starting point to maximize the coherence and integration of future designs, developments and implementations to be performed on the i4Q project. Indeed, this deliverable address different industrial scenarios:

- **Pilot 1**: Smart Quality in CNC Machining [Fidia S.p.A., (FIDIA)]. Machining and CNC Industry, machine tool providers
- **Pilot 2**: Diagnostics and IoT Services [Biesse Group, (BIES)]. Wood Processing Machining and Technological Materials Machining Industry, machine tool providers
- **Pilot 3**: White Goods Product Quality [Whirpool Corporation, (WHI)]. White Goods Products Industry production company
- **Pilot 4**: Aeronautics and Aerospace Metal Parts Quality [Factor S.L., (FACT)]. Automotive and Aeronautics Industry production company
- **Pilot 5**: Advanced In-line Inspection for incoming Prime Matter Quality Control [Riastone S.A., (RIAS)]. Ceramics Industry production company
- **Pilot 6**: Automatic Advanced Inspection of Automotive Plastic Parts [Farplas A.S., (FARP)]. Automotive Industry production company

D1.3 was developed by means of collaboration between consortium members, providing pilot information and data, as well as their estimation about all the procedures taken into account during the creation of this document. This deliverable followed the presented set of steps:

- Domain identification of the industrial pilots, their concepts and best approaches for studying the pilots' business processes.

- Creation of a common methodology for characterization of the Industrial Scenarios by using BPMN (Business Process Model and Notation) and a collaborative online tool named *draw.io* [1]. See Appendix 1 for BPMN.
- Local meetings between the partners that are defining the pilots' cases.
- Collection of the first results and compilation of initial draft.
- Analysis and refinement of the proposed approaches, after the presentation at the i4Q Kick of Meeting.
- Telco's every 2 weeks between all i4Q project partners to follow up the progress of work.
- Telco's between industrial pilots and technical developers to get feedback:
- About the pilots' needs, pilots' expectations with regards i4Q solutions, pilots' data availability, pilots' resources usability and the capability.
- About the i4Q solutions and the features offering regarding technical, functional, and service.

1.1 Methodology for characterization of industrial scenarios

In overall, a methodology is considered a systematic and theoretical analysis of the methods applied to a certain study. In i4Q, it is important to follow the steps that are going to be described next in order to ensure that each of the industrial pilots respect the same common set of principles when describing their pilots. After applying this proposed methodology, it is expected that project partners have a clear notion of what are the industrial scenarios needs. The methodology that is used in i4Q project for characterization of the industrial scenarios has two different phases as presented.

The User Scenarios Description (Section 3. User Scenarios Description) provides a detailed description of each i4Q pilot, describing the:

- "AS-IS" scenario business processes to be improved, which are currently ongoing within the enterprises. The AS-IS scenario will serve as a baseline to analyse the main expectations each stakeholder has from i4Q, giving the keys to carry out the transition between the AS-IS and the TO-BE scenarios. At the AS-IS stage, the industrial pilots have followed the next actions:
    - Describe the main facing problematics of the enterprise in a summarized way.
    - Complete the table that characterises the AS-IS business processes
        - Process Description, all the processes are named as *AS-IS Pilot "X" Business Process "n"*, and coded as *AsIs_PX_BPn*
        - Actors and Roles, enterprise department people involved
        - Information Systems, legacy systems of the enterprise that can be used by the i4Q RIDS
        - Problems and needs the enterprises are facing with the AS-IS business processes modelled

[1] https://drawio-app.com/exploring-bpmn-shape-libraries-in-draw-io/

        - Internal and external barriers the enterprises have to face with the development of current business process, and which could be solved by i4Q solutions
        - i4Q Expectations, desired improvements on the AS-IS business process considering the implementation of i4Q RIDS.
    - Model in BPMN the AS-IS business processes selected by using the *draw.io* online application.
- "TO-BE" scenario and every application that will be developed in i4Q for improving the "AS-IS" situation of the industrial pilot partners. Define the company business processes expected after the implementation of i4Q based solutions. At the TO-BE stage, the industrial pilots have followed the next actions:
    - Complete the table that characterises the TO-BE business processes, based on the previously defined and modelled AS-IS business processes
        - Process Description, all the processes are named as *TO-BE Pilot "X" Business Process "n"*, and coded as *ToBe_PX_BPn*
        - Actors and Roles, enterprise department people involved in the new business process using i4Q solutions
        - Information Systems, legacy systems of the enterprise to be used by the i4Q RIDS
        - Problems and needs the enterprises are facing with the TO-BE business processes modelled
        - Internal and external barriers the enterprises have to face with the development of TO-BE business process, with regards the i4Q solutions implementation
        - i4Q solutions involved, by indicating the codes of the i4Q solutions willing to apply in the TO-BE business process.
    - Model in BPMN the TO-BE business processes selected by using the *draw.io* online application, including the i4Q solutions, and how these solutions would change the AS-IS business processes.

2. Industrial Scenarios Characterization

i4Q Project aims to provide an IoT-based Reliable Industrial Data Services (RIDS), a complete suite consisting of 22 i4Q solutions (17 software tools and 5 guidelines) able to manage the huge amount of industrial data coming from cheap cost-effective, smart, and small size interconnected factory devices for supporting manufacturing online monitoring and control. The proposed solutions are aimed to assure data quality and process quality in order to favour manufacturing lines' continuous process qualification, quality diagnosis, reconfiguration and certification.

The i4Q Framework will guarantee data reliability with functions grouped into five basic capabilities around the data cycle: sensing, communication, computing infrastructure, storage, and analysis and optimization. i4Q RIDS will include simulation and optimization tools for manufacturing line continuous process qualification, quality diagnosis, reconfiguration and certification for ensuring high manufacturing efficiency, leading to an integrated approach to zero-defect manufacturing.

The i4Q RIDS is to be demonstrated in 6 Uses Cases from relevant industrial sectors and representing two different levels of the manufacturing process: machine tool providers and production companies:

- Industrial partners:
  - FIDIA (Metal industrial equipment);
  - BIESSE (Wood industrial equipment),
  - WHIRLPOOL (White goods manufacturer),
  - FACTOR (Metal machining),
  - RIASTONE (Ceramic pressing), and
  - FARPLAS (Plastic injection).

The main objective is to test and validate the i4Q solutions in 6 use cases, covering different manufacturing perspectives (industrial equipment manufacturers, parts and components manufacturers and final products manufacturers) and industrial sectors (metal, wood, white goods, ceramics and plastic).

This chapter aims to provide an overview on the manufacturing sector, on its evolution in Europe, on its challenges and on how i4Q solutions can support its technical advancement.

2.1 Manufacturing Domain

The industrial manufacturing sector is an important key for European Union economy, being a driver of growth and employment, generating three-quarters of Europe's exports and more than 14% of European GDP (The World Bank, 2018). Only 1 in 10 enterprises in the EU is a manufacturing, it exists 2 million companies in this sector generating 33 million jobs, and every new job in manufacturing results in the creation of between one half and 2 jobs in other sectors.

Manufacturing sector generated EUR 5.812 Billion of turnover and EUR 1.400 billion of value added in 2018, being the second largest of the NACE sections within the EU-27's non-financial business economy in terms of its contribution to employment (21,4%) and the largest contributor to non-financial business economy value added, accounting for one quarter (26,6%) of the total

(Eurostat, 2019). European SMEs are the backbone of manufacturing industry in Europe, providing around 45% of the value added and around 59 % of manufacturing employment (European Commission, 2019). These are important figures complemented with the European Union Commission strategy that intends to expand industrial production in the EU from its current share of 15,5% of GDP to 20% by 2020 (European Commission, 2014).

Manufacturing companies with the goal of producing goods adapted to specific requirements and produced under the minimum required production rate, guaranteeing high quality and limiting the use of resources in order to reduce production costs, are continuously facing the challenge of redesigning and adjusting their manufacture systems to adapt their process. Therefore, reducing waste, scraps and defects, as well as production costs and lead times is crucial to increase productivity and hence, to pursuit manufacturing excellence. In this context, the implementation of zero-defect strategies plays a decisive role.

During the last decades several manufacturing operations and manufactured products quality optimisation methodologies and tools, such as the use of sensors and automated processes, have been implemented in European manufacturing companies with the aim of improving quality management and reduce variability on the manufacture of goods, in this sense several R&D efforts have targeted on zero-defect approaches with the purpose of developing solutions to improve performance of process control by incorporating enhanced quality control solutions.

The initiative Smart Factories with high levels of digitalisation will be a key element for this new form of industrial production. Other initiatives such as the German "Industry 4.0" with a total investment of EUR 40 billion every year by 2020 (Koch et al., 2016) and a governmental fostering of close to EUR 500 million (Liu, 2016) are supporting the development of the required technologies.

European manufacturing sector key challenge is to transform cost-based competitive advantages into those that rely on sustainable, high-value-added production, enabling companies to achieve superior product quality with highly efficient, smart production processes. This approach creates new challenges, though, because of the many, highly heterogeneous, and intensely interconnected manufacturing resources and their digital counterparts.

To achieve all those objectives new technologies and solutions are needed and it is necessary to solve 3 major drawbacks:

- **Data Management**: the use of sensors, actuators and instruments in manufacturing lines collect a huge amount of data during the manufacturing process, information that is very valuable for the improvement of quality in manufacturing but, for most of the European factories it is not possible to analyse the data generated in the process on a daily basis.
- **Complexity of Solutions**: most of current solutions lack of easy-to-use advanced data preparation, production reporting and advanced analytics and prediction, requiring heavy statistical and technology training and support, making them not accessible for SMEs. Now, users are demanding access to insights from advanced analytics, without requiring them to have IT or data science advanced skills.
- **Dynamic behaviour of the manufacturing factories**: Complex systems of diverse, connected, interdependent entities which need suitable modelling and simulation approaches and data fusion techniques to interpret the collected data.

What is more, a successful smart factory needs to manage data-related processes along the entire data life cycle, including data collection, storage, distribution, analysis, use, and deletion, to ensure high data quality at all times. This includes processes related to:

- the design, deployment, and use of hardware and software;
- the planning, implementation, and monitoring of intra-organizational procedures; and
- the inter-organisational practices in the value chain.

2.2 Technical Advancement of i4Q

The whole vision of i4Q is described in detail in D1.1 – Project Vision Guide Document, which provides the clear definition of what the project wants to achieve. This section presents a high-level description of the technical advancement of i4Q that can guide towards its realisation.

This main technical objective of i4Q is the realisation of i4Q RIDS as an IoT-based Reliable Industrial Data Services toolset for assuring data quality, traceability and proper use, to achieve manufacturing lines' continuous process qualification, quality diagnosis, reconfiguration and certification. The i4Q RIDS consist of 22 i4Q solutions: 17 software tools and 5 guidelines, which are driven by the requirements (and validated by business scenarios) of industries operating in different industrial sectors.

i4Q technical objectives are listed next:

- **O2:** To design the i4Q Framework and deliver the Reference Architecture built on key digital models and ontologies for smart manufacturing and devised using multiple perspectives, related to business, usage, functional and implementation viewpoints. (WP2)
- **O3:** To build the i4Q Manufacturing Data Quality, providing methodologies, tools and infrastructure to ensure the necessary data quality to enable operational intelligence and improve data analysis results effectiveness. (WP3)
- **O4:** To build the i4Q Manufacturing Data Analytics, a set of management tools for cloud/edge lifecycle of manufacturing related AI models. (WP4)
- **O5:** To build the i4Q Rapid Manufacturing Line Qualification and Reconfiguration, a set of new and improved strategies and methods for process qualification as well as process reconfiguration and optimisation using existing manufacturing data and machine learning (ML) algorithms. (WP5)

From the objectives' definition, two main domains are considered:

- Manufacturing Data Quality; within data quality technical advancements of i4Q are devoted to release novel approaches to deal with:
    - Manufacturing Data Quality
    - Manufacturing Data Trustiness
    - Manufacturing Data Reliability
    - Manufacturing Data Traceability
    - Manufacturing Data Security
    - Manufacturing Data Analytics
    - Manufacturing Data Integration

- Manufacturing Data Storage
- Manufacturing Process Quality; within the process quality technical advancements of i4Q are devoted to release novel approaches to deal with:
  - Manufacturing Process Qualification
  - Manufacturing Process Quality Diagnosis
  - Manufacturing Process Reconfiguration
  - Manufacturing Process Certification and Audit

2.2.1 Manufacturing Data Quality

2.2.1.1 Manufacturing Data Quality

i4Q project is devoted to provide methodologies, tools and infrastructure to ensure the necessary data quality to enable operational intelligence and improve data analysis results effectiveness. Manufacturing data quality also ensures the needed accuracy and reliability of the data measured along the value chain. Data quality in manufacturing boosts (i) product quality in the supply chain; and (ii) process quality of the manufacturing companies. The i4Q scope is to provide solutions that improve data **quality**, **consistency** and **integrity** to allow the use of available information and add-on sensors in diagnostic analytic tools. Data Quality in i4Q includes the systematic identification of the factors that influence data quality in manufacturing by using a data quality management strategy, specifically conceived for the manufacturing sector, applying blockchain technologies for the needed data trustiness and traceability. Manufacturing data quality bears in mind cutting-edge technologies for wired and wireless trusted data communications, putting in place data security and protection methods, and implementing a distributed data storage system addressing the specificities of the manufacturing sector.

2.2.1.2 Manufacturing Data Trustiness

Manufacturing data trustiness will enable to place the necessary smart contracts in place, to enable full control over data. Blockchain technologies are also used in i4Q project to ensure data trustiness. Data trustiness is achieved by the governance of blockchain technology to access to specific data. The use of specific and appropriate smart contracts in blockchain technology enables **traceability**, provenance and verification, providing full control to the data owner and achieving manufacturing data trustiness. i4Q project supports a direct interaction from the manufacturing devices to the blockchain application to maintain a high level of trust in the data. The blockchain shall be used as a source of trust and **integrity** between multiple parties. In addition, i4Q manufacturing data trustiness looks after data privacy and confidentiality. i4Q manages trustiness in the sense in which there might be data that only a defined set of participants could be eligible to access; therefore, i4Q focuses on encryption techniques to be able to grant access based on a given access policies list.

2.2.1.3 Manufacturing Data Reliability

i4Q project ensures manufacturing data reliability through the maintenance of, and the assurance of the accuracy and consistency of, data over its entire life-cycle. Data reliability ensures that the data is the same as when it was originally recorded, aiming to prevent unintentional changes to information. Data **quality**, **security** and privacy is also used to provide data reliability in the i4Q solutions. i4Q guarantees data reliability with functions grouped into five basic capabilities around the data cycle: sensing, communication, computing infrastructure, **storage**, and **analysis** and optimization; based on a microservice oriented architecture for the end users.

2.2.1.4 Manufacturing Data Traceability

i4Q data traceability will impact the data **quality** boosting product quality in the supply chain for manufacturing companies. i4Q solutions that deal with traceability of collected data, includes metadata regarding accuracy and reliability of the data measured. This will help to consolidate the information and implement best practices. i4Q project manages the needed metadata for traceability and interoperability to ensure data quality and have access to data coming from many different sources. Traceability and blockchain-based technologies go hand in hand.

2.2.1.5 Manufacturing Data Security

i4Q project integrates cutting-edge technologies for wired and wireless trusted data communications, putting in place data security and protection methods, and implementing a distributed data **storage** system addressing the specificities of the manufacturing sector. Data security is pursued in three main directions that call for proper security protocols:

- Confidentiality, ensuring that information is not accessed by unauthorised persons.
- Authentication, ensuring that the users of critical functions are the persons they claim to be.
- Integrity, ensuring that external occurrences cannot alter the information in such a way to be not detected by authorised persons.

Within the i4Q project, collected data can be delivered by diverse types of devices and be transmitted through and processed by a significant number of layers and technologies. This translates into the necessity of that i4Q solutions that provide recommendations and guidelines to enable multilayer cyber security features in Industrial Internet of Things (IIoT), as well as the tools to implement these recommendations, enabling IIoT devices to interact with the platform securely in all stages of a manufacturing scenario.

2.2.1.6 Manufacturing Data Analytics

i4Q manufacturing data analytics is carried out by implementing big data technologies for offline and online streaming data processing enabling, categorization and classifications of manufacturing data, and derive actionable insights. Manufacturing data analytics involves a set of management tools for cloud/edge lifecycle of manufacturing related artificial intelligence (AI) models, which are able to manage large amounts of industrial data coming from interconnected factory devices. Data analytics has to make sure of the manufacturing data **quality**. In this regard, i4Q AI-based data analytics tools and process quality diagnostics will empower the decision-maker as well as providing simulation models to support plant reconfiguration. i4Q Manufacturing Data Analytics for Manufacturing Quality Assurance will develop tools for the analysis of manufacturing data by combining simulation and real data in the form of digital twins, including aspects of AI model lifecycle across a cloud-edge continuum.

2.2.1.7 Manufacturing Data Integration

Manufacturing data integration enables i4Q solutions to provide a secure and safe oriented communication infrastructure and **security** mechanisms. The blockchain technology can be used as a source of manufacturing data **trust** and integrity between multiple parties. The concept of data integration focuses on preparing and managing manufacturing data through reading, cleaning, storing, indexing, enriching, searching & retrieving. The key characteristics of the data to be managed and integrated are: i) variety – supporting different data types from different sensors/sources; ii) velocity – most of the data includes more or less intensive data streams to be processed in real-time iii) volume – data size to be processed is typically large (GBs) to very large (TBs). The result of manufacturing data integration is to have a i4Q distributed server-based platform for consuming, processing and serving the data to the users.

2.2.1.8 Manufacturing Data Storage

i4Q solutions for manufacturing data storage implement a distributed storage architecture and infrastructure capable of handling an exponential increase of data volumes, integrating with services for data integration and fusion. The increasing amount of collected data requires flexible data storage and data **analysis** infrastructure able to process information without affecting data **quality**. One of the main aspects to consider in manufacturing 4.0 industries is the high degree of digitization expected in companies, resulting in most manufacturing devices acting as sensors or actuators and generating vast amounts of data.

i4Q data storage solutions have to provide an infrastructure able to absorb large volumes of data coming into the system at high speeds. Similarly, i4Q manufacturing data storage has to be elastic as possible, to adapt the computing resources, either local to the factory or from remote systems like public or private clouds if needed, although bearing in mind possible data **privacy** restrictions. In addition to the storage capabilities, the system must provide easy ways to access this data so other platform components and microservice applications can easily consume and use it to improve the efficiency of the system. In this context, i4Q aims to provide tools to create local data repositories that become central data repositories to manufacturing environments or that give the possibility of federating repositories to ease the data sharing across different premises of a company or among different actors in the value chain. Similarly, it will provide an intermediate layer that helps to homogenize nomenclature, filter or aggregate different data sources or to facilitate spatio-temporal data reconciliation. These efforts will substantially increase the efficiency in which data is accessed both internally and externally, if required, and facilitate both its ingestion and its consumption for data analysis or similar purposes.

2.2.2 Manufacturing Process Quality

2.2.2.1 Manufacturing Process Qualification

i4Q solutions include manufacturing process qualification as an essential step during the production processes, ensuring good manufacturing practice and final product quality through adequate control over processes, data collection and statistical procedures for evaluation of process stability and process performance.

Manufacturing process qualification deals with real-time monitoring the stability, capability and performance of manufacturing processes. Manufacturing process qualification solutions are closely related with the rapid quality diagnosis (subsection 2.2.2.2) which enable to evaluate the process' quality.

Typical process qualification methods are improved in i4Q thanks to automated continuous process qualification and the use of real-time data. Continuous process qualification enables to (i) determine that the outputs are within limits; (ii) use diagnosis strategies to detect cause of defect and recommend rapid corrective actions; (iii) apply simulation to guide preventive actions; (iv) adopt optimization to reconfigure the production line and v) certify process and data based on reliable collected data.

The i4Q RIDS includes an automated inline process qualification to evaluate the capability of the process to produce products that meet the quality requirements. i4Q project will provide an automated manufacturing process qualification method to manage real-time data provided by architectures, algorithms and smart data analytics to faster the continuous process validation after process reconfiguration, monitoring the stability, capability and performance of manufacturing processes.

2.2.2.2 Manufacturing Process Quality Diagnosis

i4Q solutions for rapid quality diagnosis serve to evaluate the process' quality through diagnosing the condition of the manufacturing line. The manufacturing process quality diagnosis evaluates among others: (i) data fidelity; (ii) product-quality; and (iii) process condition. Smart alerting system is implemented in the context of quality diagnosis, including auto alerting systems and data visualization tools to achieve zero defect manufacturing. Based on the diagnosis, action recommendations are provided, such as: (i) sensor/data processing recalibrations, (ii) process line/machine reconfiguration, or (iii) maintenance actions. i4Q manufacturing process quality diagnosis provides rapid diagnosis on the possible cause of failures when the outputs are out of range. i4Q aims to differentiate its offer by transforming the solution as a IoT-based Reliable Industrial Data Services by integrating an Industrial Data Management System supported by AI-based data analytics tools and process quality diagnostics to empower the decision-maker as well as providing simulation models to support plant reconfiguration (subsection 2.2.2.3).

2.2.2.3 Manufacturing Process Reconfiguration

Rapid Manufacturing Line Qualification and Reconfiguration will develop new and improved strategies and methods for process qualification. i4Q project integrates digital twins (DT) concept into existing production lines and legacy components, using it as a driver for line reconfiguration. Among others, the DT will be used to obtain virtual sensors that increase available data, to supply Key Performance Indicators of the product quality, and to simulate potential line reconfigurations aimed at correcting deviations on the process. Thus, it will aid in moving towards intelligent automatic reconfiguration. Besides DT, i4Q project uses simulation strategies to investigate whether small changes in the control can reduce or even eliminate the defects in the production. In this regard, another key aspect is to consider intelligibility of the proposed reconfigurations, ensuring that non-simulation experts may also exploit the prescriptive analyses. Moreover, optimization solutions will use simulation to evaluate different possible scenarios and propose changes in the configuration of the line (including design) to achieve improved quality targets. After the proposed configuration parameters are confirmed, these optimization microservices will evaluate the new process output characteristics to validate the success of the optimization and/or adapt its reasoning rules according to the achieved results. Based on this learning approach, i4Q project will develop strategies for machine parameter calibration, line setup and line reconfiguration. The objective is to increase productivity and reduce the efforts for line reconfiguration through AI, considering both automated approaches and collaboration with humans. To build the i4Q Rapid Manufacturing Line Qualification and Reconfiguration, a set of new and improved strategies and methods for process qualification as well as process reconfiguration and optimization using existing manufacturing data and machine learning algorithms.

2.2.2.4 Manufacturing Process Certification and Audit

i4Q certification and audit will enable Manufacturing Line Data Certification Procedure which aims to define an audit procedure applied to the manufacturing resources to ensure reliable and accurate generated data during the manufacturing processes. Manufacturing process certification and audit is devoted to ensure high manufacturing efficiency, leading to an integrated approach to zero-defect manufacturing. i4Q project will develop recommendations for certification and audit guidelines for data quality in smart factories through audit procedures applied to the manufacturing resources (machine, cell or manufacturing line) to ensure that the data resulting from the manufacturing processes are accurate and reliable. In addition, it will provide recommendations for process reconfiguration, audit strategies, certificates and regulations. The procedure will describe the logical sequence of the activities to be performed, elements of the manufacturing resources to be audited (sensors, controls, software, etc.), calibration devices to be used and tests to be performed as well as the frequency with which the procedure is to be performed. This procedure will also serve as a basis to complement existing quality certifications (i.e. ISO 9000) introducing as a new factor to consider: the quality of the data generated during manufacturing processes. The procedure addresses: definition and vocabulary, frame and application areas, prerequisites, planning, implementation, controlling, improvement and documentation of data driven qualification, reconfiguration, and quality control. It can be used as a basis for future standardisation in European Committee for Standardisation or National Standardisation, also.

3. User Scenarios Description

In this section, the i4Q project use cases are described in detail. For each pilot, a description of the current state (AS-IS), and the desired scenario (TO-BE) are defined, together with the i4Q solutions applied, and to be developed during the course of i4Q project.

The first subsection presents and analyses the current situation of the use case, introducing the companies involved, describing their current business processes and the actors and roles involved in the business process, the information systems implicated, the main problems and needs, the internal and external barriers, and finally the i4Q expectations.

After the analysis of the current situation, in the second subsection, the future business processes (to-be scenario) are presented with the application of i4Q solutions. Depending on the use case, the i4Q solutions applied and required will be different one from another. Each pilot defines the i4Q solutions which should be developed for achieving their objectives.

Each business process is modelled using *draw.io* [2] as a free diagramming application that allows users to create and share diagrams within a web browser. The online tool works with *G Suite/Google Drive* and *Dropbox*. *Draw.io* provides an intuitive interface with drag and drop functionality, customizable diagram templates, and an extensive shape library. Users are able to create and edit a variety of diagrams including flowcharts, org charts, process diagrams, ER diagrams, UML, network diagrams, and more. *Draw.io*'s functionality allows users to track and restore changes, import and export various formats, and automatically publish and share work. Business Process Modelling Notation (BPMN) diagrams help users present complex processes and workflows.

An acronym has been created and assigned to each Pilot business process, e.g. *AsIs_P1_BP1* refers to the Pilot 1 AS-IS Business Process 1. These acronyms and reference numbers will be used throughout the documentation of the project to refer to the applications in the pilot use cases. For the i4Q solutions, D1.3 uses the code defined in D1.1 (see D1.1. Table 1. i4Q Project results start and end TRL)

The deliverable D1.3 "Demonstration scenarios and monitoring KPIS definition" summarises the main business processes of the industrial pilots involved in the i4Q project. It represents the current processes of the following industrial pilot scenarios and the future scenarios of each pilots' business processes by applying part of the i4Q solutions:

- Pilot 1: Smart Quality in CNC Machining [FIDIA, CESI, ITI]
- Pilot 2: Diagnostics and IoT Services [BIES, ENG, TIAG]
- Pilot 3: White Goods Product Quality [WHI, ENG]
- Pilot 4: Aeronautics and Aerospace Metal Parts Quality [FACT, EXOS, UPV]
- Pilot 5: Advanced In-line Inspection for incoming Prime Matter Quality Control [RIAS, UNI, KBZ]
- Pilot 6: Automatic Advanced Inspection of Automotive Plastic Parts [FARP, ITI, AIMP]

[2] https://drawio-app.com/exploring-bpmn-shape-libraries-in-draw-io/

3.1 Pilot 1: Smart Quality in CNC Machining

FIDIA develops and produces a wide range of numerical controls and milling machines. With high-speed technology, that allows to perform both the roughing and the finishing processes on metal parts, manual finishing at the end of the milling process is virtually eliminated. More complex forms can be produced with improved quality, while machining times are significantly reduced. This complex task can be achieved only with a strict control of all the processing parameters and conditions and can be disrupted by unexpected problems.

Vibrations are well-known issues in the machining and metal cutting sector, where the spindle vibration is the primary responsible for poor surface quality in workpieces. The consequences range from the need to finish manually the metal surfaces, resulting in time consuming and costly operations, to the scrap of high value parts, with the corresponding loss both in terms of time and profit. The use case objective is to be able to detect, both online and offline, the presence of the main causes of vibration and their impact on the final surface quality. At the same, an alternative processing condition could be suggested to reduce the vibration effects.

At present it is not possible to predict the final surface quality, due to the high number of factors on which such performance indicator depends. Thus, it is the operator responsibility to decide (based on his experience and on the available controller signals) whether the final quality will be in line with customers' requirements and if the current processing condition should be altered to achieve the sought objective. In particular the detection of chatter (a highly disruptive vibrations linked to the equipment natural resonant frequencies) can be achieved only through an online analysis of the vibration Fast Fourier Transform (FFT), that requires an HW and SW toolkit not integrated with the machine tool controller.

Pilot 1 includes three different business processes, which have been modelled both in the AS-IS analysis of the current situation, and in the TO-BE analysis of the expected scenarios that implement and apply i4Q solutions:

- AsIs_P1_BP01: Ensure final surface quality
- AsIs_P1_BP02: Chatter detection and avoidance
- AsIs_P1_BP03: Evaluation of machine tool condition
- ToBe_P1_BP01: Ensure final surface quality
- ToBe_P1_BP02: Chatter detection and avoidance
- ToBe_P1_BP03: Evaluation of machine tool condition

3.1.1.1 As-Is: Analysis of the Current Situation

At present accelerometers are installed only on demand on FIDIA customers machine tools to detect the current vibration level. However, the only relevant information exploited is whether the vibration root mean square (RMS) acceleration value exceeds a predefined threshold, which allows only to detect collisions or abnormal cutting levels. As a consequence, the operator has to adapt the processing parameters “on the fly” based only on his experience to guarantee that the final surface quality is in line with customers’ requirements. After the processing end, the workpiece surface quality is checked and, in the case it is not acceptable, the part is either reworked or scrapped. Furthermore, the operator has no means to understand if the machine tool processing performance is degrading and if the degradation can be related to the wear of specific components. As a consequence, when maintenance is performed, several machine tools sections have to be disassembled to verify the components status and, eventually, proceed with their repair or replacement.

3.1.1.2 AsIs_P1_BP01: Ensure final surface quality

Process Name	"Ensure final surface quality"
Process Description	When a part is scheduled for production, the operator prepares the machine tool for the milling process and sets the relevant processing parameters on the controller. During the milling process itself, the operator evaluates (based on his experience and on the available information) whether the final quality will be in line with customers' requirements and if the current processing condition should be altered to achieve the sought objective. After the end of the process, the part is sent to quality control department for checking. If the part surface and dimension are in line with the customer's requirements, the product is forwarded to its next stage (that may well be its delivery). On the contrary, if the part quality is insufficient, the inspector decides if the part can be salvaged by reworking its surface or if it has to be scrapped altogether. Depending on the choice, the loss of money and resources has different orders of magnitude, but it is nonetheless considerable.
Actors and Roles	Scheduling department, processing operator and quality inspector.
Information Systems	Machine tool CNC, USB 3-axis accelerometer, part program file on DB or FTP.
Problems and needs	At present it is not possible to predict the final surface quality with the required level of precision, due to the high number of factors on which such performance indicator depends.
Internal and external barriers	
i4Q Expectations	Development of a system for in process automatic estimation of the final surface quality and of a support system for proposing the best processing conditions.

Table 1. Pilot 1: AS-IS P1_BP01 Ensure final surface quality

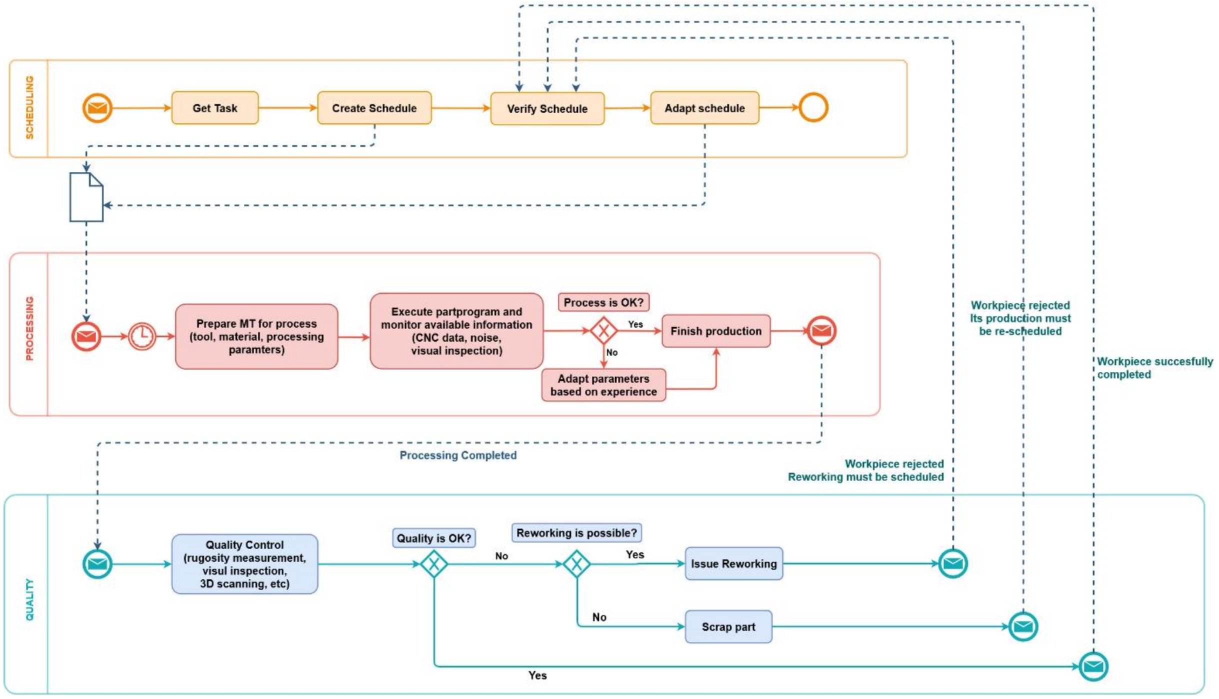

Figure 1. Pilot 1: AS-IS P1_BP01 Ensure final surface quality

3.1.1.3 AsIs_P1_BP02: Chatter detection and avoidance

Process Name	"Chatter detection and avoidance"
Process Description	The chatter is an highly disruptive vibration linked to the equipment natural resonant frequencies. If available, during part processing, the operator may use a third party HW and SW toolkit (not integrated with the FIDIA machine tool controller) to perform an online analysis of the vibration Fast Fourier Transform, that is the only method to ensure the chatter detection. If the chatter is detected the operator can alter the current processing condition to remove the chatter and thus improve the final surface quality. After the process end, the part is sent to quality control department for checking. If the part surface and dimension are in line with the customer's requirements, the product is forwarded to its next stage (that may well be its delivery). On the contrary, if the part quality is insufficient, the inspector decides if the part can be salvaged by reworking its surface or if it has to be scrapped altogether. Depending on the choice, the loss of money and resources has different orders of magnitude, but it is nonetheless considerable.
Actors and Roles	Scheduling department, processing operator and quality Inspector
Information Systems	Machine tool CNC, USB 3-axis accelerometer, part program file on DB or FTP.
Problems and needs	At present it is not possible to predict the final surface quality, due to the high number of factors on which such performance indicator depends.
Internal and external barriers	

i4Q Expectations	Development of a system for in process automatic detection of chatter presence and a support system for proposing the best processing conditions.

Table 2. Pilot 1: AS-IS P1_BP02 Chatter detection and avoidance

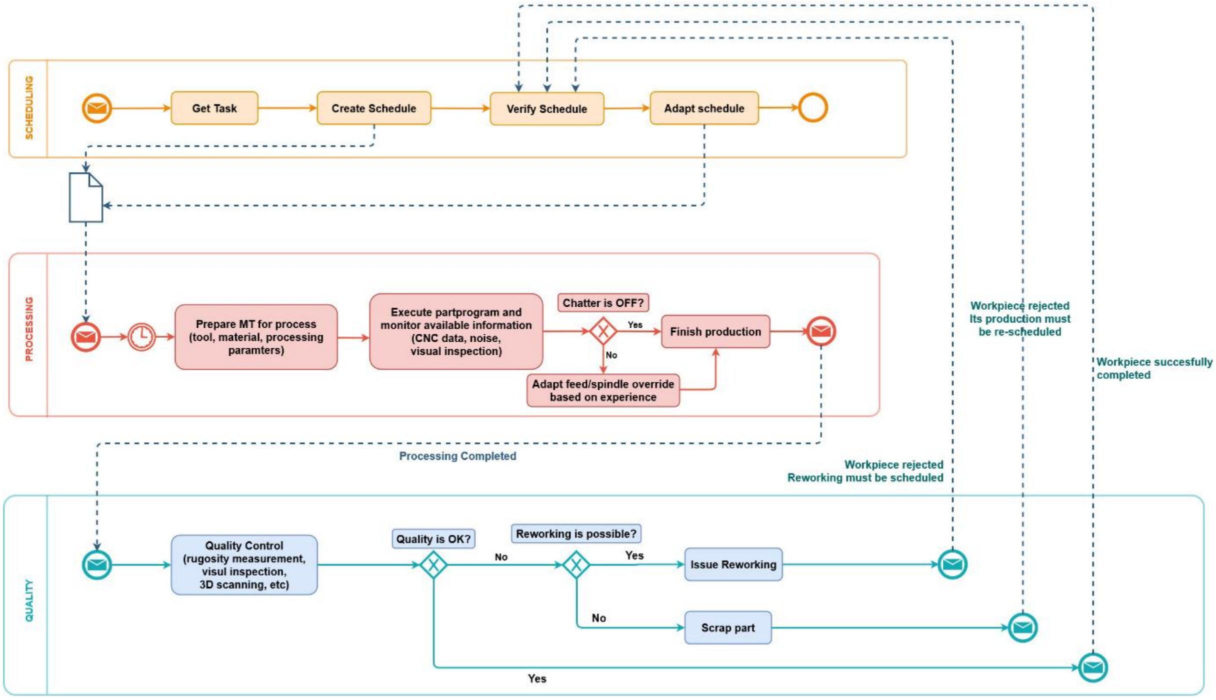

Figure 2. Pilot 1: AS-IS P1_BP02 Chatter detection and avoidance

3.1.1.4 AsIs_P1_BP03: Evaluation of machine tool condition

Process Name	"Evaluation of machine tool condition"
Process Description	Over time problems may arise in the kinematic chain of the machine tool, e.g. in the spindle bearings, axis joints, belts and gearboxes, etc. These problems (such as clearances or wear) may lead to an unacceptable loss of precision and the consequent reduction of processed workpieces surface quality. In order to avoid these problems a maintenance intervention is usually periodically scheduled. The maintenance operator disassembles selected machine tool parts to inspect them and, if required, performs a repair/replacement of broken parts. The operator then tests the machine tool to verify that the behaviour is in line with nominal tolerances.
Actors and Roles	Scheduling department, maintenance operator
Information Systems	Machine tool CNC, USB 3-axis accelerometer, part program file on DB or FTP.
Problems and needs	There is no simple way of detecting the insurgence of specific component failure modes.
Internal and external barriers	

i4Q Expectations	Analysis of available information to detect a deviation from nominal conditions and identification of the component causing the deviation.

Table 3. Pilot 1: AS-IS P1_BP03 Evaluation of machine tool condition

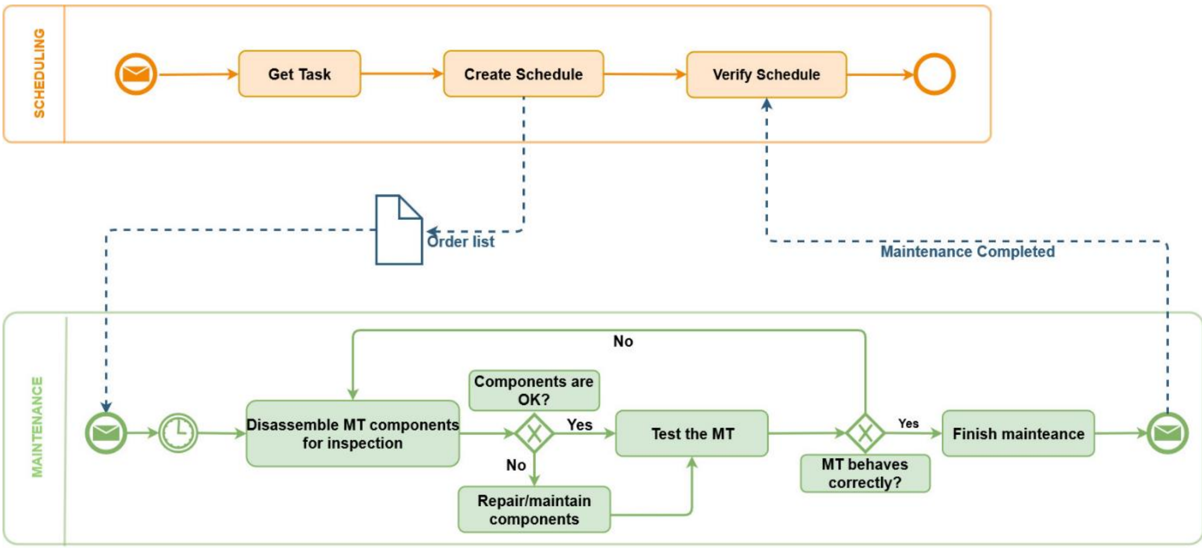

Figure 3. Pilot 1: AS-IS P1_BP03 Evaluation of machine tool condition

3.1.2 To-Be: Analysis of the Expected Scenarios

3.1.2.1 ToBe_P1_BP01: Ensure final surface quality

Process Name	"Ensure final surface quality"
Process Description	When a part is scheduled for production, the operator prepares the machine tool for the milling process and sets the processing parameters on the controller. The i4Q platform will be connected to the machine tool controller and other available sensors systems to automatically retrieve process data and signals. The i4Q AI will be trained to correlate a range of processing parameters with the final surface quality (manually measured after the process ends by a rugosimeter). During the process, the i4Q AI will predict the final surface quality and propose processing parameters that may be improved to the operator. After the process ends the part is sent to quality control for checking. It is expected a reduction in the number of parts that does not comply with customer's requirements.
Actors and Roles	Scheduling department, processing operator and quality Inspector
Information Systems	Machine tool CNC, USB 3-axis accelerometer, part program file on DB or FTP. The source of data is the same as in the AS-IS, only used differently when applying the TO-BE scenario. i4Q solutions.
Problems and needs	There is not simple to predict the final surface quality and propose processing parameters

Process Name	“Ensure final surface quality”
Internal and external barriers	Customer may be unwilling to buy additional monitoring equipment.
i4Q solutions involved	Necessarily • i4Q Data Quality Guidelines / QualiExplore • i4Q Trusted Networks with Wireless & Wired Industrial Interfaces • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Data Integration and Transformation Services • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Prescriptive Analysis Tools • i4Q Rapid Quality Diagnosis Others • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit • i4Q Manufacturing Line Data Certification Procedure

Table 4. Pilot 1: TO-BE P1_BP01 Ensure final surface quality

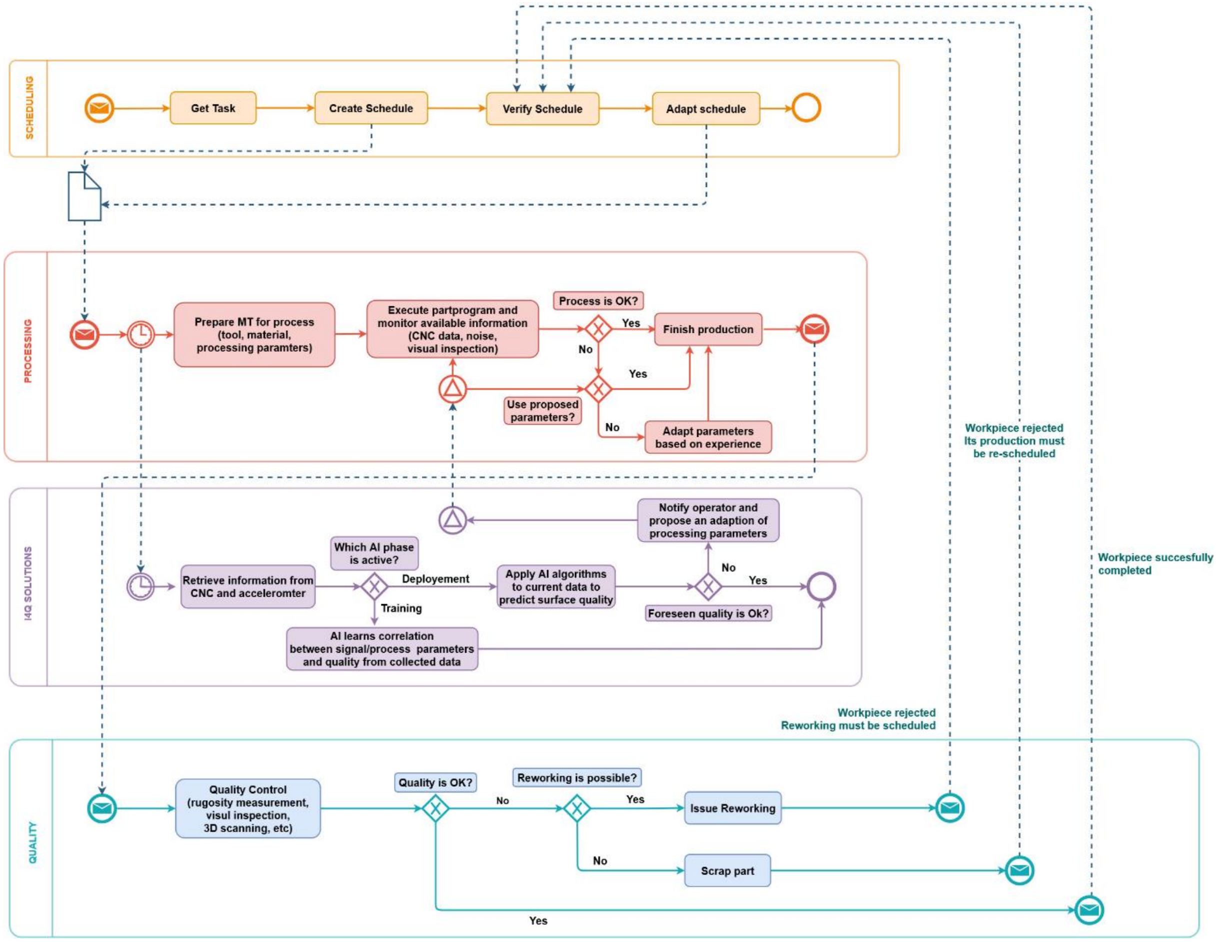

Figure 4. Pilot 1: TO-BE P1_BP01 Ensure final surface quality

3.1.2.2 ToBe_P1_BP02: Chatter detection and avoidance

Process Name	"Chatter detection and avoidance"
Process Description	The chatter is an highly disruptive vibration linked to the equipment natural resonant frequencies. The i4Q platform will be connected to the machine tool controller and other available sensors systems to automatically retrieve process data and signals. During part processing, the i4Q solution will compute the FFT of the acquired temporal vibration signal, will identify the frequencies of the main vibration modes and will compare them with the spindle rotation speed to identify the forced vibrations and related harmonics: all remaining signals will be considered chatter. The i4Q solution will notify the chatter presence to the operator and propose process parameters that reduce or eliminate its impact. After the process ends, the part is sent to quality control for quality checking. It is expected a reduction in the number of parts that does not comply with customer's requirements.
Actors and Roles	Scheduling department, processing operator and quality Inspector
Information Systems	Machine tool CNC, USB 3-axis accelerometer, part program file on DB or FTP. The source of data is the same as in the AS-IS, only used differently when applying the TO-BE scenario. i4Q solutions.
Problems and needs	There is not simple to detect and avoid highly disrupted vibration linked to the equipment resonant frequencies.
Internal and external barriers	Customer may be unwilling to buy additional monitoring equipment.
i4Q solutions involved	Necessarily • i4Q Data Quality Guidelines / QualiExplore • i4Q Trusted Networks with Wireless & Wired Industrial Interfaces • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Data Integration and Transformation Services • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Prescriptive Analysis Tools • i4Q Rapid Quality Diagnosis Others • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit • i4Q Manufacturing Line Data Certification Procedure

Table 5. Pilot 1: TO-BE P1_BP02 Chatter detection and avoidance

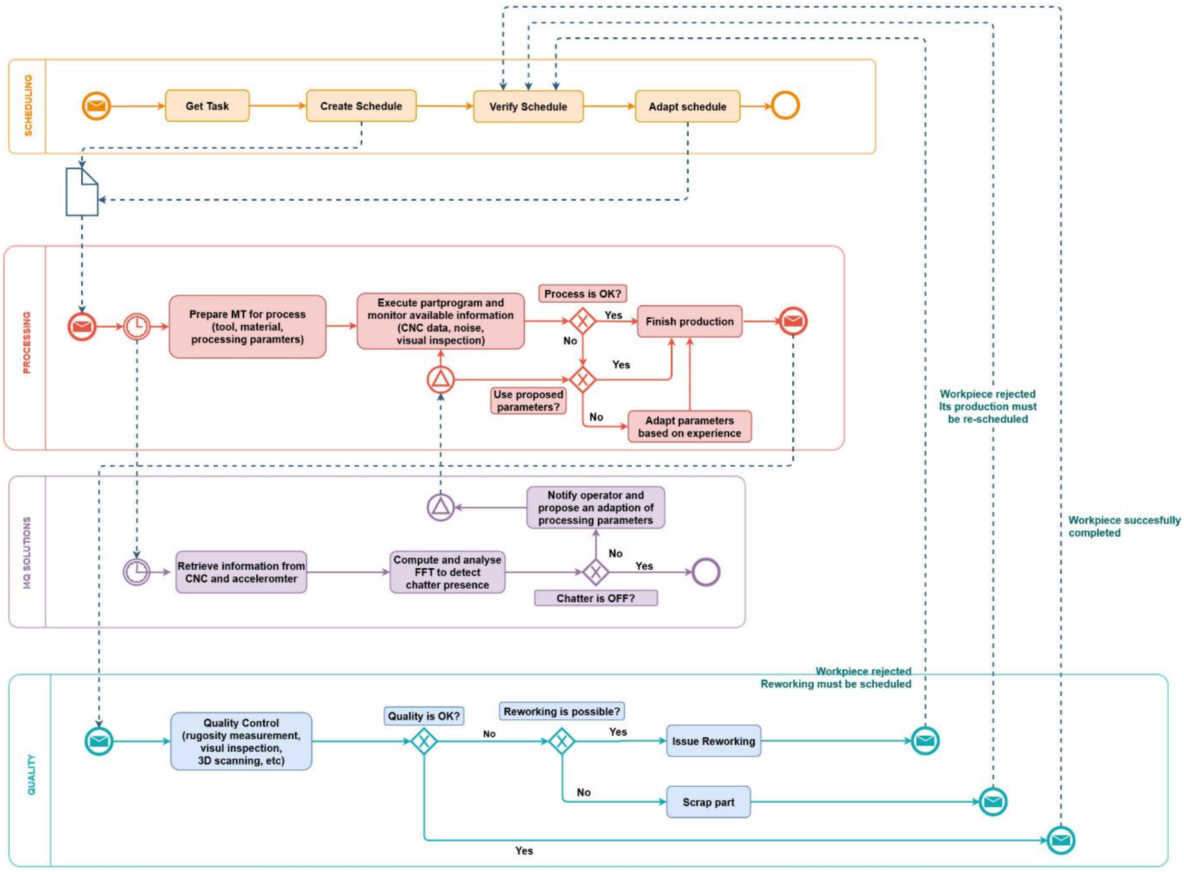

Figure 5. Pilot 1: TO-BE P1_BP02 Chatter detection and avoidance

3.1.2.3 ToBe_P1_BP03: Evaluation of machine tool condition

Process Name	"Evaluation of machine tool condition"
Process Description	In order to avoid kinematic chain problems, the i4Q platform will be connected to the machine tool controller and other available sensors systems to automatically retrieve process data and signals. In particular the i4Q AI will be trained to correlate a range of processing parameters (collected during special test sessions periodically executed on the machine tool) with the nominal equipment condition. When the i4Q AI will detect a drift in some of these parameters, the operator will be notified of a possible problem as well as the component to which the drift may be due. The maintenance operator will disassemble the identified machine tool component to inspect it and verify if maintenance is actually required, then will provide a feedback to instruct the AI accordingly.
Actors and Roles	Scheduling department, maintenance operator
Information Systems	Machine tool CNC, USB 3-axis accelerometer, part program file on DB or FTP. The source of data is the same as in the AS-IS, only used differently when applying the TO-BE scenario. i4Q solutions.
Problems and needs	There is no simple way of detecting the insurgence of specific component failure modes

Process Name	“Evaluation of machine tool condition”
Internal and external barriers	Customer may be unwilling to buy additional monitoring equipment.
i4Q solutions involved	Necessarily • i4Q Data Quality Guidelines / QualiExplore • i4Q Trusted Networks with Wireless & Wired Industrial Interfaces • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Data Integration and Transformation Services • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Infrastructure Monitoring • i4Q Digital Twin • i4Q Prescriptive Analysis Tools / i4Q Rapid Quality Diagnosis Others • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit • i4Q Manufacturing Line Data Certification Procedure

Table 6. Pilot 1: TO-BE P1_BP03: Evaluation of machine tool condition

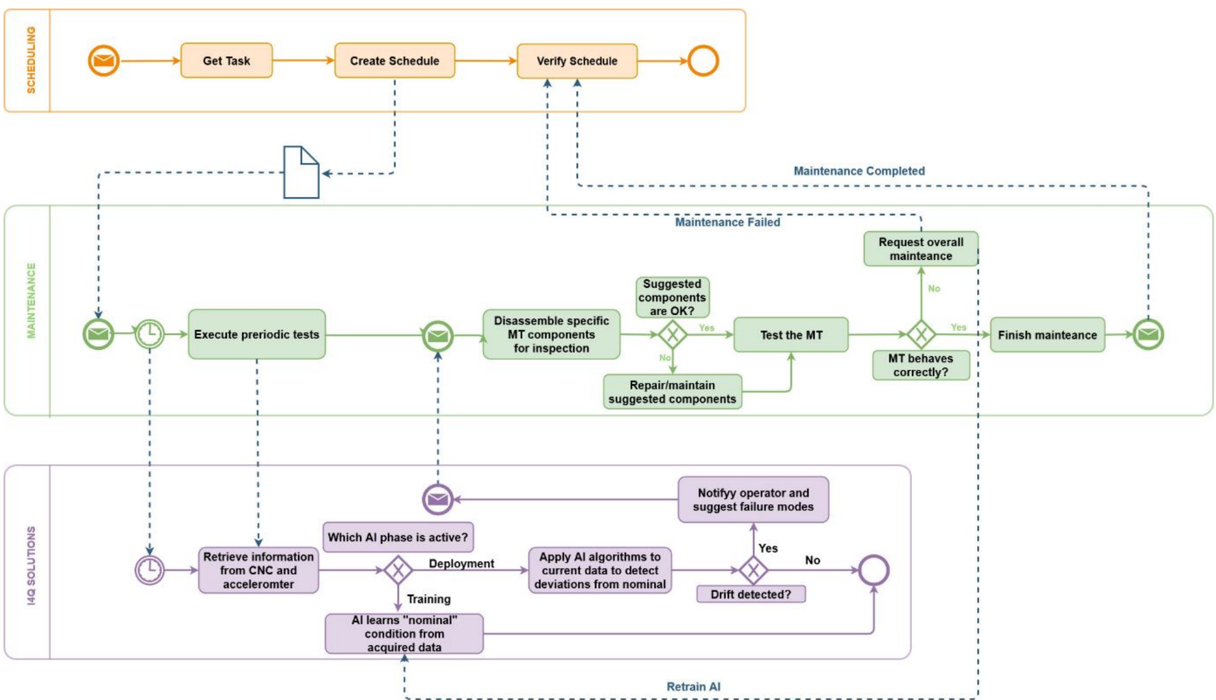

Figure 6. Pilot 1: TO-BE P1_BP03: Evaluation of machine tool condition

3.2 Pilot 2: Diagnostics and IoT Services

Biesse aims at increasing data quality by using additive and virtual sensors and adopting an edge architecture to increase computational processing capacity on the machine's PC. Additive sensors, actuators and instruments will provide data to the machine's PC, where analysis and prediction will be done online. Besides, the proposal solution ensures automated data collection using open protocols, standardized activities and efficient storage. Machine integration to smart factory will be done thanks to OPC UA (Open Platform Communications Unified Architecture) communication protocol supported by the machine. At the end, aggregated data and results will be sent to the Biesse Digital Platform (Sophia) for remote control and deep storage. KPIs (Key Performance Indicators) will be checked day by day, so that production data can lead to an integrated approach to zero-defect manufacturing, according to the plan this issue will be treated along D1.8. The proposed solutions will be developed for the top CNC (computer numerical control) woodworking solution by Biesse. The tester machine will be installed at an important Italian customer, where optimized manufacturing operations and high-quality are needed.

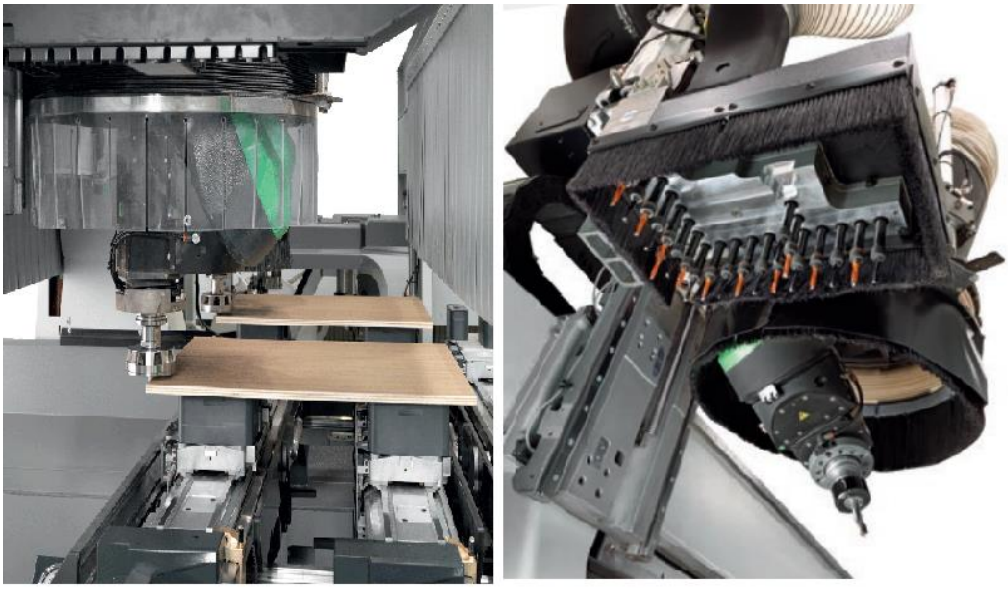

Figure 7. Pilot 2: Electrospindle in CNC Rover

Pilot 2 includes two different business processes, which have been modelled both in the AS-IS analysis of the current situation and in the TO-BE analysis of the expected scenarios that implement and apply i4Q solutions:

- AsIs_P2_BP01: Diagnostic of axis movement and torque monitoring
- AsIs_P2_BP02: Electrospindle Monitoring
- ToBe_P2_BP01: Diagnostic of axis movement and torque monitoring
- ToBe_P2_BP02: Electrospindle Monitoring

3.2.1 As-Is: Analysis of the Current Situation

In general, the processes of both As-Is case studies are divided into 3 macro blocks (pools):

- **Customer production**: this pool indicates the activities carried out at customer site represented by the corresponding lane in the drawio diagram;

- **Sophia**: it is the machine problem manager that carries out the function to open ticket to Biesse support. This manager tool is not on board, but it is on cloud;
- **Biesse support**: it is the Biesse's process where the support and maintenance activities are carried out.

In case of the process **AsIs_P2_BP01**, the process starts in the lane "CALIBRATION" that is inside the **Customer production** pool, when the machine is started. This phase will no longer be crossed again until the machine restart.

During the calibration all axes torque is recorded with a cycle frequency of 2 ms, and then checked in the "AXES TORQUE ANALYSIS" lane, where the analysis consists to verify that the recorded values are lower than the thresholds. These thresholds allow to intercept particularly heavy movements, such as collisions, but it does not allow to identify drifts. Anyway, if the test result is Warning or KO, the control sends a message on HMI (Human Machine Interface), that is an on-board machine message. In case of KO result, the machine is also stopped, otherwise, the running process is not interrupted.

Once the axes calibration is completed, the system performs also a comparison of the micro-marker position with the reference thresholds values. The management of the KO, Warning and OK is as already shown for AXES TORQUE ANALYSIS. Therefore, in the case of OK or Warning result, the process can move to the next phase, which is the "PROCESSING EXECUTION".

In "PROCESSING EXECUTION" lane, after a machine set-up, the machine is ready for automatic processing until the end of production. During that process the torque value is constantly monitored (every CNC loop) through "AXES TORQUE ANALYSIS" lane.

While, in the second process, **AsIs_P2_BP02**, this concerns electrospindle monitoring and the parameters are analyzed only during the processing state ("PRODUCTION"). In particular, if the spindle is rotating, the parameters under investigation are its temperature and current. While, when changing the tool, the analyzed parameter is the lock and unlock time. Also, these controls are based on threshold analysis, like the torque; the only differences are:

1. for the current analysis, if the data are greater than the warning threshold, a feed speed adapter is performed to bring the current back into the standard.
2. for the lock and unlock time analysis, if the procedure fails, the PLC (Programmable Logic Controller) repeats the operation N times before to stop the machine.

In general, for both As-Is case studies processes, during calibration and processing phases, the machine records information on the machine logfile, such as alarms or events that have occurred (e.g., KO, Warning or OK results). Afterwards, these logfiles are indicated in the drawio as "Notes" block, that are periodically sent to the Biesse Digital Platform (i.e., **Sophia** pool). Typically, the upload frequency is approximately into the range of a few minutes.

Later, Sophia will be able to extracts logfiles, events and save this information to its database, that can be used from every part of the world. Furthermore, Sophia can track down KO events, for example the ones recorded during "AXES TORQUE ANALYSIS", "TEMPERATURE ANALYSIS", "CURRENT ANALYSIS" or "LOCK/UNLOCK TIME ANALYSIS" and consequently opens a service support request to **Biesse support** pool.

In the “HOTLINER” lane the service team takes in charge the request within one hour and starts to analyse the problem. For a better understanding of the causes, the hotliner usually checks the events recorded in Sophia's logfile and then may have a call with the customer if further testing may be required at this stage. The outcome of this first low-level diagnosis can lead to:

1. In the best hypothesis, the problem is solved with the recovery and start-up of the machine;
2. In the intermediate hypothesis, the machine is partial restarted. However, maintenance is required for a completed recovery. This is a maintenance task with medium priority;
3. In the worst case, the machine stop is confirmed and high priority maintenance is required.

Cases 2 and 3 need maintenance tasks with different priorities, that are managed with support in the field by the service team.

Available algorithms don't currently allow to perform in-depth analysis; therefore, the problems diagnosis can be only approximate and the probability to identify the single component damaged is quite low. Therefore, maintenance will require disassembling some components for inspection, so this inefficiency will have an impact on troubleshooting time and maintenance cost increasing.

However, once the maintenance is complete, the machine can be restarted.

3.2.1.1 AsIs_P2_BP01: Diagnostic of axis movement and torque monitoring

Process Name	“Diagnostic of axis movement and torque monitoring”
Process Description	The process includes the monitoring and diagnostic of axis motion, through: • Check of micro-marker values respect to a standard tolerance range, during the calibration of the axes. Micro-marker consists in a sensor able to check the right reference position for each axis. This control allows to identify anomalies during the start-up phase of the machine, while monitoring can no longer be carried out during processing. • Check and notification that axes torque values are lower than the threshold of maximum torque available by drivers. This allows to identify particularly heavy movements (e.g., collisions) but does not allow to identify phenomena such as chattering, vibrations and premature or normal physiological degradation of the components. Unfortunately, kinematic and dynamic analysis of the axes can only be investigated through on-demand and off-line analysis, using tools such as MATLAB: for example, from Biesse experience we know that the FFT and Campbell analysis of axis torque contains information about screw eccentricity and bearing defects, their identification and analysis trend can be used for predictive analysis.The impossibility to intercept these anomalies can result in: • Insufficient quality of surface processing with the need for further finishing operations, or to definitively discard the

	product. Therefore, this can lead to an increase of the production time or the occurrence of production stops; • Unexpected breakage of machine components can lead to production limitations or stops. Every message on HMI is wroten on the logfile, that is indicated by note blockes in the customer production pool.
Actors and Roles	Biesse Customer: Production manager, Quality manager and Machine operators Biesse : Quality, Automation, Service and Salesforce department
Information Systems	Machine tool CNC, drive data, position sensors, OPC UA standard protocol, digital platform Biesse (Sophia)
Problems and needs	It is not possible either to intercept in advance components that will break or to identify the defects that will cause a quality degradation in the processing. Therefore, the identification of the problems can only be done with technical assistance by Biesse, without the possibility to recognize the causes by remote support and plan assistance finalized to resolve the issues which impact machine downtime, customer satisfaction and costs.
Internal and external barriers	• Test cycles to sample data under known constraints in order to ensure repeatability and comparability among measures. • Limits in data sampling frequency. • Micro-marker data are acquired only during the axes calibration.
i4Q Expectations	Define techniques aimed to acquire and elaborate data of torque and micro-marker axes, in order to detect phenomena such as chattering, vibrations and premature or normal physiological degradation of the components and to avoid unexpected breakage. Self-diagnosis: enhance the intelligence of the machine with self-diagnosis tools and make the outputs available (e.g., more details on the errors issued, ...) to the users (i.e., machine operator, Biesse support) and to the Biesse Digital Platform (Sophia).

Table 7. Pilot 2: AS-IS P2_BP01 Diagnostic of axis movement and torque monitoring

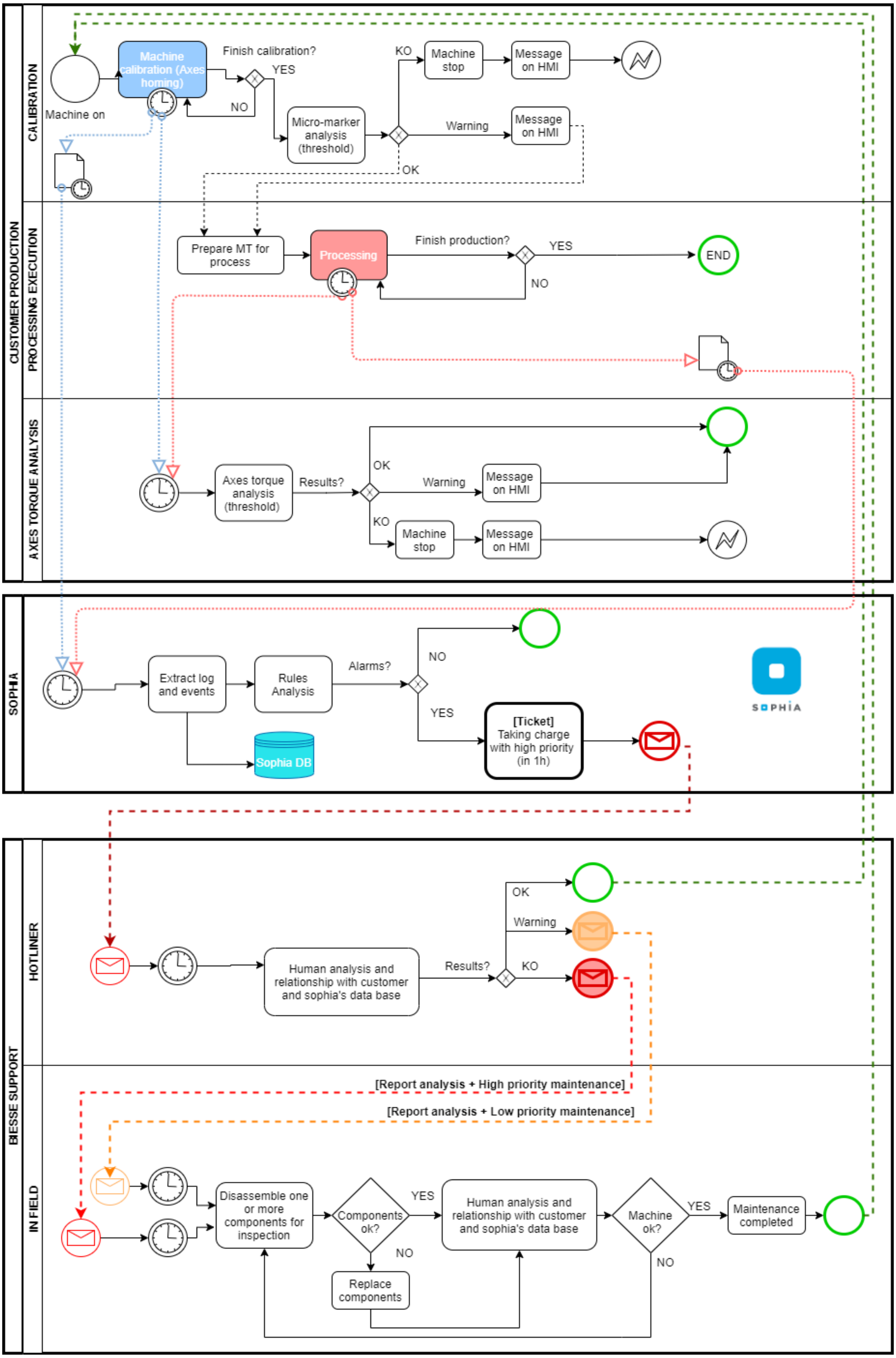

Figure 8. Pilot 2: AS-IS P2_BP01 Diagnostic of axis movement and torque monitoring

3.2.1.2 AsIs_P2_BP02: Electrospindle Monitoring

<table>
<tr><th>Process Name</th><th>“Electrospindle Monitoring”</th></tr>
<tr><td>Process Description</td><td>The process supervises the telemetry data of electrospindle, such as absorbed currents, stator and bearings temperatures and tool lock/unlock times.

PLC acquires and elaborates this data while the electrospindle is performing milling, drilling or cutting operations and during tool changes:
The control of the absorbed currents consists in verifying the critical thresholds that could damage the motor are not exceeded. PLC can protect the electrospindle by reducing the processing feed speed or stopping it completely if necessary.
The control of stator and bearings temperatures allows identifying values higher than thresholds defined by the electrospindle manufacturer, which could damage the windings or identify mechanical anomalies. In these situations, PLC can stop the machining.
The control of lock/unlock times in tool changes consists in verifying these values do not exceed predetermined thresholds, beyond which PLC declares the failure and prepares a new tool change attempt.
However, the monitoring is not effective to detect slow degradation about the electrospindle health status. Therefore, machine downtime due to breakage of components or deterioration of the process quality may occur.</td></tr>
<tr><td>Actors and Roles</td><td>Biesse Customer: Production manager, Quality manager and Machine operators

Biesse: Quality, Automation, Service and Salesforce department</td></tr>
<tr><td>Information Systems</td><td>Machine tool CNC, drive data, temperature sensors, 3 axis accelerometers, OPC UA standard protocol, digital platform Biesse (Sophia).</td></tr>
<tr><td>Problems and needs</td><td>The controls already implemented allow monitoring of electrospindles, based on thresholds algorithms. These analyses make it possible to intercept breakages or machine stops as they occur. Therefore, it is not possible to analyse drift trends, which instead would allow reducing costs and assistance times in advance.</td></tr>
<tr><td>Internal and external barriers</td><td>At the moment the analysis of this data can only be done in the time domain using algorithms based on thresholds control. Therefore, it is not possible to analyse neither drifts over time nor frequency spectra from which it is possible to intercept component breaks in advance.
Accelerations when monitoring on the electrospindle.</td></tr>
</table>

i4Q Expectations	Define data acquisition and algorithm development methodology to identify drift phenomena Self-diagnosis: enhance the intelligence of the machine with self-diagnosis tools and make the outputs available (e.g., more details on the errors issued, ...) to the users (i.e., machine operator, Biesse support) and to the Biesse Digital Platform (Sophia).

Table 8. Pilot 2: AS-IS P2_BP02 Electrospindle Monitoring

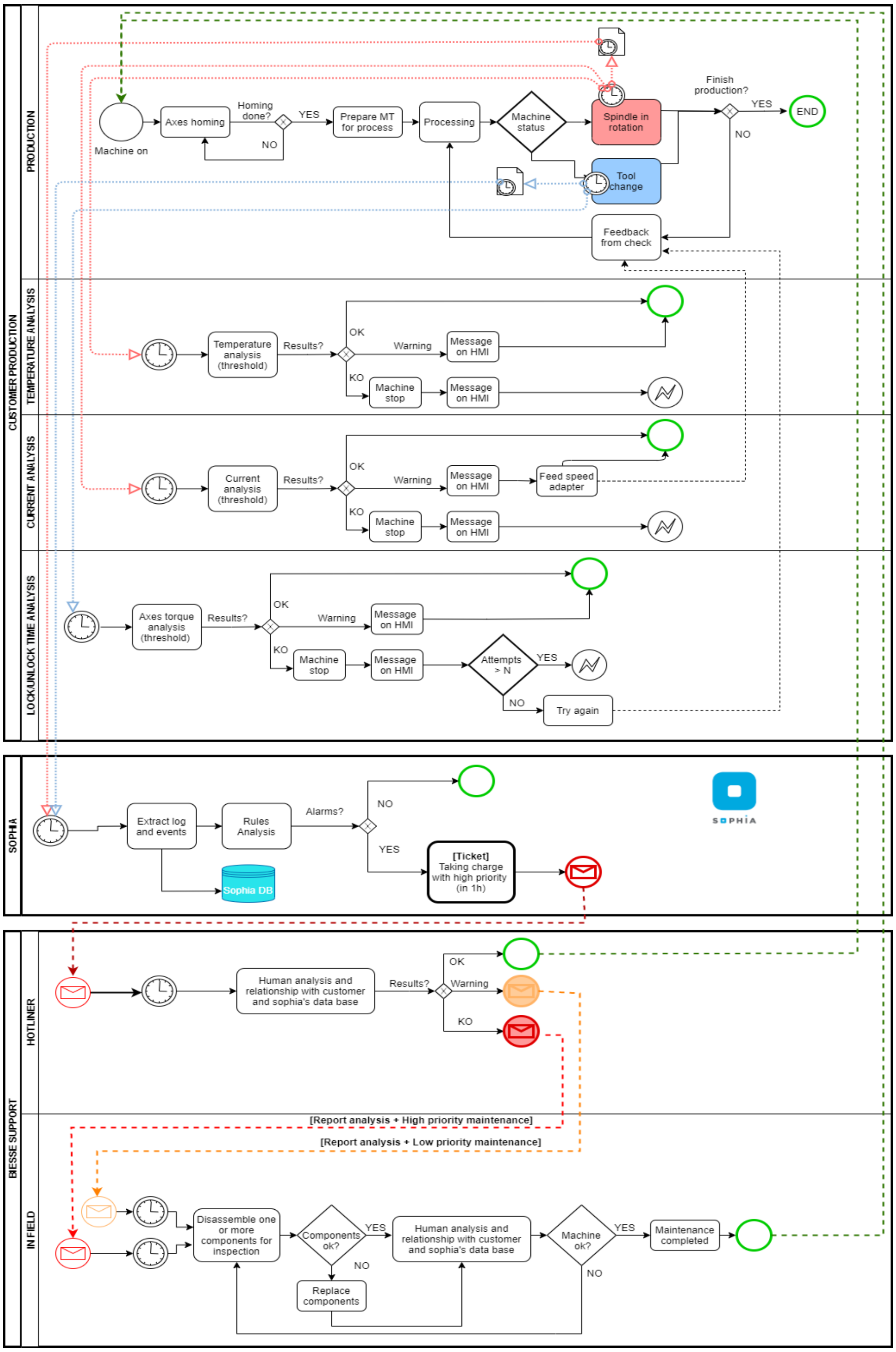

Figure 9. Pilot 2: AS-IS P2_BP02 Electrospindle Monitoring

3.2.2 To-Be: Analysis of the Expected Scenarios

In the To-Be scenarios, Biesse intends to integrate the i4Q solutions into the current process. In detail, in the **Customer production** pool the new lane "i4Q solutions" is introduced, with the following aims:

1. Define the algorithms, in time and frequency domain, that are able to perform a predictive components degradation;
2. Define the right edge-cloud architecture, where the considerable amount of data can be analyzed;
3. Build an "admin" interface for an expert user where it is possible to define the testing parameters for the expected analysis;
4. Build an "user" interface (i.e., machine operator, Biesse support), where it is reported the diagnosis performed by algorithms.

Data will be recorded during different machine phases (e.g., calibration, processing, ...); in addition to As-Is scenarios, test cycles will be developed in order to acquire data under well-known boundary conditions.

New algorithms, in the time domain and in the frequency domain, should be able to intercept machine trends and which is the suspected components that cause KO or Warning results. This high-level information will be stored in a database that will be an input to Sophia.

Therefore, i4Q solutions will be able to intercept premature or normal physiological degradation of the components, while Sophia will be able to manage tickets with different priority (i.g., red ticket in case of a high-level problem or orange ticket when a drift is detected).

This innovation will impact in both lanes of **Biesse support**:

1. "HOTLINER": manage incoming tickets with different priorities and plan a more focused maintenance support to solve the problem;
2. "IN FIELD": perform a faster maintenance support.

Furthermore, with the aim to increase the reliability of the algorithms, Biesse requires to collect feedback from **Biesse support** to i4Q solutions, especially in case of wrong diagnosis. For example, a feedback can require a tuning of thresholds or improvements of the algorithms.

3.2.2.1 ToBe_P2_BP01: Diagnostic of axis movement and torque monitoring

Process Name	"Diagnostic of axis movement and torque monitoring"
Process Description	The process includes diagnostics on the movement of the machine axes and torque monitoring, and the use of the IoT to improve the information available to the customer and to Biesse Support. Through i4Q platform it will in fact be possible not only to detect phenomena such as chattering, vibrations and premature or normal physiological degradation of the components and to avoid unexpected breakage, but also to enrich self-diagnosis and make the outputs available to the user.

Process Name	"Diagnostic of axis movement and torque monitoring"
Actors and Roles	Biesse Customer: Production manager, Quality manager and Machine operators Biesse : Quality, Automation, Service and Salesforce department
Information Systems	Machine tool CNC, drive data, position sensors, OPC UA standard protocol, digital platform Biesse (Sophia). i4Q solutions
Problems and needs	Hardware currently available may not be enough to identify all the causes of degradation. Consequently, the analysis could highlight limitations that also require future hardware developments.
Internal and external barriers	• Test cycles to be performed possibly with additional activities to the standard processing ones, which customers could sense as reduction in machine productivity. • The acquisition of micro-marker data is done only during the axes calibration, otherwise a specific test cycle is needed.
i4Q solutions involved	Necessarily • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Data Integration and Transformation Services • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Edge Workloads Placement and Deployment • i4Q Infrastructure Monitoring • 4Q Rapid Quality Diagnosis • i4Q Prescriptive Analysis Tools • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit • i4Q Manufacturing Line Data Certification Procedure Others • i4Q Data Quality Guidelines / QualiExplore • i4Q AI Models Distribution to the Edge

Table 9. Pilot 2: TO-BE P2_BP01 Diagnostic of axis movement and torque monitoring

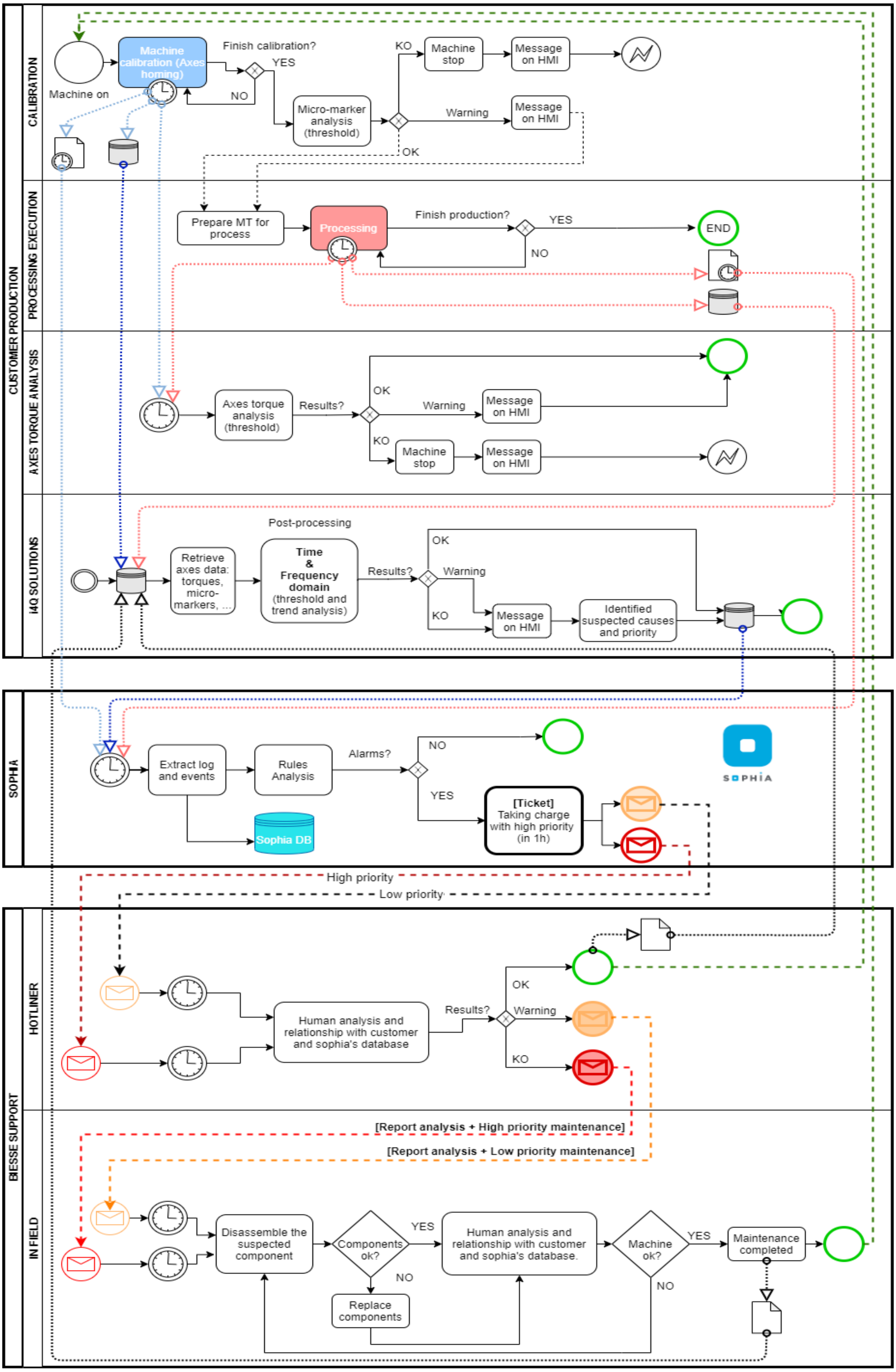

Figure 10. Pilot 2: TO-BE P2_BP01 Diagnostic of axis movement and torque monitoring

3.2.2.2 ToBe_P2_BP02: Electrospindle Monitoring

Process Name	"Electrospindle Monitoring"
Process Description	The process includes diagnostics on the electrospindle, and the use of IoT would improve the information available to the customer and to Biesse Support. This information is conditioned by the boundary conditions; therefore, it will be necessary to design test cycles to acquire data in a controlled manner. Through i4Q solutions it will in fact be possible not only to detect unexpected breakage on the electrospindle due to premature or normal physiological degradations, but also to enrich self-diagnosis and make the outputs available to the user.
Actors and Roles	Production manager, Quality manager and Machine operators (Customer) Quality, Automation, Service and Salesforce department (Biesse)
Information Systems	Machine tool CNC, drive data, temperature sensors, 3 axis accelerometers, OPCUA standard protocol, digital platform Biesse (Sophia). i4Q solutions.
Problems and needs	Hardware currently available may not be enough to identify all the causes of degradation. Consequently, the analysis could highlight limitations that also require future hardware developments.
Internal and external barriers	Test cycles to be performed possibly with additional activities to the standard processing ones, which customers could sense as reduction in machine productivity.
i4Q solutions involved	Necessarily • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Data Integration and Transformation Services • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Edge Workloads Placement and Deployment • i4Q Infrastructure Monitoring • i4Q Rapid Quality Diagnosis • i4Q Prescriptive Analysis Tools • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit • i4Q Manufacturing Line Data Certification Procedure Others • i4Q Data Quality Guidelines / QualiExplore • i4Q AI Models Distribution to the Edge

Table 10. Pilot 2: TO-BE P2_BP02 Electrospindle Monitoring

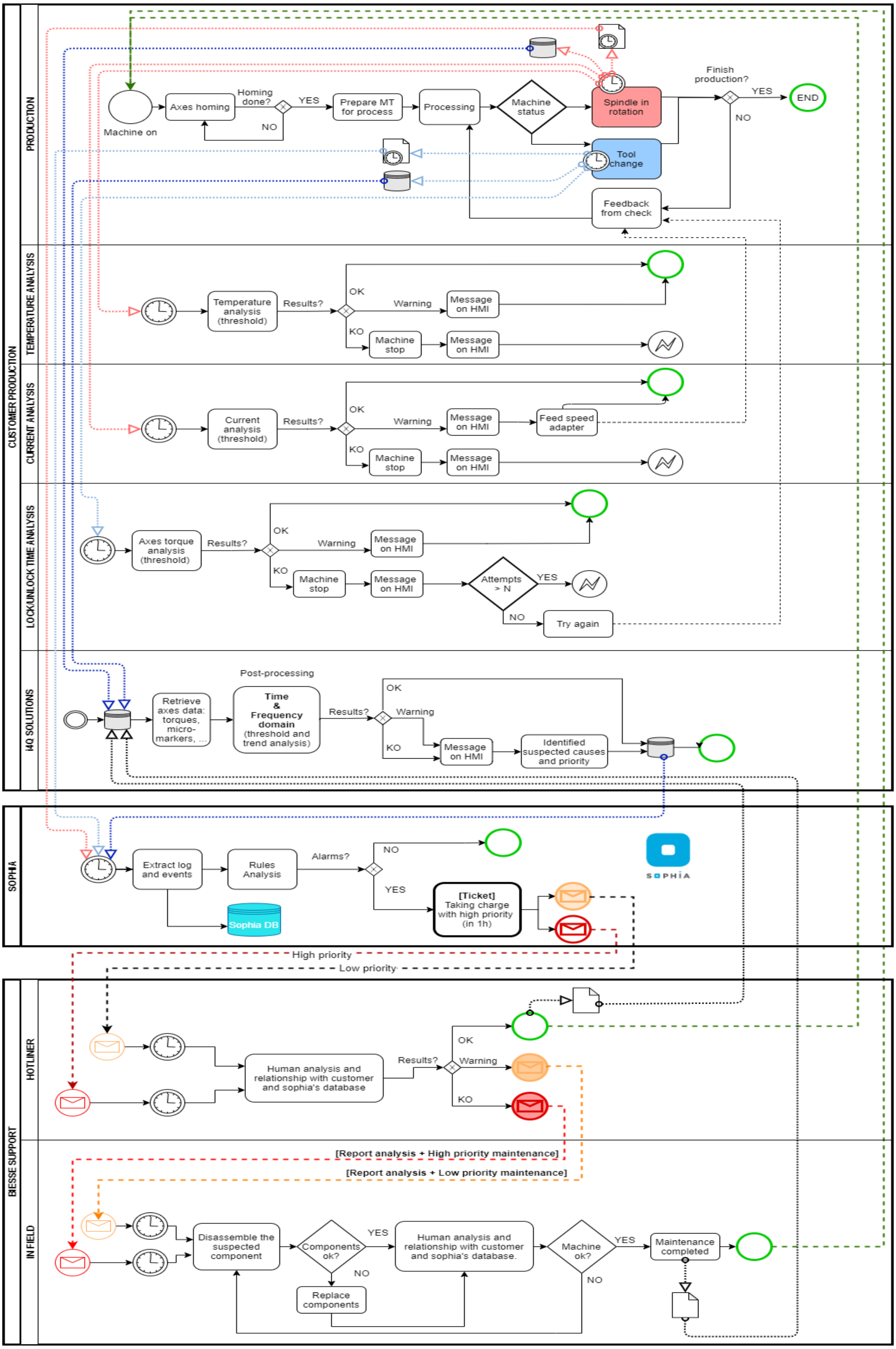

Figure 11. Pilot 2: TO-BE P2_BP02 Electrospindle Monitoring

3.3 Pilot 3: White Goods Product Quality

Whirlpool EMEA is the use case owner of the third pilot of i4Q. Whirlpool is the largest company in the white good sector and produces Refrigerators, Microwave and ttraditional Ovens, Cooktops, Dishwashing, Washing and Clothes drier. The use case is based in Radomsko factory (Poland) and is based on the improvement of an important business process which is currently in place to monitor the product conformity in production. Product conformity is the internal acknowledgement that a single unit sold in the market is respecting the performance parameters declared (i.e. Energy Consumption, Cleaning and Drying Performance, Water Consumption, Cycle duration and Noise).

The most direct way to certify that every unit produced is respecting these parameters is to perform an intensive test, however this is not possible since these tests requires hours and very expensive measurement system, so, currently, the process is based on a statistical test performed on a small percentage of production (3% to 4%).

However, i4Q can provide a step improvement in this topic: the expected to be scenario is based on the development of an AI based solution that is able to infer a prediction of each product performance conformity based on very few parameters measure alongside the production line, especially those gathered at the final test (EoL – end of life - test). This new approach could provide a lot of advantages that will reflect on the overall perceived quality from the final consumer, as well as an improvement of internal quality processes and KPI.

Pilot 3 includes one business process, which has been modelled both in the AS-IS analysis of the current situation and in the TO-BE analysis of the expected scenarios that implement and apply i4Q solutions:

- AsIs_P3_BP01: Factory Product Conformity Monitoring
- ToBe_P3_BP01. Full production product conformity automatic assessment

3.3.1 As-Is: Analysis of the Current Situation

3.3.1.1 AsIs_P3_BP01: Factory Product Conformity Monitoring

Figure 12. Conformity Monitoring

The AS-IS business process is a standard procedure within all Whirlpool and it is described by a series of standards. Here we are reporting a simplified one.

Annually, each PQM (Plant Quality Manager) establish the sampling plan for products to be submitted to periodic testing for verification of compliance with the values stated on the energy label. The Sampling Plan is based on production forecast taking into consideration all regulatory attributes identified for each platform (e.g., Energy, Water consumption, Noise, Rinse etc..) covering at least 100 ppm (parts per million) of the planned volumes, distributed on the different Technical Models.

In accordance with the sampling plan, the PQM (Plant Quality Manager) picks up from the Finished Product Warehouse the products to be sent to the reference Global Product Organization (GPO) laboratories, responsible for carrying out the tests (only one unit for each Technical Model).

Each product is identified by a label reporting

- Factory where manufactured,
- Production date,
- Model Name,
- SKU (Stock Keeping Unit),
- Technical model,
- Stage number.

The laboratory carries out the test according to the test specifications mentioned in the laboratory request.

At the end of the test, the laboratory updates the Lab Request and sends the Test Report to the PQM.

If test results indicate compliance with requirements, the GPO Laboratory is in charge to return the product to the plant using an adequate repacking. In case of noncompliant test results, the PQM must collect three additional units of the same Technical Model. In Case of Noncompliant Results, PQM inform the PQL (Product Quality Leader) by email with the link to the Test Report. PQM also opens a specific internal procedure for the management of problem solving.

PQL setups and informs the Cross Functional Technical Team (CFT), which includes at least the following functions: PQM, GPO/GPD, Central Quality, Manufacturing Quality. .

The goal of the next phase, driven by the PQL and conducted by the CFT, is:

- make a preliminary analysis of the failures
- share with PQL the “potential” origin of issues
- speed up the problem solving, driving the preliminary analysis to the right owners

Moreover a business risk assessment is also done in order to evaluate the level of risk and its effects on the markets and Central Business Team is then responsible for the final decision about possible recovery actions (i.e.: stop of production, quarantine of stocks, market actions, etc.).

Process Name	“Factory Product Conformity Monitoring”
Process Description	The process rules the task of the Factory in the continuous monitoring of Product Conformity. It is carried out by a cooperation of multiple

Process Name	"Factory Product Conformity Monitoring"
	actors and its main focus is the realization of Product Testing (mostly manual) on product sampled after the production (each product family own a specification of laboratory test to be conducted) The results of the test, if considered meaningful (according to specific standard) and negative (I.e. not conform) are then evaluated by a multifunctional team involving.Central Quality, Central Business Team in order to decide further steps.Depending on severity of the potential damage, these can vary from a simple process check to a, rarer, product recall from market.
Actors and Roles	Factory, Laboratory, Central Business Team,
Information Systems	None test report are stored as documents in Google Drive (company shared drive).
Problems and needs	Current approach is using intensively human force and high-cost equipment to perform test on a statistical base. This implies that some non-conform product can still reach the market dissatisfying our consumer. Also, the decisional process behind batch block, production suspension etc. is poorly supported by a consistent base of data, turning into slow reaction time from negative event to actions.
Internal and external barriers	Use different data sources, owned by different departments and not yet unified. Still unknown the possibility to correlate production data to potential non-conformity. Available technologies for machine learning and data aggregation are unknown.
i4Q Expectations	i4Q should provide a mechanism to perform virtual test, on 100% of production and either decide on conformity of product or help decision on that. The virtual test can be considered as a Prediction of non-conformity of the products extensible from single product to entire batch. The i4Q tools will also help all the decision chain to improve effectiveness and efficiency of actions (more accurate in less time).

Table 11. Pilot 3: AS-IS P3_BP01 Factory Product Conformity Monitoring

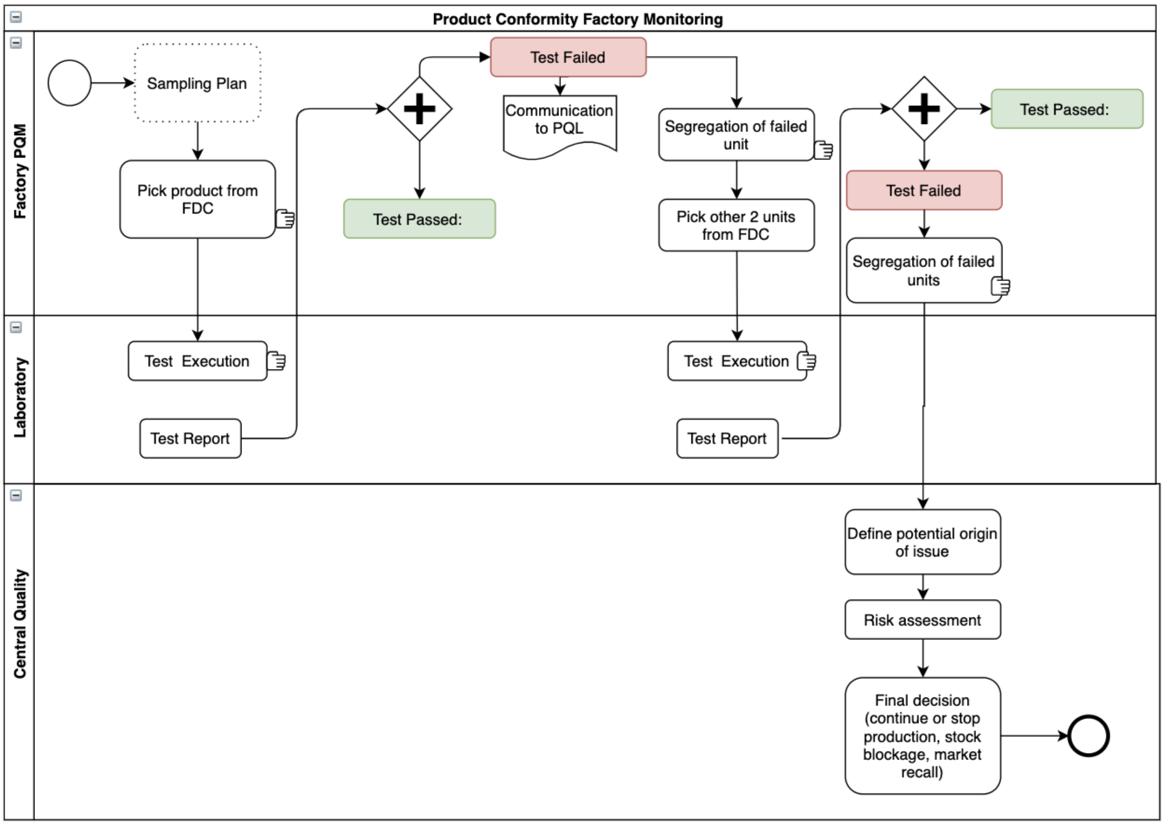

Figure 13. Pilot 3: AS-IS P3_BP01 Factory Product Conformity Monitoring Schema

3.3.2 To-Be: Analysis of the Expected Scenarios

3.3.2.1 P3_BP01. Full production product conformity automatic assessment

In the to-be scenario the physical test is substituted by a Virtual Test performed by an AI enabled set of i4Q solutions: the i4Q Virtual Test has these advantages:

- Can be performed of 100% of production, improving the statistical relevance of conformity monitoring.
- Can speed up the process of alerting, allowing to take decisions faster
- Can reduce the amount of sampling with a significant cost reduction in Human Labour
- Can reduce the investment on factory laboratory equipment

The virtual test system is expected to generate prediction of potential non-conformity on all the production and keep track of the results of predictions: these data will be used to generate automatic alert to the Central Quality Team that will analyse the data and help decision maker on final actions about stopping the batch, suspend production etc.

This process will also be enhanced by a Data Visualization and Analytical tool that user will access as a DSS.

Process Name	"Full production product conformity automatic assessment"
Process Description	The to-be process shows a great simplification: the physical test on sampled products is substituted by a virtual laboratory which is able to

Process Name	"Full production product conformity automatic assessment"
	infer the product conformity on 100% of production examining the data recorded for each product at various production gates (e.g. End of Life test). The result of the virtual tests is then used to communicate automatically to relevant actors the need of a further analysis to decide whether to block the batch and to stop production. The workaround of the issue will be also supported by a powerful analytical tool
Actors and Roles	Factory Central Business Team
Information Systems	WHR Databases, i4Q solutions
Problems and needs	This new process must earn user trust, so a medium to long validation period is expected. The new process will be not substituting the old one until a full confidence on results will be achieved. However, the new process could also influence positively the old one (e.g.: reducing the sampling rate, modulate the sampling algorithm)
Internal and external barriers	Data availability: despite rich,it can turn out that some data needed to improve correlation are not yet captured (e.g. traceability). Data Quality: some data are still human generated and can be subject of difficult interpretation or not accurate.. Difficult Machine Learning process; High risk of low correlation of data.
i4Q solutions involved	Necessarily: • i4Q Data Quality Guidelines / QualiExplore • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Data Integration and Transformation Services • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard Others • i4Q Prescriptive Analysis Tools

Table 12. Pilot 3: TO-BE P3_BP01 Full production product conformity automatic assessment

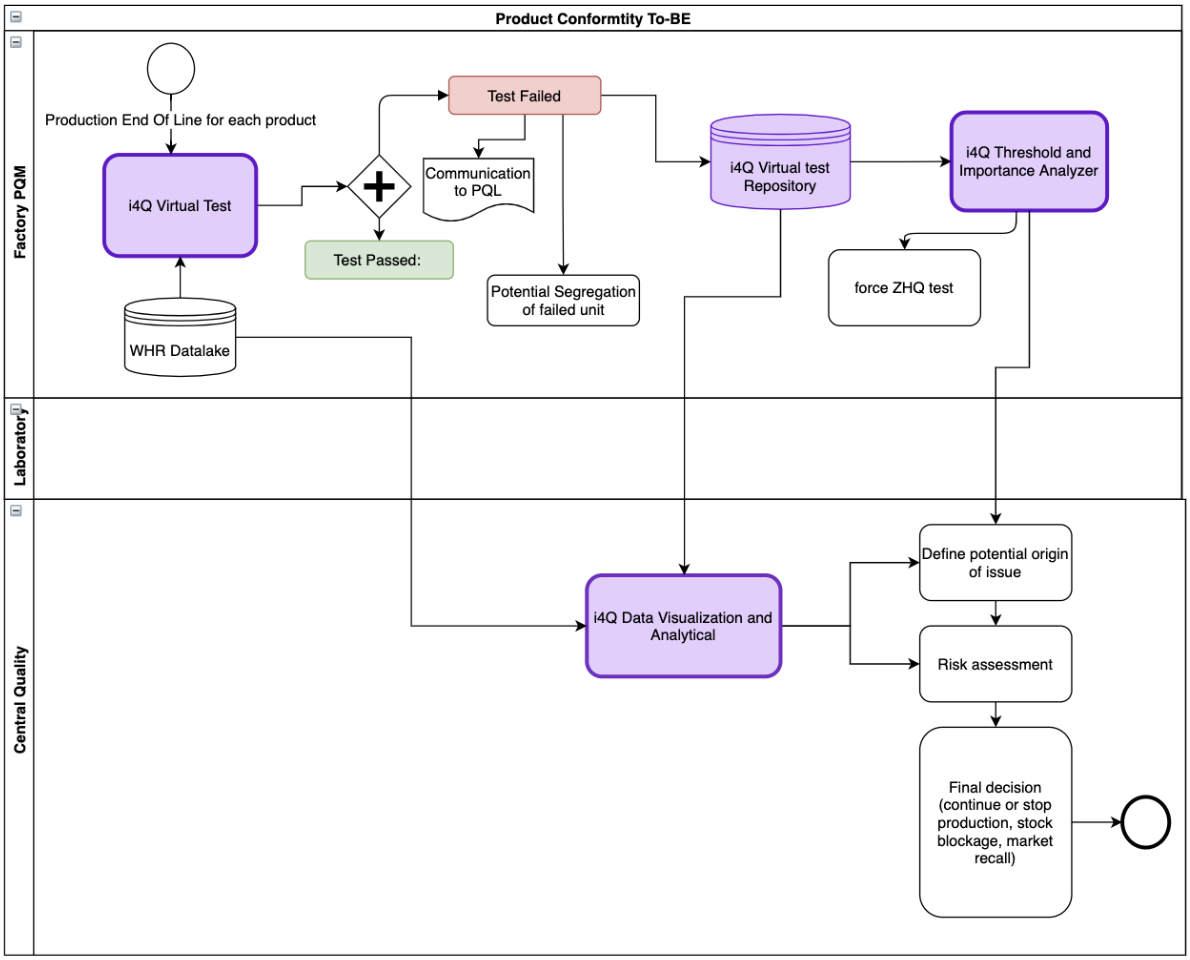

Figure 14. Pilot 3: TO-BE P3_BP01 Factory Product Conformity Monitoring

3.4 Pilot 4: Aeronautics and Aerospace Metal Parts Quality

During the CNC machining process many factors rule the dimensional and aesthetic quality of the manufactured parts and that is why quality control of the parts must be carried out during the production process. This while-producing quality control is very complex, takes a lot of time and requires very expensive measuring equipment. It is also not a 100% effective which causes scrap and all the data collected from the measurements are only analyzed for that specific production.

Factor will exploit the i4Q RIDS to make a 100% while-producing quality control of the manufacturing and use all the data obtained from this control to anticipate future manufacturing problems by treating this data with algorithms.

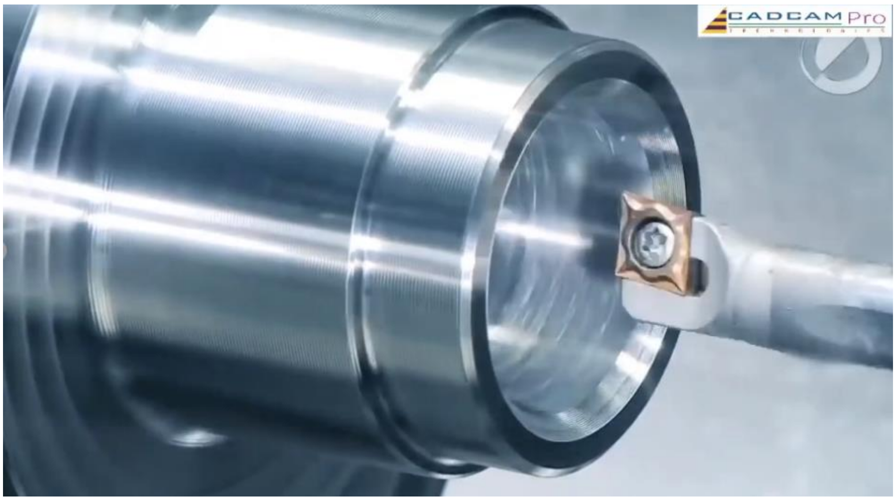

Figure 15. FACTOR machining

Pilot 4 includes two business processes, which has been modelled both in the AS-IS analysis of the current situation and in the TO-BE analysis of the expected scenarios that implement and apply i4Q solutions:

- AsIs_P4_BP01: In-line product quality control
- AsIs_P4_BP02: Machine adjustments in the machining process
- ToBe_P4_BP01: In-line product quality control
- ToBe_P4_BP02: Automatic online correction of the CNC machining process

3.4.1 As-Is: Analysis of the Current Situation

3.4.1.1 AsIs_P4_BP01: In-line product quality control

Process name	" Quality control of the product in manufacturing "
Process description	The in-line control process begins once the machine has started production and the quality department checks the part and confirms that it is OK. From this moment on, the operator must take some samples of parts during the manufacturing process, according to the quality department indications. After that, he goes to the inspection area and proceed to measure 100% of the levels that the quality department has stipulated in the "Inspection Guideline" document and record the measurements. Once all the measurements have been carried out, the piece is classified as OK or NOK. In the case of being OK, it must be determined whether the part requires any correction or not. The production process continues until the next quality control inspection as indicated by the quality department. In the case where the part is NOK, the machine must be stopped and the incident produced corrected. This incident can be corrected by the operator or by the assembler. The quality department will be notified to carry out the segregation of NOK parts from the last interval of parts manufactured up to that moment and will identify and segregate the non-conforming batch. Once the non-conformity has been corrected, another measurement of the piece will be carried out until it is in accordance with the

	specifications indicated in the guideline, and the machine can be started up until the next scheduled measurement.
Actors and roles	Quality department, machine operator and machine assembler.
Information systems	CNC machine tool, inspection guideline, part drawing.
Problems and needs	At present, it is not possible to inspect 100% of the production in-line due to the long time necessary to do it manually. Also, the data obtained is not processed for future manufacturing.
Internal and external barriers	To achieve this objective, human and material resources should be 5 times bigger than it is at the moment, which is not economically viable.
i4Q Expectations	Development of an automated system for collecting the piece, cleaning and measuring all or some of the most critical dimensions. Subsequent treatment of the data obtained from the measurements.

Table 13. Pilot 4: AS-IS P4_BP01: In-line product quality control

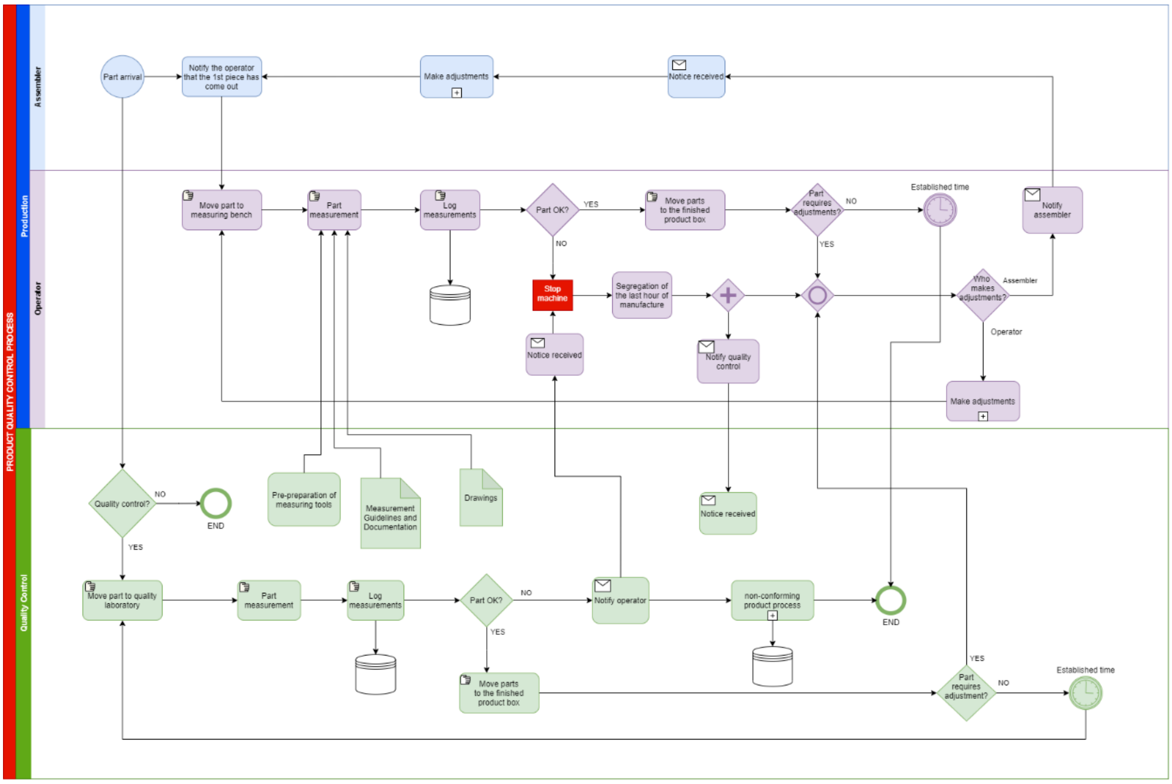

Figure 16. Pilot 4: AS-IS P4_BP01: In-line product quality control

3.4.1.2 AsIs_P4_BP02: Machine adjustments in the machining process

Process name	" Machine adjustments in the machining process "
Process description	The in-line control process begins once the machine has started production and the quality department checks the part and confirms that it is OK. From this moment on, possible stops due to various incidents begin to occur. These incidents are: loss of quality of the parts, vibrations, high temperature, tool breakage, tool wear, machine alarms, NOK visual appearance, metal chips status, high power consumption of the machine due to loss of tool efficiency and metal chip jams.

Process name	" Machine adjustments in the machining process "
	When these incidents occur, the machine operator is who must find out the problem and then decide how to solve it. This process is long and expensive and runs the risk of not making the right decision due to lack of data. Sometimes it causes breakages with a high economic value and, in every case, losses in quality, efficiency and performance (OEE). In addition, all these incidents are not recorded and no further study of the data resulting from these stops is made.
Actors and roles	Engineering department, machine operator and machine assembler.
Information systems	CNC machine tool, visual inspection.
Problems and needs	At present it is not possible to automate the detection and resolution of these incidents. Some of them are detected by the CNC machine tool but others must be detected by the visual inspection of the operator. This creates an early detection problem.
Internal and external barriers	To achieve this objective, certain parts of the machine that are currently not sensorized should be sensorized and all the data obtained processed for subsequent treatment and automated correction online.
i4Q Expectations	Development of an automatic online data collection system and online correction of different machine parameters.

Table 14. Pilot 4: AS-IS P4_BP02: Machine adjustments in the machining process

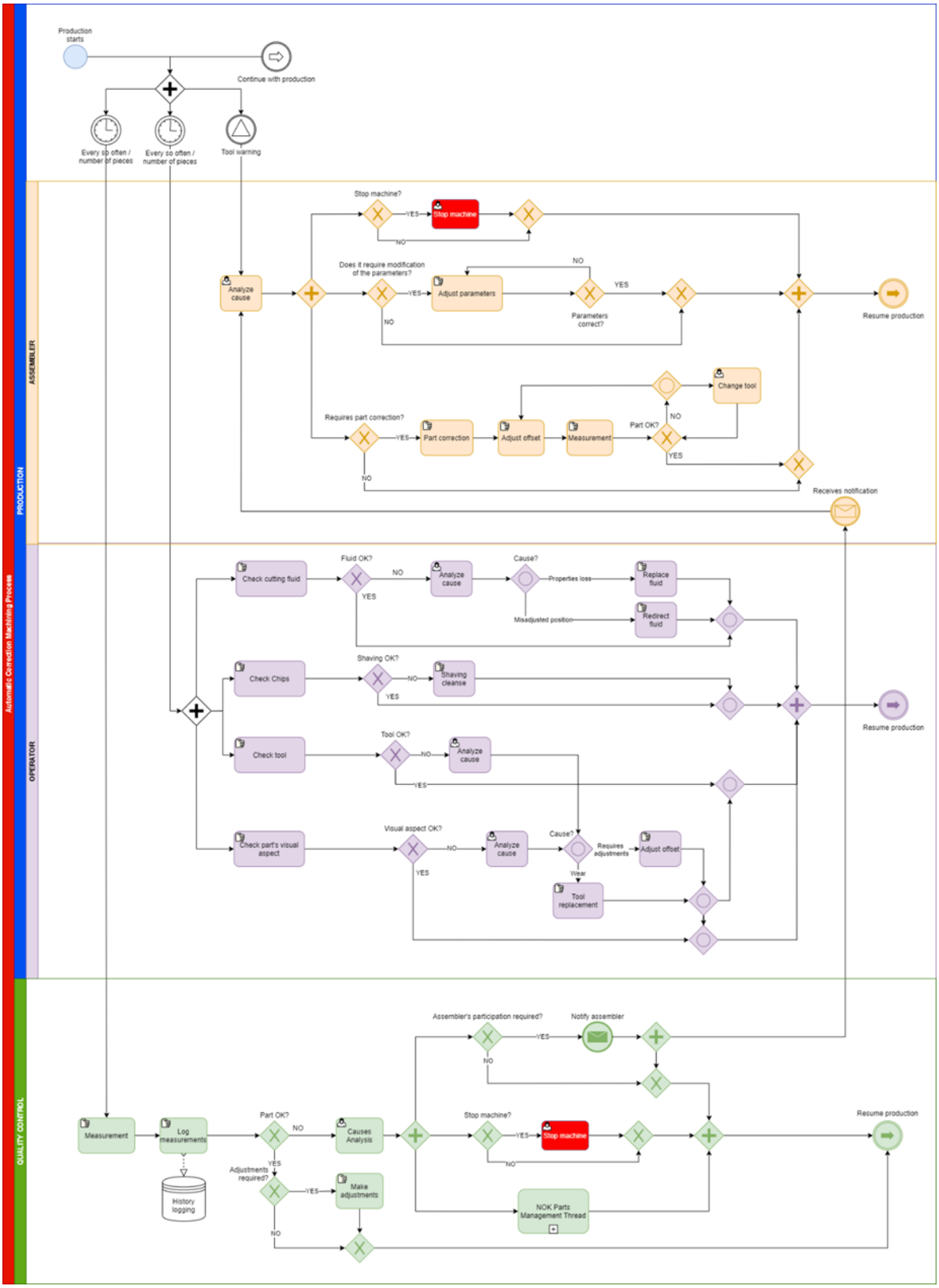

Figure 17. Pilot 4: AS-IS P4_BP02: Machine adjustments in the machining process

3.4.2 To-Be: Analysis of the Expected Scenarios

3.4.2.1 ToBe_P4_BP01: In-line product quality control.

Process name	" In-line product quality control "
Process description	The in-line control process begins once the machine has started production and the quality department checks the part and confirms that it is OK. The i4Q RIDS will be connected to the machine controller, tool and other sensor systems available for the collection of the pieces as they leave the machine, their cleaning and their measurement. The Artificial Intelligence i4Q solution will be trained to correlate a range of processing parameters with the quality of the manufactured parts. During the process, the AI i4Q solution will predict the final quality of the part and will propose to the machine controller the machine parameters that can improve the quality of said part or stop the machine.
Actors and roles	Engineering department, machine operator, machine assembler.
Information systems	CNC machine tool, inspection guideline and part drawing, i4Q solutions.
Problems and needs	It is necessary to have a system for inspection/control of the manufacturing process that allows the permanent reading and storage of the data of the manufactured parts for subsequent analysis.
Internal and external barriers	The barriers are on the one hand internal as the appropriate information systems infrastructure and training of manufacturing staff is not in place, and on the other hand external as there are no qualified staff to operate/analyse these information systems.
i4Q solutions involved	Necessarily: • i4Q Data Quality Guidelines / QualiExplore • i4Q Trusted Networks with Wireless & Wired Industrial Interfaces • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard Others • i4Q Data Integration and Transformation Services • i4Q AI Models Distribution to the Edge

Table 15. Pilot 4: TO-BE P4_BP01: In-line product quality control

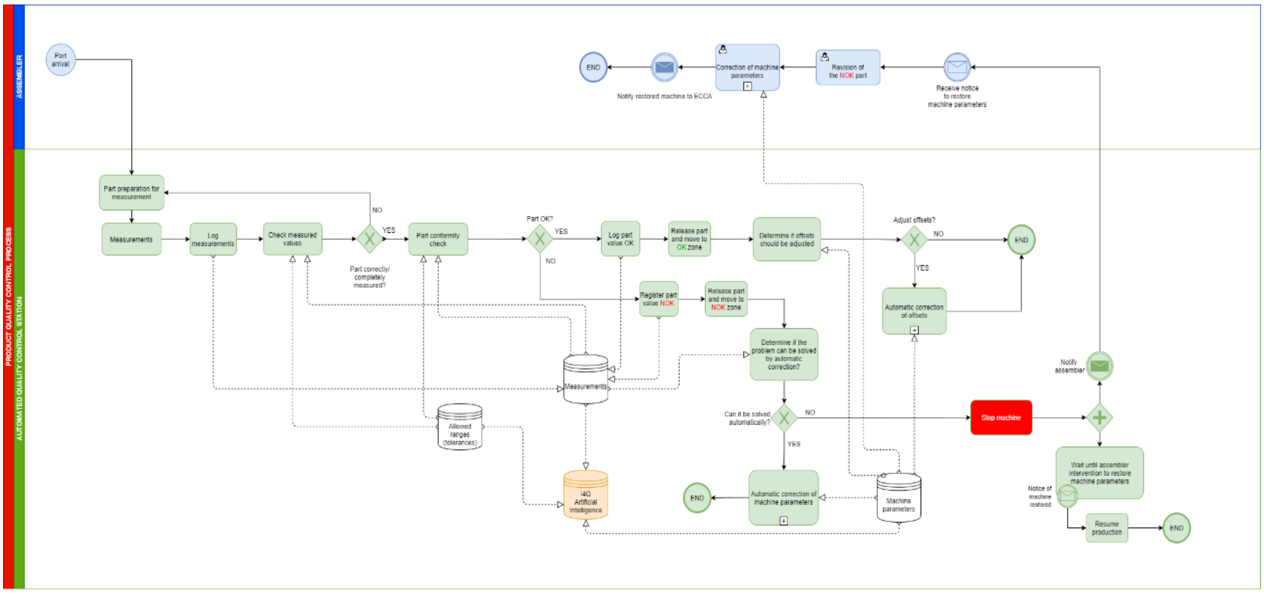

Figure 18. Pilot 4: TO-BE P4_BP01: In-line product quality control

3.4.2.2 ToBe_P4_BP02: Automatic online correction of the CNC machining process

Process name	" Automatic online correction of the CNC machining process "
Process description	When the assembler leaves the machine manufacturing the first quality-authorized OK part, the in-line production control process begins. The i4Q RIDS will connect to the machine tool controller and other available sensor systems to know the status of the machine. Artificial Intelligence i4Q solutions will be "trained" to correlate a range of processing parameters with the correct operation of the machine. During the process, the AI i4Q will predict the state of the machine and propose to the machine controller the machine parameters that must be corrected so that it continues to work in optimal conditions or stop the machine clearly determining what is happening.
Actors and roles	Engineering department, machine operator, machine assembler.
Information systems	CNC machine tool, machine operator, machine assembler, temperature, vibration, artificial vision and laser sensors. i4Q solutions
Problems and needs	In the manufacturing process CNC machine tools detect some of the problems encountered but others must be detected by visual inspection by an operator, making it impossible to have an early detection system to automate possible solutions. An information system is needed that collects the state of the machines and, based on the data analysed, establishes an early detection system for the state of the machines.
Internal and external barriers	The obstacles are internal, as it would be necessary to sensor certain parts of the machine that are not currently sensorised and to process all the data obtained for subsequent treatment and automated online correction.
i4Q solutions involved	Necessarily • i4Q Data Quality Guidelines / QualiExplore • i4Q Trusted Networks with Wireless & Wired Industrial Interfaces • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository

	• i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Rapid Quality Diagnosis • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit • i4Q Infrastructure Monitoring • i4Q Digital Twin • i4Q Data-Driven Continuous Process Qualification • i4Q Rapid Quality Diagnosis • i4Q Prescriptive Analysis Tools • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit Others • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q AI Models Distribution to the Edge

Table 16. Pilot 4: TO-BE P4_BP02: Automatic online correction of the CNC machining process

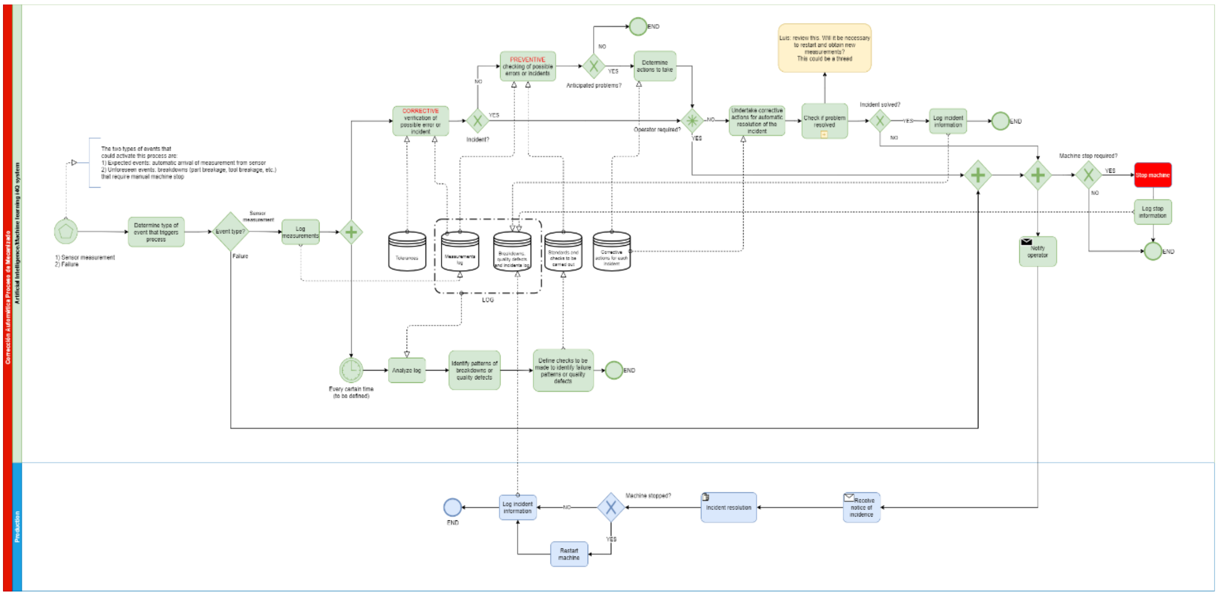

Figure 19. Pilot 4: TO-BE P4_BP02: Automatic online correction of the CNC machining process

3.5 Pilot 5: Advanced In-line Inspection for incoming Prime Matter Quality Control

RiaStone (RIAS) is part of "Visabeira Industria", a sub-holding of the "Visabeira Group" conglomerate. RiaStone is a fully automated "greenfield" production plant that was created in 2014, after being awarded a contract by IKEA Sweden for the manufacturing of 486 million tableware products in the timeframe 2014-2026. RIAS manufactures the IKEA's worldwide supply of "Dinera", "Fargrik" and "Flitighet" tableware families, through an innovative industrial ceramics production process: tableware automated single firing.

RIAS has the urgent need to improve its Overall Production Effectiveness (OPE) Key performance Indicator; presently RIAS has an OPE of ~92%, having as main improvement goal to reach an OPE of 99%. This improvement ambition requires new approaches to production, promoting innovative defect management and production control methods, namely in-line inspection technologies, and integration of ICT tools for autonomous, automatic, smart system decision taking.

There are several difficulties and inefficiencies in the processes being used today, impacting overall production efficiency, and causing significant levels of product rejection (waste to be scrapped) as a result of poor quality of incoming raw matters, which today are not detected by quality control (QC) inspection, namely, in the isostatic pressing process that creates the product's structure by pressing the raw matters into the desired shape, the density and composition variations of incoming prime matters produce volumetric mass density differences in post-pressing raw greenware, directly affecting the quality levels in finished stoneware products.

Pilot 5 includes two business processes, which has been modelled both in the AS-IS analysis of the current situation and in the TO-BE analysis of the expected scenarios that implement and apply i4Q solutions:

- AsIs_P5_BP01: Data collection and analysis for raw matter quality control
- AsIs_P5_BP02: Final product QC causal relation analysis
- ToBe_P5_BP01: Data collection and analysis for raw matter quality control
- ToBe_P5_BP02: Final product QC causal relation analysis

3.5.1 As-Is: Analysis of the Current Situation

Presently, QC techniques applied to incoming prime matters, namely ceramic pastes, is performed through lot sampling, by using the traditional methods of collecting two working paste sample amounts and performing two separate QC operations, a regular chemical laboratory analyses, and a physical QC test performed in an isostatic press by using the sampled paste to produce one greenware test plate. Both QC methods rely on non-timely practical approaches, that effectively do not allow for an immediate and accurate confirmation that incoming ceramic pastes comply with the exact formulas that allow for trouble free production of greenware products.

Further, the products' QC process is mainly carried out at the end of the production line, in the selection and packing stage, by human visual inspection. Intermediate quality checkouts are performed over limited production samples. In this process, the human QC operator visually inspects each finished piece and categorizes it into three quality standards: A (best quality), B (sufficient quality) and C (rejected as scrap). The operator also describes the defects encountered, which can, in the future, be correlated with the quality of the raw matters and with other variations on each stage of the production process. Moreover, there is no track-and-trace method for individual pieces during the production process. Hence, there is a need to find strategies that enable the aforementioned correlations between the various datasources.

Figure 20. First stage of the production process: Silos, Presses and Finishing

3.5.1.1 AsIs_P5_BP01 – Data collection and analysis for raw matter quality control

Process Name	"Data collection and analysis for quality control of raw matters"
Process Description	The raw matters arrival, storage and distribution is performed as follows: • The raw matter arrives by truck to the RIAS factory and is unloaded through a pressurization process to one of six silos that feed the production line. • With each arriving truck, two sample bags, with (supposedly) raw matter retrieved from the truck's load, are delivered for quality inspection. • Each silo can load 6 metric tons of raw matter. The matter is dispensed towards the production line by tubes connected to the isostatic presses **Figure 21** by blowing compressed air into the silo. • The six silos are arranged in groups of two and are used according to a full-empty strategy (each silo is used until is empty, while the other one is filled up). • Two separate QC operations, a regular chemical laboratory analysis and a physical QC test are performed in a test isostatic press, by using the sampled paste, provided by the raw matter provider, to produce one Greenware test plate.
Actors and Roles	RiaStone Production, RiaStone Quality Assurance (QA), raw matter provider
Information Systems	Excel-based reports of the QC processes (rarely performed)
Problems and needs	There is no present way of actively analyse the raw matter composition and overall quality since: • The sample bags delivered with each truck arrival may not be from the same batch as the one in the truck, since the sampling process is hard and there is no guarantee that it is being done correctly. • The raw matter composition is a proprietary secret of the provider, there is no composition and quality benchmark.

Process Name	“Data collection and analysis for quality control of raw matters”
	• Even if the raw matter presents a good quality level at arrival time, the overall quality of the raw matter may be affected while it is stored in the silo, due to temperature and humidity variations, heterogenization through cascading effects, • Due to the above problems, the QC analysis is often neglected since there is no way to compare it to an accurate benchmark.
Internal and external barriers	Internal Barriers • Lack of composition and quality sensing capabilities applied directly on the raw matter feeding system that connects the silos to the presses. • Data collection process is inefficient and poor, since it relies on the two QC analysis processes described above. External Barriers • The raw data provider will not provide the composition and quality benchmark.
i4Q Expectations	Through the envisaged installation of a spectrometry sensing device directly on the tubes that feed raw matter to the production process, it is expected that data collection and analysis will be achieved during i4Q. The main goal is to analyse raw matter’s composition data, in order to continuously probe its quality and effects on the overall final product quality. Further, comparison analyses between the quality of raw matter upon its arrival and its quality upon production line feeding will enable a better understanding of the changes that occur during storage as well as strategies to mitigate quality issues in the future.

Table 17. Pilot 5: AS-IS P5_BP01: Data collection and analysis for raw matter quality control.

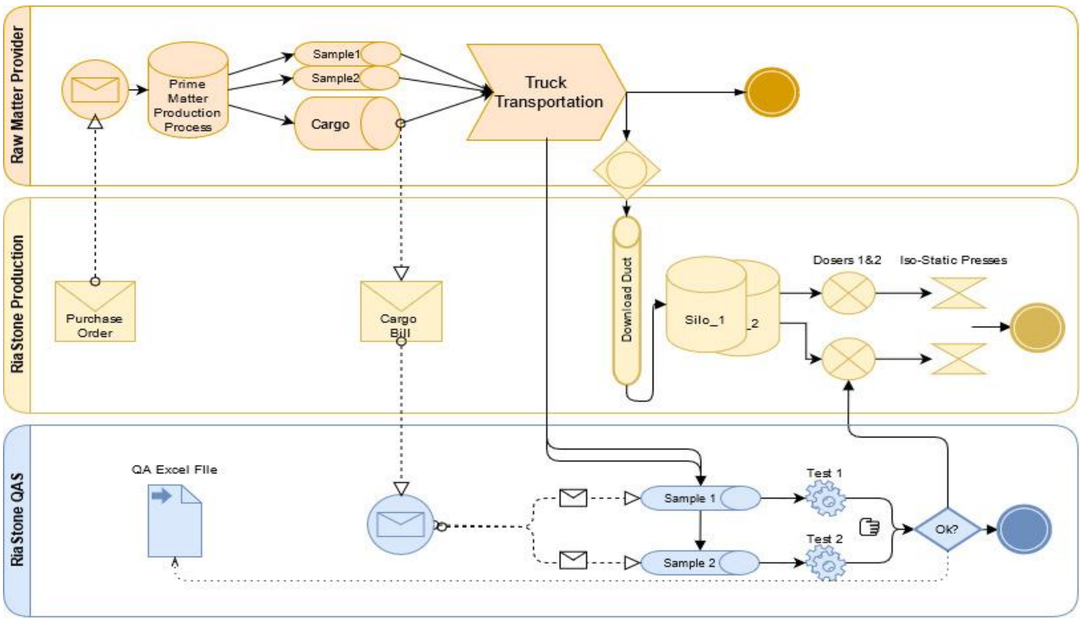

Figure 21. Pilot 5: AS-IS P5_BP01: Data collection and analysis for raw matter quality control

3.5.1.2 AsIs_P5_BP02 – Final product QC causal relation analysis

Process Name	"Final product QC causal relation analysis"
Process Description	The final product's QC process is carried out at the end of the production line, in the selection and packing stage, by human visual inspection. In this process, the human QC operator visually inspects a sample set of finished pieces, taken from each batch, and categorizes it into three quality standards: A (best quality), B (sufficient quality) and C (rejected as scrap). The operator also describes the defects encountered, which can then be defined as a consequence of a particular stage across the production process. Currently, the QC process does not record quality metrics for individual pieces because there is no track-and-trace method in place. This means that the only way to actively track the root cause of any defect is empirically (human knowledge about the processes) or by estimating the production time for that particular batch of final pieces. RiaStone is undergoing two parallel projects, one for a track-and-trace method and another for automated inspection through image processing methods, but there is no guarantee that either of them will be ready to use under i4Q (yet). Finally, the "data silo" arrangement to store data coming from different stages of the production process (raw matter, pressing, glazing, final QC) hinders the capability of having an efficient root cause analysis that links quality issues with the parameters captured in each production phase.
Actors and Roles	RiaStone QC and Ria Stone Production (main actors)
Information Systems	Excel-based reports of the final products' QC processes
Problems and needs	Currently, there is no way to correlate the quality of the raw matter with the quality of the finished product. This issue is due to: • No track-and-trace methods: a batch tracking strategy is needed at this stage, along with data collection on the tracking procedure. • The QC process data is collected only from the sample sets and not for each finished piece. Also, it is aggregated in the form of Excel-based reports: a better data structure and storage system is needed.
Internal and external barriers	Internal Barriers • Two projects (track-and-trace, automated quality inspection) are running parallelly to i4Q, but they may not be ready to use during the project. External Barriers • The raw matter's composition is a business secret belonging to the supplier.

Process Name	“Final product QC causal relation analysis”
i4Q Expectations	Within i4Q it is expected that data correlation and analytics methods are developed and deployed in order to analyse the causal relations between data collected and analysed during the production process and final products’ QC process data. Further, a systematic data collection process on the final QC stage is essential.

Table 18. Pilot 5: AS-IS P5_BP02: Final product QC causal relation analysis - Description

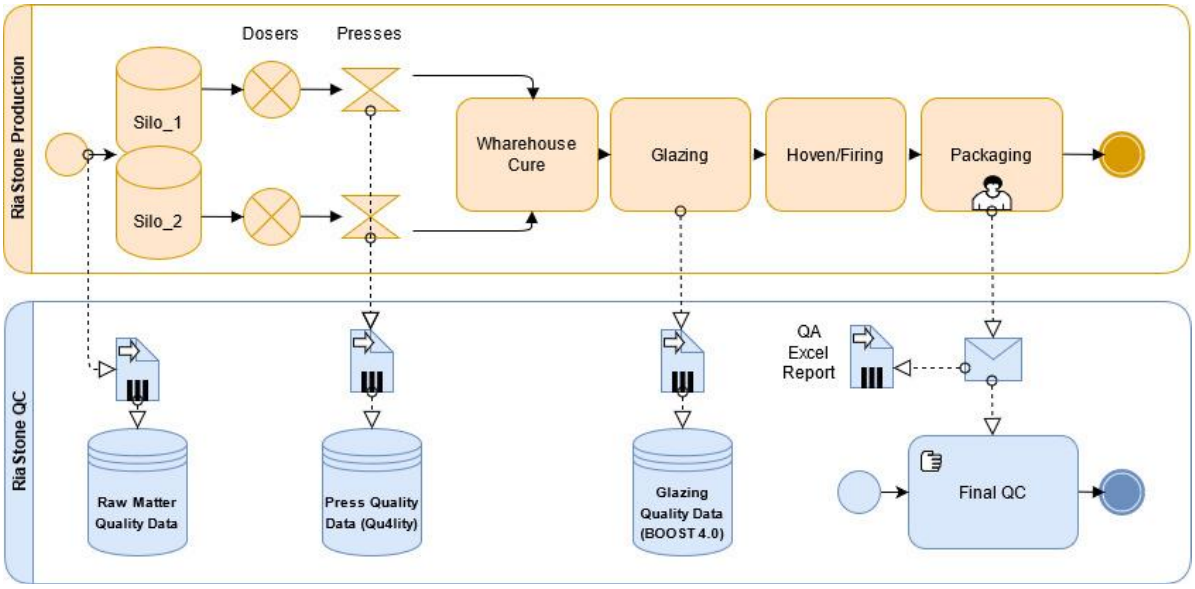

Figure 22. Pilot 5: AS-IS P5_BP02: Final product QC causal relation analysis - Schema

3.5.2 To-Be: Analysis of the Expected Scenarios

3.5.2.1 ToBe_P5_BP01 – Data collection and analysis for raw matter quality control

Process Name	“Data collection and analysis for raw matter quality control”
Process Description	The envisaged data collection for raw matter QC process is defined as follows: • Upon arrival of the raw material, an automatic procedure to measure the composition of the raw matter is performed (via a sensor installed at the exit of silos). • The raw matter composition data are stored in a centralized data storage system. • From the results of the QU4LITY Project (Grant agreement 825030), a Proof-of-Concept (PoC) for Quality Control of the pressing processes will infer the overall quality of the pressing process results, detecting defects right after the product exits the hydraulic press. • This anomaly detection procedure will be correlated with the raw matter composition data in order to identify what is the

Process Name	“Data collection and analysis for raw matter quality control”
	cause of the defect, and if the defect is directly correlated with variations on the composition of the raw matter. • Further, other defects may be only detected at the end of the production process. Hence, the correlation analysis will also be performed at the end of the process, trying to correlate defects with raw matter composition variations. • Such correlation analyses will enable RiaStone to develop knowledge about the root causes of their defects, related to the raw matter, and will provide justified reports on how the variations of the raw matter composition interfere with the overall quality of the production line at RiaStone.
Actors and Roles	RiaStoneProduction RiasStone QA i4Q Solutions, raw matter provider (secondary actor)
Information Systems	Composition sensor, Data Storage System, RiaStone reporting tools, i4Q solutions
Problems and needs	Hardware currently available may not be enough to accurately identify variations in raw matter composition. There is also the need to integrate the i4Q solutions that will realize this business process with already existing systems at RiaStone (those ones used both in production and PoC – proof of concepts - from other projects).
Internal and external barriers	Internal Barriers • The composition sensor must be installed (ongoing). External Barriers • The knowledge about the composition of the raw matter may be seen as a mistrustful procedure from the view of the supplier.
i4Q solutions involved	Necessary: • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Data Integration and Transformation Services • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Rapid Quality Diagnosis Other i4Q solutions: • i4Q Data Quality Guidelines / QualiExplore

Table 19. Pilot 5: TO-BE P5_BP01: Data collection and analysis for raw matter quality control – Description

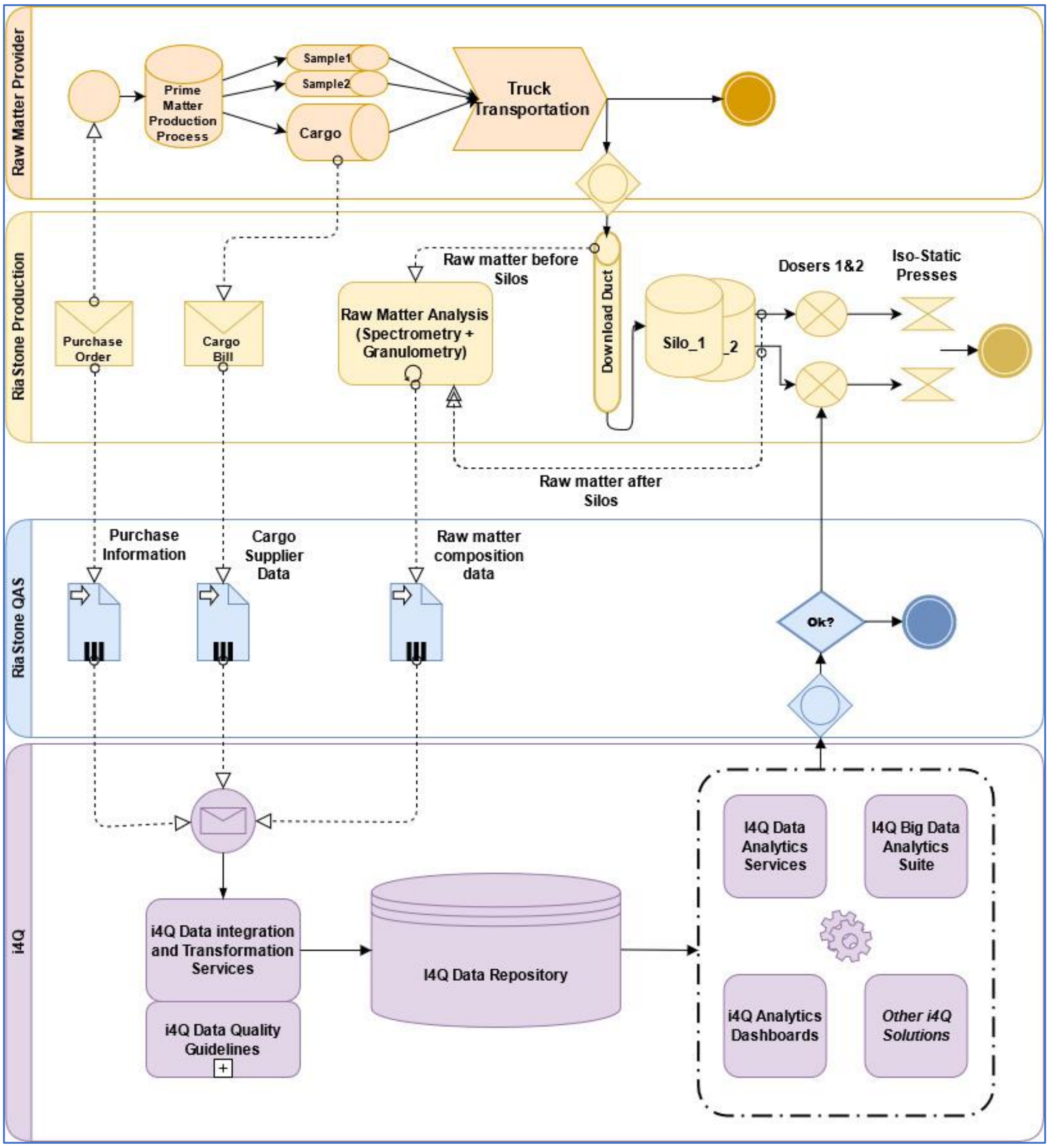

Figure 23. Pilot 5: TO-BE P5_BP01: Data collection and analysis for raw matter quality control - Schema

3.5.2.2 ToBe_P5_BP02 – Final product QC causal relation analysis

Process Name	Final product QC causal relation analysis
Process Description	Besides the defects that are related to the raw matter composition, there are other defects that can be correlated with other processes within the production line. For instance, the PoC created during the BOOST 4.0 project (Grant agreement 780732) identified that certain defects related to the glazing process could be directly correlated with the density of the glazing material. This and other correlations between defects and the different production line processes with be mapped in order to provide a clear view on what processes produce a certain defect. In order to fulfil the above business process, track-and-trace strategies will be developed in order to have a product tracking method so that the

Process Name	Final product QC causal relation analysis
	defects can be accurately mapped to individual products (best case scenario) or, at least, specific batches. This will support the root cause and causal relation analyses at the heart of this business process. After the causal relation analyses are performed and the defects mapped to their root causes (whenever possible), a prediction and anomaly detection model will be built to predict future defects depending on variations of key parameters throughout the production line.
Actors and Roles	RiaStone QC manager and RiaStone Production (main actors)
Information Systems	Sensors scattered throughout the production line, data storage systems, QC reports (Excel-based for now), i4Q solutions
Problems and needs	Currently there is no track-and-trace method for individual pieces on the production line. An internal project for this purpose is ongoing, but it is still not clear that it will be ready to use on i4Q. Hence, a strategy to track (at least) individual batches throughout the production line is necessary. Further, the causal relation analysis has to be developed for the whole production line.
Internal and external barriers	Internal Barriers • No track-and-trace of individual pieces (for now) • No causal relation analysis is performed right now External Barriers • Not applicable.
i4Q solutions involved	Necessary: • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Data Integration and Transformation Services • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics DashboardOther Other • i4Q Data Quality Guidelines / QualiExplore • i4Q Digital Twin • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit

Table 20. Pilot 5: TO-BE P5_BP02: Final product QC causal relation analysis - Description

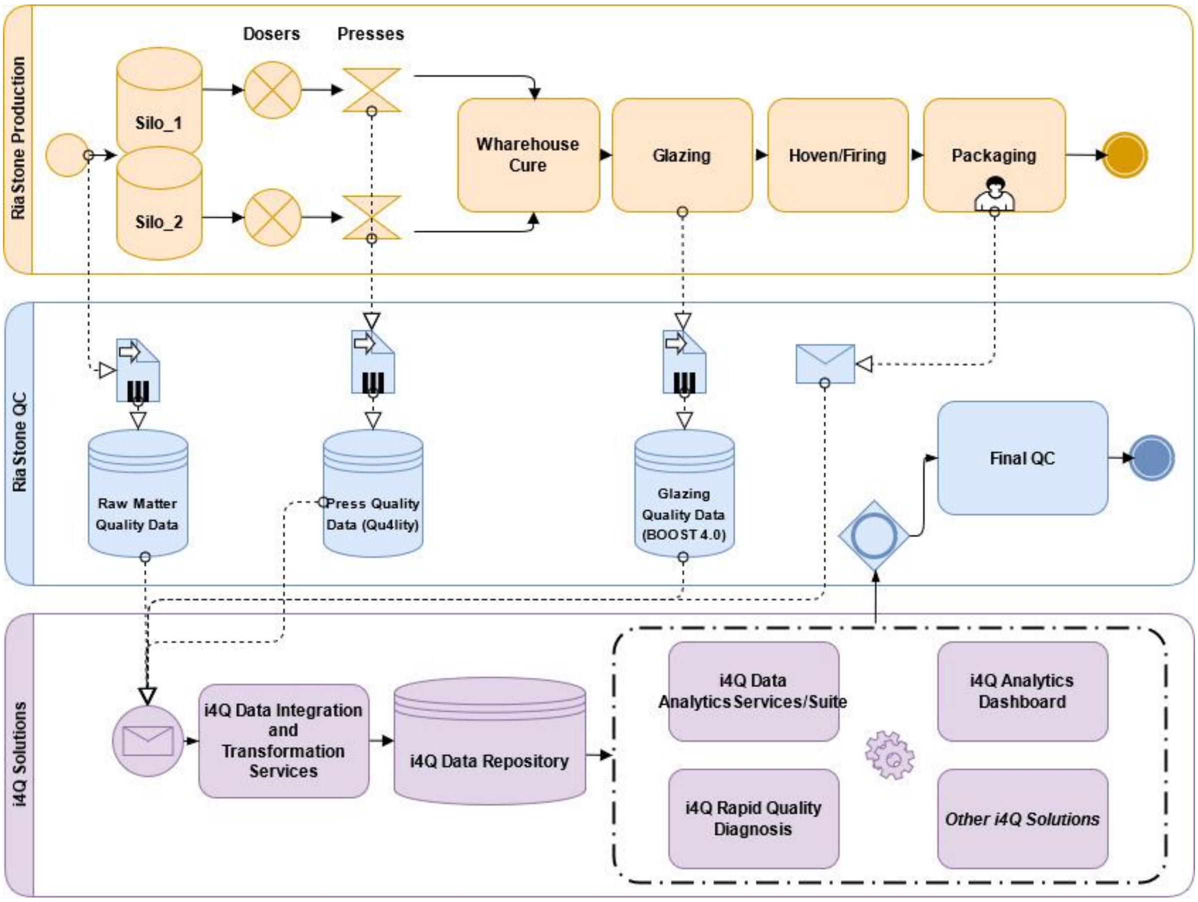

Figure 24. Pilot 5: TO-BE P5_BP02: Final product QC causal relation analysis - Schema

3.6 Pilot 6: Automatic Advanced Inspection of Automotive Plastic Parts

Plastic injection moulding technique is very common and successful technique to produce high-quality solid parts. Injection moulding is an established production process in which a molten plastic material is injected into a mould cavity. The melted plastic then cools and hardens and the finished part is removed. Though the mould design process is critical and challenging, injection moulding itself is a reliable method for producing solid plastic parts with a high-quality finish. This technique is one of the most commonly used production processes for components in the automotive industry where repeatability, scalability and cost are all of great importance, since it is ideal for producing plastic parts with relatively simple geometries and results in parts with high surface finish quality. At the same time, consistency, safety, and quality of manufactured pieces are of the utmost importance in the automotive sector. Farplas aims to increase manufacturing process productivity through rapid error identification, which has the potential to reduce the production cycle in by 18% which means 180 piece per day for one machine and increase the performance in the detection of defective pieces up to a 99% (from around 83% nowadays). Since production environment is highly dynamic and production technique itself is very complex it is very hard to detect defects on the visual side of the product. Since location, geometry and visibility is changing from time to time and process to process, the detection process still highly human dependent. **Figure 25** shows some common visual defects which occurs during plastic injection.

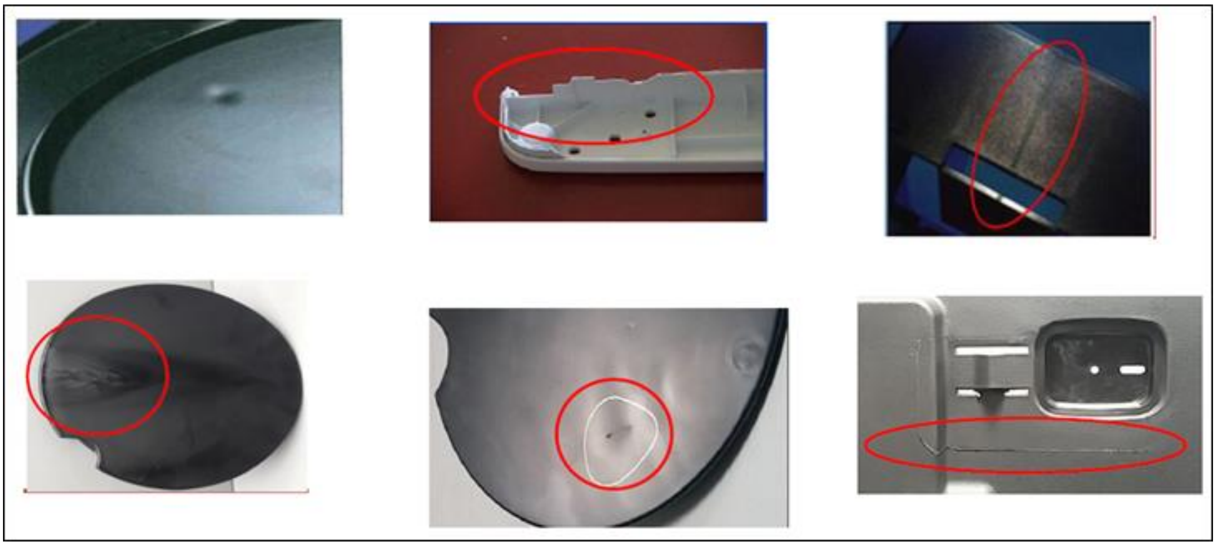

Figure 25. Injection visual defects a-Sink mark,b-short-shot,c-weld line,d-flow line-e-surface delamination,f-flash

Pilot 6 includes two business processes, which has been modelled both in the AS-IS analysis of the current situation and in the TO-BE analysis of the expected scenarios that implement and apply i4Q solutions:

- AsIs_P6_BP01 Plastic Injection Moulding Machine Parameter Optimization
- AsIs_P6_BP02 Plastic Injection Visual Part Inspection
- ToBe_P6_BP01 Autonomous parameter optimization for the injection process
- ToBe_P6_BP02 Automatic Quality Inspection

3.6.1 As-Is: Analysis of the Current Situation

The inspection and quality assurance in the production of plastic injected parts for the automotive industry relies on the following techniques: i) Visual inspection of the injection process in the manufacturing plant by the operator or technician close to the machine, using as reference standard parts or negative models for comparison and to measure critical dimensions. ii) Technical measurement of some reference samples taken from the lot and performed by qualified technicians.

Up to now, neither of those approaches achieve the ideal of 100% control and inspection, and it depends, in most cases, on the specialisation and qualification of the assigned technician, introducing "human variables" in this validation process that has a strong influence on the final validation results.

For the original equipment manufacturer (OEM) in the automotive industry, the 0% defects are a basic requirement to introduce these plastic parts in the final assembling of the car structure in their facilities. If there is any defective part detected by the OEM, all the production sent by the TIER 1 provider is rejected until the problem is solved, causing delays on the whole process assembly, influencing also in other parallel process of the car assembly (and subsequently in the associated parts production that comes from other TIERs 1).

Visual side of the products usually more reflective and harder to inspect using standard machine vision systems especially in changing production environment. Machine performance highly sensitive to daylight and performs different performance for each different production shift, therefore plastic injection manufacturers cannot rely on autonomous system solely.

Currently approximately %18 of the production cycle time belongs visual quality control performs by operator. Visual quality control operation is the first operation of the workflow after plastic injection. Operator retrieves injected parts from conveyor and performs visual quality control according to instructions for between 5-15 seconds depends on product geometry. **Figure 26** shows one example of production cell and operator who performs manual quality control to detect defective parts.

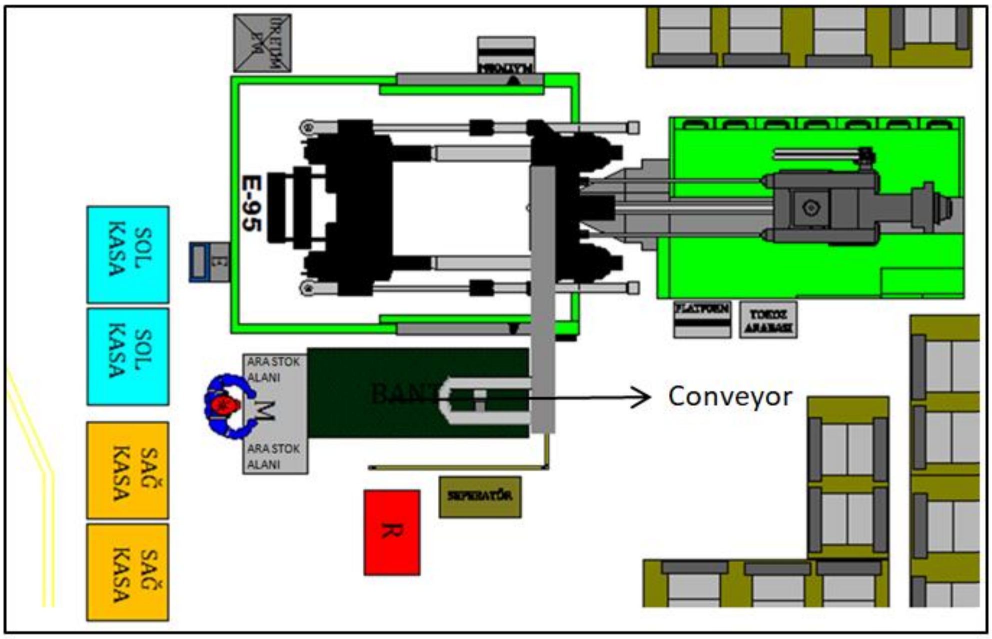

Figure 26. Plastic injection lay-out and manual visual defect inspection performed by operator

3.6.1.1 AsIs_P06_BP01 Plastic Injection Moulding Machine Parameter Optimization

Process Name	"Plastic Injection Moulding Machine Parameter Optimization"
Process Description	Plastic injection moulding production takes place parallelly with the visual quality inspection phase. If the scrap rate is higher than a certain percentage problem-solving activity start. The new parameter selection phase goes as a try-fail method. This process is highly costly because of produced scraps and long time.
Actors and Roles	Process Engineering, Quality Engineering, Maintenance Engineering, Automation Engineering, Production Engineering, Production Team, IT Team, Packaging Team
Information Systems	SAP, Hadoop, Spark, Kafka, Euromap
Problems and needs	Problem: High costs due to the predictive parameter determination phase

Process Name	"Plastic Injection Moulding Machine Parameter Optimization"
	Need: Automatized rapid error identification for plastic injection moulding production
Internal and external barriers	Internal Barriers • Environmental conditions • Limited cycle time • Dynamic production environment External Barriers • Strict quality expectation requirements
i4Q Expectations	i4Q solutions are going to learn the process and automatically set the optimized plastic injection moulding machine parameters for each mould/part design. The process should not take too long and defected part percentage should be low.

Table 21. Pilot 6: AS-IS P6_BP01 Plastic Injection Moulding Machine Parameter Optimization

All data came from Injection machine, the water collector and energy analyzer are connected with injection machine. We can say that they came from preparation part.

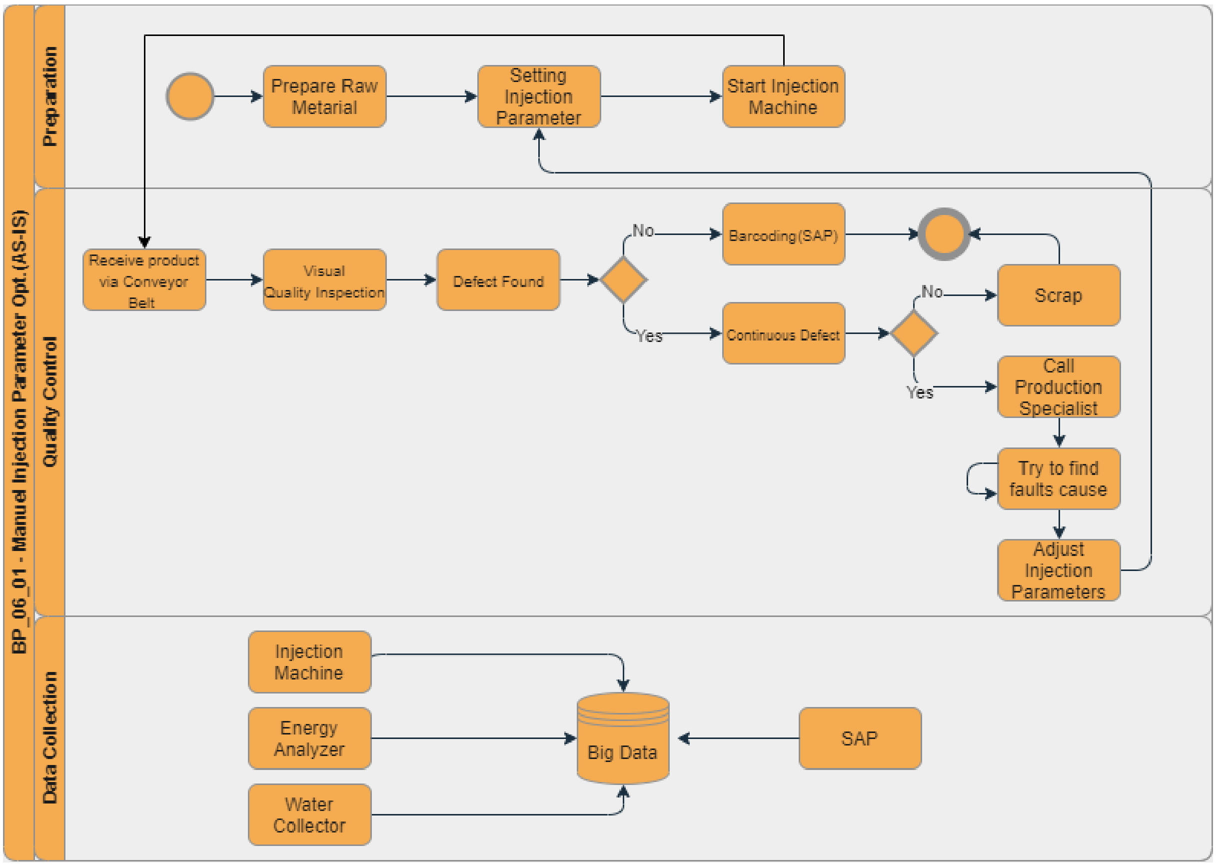

Figure 27. Pilot 6 AS-IS P6_BP01 Plastic Injection Moulding Machine Parameter Optimization

3.6.1.2 AsIs_P06_BP02 Plastic Injection Visual Part Inspection

Process Name	"Plastic Injection Visual Part Inspection"
Process Description	Produced parts that are coming from plastic injection moulding machine has to be visually inspected one by one, by hand and eye to ensure that there are no faulty or defected piece is sent to the OEM.
Actors and Roles	Process Engineering, Quality Engineering, Maintenance Engineering, Automation Engineering, Production Engineering, Production Team, IT Team, Packaging Team
Information Systems	SAP, Hadoop, Spark, Kafka
Problems and needs	Problem: Human dependent visual defect quality inspection increases cost and reduces efficient production. Need: Automated quality inspection required to make quality inspection process autonomous and independent from human attention.
Internal and external barriers	Internal Barriers • Environmental conditions • Limited cycle time • Dynamic production environment External Barriers • Strict quality expectation requirements
i4Q Expectations	Automated quality inspection process and procedure which discards any defected parts to establish zero-defect scenario will be implemented. Corelation between injection parameters and final product quality will be analysed to extract further beneficial solutions from data.

Table 22. Pilot 6: AS-IS P6_BP02 Plastic Injection Visual Part Inspection

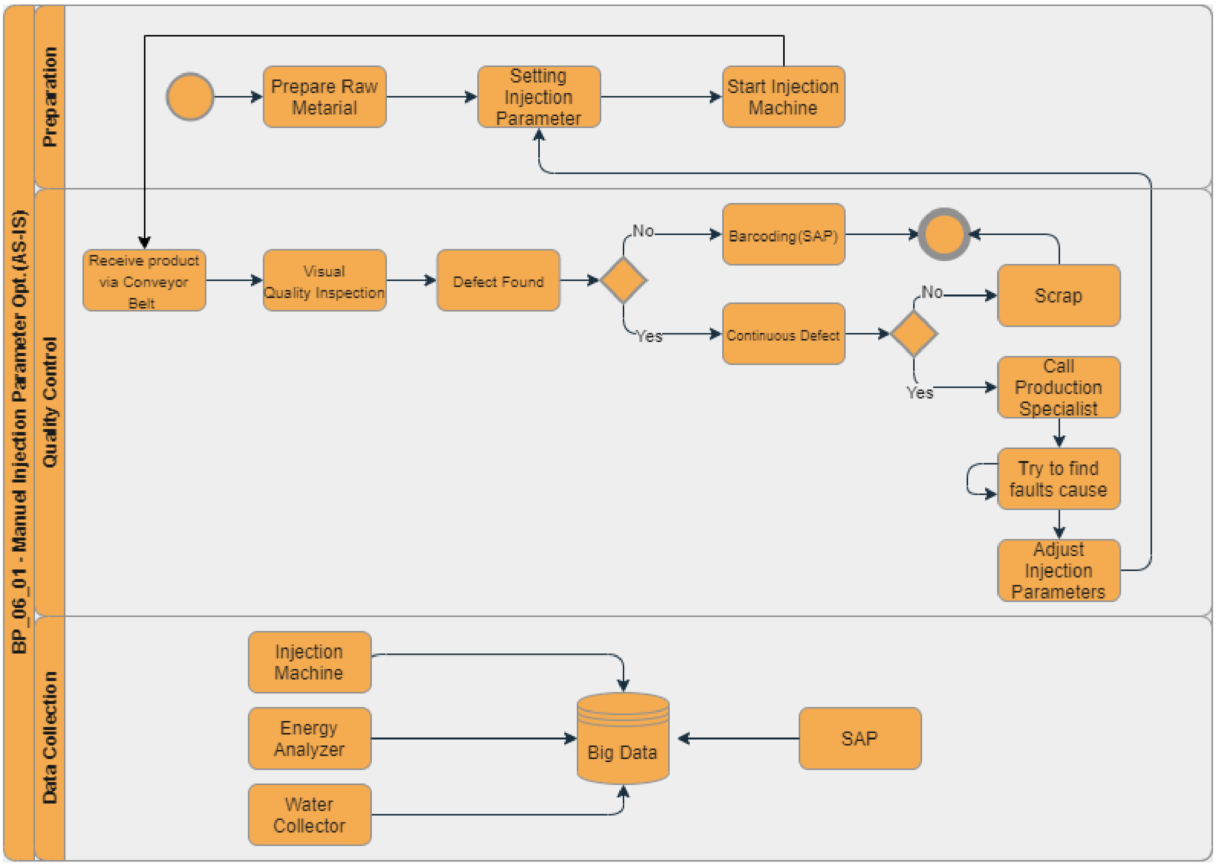

Figure 28. Pilot 6: AS-IS P6_BP02 Plastic Injection Visual Part Inspection

3.6.2 To-Be: Analysis of the Expected Scenarios

3.6.2.1 ToBe_P06_BP01 Autonomous parameter optimization for the injection process

Process Name	"Autonomous parameter optimization for the injection process"
Process Description	information related to the injection process will be collected by the i4Q solutions, and analysed and correlated with that coming from the inspection at ZG3D system, in order to find hidden patterns that will allow to "learn and improve" the injection process, thus increasing the efficiency of the process and reducing the number of final defective pieces.
Actors and Roles	Process Engineering, Quality Engineering, Maintenance Engineering, Automation Engineering, Production Engineering, Production Team, IT Team, Packaging Team
Information Systems	SAP, Hadoop, Spark, Kafka, Moulding Machine, i4Q solutions
Problems and needs	Problem: Detecting the specific parameters for each piece coming from plastic moulding machine not only in the production line but anywhere (including storage, dispatch, feedback from customer, etc.) so that in i4Q infrastructure parameter and production optimization can be done and monitor/forecast how possible changes going to affect the production line.

Process Name	"Autonomous parameter optimization for the injection process"
	Needs: Ensuring that the parts and their corresponding parameters are correctly labeled, and building a digital twin of the factory to visualize possible changes.
Internal and external barriers	Internal Barriers: • Limited cycle time • Dynamic production environment External Barriers: • Strict quality expectation requirements
i4Q solutions involved	• i4Q Data Quality Guidelines / QualiExplore • i4Q Trusted Networks with Wireless & Wired Industrial Interfaces • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Data Integration and Transformation Services • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Infrastructure Monitoring • i4Q Digital Twin • i4Q Data-Driven Continuous Process Qualification • i4Q Manufacturing Line Reconfiguration Guidelines / i4Q Manufacturing Line Reconfiguration Toolkit • i4Q Manufacturing Line Data Certification Procedure

Table 23. Pilot 6 TO-BE P6_BP01: Autonomous parameter optimization for the injection process

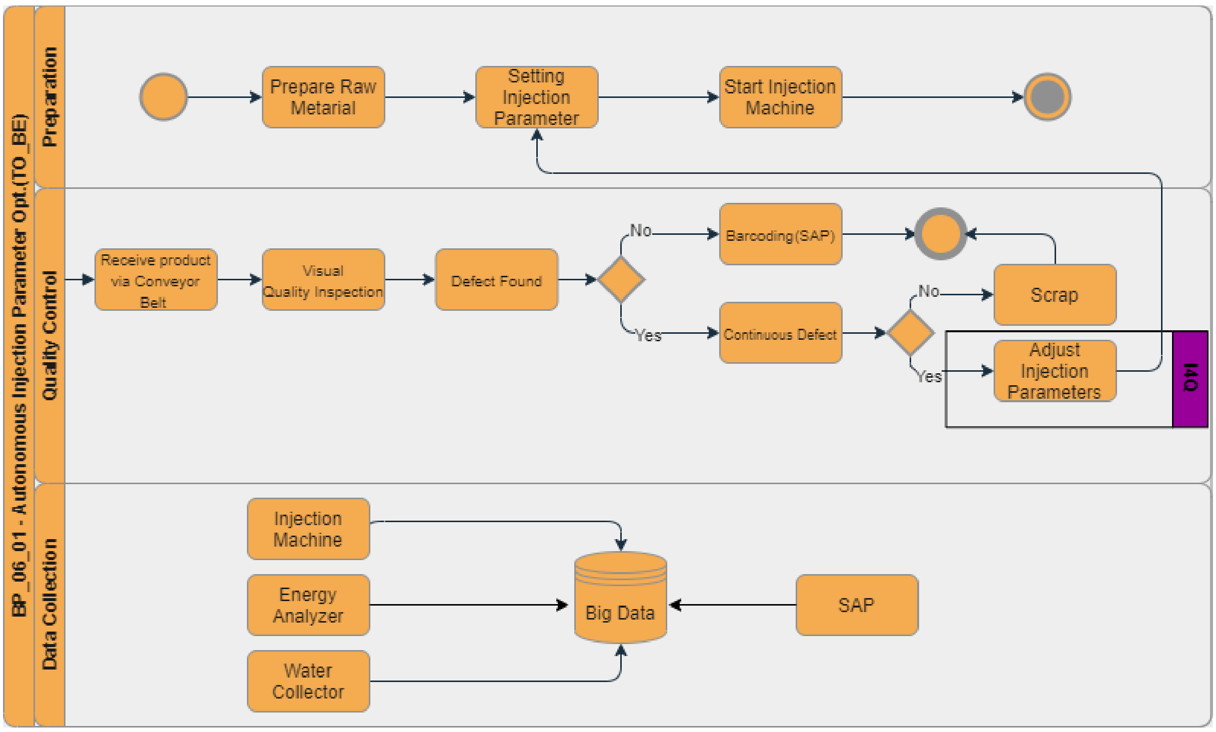

Figure 29. Pilot 6 TO-BE P6_BP01: Autonomous Injection Parameter Optimization - Schema

3.6.2.2 *ToBe_P6_BP02 Automatic Quality Inspection*

Process Name	"Automatic Quality Inspection"
Process Description	Since the quality inspection automation has potential to reduce the production cycle by 18% and increase the performance in the detection of defective pieces up to 99% from around 83%. For these purposes, ZG3D artificial vision-based inspection system will be implemented to the end of the production line of a plastic injection molding machine. Device is going to detect the fault parts and it will be ensured that these parts are separated from unfaulty parts.
Actors and Roles	Process Engineering, Quality Engineering, Maintenance Engineering, Automation Engineering, Production Engineering, Production Team, IT Team, Packaging Team
Information Systems	SAP, Hadoop, Spark, Kafka, i4Q solutions
Problems and needs	Problem: Having an accuracy rate up to 99% might be hard to obtain since plastic injection defects could even be really hard even for an operator or technician. And low false positive detection is even more important than having high accuracy since customers' demands zero defect parts in most situation. Needs: Creating a balanced and adequately sized training set and creating an artificial intelligence model that will meet the specified requirements.
Internal and external barriers	Internal Barriers: • Limited cycle time • Dynamic production environment External Barriers: • Strict quality expectation requirements
i4Q solutions involved	• i4Q Blockchain Traceability of Data • i4Q Cybersecurity Guidelines / IIoT Security Handler • i4Q Guidelines for Building Data Repositories for Industry 4.0 / i4Q Data Repository • i4Q Data Integration and Transformation Services • i4Q Services for Data Analytics / i4Q Big Data Analytics Suite /i4Q Analytics Dashboard • i4Q Rapid Quality Diagnosis • i4Q Manufacturing Line Data Certification Procedure

Table 24. Pilot 6: TO-BE P6_BP02 Automatic Quality Inspection

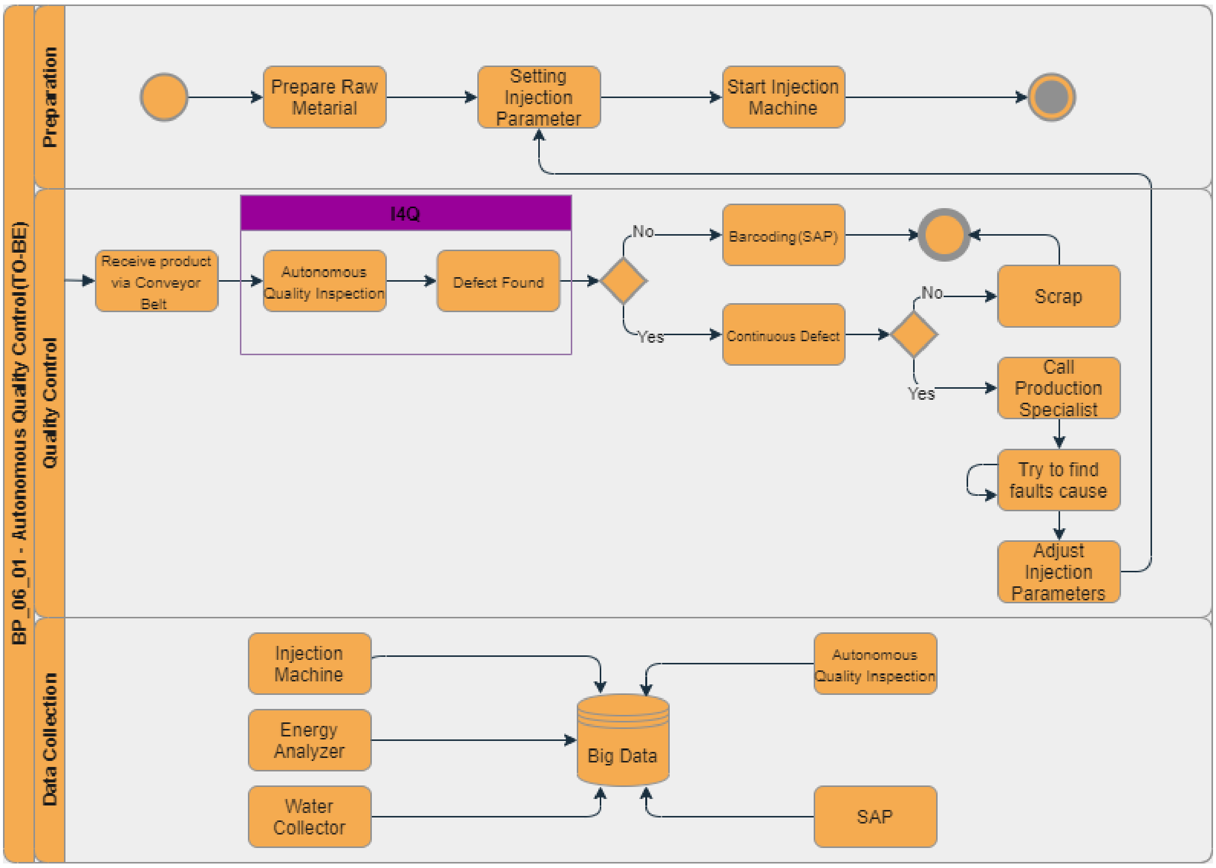

Figure 30. Pilot 6 TO-BE P6_BP02: Automatic Quality Inspection - Schema

4. User Scenarios Classification and Analysis

In this section it is identified how the technical advancements listed in Technical Advancement of i4Q are fulfilled by the developement of each of the 22 i4Q solutions. Moreover, it is shown and analysed how the TO-BE business processes, modelled in the use cases, are expecting to use all the 22 i4Q solutions inclued in the RIDS.

4.1.1 Mapping of i4Q solutions with i4Q Technical Advancements

Table 25 enables to map how the 22 i4Q solutions fulfill the technical advancements identified in Section 2.2., taking into account the manufacturing data quality and manufacturing quality processess. From the table it can be concluded that all the technical advancements are completelly fulfilled by the implementation of the i4Q solutions.

		Technical Advancement												
		Manufacturing Data								Manufacturing Process				
ID	i4Q solutions	Quality	Trustiness	Reliability	Traceability	Security	Analytics	Integration	Storage	Qualification	Quality Diagnosis	Reconfiguration	Certification	Audit
1	i4Q^{DQG}	X												
2	i4Q^{QQE}	X												
3	i4Q^{BC}	X	X	X	X			X						
4	i4Q^{TN}	X		X				X						
5	i4Q^{CSG}					X								
6	i4Q^{SH}					X								
7	i4Q^{DRG}													
8	i4Q^{DR}			X		X		X	X					
9	i4Q^{DIT}	X		X			X	X						
10	i4Q^{DA}						X							
11	i4Q^{BDA}						X							
12	i4Q^{AD}						X							
13	i4Q^{AI}						X			X	X			
14	i4Q^{EW}						X			X	X			
15	i4Q^{IM}	X					X				X			
16	i4Q^{DT}						X					X		
17	i4Q^{PQ}									X	X	X		
18	i4Q^{QD}	X					X				X			
19	i4Q^{PA}						X					X		
20	i4Q^{LRG}											X		
21	i4Q^{LRT}											X		
22	i4Q^{LCP}												X	X

Table 25. Characterization of industrial scenarios covered by i4Q partners

4.1.2 Mapping user scenarios with i4Q solutions

The goal of i4Q is the creation of 22 microservices, belonging to the RIDS, to improve the quality of manufactured products aiming at zero-defect manufacturing, therefore pushing forward the concept of a smart, fully digitised factory. The i4Q RIDS is a complete service that encompasses 22 solutions founded on a modular way, aiming to support the complete flow of industrial data, starting from data collection to data analysis, simulation and prediction. In this regard, all the TO-BE business processes defined in the use cases have their expectations on using the related solutions (**i4Q**^{DQG}, **i4Q**^{QE}**)**. RIDS provides solutions to ensure data quality, security and trustworthiness, such as blockchain-based data services and distributed storage. With regards blockchain technology (**i4Q**^{BC})**,** only the *ToBe_P6_BP02* is expecting to use it, as this solution will improve trust and acceptability by providing security and trust in the data flows. The i4Q RIDS also includes a set of services for data integration and fusion (**i4Q**^{DIT}), data analytics (**i4Q**^{DA}**, i4Q**^{BDA}, **i4Q**^{AD}**, i4Q**^{PQ}**)** and data distribution (**i4Q**^{DR}, **i4Q**^{DIT}). All of these microservices will be used by all the TO-BE business processes defined, exceptualizing the **i4Q**^{PQ} solution that is only expected for TO-BE business processes of Pilot 1 (P1_BP01, P1_BP02, P1_BP03), Pilot 4 (P4_BP02), Pilot 5 (P5_BP02) and Pilot 6 (P6_BP01).

Execution of AI workloads is enabled and managed through dedicated services based on a cloud/edge architecture (**i4Q**^{AI} **, i4Q**^{EW}). According to the user scenarios expectations, only Pilot 2 will use these two microservices. Monitoring at various levels is provided in i4Q through scalable monitoring tools. With this respect, **i4Q**^{IM} solution will be used in the TO-BE business processes P1_BP03, P2_BP01, P2_BP02, P4_BP02, P6_BP01 in order to monitor smart manufacturing workload and generate predictive failure alerts, taking corrective actions when a predicted problem occurs. On the other hand, **i4Q**^{AD} is intended to be applied by all the Pilots use cases defined.

Digital twins are used to enable full digitisation of the manufacturing process and providing simulation and modelling capabilities (**i4Q**^{DT}). Thus, only P1_BP03, P4_BP02, P5_BP02, P6_BP01 are expected to apply this i4Q solution. Digital twins are also used for process qualification (**i4Q**^{LCP}) to obtain virtual sensors, explore potential upgrade actions and extend existing process data. According to the TO-BE business process modelled by the enterprises, only Pilot 1, 2 and 6 find very useful the **i4Q**^{LCP} solution. Additionally, digital twins support quality diagnosis of the manufacturing line (**i4Q**^{QD}). All the pilots, except Pilot 3, are willing to have in their enterprise a tool for the rapid diagnosis of manufacturing line on the possible cause of failures, evaluating data fidelity, product-quality and process condition, and providing action recommendations for sensor/data processing recalibrations, process line/machine reconfiguration or maintenance actions.

Partners that constitute the industrial consortium of i4Q project make up a varied representation of industrial scenarios tahtn can be targeted by i4Q RIDS. **Table 26** shows 22 i4Q solutions and how are they covered by the TO-BE business processes defined on the six industrial user scenarios. Soft grey cels of **Table 26** indicate that the solution is not sofar needed by the use cases, according to their i4Q expectations. The i4Q RIDS adopts a modular microservices-based approach to be adapted and integrated in different manufacturing scenarios, for diverse companies and at varying maturity levels.

ID	i4Q solutions	Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6
1	$i4Q^{DQG}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01
2	$i4Q^{QE}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01
3	$i4Q^{BC}$						P6_BP02
4	$i4Q^{TN}$	P1_BP01 P1_BP02 P1_BP03			P4_BP01 P4_BP02		P6_BP01
5	$i4Q^{CSG}$				P4_BP01 P4_BP02		P6_BP01 P6_BP02
6	$i4Q^{SH}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02		P4_BP01 P4_BP02		P6_BP01 P6_BP02
7	$i4Q^{DRG}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01 P6_BP02
8	$i4Q^{DR}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01 P6_BP02
9	$i4Q^{DIT}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01 P6_BP02
10	$i4Q^{DA}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01 P6_BP02
11	$i4Q^{BDA}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01 P6_BP02
12	$i4Q^{AD}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02	P3_BP01	P4_BP01 P4_BP02	P5_BP01 P5_BP02	P6_BP01 P6_BP02
13	$i4Q^{AI}$		P2_BP01 P2_BP02		P4_BP01 P4_BP02		
14	$i4Q^{EW}$		P2_BP01 P2_BP02				
15	$i4Q^{IM}$	P1_BP03	P2_BP01 P2_BP02		P4_BP02		P6_BP01
16	$i4Q^{DT}$	P1_BP03			P4_BP02	P5_BP02	P6_BP01
17	$i4Q^{PQ}$	P1_BP01 P1_BP02 P1_BP03			P4_BP02	P5_BP02	P6_BP01
18	$i4Q^{QD}$	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02		P4_BP02	P5_BP01 P5_BP02	P6_BP02

ID	i4Q solutions	Pilot 1	Pilot 2	Pilot 3	Pilot 4	Pilot 5	Pilot 6
19	i4Q^PA^		P2_BP01 P2_BP02	P3_BP01	P4_BP02		
20	i4Q^LRG^	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02		P4_BP02		P6_BP01
21	i4Q^LRT^	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02		P4_BP02	P5_BP02	P6_BP01
22	i4Q^LCP^	P1_BP01 P1_BP02 P1_BP03	P2_BP01 P2_BP02				P6_BP01 P6_BP02

Table 26. Pilots TO-BE business processes mapped with i4Q solutions

In order to identify the relationships between the Pilots' TO-BE business processes and the i4Q solutions, a deep analysis has been carried out based on the end users' expectations. Moreover, a set of meetings have been performed, in which each pilot has explained their AS-IS and TO-BE business processes modelled using BPMN. During these meetings all the i4Q solution developers have been attending in order to ensure how the enterprises' expectations could be fulfilled by each i4Q solution, and making sure that the required solutions were applicable. The mapping between user scenarios and i4Q solutions enables to have a broad view on how the i4Q solutions will be developed. Moreover, it has assured that all the offered solutions in the i4Q project are at least represented by one TO-BE business process. Finally, the performed analysis and the mapping activities has allowed to Pilots and i4Q solution developers to define in a more efficient way the functional requirements, all in all taking into account that we are in the first stages of the project, so that requirements are defined in D1.4 Requirements Analysis and Functional Specification in a more general way.

Further versions of D1.3 and D1.4, which will be D1.8 and D1.9 will be more precisely on the TO-BE business processes and the functional requirements definition. Moreover, base line key performance indicators will be defined in order to measure the impact of i4Q solutions implementation on each of the business processes in which i4Q solutions are applied.

5. Conclusions

The D1.3 – Demonstration Scenarios and Monitoring KPIs Definitionis a reference document focused on defining the current situation, and AS-IS scenarios, of the pilots participating in i4Q project. For doing this, the current business processes are described and represented. Based on the AS-IS scenarios, the top-level problems and improvements associated to the industrial pilots are defined. Then, the TO-BE scenarios are determined for each use case, by improving AS-IS business process with the implementation of i4Q solutions. In this regard, the companies determine the improvements that are expected in the business processes after the implementation of i4Q based solutions. The TO-BE use cases scenarios are identified for their improvement, and matched with the i4Q solutions. Therefore, D1.3 serves as the reference for guidance of which applications will be developed for project pilots.

This deliverable proposes a methodology for keeping the coherency in the common analysis of the business processes that came across the several industrial sectors, which are part of i4Q. The proposed methodology allows to properly define the AS-IS business processes and the TO-BE expected business processes, which contains expected improvements by the application and implementation of the i4Q solutions.

The current manufacturing scenario and technical advancements provided by the i4Q project are described at the beginning of the D1.3.

Moreover, a mapping between i4Q solutions and the list of technical advancements has been performed by the technical developers, concluding that the i4Q solutions provide the knowledge, guidelines, tools and services to fulfil the technical advancements defined in terms of manufacturing data and manufacturing process quality.

Finally, a mapping between i4Q solutions and the TO-BE business process has allowed to ensure that the 22 i4Q solutions belonging to the RIDS will be implemented along the project.

As part of WP1, Task 1.3 " Use cases scenarios and KPIs" is parallelly tackled on Task 1.4 "Requirements Analysis and Functional Specification", which is already on going taking the results of this deliverable as a direct input, and Task 2.3 “Business Viewpoint”. Moreover, D1.3 is the first output of Task 1.3, the second output will be documented in D1.8. Hence, activities will further focus on:

- Proposing KPIs to evaluate the impact of the introduction of i4Q solutions in the described application scenarios;
- Preparing the Business Viewpoint (WP2, Task 2.3 and connected output D2.3);
- Determining the transition steps identified to support the transition from the AS-IS situations to the desired TO-BE cases; and
- Preparing the test cases validation (WP6, Tasks 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6).

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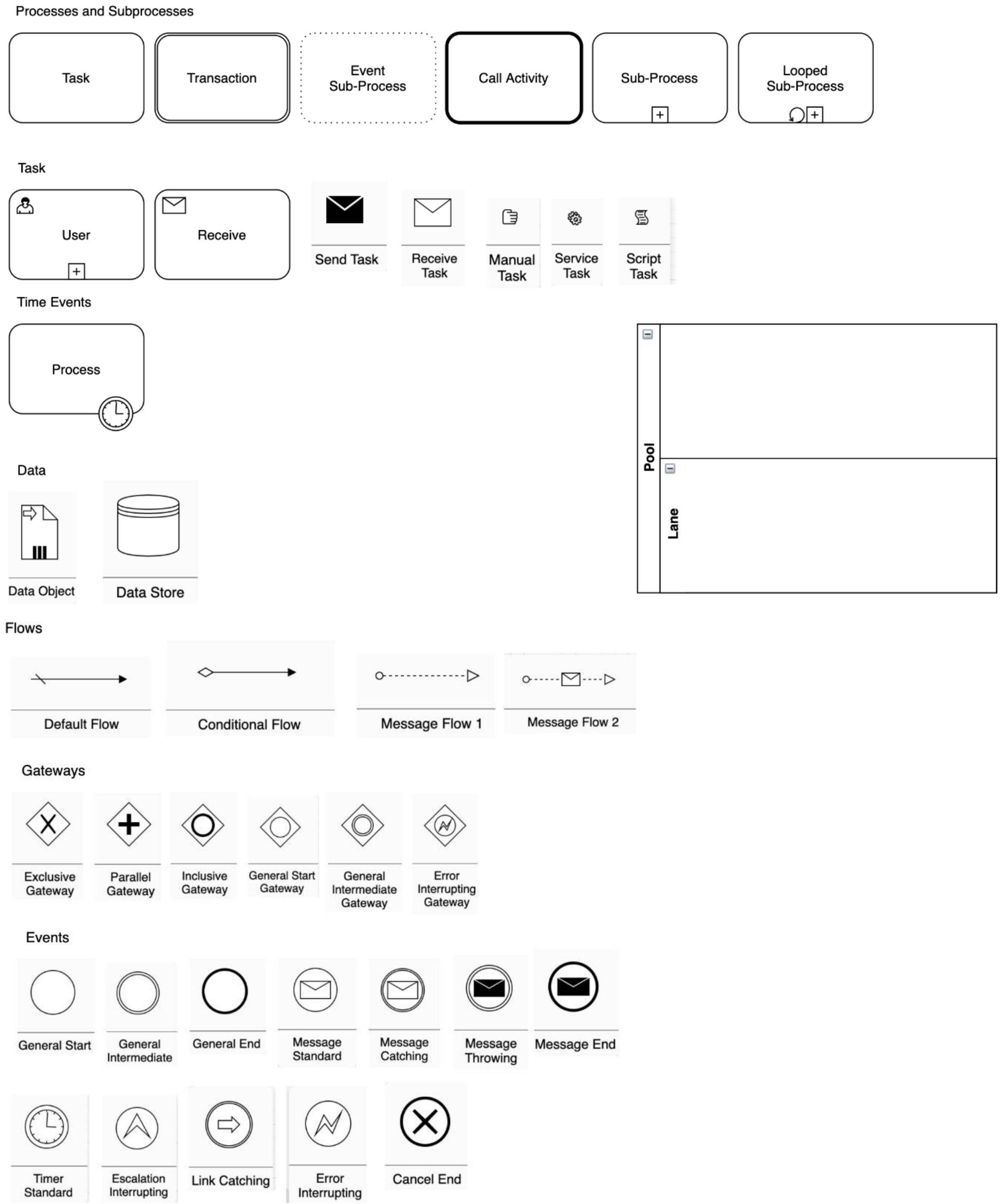
Appendix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Event Sub-Process
Call Activity
Sub-Process
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User
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Send Task
Receive Task
Manual Task
Service Task
Script Task
Time Events
Process
Pool
Lane
Data
Data Object
Data Store
Flows
Default Flow
Conditional Flow
Message Flow 1
Message Flow 2
Gateways
Exclusive Gateway
Parallel Gateway
Inclusive Gateway
General Start Gateway
General Intermediate Gateway
Error Interrupting Gateway
Events
General Start
General Intermediate
General End
Message Standard
Message Catching
Message Throwing
Message End
Timer Standard
Escalation Interrupting
Link Catching
Error Interrupting
Cancel End