D1.4 – Requirements Analysis and Functional Specification

WP1 – Industrial Scenarios and Requirements Analysis

i4Q has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958205.

Document Information

GRANT AGREEMENT NUMBER	958205	ACRONYM	i4Q
FULL TITLE	Industrial Data Services for Quality Control in Smart Manufacturing		
START DATE	01-01-2021	DURATION	36 months
PROJECT URL	https://www.i4q-project.eu/		
DELIVERABLE	D1.4 – Requirements Analysis and Functional Specification		
WORK PACKAGE	WP1 – Industrial Scenarios and Requirements Analysis		
DATE OF DELIVERY	CONTRACTUAL: April 2021	ACTUAL	April 2021
NATURE	Report	DISSEMINATION LEVEL	Public
LEAD BENEFICIARY	TUB		
RESPONSIBLE AUTHOR	Anna M. Nowak-Meitinger (TUB), Roland Jochem (TUB)		
CONTRIBUTIONS FROM	1-CERTH, 2-ENG, 3-IBM, 4-ITI, 5-KBZ, 6-EXOS, 7-IKER, 8-BIBA, 9-UPV, 10-TUB, 11-UNI, 12-TIAG, 13-CESI, 14-AIMP, 19-WHI, 20-BIES, 21-FACT, 22-RIAS, 23-FARP, 24-FIDIA		
TARGET AUDIENCE	1) i4Q Project partners; 2) industrial community; 3) other H2020 funded projects; 4) scientific community		
DELIVERABLE CONTEXT/ DEPENDENCIES	This document correlates to D1.1 and D1.3. This document has a second iteration in Sep 2021 (D1.9). • D1.4 is focused on the first version of pilot-specific and solutions-related requirements, their elicitation, analysis, validation, and documentation. • D1.9 is focused on the second version of pilot-specific and solutions-related requirements and the definition of functional specifications. D1.4 provides input for WP2-6, especially for: • D2.3 Report of Business Viewpoint • D2.4 Report on Usage Viewpoint • D2.5 Functional Specifications • D2.6 Technical Specifications		
EXTERNAL ANNEXES/ SUPPORTING DOCUMENTS	None		
READING NOTES	None		

ABSTRACT	The deliverable D1.4 "Requirements Analysis and Functional Specification v1" summarises the first version of requirements engineering in i4Q Project adopting ISO/IEC/IEEE 29148, ISO/IEC/IEEE 12207 and ISO/IEC/IEEE 15288. The main results are the lists of requirements for the six pilot use cases and the 22 i4Q Solutions and their analysis as a basis for the definition of the functional specifications. In the preceding deliverable D1.3 "Demonstration scenarios and monitoring KPIS definition" the current AS-IS and expected TO-BE processes of the six pilot use cases were defined as a basis for the requirements elicitation. In addition, a state-of-the-art analysis about requirements in similar use cases is performed. Further knowledge and expertise are gathered within the consortium. Based on this, missing functionalities and implementation needs, which are the foundation for the work to be performed in the work packages 2 to 6 can be found. Technical discussions and templates were used to elicit requirements. For the second version of this deliverable (D1.9), SysML should be used in order to model and document the complex requirements structures and functional specifications for the pilots and i4Q Solutions.

Document History

VERSION	ISSUE DATE	STAGE	DESCRIPTION	CONTRIBUTOR
0.1	05-Feb-2021	ToC	Table of contents and sections allocation to partners	TUB
0.2	10-Feb-2021	Working version	ToC restructured and devided in D1.4 and D1.9 (v2)	TUB
0.2	12-Apr-2021	Working version	Proposal of structure for point 4.2 Model in SysML – System Requirements, based on Pilots Business Process (D1.3) and Pilots Requirements of this deliverable.	EXOS
0.2	15-Apr-2021	Working version	Inclusion of the first SysML Requirements diagrams, Pilot FACTOR, to serve as an example for the rest of the Pilots, and design of the rest of the systems diagrams for further version, D1.9, of this deliverable.	EXOS
0.2	15-Apr-2021	Working version	Inclusion of lists of requirements in Section 2&3	TUB
0.3	16-Apr-2021	Working version	Inclusion of Section 4.1 and finalizing all other sections	TUB
0.4	16-Apr-2021	1st draft	TUB-internal review	TUB
0.5	17-Apr-2021	Working version	Internal review process	EXOS, UNI
0.6	21-Apr-2021	Working version	Final review process TUB	TUB
0.7	23-Apr-2021	Working version	Final input from partners	EXOS, ITI, TUB
0.8	23-Apr-2021	Working version	Final formatting and review	TUB
1.0	26-Apr-2021	2nd draft	Document ready for final review & submission	TUB
2.0	30-Apr-2021	Final doc	Quality check and issue of final document	CERTH

Disclaimer

Copyright message

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS/ACRONYMS

AI	Artificial Intelligence
API	Application Programming Interface
AV	SysML - ARCHITECTURE View
BP	Business Process
CNC	Computer Numerical Control
CMMS	Computerized Maintenance Management System
DB	Database
DDS	Data Distribution Service
ERP	Enterprise Resource Planning
GDPR	General Data Protection Regulation
HSM	Hardware Security Module
IACS	Industrial Automation and Control Systems
ICT	Information and communications technology
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LPWAN	Low-Power Wide-Area Network
MBSE	Model-Based Systems Engineering
MES	Manufacturing Execution System
ML	Machine Learning
MPFQ	Material-Process-Functions-Quality
MS	Milliseconds
NFR	Non-Functional Requirement
OEE	Overall Equipment Effectiveness
OPE	Overall Production Effectiveness

PC	Pilot Case
PLC	Programmable Logic Controller
PPM	Parts per Million
PVA	Polyvinyl Alcohol
QC	Quality Control
REQ	Requirement
REST	Representational State Transfer
RIDS	Reliable Industrial Data Services
SAV	SysML - System ANALYSIS View
SDN	Software Defined Networks
SDV	SysML - System DESIGN View
SIV	SysML - System IMPLEMENTATION View
SITV	SysML - System INTEGRATION & TEST View
SOA	Service Oriented Architecture
SRV	SysML - System REQUIREMENTS View
TC	Test Case
TCM	Tool Condition Monitoring
TCP	Transmission Control Protocol
TSCH MAC	Time Slotted Channel Hopping and Media Access Control
TSN	Time-Sensitive Networking
URLLC	Ultra-Reliable and Low Latency Communication
USB	Universal Serial Bus
WP	Work Package
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network
ZDM	Zero-Defects Manufacturing

Executive summary

Deliverable D1.4 "Requirements Analysis and Functional Specification v1" summarises the requirements for the six pilot use cases and the 22 i4Q Solutions as a basis for the definition of the functional specifications. In the preceding deliverable D1.3 "Demonstration scenarios and monitoring KPIS definition" the current AS-IS and expected TO-BE processes of the six i4Q pilot use cases were defined. Through technical discussions between end-users and technical providers, the gaps between the AS-IS and TO-BE scenarios were analysed as a basis for the requirements elicitation.

The requirements elicitation procedure is performed according to "Stakeholder Needs and Requirements Definition process" described in ISO/IEC/IEEE 12207 (ISO/IEC/IEEE 12207:2017-11, p. 59ff) and documented in two requirements templates, one for the end-user perspective and one for the technical provider perspective of the i4Q Solutions. These templates are the basis for the requirements analysis in which the requirements are analysed in terms of wording, duplication, clustering, potential conflicts, (inter-)dependencies, interactions, and priorities. The findings will be later documented in the open-source systems modelling language SysML[1]. The result will be the first version of complete sets of requirements for each i4Q Solution. Finally, the overall context description will give an overview on how the requirements are related to each other.

The main results of this document are:

- The overview of the pilot use cases´ main challenges and their stakeholder requirements.
- The mapping of the i4Q Solutions to the end-user requirements.
- First version of complete sets of requirements for each i4Q Solution.
- The overview and overall context description of the current situation in requirements engineering.
- Outlook of further requirements elicitation and analysis as well as functional specifications using SysML.

[1] https://sysml.org/

Document structure

Section 1 Introduction: Description of the purpose and the approach of the requirements engineering procedure in i4Q Project.

Section 2 Requirements Elicitation: This section provides 1) the description of the requirements elicitation procedure, 2) a state-of-the-art analysis of research papers that summarizes requirements of similar use cases, 3) identification of the main challenges and requirements of the six pilot use cases and 4) further knowledge and expertise.

Section 3 Requirements Analysis: In this section 1) the requirements analysis method is described, 2) mapping of the i4Q Solutions to the end-user's requirements is provided and 3) all i4Q Solutions are introduced with their main functions/services, sets of requirements.

Section 4 Overall Context Description: The overall relationships and interfaces of the requirements and their relationships to the pilots are described. An outlook will explain how SysML models will document all requirements, functional specifications and their relations and dependencies.

Section 5 Conclusions: Summarises the main results of the deliverable.

1. Introduction

This deliverable contains the requirements' engineering process of i4Q Project. It is a complex and extensive process as there are 24 partners with different starting points, various needs, and expectations for the complete set of solutions consisting of Internet of Things (IoT)-based Reliable Industrial Data Services (RIDS), the so called 22 i4Q Solutions. Therefore, a suitable requirements elicitation and analysis procedure is developed according to ISO/IEC/IEEE 29148 (ISO/IEC/IEEE 29148:2018-11), ISO/IEC/IEEE 12207 (ISO/IEC/IEEE 12207:2017-11) and ISO/IEC/IEEE 15288 (ISO/IEC/IEEE 15288:2015-05-15). These standards are used as the basis for collecting companies' requirements for Smart Manufacturing in the context of quality control and adapted to the i4Q approach. Additionally, the process is performed with respect to the standards VDI 2221 (VDI 2221-1:2019-11 and VDI 2221-2:2019-11) and VDI 2206 (VDI 2206:2004-06) which describe the design of technical products and systems (VDI 2221) as well as a design methodology for mechatronic systems (VDI 2206). The first activity of product design is to clarify and itemise the problem or task (VDI 2221-1:2019-11, pp. 32-36) with the result of requirements as an information base. This is to be performed in this deliverable.

The six pilots define as end-users the context of use in i4Q Project. During requirements engineering they describe their stakeholder needs and requirements that should be fulfilled and achieved by the i4Q Solutions. The system limitations of the requirements engineering in the i4Q Project are focused on stakeholder, system, and software requirements which all contribute to fulfil the i4Q business requirements, e.g., the realization of Zero-Defect-Manufacturing through the set of i4Q Solutions. **Figure 1** describes this model, including several examples.

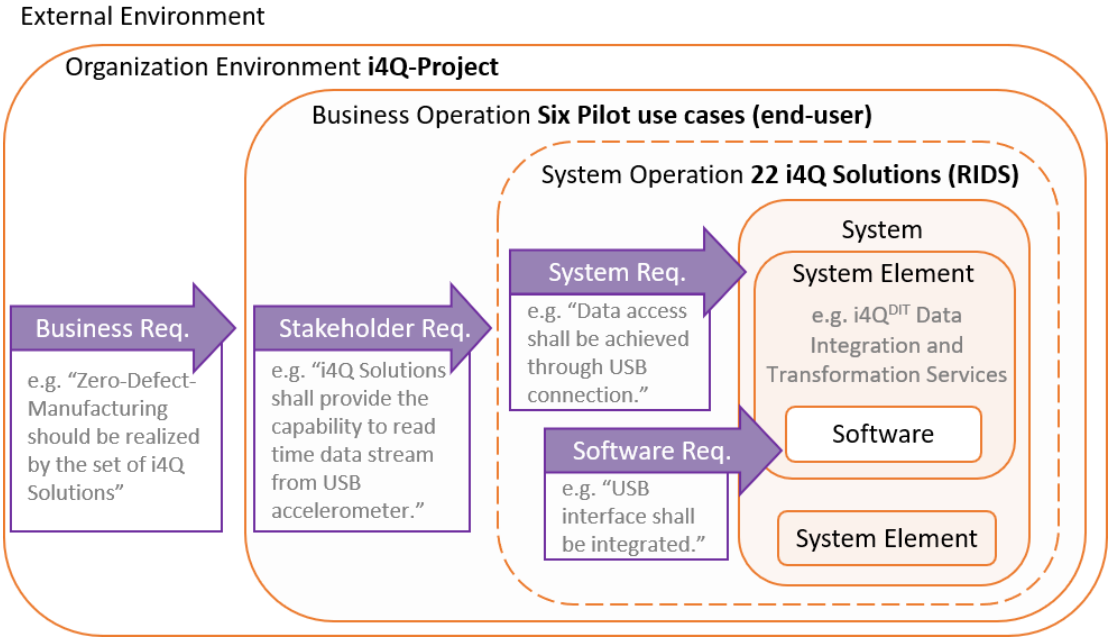

Figure 1. System limitations of requirements engineering in i4Q Project (following ISO/IEC/IEEE 29148:2018-11)

In the previous deliverable D1.3 the AS-IS and TO-BE scenarios are described. In order to define these scenarios pilot specific technical discussions between end-users and solution providers were held. During these discussions, several end-user requirements could be derived. These stakeholder requirements are recursively transformed into functional, system, and software

requirements and mapped to the i4Q Solutions by the technical partners. This interdisciplinary i4Q approach combines stakeholder interests, requirements of end-users in factories, and technical providers of software solutions at the same time. These two perspectives are matched during requirements engineering to elicit complete sets of requirements for each i4Q Solution (**Figure 2**).

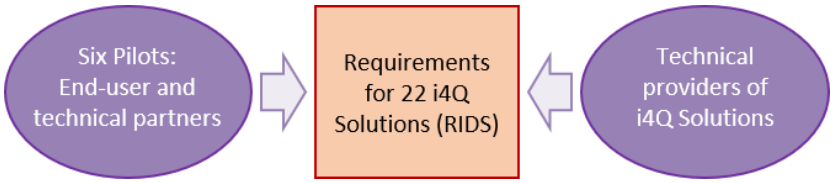

Figure 2. The two perspectives of requirements for Smart Manufacturing with i4Q RIDS

The detailed requirements elicitation procedure is described and documented in Section 2. The end-user requirements will be listed according to the six pilot use cases (detailed description can be found in D1.1):

- 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

All elicited requirements are mapped to the 22 i4Q Solutions to analyse them and prepare the information base for the function structures. The method and results are described in Section 3. There, the resulting sets of requirements are documented for the following 22 i4Q Solutions (detailed description can be found in D1.1).

- i4Q^{DQG} - i4Q Data Quality Guidelines
- i4Q^{QE} - i4Q QualiExplore for Data Quality Factor Knowledge
- i4Q^{BC} - i4Q Blockchain Traceability of Data
- i4Q^{TN} - i4Q Trusted Networks with Wireless & Wired Industrial Interfaces
- i4Q^{CSG} - i4Q Cybersecurity Guidelines
- i4Q^{SH} - i4Q IIoT Security Handler
- i4Q^{DRG} - i4Q Guidelines for building Data Repositories for Industry 4.0
- i4Q^{DR} - i4Q Data Repository
- i4Q^{DIT} - i4Q Data Integration and Transformation Services
- i4Q^{DA} - i4Q Services for Data Analytics
- i4Q^{BDA} - i4Q Big Data Analytics Suite
- i4Q^{AD} - i4Q Analytics Dashboard
- i4Q^{AI} - i4Q AI Models Distribution to the Edge
- i4Q^{EW} - i4Q Edge Workloads Placement and Deployment
- i4Q^{IM} - i4Q Infrastructure Monitoring
- i4Q^{DT} - i4Q Digital Twin simulation services

- i4Q^{PQ} - i4Q Data-driven Continuous Process Qualification
- i4Q^{QD} - i4Q Rapid Quality Diagnosis
- i4Q^{PA} - i4Q Prescriptive Analysis Tools
- i4Q^{LRG} - i4Q Manufacturing Line Reconfiguration Guidelines
- i4Q^{LRT} - i4Q Manufacturing Line Reconfiguration Toolkit
- i4Q^{LCP} - i4Q Manufacturing Line Data Certification Procedure

In Section 4 the results of the first version of requirements are evaluated. The main needs for the further requirements elicitation and analysis and functional specifications are discussed. Also, the use of the open-source system modelling language SysML[2] will be presented. For the next iterations of requirements elicitation and analysis the procedures will be adjusted to derive more detailed and specific requirements and include additional information. The open-source system modelling language SysML[2] will be used to describe, visualize, and document complex structures of requirements interfaces and (inter-)dependencies. This forms the basis for the functional specifications. The second version of this document will provide a detailed definition of the system and software requirements as well as the functional specification (deliverable D1.9).

[2] https://sysml.org/

2. Requirements Elicitation

2.1 Requirement's elicitation procedure

A suitable requirements elicitation and analysis procedure for i4Q project is developed according to ISO/IEC/IEEE 29148 (ISO/IEC/IEEE 29148:2018-11), ISO/IEC/IEEE 12207 (ISO/IEC/IEEE 12207:2017-11) and ISO/IEC/IEEE 15288 (ISO/IEC/IEEE 15288:2015-05-15). These standards are used as the basis for the requirements elicitation procedure that is aligned to "Stakeholder Needs and Requirements Definition process" (ISO/IEC/IEEE 12207:2017-11, p. 59ff). Furthermore, this procedure is performed with respect to the standards VDI 2221 (VDI 2221-1:2019-11 and VDI 2221-2:2019-11) and VDI 2206 (VDI 2206:2004-06) which describe the design of technical products and systems (VDI 2221) as well as a design methodology for mechatronic systems (VDI 2206). The first activity of product design is to clarify and itemise the problem or task (VDI 2221-1:2019-11, pp. 32-36) with the result of requirements as an information base. To achieve this, interdisciplinary, technical discussions, and requirements templates (**Figure 3**) are performed. The previous step is to define the AS-IS and TO-BE business processes in the factories of the end-user pilot cases which is documented in deliverable D1.3. During the technical discussions between end-users and experienced, technical partners the gaps between the AS-IS and TO-BE situations are analysed, and the end-user needs are derived. The focus is on data flow and quality control in manufacturing processes. Furthermore, the appropriate i4Q Solutions are mapped to the specific TO-BE scenarios of each pilot case and the feasibility of implementation and usage of the i4Q Solutions is discussed. In this step, stakeholder needs are transformed into system and software requirements. To gather all this information, two requirements' templates including all types of requirements are set up in which the requirements are collected.

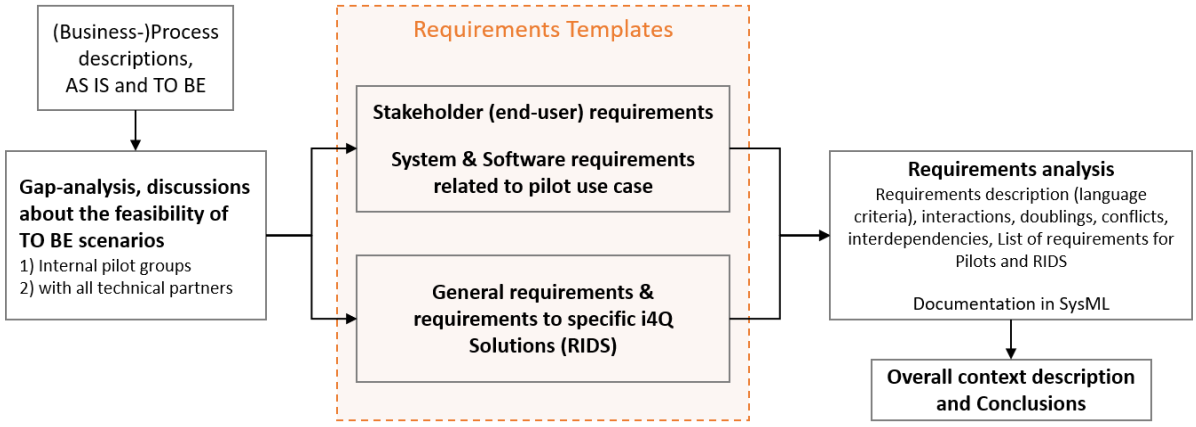

Figure 3. Requirements' elicitation procedure in i4Q Project

In the first template *pilot requirements template* the end-user needs, and objectives are collected and the corresponding technical requirements are added (**Figure 4**). Goals and objectives that the end-user expects are named first. These are the stakeholder requirements according to wording in ISO/IEC/IEEE 29148 (ISO/IEC/IEEE 29148:2018-11). To these objectives the associated (business-) processes and information about provided and needed data, e.g., format, quantity, source, and other information are added. The specific technical requirements are described considering conditions, constraints, and priority (mandatory, non-mandatory). To achieve traceability, the requirements get a unique identifier (ID) and version number. The type of

requirement is assigned as well as the difficulty of realisation and if needed, a short rationale which gives a justification for the requirement. Also, risks may be added. Important is the mapping of the appropriate i4Q Solution to the requirement. This information is gathered within technical discussions in which the technical partners support the end-users to describe their requirements more precisely and map them to the i4Q Solutions. Technical details about the factories, e.g., which hardware and software are already used as well as the technical feasibility of the TO-BE scenarios are discussed. System and software requirements are derived which are correlated to end-users needs/goals and could be aligned to the i4Q Solutions (**Figure 4**, and Appendix I). Design constraints are defined and related to functional, performance, process, non-functional, and interface specifications. Further related requirements that appear but which are not pilot-specific shall be included in the second template.

The second template *further requirements template* includes general needs, expectations, and requirements to i4Q Solutions from all 24 partners considering the i4Q Project objective to create sustainable IoT-based RIDS that ensure data quality, traceability, and proper use, in order to achieve continuous process qualification, quality diagnosis, reconfiguration and certification of manufacturing lines. This template also includes requirements that are assigned to specific i4Q Solutions which are not associated to one specific pilot use case but to the i4Q Solutions itself that will be implemented and used by several end-users. These requirements are mostly defined by the i4Q Solution providers.

Improvement need/goal optimization need/goal project objectives/goals	*(Business-)Process to be carried out by the solutions*	*Data Quality*	
		Provided data (format, quantity, data source)	Expected data from-Solutions
The solutions shall provide the capability to read time data stream from USB accelerometer.	P1_BP01, P1_BP02, P1_BP03	Vibration time data from Sequoia (or alternative) USB accelerometer	Correct reading confirmation

Requirement definition (related to the solution)	*ID*	*Vers.*	*Type of requirement (optional)*	*Mapping to solutions*	
				Name of the specific solution	All solutions
Data access shall be achieved through USB connection.	PC1r3	v1	technical requirement	Solution 1	-

Figure 4. Draft extract from the pilot requirements template

The lists of requirements are the first interim result which is the basis for the requirements analysis in Section 3. In the following sub-sections, a state-of-the-art analysis of scientific research papers summarizes requirements of similar use cases, then, main challenges and requirements of the six pilot use cases are identified and finally, further knowledge and expertise are described.

2.2 State-of-the-art analysis

Methodology

To determine the state-of-the-art regarding requirements for industrial data services for quality control in smart manufacturing, a systematic literature review was conducted. A systematic literature search is characterized by transparency, reproducibility, and reliability, and aims to synthesize findings from existing publications. Accordingly, the following section presents the procedure for searching and selecting significant literature on requirements for i4Q RIDS.

Literature Search

The literature search was conducted in February 2021 using the three databases 'Web of Science', 'Science Direct' and 'EBSCOhost'. Four different search queries consisting of different combinations of keywords were selected and applied in each database. These search terms are shown in **Table 1**, and their specific syntax was adapted to the default settings of the databases.

In addition, only articles in English or German were included. To ensure current research results, articles published before 2011 were not included. Thus, the analysis is limited to the last ten years. Similarly, the search was limited to matching hits in the title, abstract, or keywords of the literature. Wherever possible, available categories and topics were selected to individualize the results.

All in all, this literature search led to 257 potentially relevant articles. The allocation of these initial results is presented in **Table 2**.

Requirement*	AND	1. Digit* AND Qualit* AND (Produ*tion OR Manufacturing)
		2. Zero-Defect Manufacturing
		3. Smart Data AND Industr* 4.0 AND Qualit*
		4. (Data predict* OR Data traceab*) AND Qualit* AND (Produ*tion OR Manufacturing)

Table 1. Search terms

Database	Results
Web of Science	132
Science Direct	99
EBSCOhost	26
Σ	**257**

Table 2. Initial results

Selection process

After having identified potentially relevant literature, the results of this initial search were refined through a multi-stage selection process described as follows. **Figure 5** visualizes the procedure and the utilized criteria as well as the remaining articles per step.

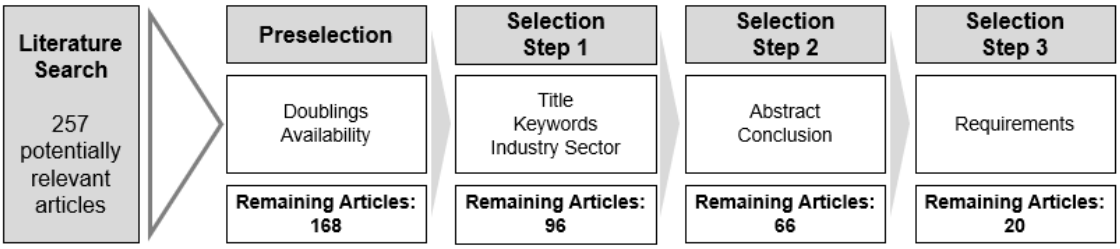

Figure 5. Literature Search and Selection Process

First, the 257 papers were preselected by rejecting doublings. In the same manner, the articles' availability was manually checked since the literature must be freely available for members of TU Berlin. Overall, 168 papers overcame the preselection and were transferred to the detailed selection process.

In step 1, two researchers examined these papers investigating whether their title and keywords are relevant regarding requirements elicitation for i4Q RIDS. Besides, the further analysis focusses on certain industry sectors, namely production or manufacturing, to exclude negligible branches. Consequently, still 96 of the articles are classified as significant. **Table 3** reveals both the total results and the number of remaining, relevant papers after step 1, depending on the keyword combinations and databases.

Query No.	Web of Science		Science Direct		EBSCOhost	
	Total Results	Relevant Results	Total Results	Relevant Results	Total Results	Relevant Results
1	50	21	46	17	16	1
2	4	4	9	8	0	0
3	15	10	12	6	1	1
4	63	18	32	9	9	1
Σ	**132**	**53**	**99**	**40**	**26**	**3**

Table 3. Relevant Results after Selection Step 1

In step 2, each of the remaining 96 papers were selected based on the relevance of the respective abstract and conclusion. As a result, 66 articles remain (**Table 4**).

Query No.	Web of Science		Science Direct		EBSCOhost	
	Total Results	Relevant Results	Total Results	Relevant Results	Total Results	Relevant Results
Abstract	53	**36**	40	**30**	3	**0**

Table 4. Relevant Results after Selection Step 2

In step 3, the final and most useful papers were selected, resulting in 20 convincing articles (**Table 5**). For this last evaluation, the remaining articles were scanned in detail to prove that requirements are explicitly defined in text or table form.

Query No.	Web of Science		Science Direct		EBSCOhost	
	Total Results	Relevant Results	Total Results	Relevant Results	Total Results	Relevant Results
Requirement	36	**13**	30	**7**	0	**0**

Table 5. Relevant Results after Selection Step 3

At the end of the described literature search and multi-stage selection process 9 of the 20 articles provided 36 useful requirements (**Table 6**). These papers provide the basis for the following in-depth analysis to identify the state-of-the-art requirements related to industrial data services for quality control in smart manufacturing.

Table 6). These papers provide the basis for the following in-depth analysis to identify the state-of-the-art requirements related to industrial data services for quality control in smart manufacturing.

ID	Requirements	Level of req	Type of req.	Keywords	Literature
Lit1	Predictive machine maintenance should use live data.	General	Functional/ Technical req.	Tool exchange, predictive machine maintenance	(Pfirrmann et al. 2019, p. 3067)
Lit2	Process data should be recorded by suitable sensors at the highest possible frequency.	General	Functional/ Technical req.	Process data	(Pfirrmann et al. 2019, p. 3067)
Lit3	Different generations of machines should be compatible in usage.	General	Interface req.	Process data management, generation of machine	(Pfirrmann et al. 2019, p. 3069)
Lit4	Data should be recorded along the production process chain.	General	Functional/ Technical req.	Real time data, production process chain	(Pfirrmann et al. 2019, p. 3068)

ID	Requirements	Level of req	Type of req.	Keywords	Literature
Lit5	A suitable interface should be used for the acquisition of the machine data.	General	Interface req.	Interface	(Pfirrmann et al. 2019, pp. 3067–3068)
Lit6	Uniform and open interfaces should be used to merge data in a database.	General	Interface req.	Open Interface, database	(Pfirrmann et al. 2019, pp. 3069–3070)
Lit7	Evaluation of the series production environment should be automated.	General	Functional/ Technical req.	Series production environment	(Pfirrmann et al. 2019, p. 3069)
Lit8	Process data should be mapped with the combination of machine-internal data and external sensors.	General	Functional/ Technical req.	Series data	(Pfirrmann et al. 2019, p. 3069)
Lit9	Access and participation rules regarding safety should be shared by the responsible actor with other authorized participants.	General	Security req.	Access and participation rules	(Kuhn et al. 2021, p. 391)
Lit10	Computerized Maintenance Management System (CMMS) should be integrated with other manufacturing execution systems such as Enterprise Resource Planning (ERP) and dynamic on-line machine tool monitoring and part inspection systems.	System	Functional/ Technical req.	CMMS	(Wan et al. 2017, p. 16)
Lit11	Companies should be aware of monitoring of risk factors for	General	Functional/ Technical req.	Risk factors, assembly lines	(Unver et al. 2020, p. 867)

ID	Requirements	Level of req	Type of req.	Keywords	Literature
	example in assembly lines.				
Lit12	The operator should have an overview of who uses which parts and when.	System	Functional/ Technical req.	Operator, parts	(Kuhn et al. 2021, p. 391)
Lit13	Data outcome of every step of the workflow should be specified and the levels should be stored in a global factory-wide database.	General	Functional/ Technical req.	Global factory, workflow, database	(Azevedo and Almeida 2011, p. 756)
Lit14	Data-driven approaches should be applied with correct data.	System	Functional/ Technical req.	Data-driven, correct data	(Günther et al. 2019, p. 589)
Lit15	Different systems should be able to interact with each other independently of the language.	General	Interface req.	Different systems, language	(Wan et al. 2017, p. 23)
Lit16	E-maintenance systems should allow different people to learn from previous experiences.	General	Usability and quality req.	E-maintenance	(Wan et al. 2017, p. 15)
Lit17	Knowledge-based systems should be able to use experience (data) and histories of development processes.	System	Functional/ technical req.	Real-time data, development processes, knowledge-based systems	(Azevedo and Almeida 2011, p. 764)
Lit18	The on-line monitoring of machine tool performance and in-process inspection of machined parts should be linked to machine tool maintenance.	System	Functional/ technical req.	On-line monitoring, inspection, parts, machine tool	(Wan et al. 2017, p. 15)

ID	Requirements	Level of req	Type of req.	Keywords	Literature
Lit19	The system should be able to operate in real time, i.e., the transaction process of the system must reflect the speed of production.	System	Functional/ technical req.	Real time, production speed	(Kuhn et al. 2021, p. 391)
Lit20	Information and Communication Technologies (ICT) should be made available as a platform for the exchange of information and knowledge between stakeholders.	System	Functional/ technical req.	Information and communications technology (ICT)	(Wan et al. 2017, p. 15)
Lit21	An ideal system should allow a widespread use by not being dependent on a particular control system manufacturer.	System	Interface req.	Control system manufacturer	(Barton et al. 2019, p. 1333)
Lit22	Any standardized solution should be able to run on legacy systems.	System	Interface req.	Legacy systems	(Mantravadi et al. 2020, p. 15)
Lit23	By using low-cost programmable logic controllers (PLCs) and the existing infrastructure, costs and complexity should be reduced.	General	Usability and quality req.	PLC	(Mantravadi et al. 2020, p. 11)
Lit24	Cryptographic method should have low requirements on memory and computation time.	General	Functional/ Technical req.	Cryptographic method, memory and computation time, authenticity	(Mantravadi et al. 2020, p. 12)

ID	Requirements	Level of req	Type of req.	Keywords	Literature
Lit25	Cryptographic method should be resistant to computational attacks.	General	Security req.	Computational attacks, cryptographic method, authenticity	(Mantravadi et al. 2020, p. 12)
Lit26	Cybersecurity around automated production lines should be implemented to prevent sabotage.	General	Security req.	Authenticity, confidentiality, cybersecurity	(Mantravadi et al. 2020, p. 11)
Lit27	Depending on the required computing power and reaction time, the data should be evaluated by a smart controller and/or transmitted to other computers.	General	Interface req.	Smart controller, reaction time, computing power	(Barton et al. 2019, p. 1332)
Lit28	Future factories using 5G should focus on authenticity and confidentiality when using wireless communications.	General	Functional/ Technical req.	Authenticity, confidentiality, 5G, wireless communication	(Mantravadi et al. 2020, p. 11)
Lit29	Industrial-IoT (IIoT)-devices should use authenticated keys to prevent sabotage.	System	Security req.	IIoT, authenticity, sabotage	(Mantravadi et al. 2020, p. 11)
Lit30	Machines should simply exchange shared keys when they need to connect to a new peer.	General	Security req.	Machines, keys, new peer	(Mantravadi et al. 2020, p. 11)
Lit31	Models should be retrained for different quality requirements.	System	Usability and quality req.	Model, quality	(Mamledesai et al. 2020), p. 2
Lit32	Smart controller should be implemented as an additional system	General	Interface req.	Smart controller, machine control system	(Barton et al. 2019, S. 1332)

ID	Requirements	Level of req	Type of req.	Keywords	Literature
	parallel to the machine control system.				
Lit33	In Tool condition monitoring (TCM), the tool change policy (TCP) should be carried out autonomously and independently.	System	Functional/ Technical req.	Tool condition monitoring, tool change policy	(Mamledesai et al. 2020, p. 2)
Lit34	TCM should work with different materials, tool geometries and tool coatings.	System	Functional/ Technical req.	Tool condition monitoring	(Mamledesai et al. 2020, p. 4)
Lit35	Tool monitoring should enable autonomous detection of damage to the cutting inserts.	General	Functional/ Technical req	Tool monitoring, autonomous detection, inserts	(Mamledesai et al. 2020, p. 3)
Lit36	Smart factories should ensure high reliability and low latency to high data rates.	General	Functional/ Technical req	Smart factories, reliability, low latency, data rates	(Yang et al. 2020, p. 5567)

Table 6. Overview of elicited requirements

2.3 Pilot Cases

After eliciting requirements from literature, in which several use cases were discussed, the six i4Q specific pilot uses cases with their main challenges and stakeholder requirements are now presented. The template which was used for the gathering all specific information about the pilots alongside the project partners is attached in the Appendix I. The listed requirements are already prepared in language criteria and syntax as explained in Section 3.1. These requirements will be mapped to the i4Q Solutions in Section 3.2.

2.3.1 Pilot 1: Smart Quality in CNC Machining

2.3.1.1 Main Challenges

The main objective of the FIDIA pilot case is the monitoring and adaption of processing conditions to guarantee that the workpiece quality is in line with customers' requirements. The proposed objective requires the addressing of the following challenges:

1. The **collection and synchronization** of data coming from different sources: machine CNC, local Mongo DB, USB accelerometer, part programs, test sessions recordings.
2. The **secure transfer and storage** of factory data to a remote repository where analysis can be performed with more powerful systems than the ones available at factory level.
3. An **estimation of the final surface quality**: the correlation of the processing conditions (axial and radial depths of cut, axes feed, spindle rotation speed, workpiece material, tool geometry) with the final workpiece quality requires an Artificial Intelligence (AI) based tool capable of extending over multiple dimensions. Appropriate testing sessions will allow to train the algorithm with the provision of quality measurement, performed after the process ending through a Mitutoyo rugosimeter.
4. A **chatter detection and removal algorithm**: chatter can cause unacceptable marks on the final workpiece surface (see **Figure 6**). A Fast Fourier Transformation (FFT) analysis of vibrations and its correlation with current processing conditions (spindle speed rotation, number of tool flutes) will allow to determine if chatter is taking place during the process. An empirical stability diagram will be built during a testing campaign to support the implementation of an AI based algorithm for the online chatter presence removal (through specific feed and spindle speed override signals).

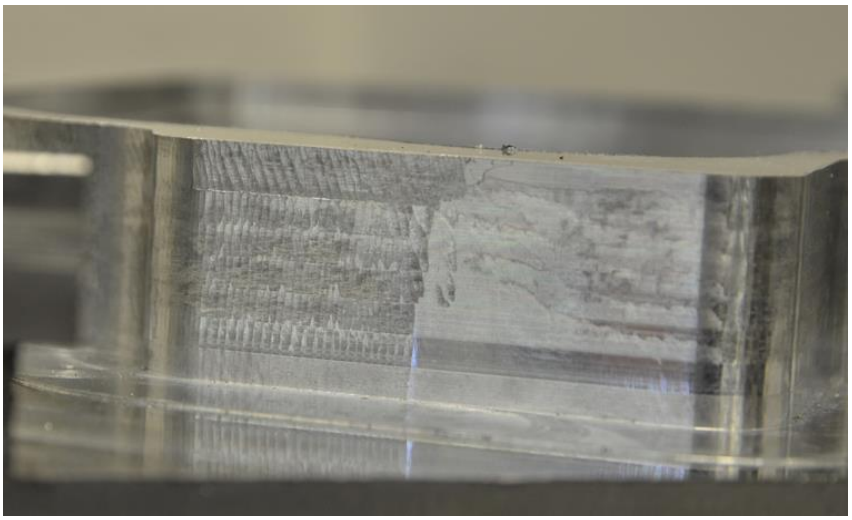

Figure 6. Chatter marks (left part of workpiece)

5. A **trend-based evaluation of machine tool conditions**: Big Data solutions are required to analyze the trends of the processing signals (positions, speeds, currents and torques) collected during the periodical execution of dedicated reference tests. The variation of such parameters during otherwise identical tests will allow to identify degradation patterns (compared to nominal conditions) by an unsupervised machine learning (ML) approach and identify possible faulty components (failure modes). New processing constraints will be imposed on the equipment to reduce the impact of failures on the process while waiting for maintenance intervention.

2.3.1.2 Table of Requirements

Table 7 shows the collected requirements of Pilot 1. The first column lists the optimisation and stakeholder requirements of Pilot 1 regarding the i4Q RIDS. Then, the requirements are assigned to the corresponding business processes from D1.3. In the third column the requirements-IDs of

the derived system requirements are named. These IDs can be found in the lists in the Requirements Analysis (Section 3) where the system requirements are listed according to the i4Q Solutions.

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Capability to read/write FIDIA CNC parameters through FapiCorbaLib.	P1_BP01, P1_BP02, P1_BP03	When the CNC is active, the system shall connect to the CNC via the FapiCorbaLib interface to (1) periodically read and store relevant processing parameters and (2) write in dedicated parameters the suggestions for improved process.	PC1r1	9-i4Q_DIT, 10-i4Q_DA
Capability to read data from the FIDIA Machine Monitor Mongo DB.	P1_BP01, P1_BP02, P1_BP03	When the system requires to retrieve old CNC parameters content, the system shall connect to the Mongo DB installed on the CNC and query the required data.	PC1r2	9-i4Q_DIT
Capability to read time data stream from USB accelerometer.	P1_BP01, P1_BP02, P1_BP03	During the milling process, the system shall connect to the CNC USB port where the accelerometer is plugged in, to retrieve with a streaming connection all the available time domain vibration signals.	PC1r3	9-i4Q_DIT, 10-i4Q_DA
Capability to retrieve part programs (txt) files from the FIDIA CNC.	P1_BP01, P1_BP02, P1_BP03	During or after the execution of PartProgram files, the system shall connect with the CNC via Windows protocols (to be identified) to retrieve the current PartProgram file from a dedicated folder.	PC1r4	9-i4Q_DIT
Capability to retrieve test sessions (csv)	P1_BP03	After the execution of test movements, the system shall connect with the CNC via	PC1r5	9-i4Q_DIT

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
recording files from the FIDIA CNC.		Windows protocols (to be identified) to retrieve the recorded files from a dedicated folder.		
Capability to apply Fast Fourier Transformation (FFT) on the accelerometer data.	P1_BP01, P1_BP02, P1_BP03	During the milling process, the system shall compute the FFT analysis of all the available time domain vibration signals.	PC1r6	9-i4Q_DIT
Capability to parse the content of part programs (txt) files to extract process characterizing information.	P1_BP01, P1_BP02, P1_BP03	After retrieving the current PartProgram file and while it is still active, the system shall parse its content to read the information (stored in the first lines) characterizing the current milling process.	PC1r7	9-i4Q_DIT
Capability to synchronize data from sources with different sampling times.	P1_BP01, P1_BP02, P1_BP03	While retrieving the information from the sources listed above, the system shall be able to compute the differences between the various time references systems and synchronize the timestamps for all retrieved data.	PC1r8	9-i4Q_DIT, 22-i4Q_LCP
Capability of extracting relevant (requested) features from ingested data/signals.	P1_BP01, P1_BP02, P1_BP03	While analysing the information retrieved from the sources listed above, the system shall be able to compute new features providing insight on the recorded process (e.g., FFT binning).	PC1r9	9-i4Q_DIT

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Capability of cleaning/filtering and structuring data to store a consistent dataset (e.g., remove of noise, duplicates, spikes, inconsistencies, aggregates etc.) to be parsed by AI/ML algorithms.	P1_BP01, P1_BP02, P1_BP03	While analysing the information retrieved from the sources listed above, the system shall be able to filter the information from errors linked to the physical limitations of available signals.	PC1r10	9-i4Q_DIT
Capability of securely moving data from factory level to cloud level.	P1_BP01, P1_BP02, P1_BP03	While moving any data from the CNC to another repository, the system shall guarantee the security of the data against any type of intrusion.	PC1r11	4-i4Q_TN, 6-i4Q_SH, 22-i4Q_LCP
Capability of storing data for future retrieval and analysis.	P1_BP01, P1_BP02, P1_BP03	When storing the data collected from the sources listed above, the system shall guarantee their safety through robust approaches (redundancy, error correction coding, etc.).	PC1r12	7-i4Q_DRG, 8-i4Q_DR
Capability to correlate foreseen processing parameters with workpiece final surface quality before the execution of the process.	P1_BP01	Before the execution of a part program, the system shall be able to foresee the final workpiece quality (surface roughness) from the analysis of the defined processing parameters.	PC1r13	11-i4Q_BDA, 21-i4Q_LRT
Capability to correlate current processing parameters with workpiece final	P1_BP01	During the execution of a part program, the system shall be able to foresee the final workpiece quality (surface roughness) from the analysis	PC1r14	11-i4Q_BDA, 18-i4Q_QD

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
surface quality during the execution of the process.		of the current processing parameters.		
Capability to propose alternative processing parameters to improve workpiece final surface quality during the execution of the process.	P1_BP01	During the execution of a part program, the system shall be able to suggest processing parameters (axis and spindle speed overrides) that improve the final workpiece quality (surface roughness).	PC1r15	11-i4Q_BDA, 17-i4Q_PQ
Capability to correlate online processing parameters with FFT data to detect the presence of chatter.	P1_BP02	During the execution of a part program, the system shall be able to determine if chatter is taking place from the analysis of the current processing parameters and the computed FFT.	PC1r16	9-i4Q_DIT, 18-i4Q_QD
Capability to correlate foreseen processing parameters with chatter insurgence before the execution of the process.	P1_BP02	Before the execution of a part program, the system shall be able to foresee if chatter will take place from the analysis of the foreseen processing parameters and the knowledge of previous chatter conditions on the same machine.	PC1r17	11-i4Q_BDA, 21-i4Q_LRT
Capability to propose alternative processing parameters to remove chatter presence during the execution of the process.	P1_BP02	During the execution of a part program, the system shall be able to suggest processing parameters (axis and spindle speed overrides) that remove or reduce the impact of chatter vibrations.	PC1r18	11-i4Q_BDA, 17-i4Q_PQ

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Capability to analyse all stored data to detect trends in recorded parameters.	P1_BP03	The system shall be able to detect trends in the data collected from the sources listed above as well as in the computed features.	PC1r19	11-i4Q_BDA
Capability to correlate trends in recorded parameters with specific equipment components degradation.	P1_BP03	The system shall be able to correlate the computed trends with the degradation of specific components (failure modes).	PC1r20	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 18-i4Q_QD, 21-i4Q_LRT
Capability to propose alternative processing parameters to reduce specific equipment components degradation rate.	P1_BP03	Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected degradation of specific components (failure modes).	PC1r21	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT
Capability of displaying all information generated by the system.	P1_BP01, P1_BP02, P1_BP03	During all the improved Business Processes (BPs), the system shall display collected information as well as generated one (adapted parameters, FFT, suggestions, degrading components) through its dashboard.	PC1r22	12-i4Q_AD

Table 7. Gathered requirements from Pilot 1

2.3.2 Pilot 2: Diagnostics and IoT Services

2.3.2.1 Main Challenges

In manufacturing processes, production and maintenance data is increasingly important, as it could be related to the machine's degradation or the job's quality, providing a way to increase product quality and machine useful life.

The main objective of BIESSE pilot case is to intercept in advance components that will broke or to identify the defects that will cause a quality degradation in the processing. This objective can be achieved by addressing the following challenges:

1. Define the most significant data (e.g., torque, speed, vibration, current, etc.) suitable for describing the state of health of the components (e.g., electro spindles, axes, pistons, etc.).
1. Root Causes Analysis: identify the types of failure and related factors.
2. Define techniques and methodologies of data acquisition from devices (e.g., sampling frequency, resolution, etc.).
3. Extrapolate the Health Indicators which describe the system status.
4. Diagnostics: define the Health Stages by monitoring Health Indicators of machine, in order to detect degradation before breakdown and increase its' useful life
5. Development of reliable and advanced continuous monitoring algorithms (in time or frequency domain).
6. Integration of i4Q outputs into Sophia (IoT Biesse digital platform).
7. Integration of i4Q outputs towards Manufacturing Execution Systems (MES) of our customers.

2.3.2.2 Table of Requirements

Table 8 shows the collected requirements of Pilot 2. The first column lists the optimisation and stakeholder requirements of Pilot 2 regarding the i4Q RIDS. Then, the requirements are assigned to the corresponding business processes from D1.3. In the third column the requirements-IDs of the derived system requirements are named. These IDs can be found in the lists in the Requirements Analysis (Section 3) where the system requirements are listed according to the i4Q Solutions.

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Define the right edge/cloud architecture.	P2_BP01 - P2_BP02	i4Q ARCHITECTURE: Define the right edge/cloud architecture.	PC2r1	14-i4Q_EW
Capability to read the BIESSE CNC parameters.	P2_BP01 - P2_BP02	i4Q - READ DATA: The system should be able to read the BIESSE CNC parameters every 2 milliseconds (ms).	PC2r2	9-i4Q_DIT
Define the right data repository.	P2_BP01 - P2_BP02	i4Q - DATA REPOSITORY: The system should be able to provide a data repository in which the CNC can store the main data (for example axes	PC2r3	7-i4Q_DRG, 8-i4Q_DR

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
		torque during the test cycles) every 2 ms.		
In case a data repository will not be provided, the system should be able to read data from the Biesse Raw Log File.	P2_BP01 - P2_BP02	i4Q - READ DATA: In case a data repository will not be provided, the system should be able to read data from the Biesse Raw Log File every 2 ms, located on machine PC.	PC2r4	9-i4Q_DIT
Capability to synchronize data from different sources.	P2_BP01 - P2_BP02	i4Q - DATA SYNCHRONIZATION: When data are read from different sources (for example BIESSE CNC and data repository) and therefore with different sample frequency and different trigger of acquisition, the system shall synchronize and align the data.	PC2r5	9-i4Q_DIT
Define the algorithms, in time and frequency domain, that have to be performed to predict a component degradation. This goal requires an interaction with the following "i4Q ALGORITHMS" group of goals.	P2_BP01 - P2_BP02	i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict the component degradation under investigation within one day, by analysis performed in time and frequency domain. This goal requires an interaction with the following "i4Q ALGORITHMS" group of goals.	PC2r6	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Develop an algorithm for an offline remaining lifetime estimation.	P2_BP01 - P2_BP02	i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict an offline remaining lifetime estimation within one day.	PC2r7	11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA
Define the machine condition during the data recording (test cycles).	P2_BP01 - P2_BP02	i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert machine condition and other constraints required for the data recording (test cycles).	PC2r8	15-i4Q_IM
Building an interface where an expert user can define the parameters to perform the required analysis.	P2_BP01 - P2_BP02	i4Q ALGORITHMS: Once an algorithm is established, the system should provide a user-interface the machine setup where can be defined to perform test cycle, according to the constraints defined in the "administration interface".	PC2r9	9-i4Q_DIT
For each algorithm define the data that we need (for example torque, micro-marker values, ...).	P2_BP01 - P2_BP02	i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert the needed data (for example torque, micro-marker values, etc.).	PC2r10	9-i4Q_DIT, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP
For each algorithm define in which way the data have to be recorded, in terms of sampling	P2_BP01 - P2_BP02	i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to define the data acquisition parameters (for example	PC2r11	9-i4Q_DIT, 21-i4Q_LRT, 22-i4Q_LCP

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
frequency, resolution, …		sampling frequency, resolution, etc.).		
Perform an uncertainty analysis with the aim to define the reliability of the developed algorithms.	P2_BP01 - P2_BP02	i4Q ALGORITHMS: For each established algorithm, the system should provide an uncertainty analysis with a confidence level of 95 %. With the aim to define the reliability of the developed algorithms to identify machine problems.	PC2r12	11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP
Scalability of the data and/or thresholds when change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, …).	P2_BP01 - P2_BP02	i4Q ALGORITHMS: When change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, etc.), the system shall scale the output data from the algorithms and/or the thresholds of the algorithms within constraint conditions.	PC2r13	9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP
The outputs from the i4Q algorithms must be messages with different priority (medium in case of preventive maintenance or high in case of machine stop) that have to be sent to Sophia platform.	P2_BP01 - P2_BP02	i4Q ALGORITHMS: When a machine problem will be intercepted, the system will send the result to Sophia platform in ascending order of priority (medium in case of preventive maintenance or high in case of machine stop). The message could contain the following information: suspected component; type of problem; priority; etc.	PC2r14	12-i4Q_AD

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Biesse support (hotliner or filed) should be able to send feedback to the i4Q platform, with the aim of increasing the reliability of the i4Q solutions.	P2_BP01 - P2_BP02	i4Q ALGORITHMS: The system should provide an user interface to collect feedback from hotliner or field, with the aim to increase the reliability of the i4Q algorithms	PC2r15	12-i4Q_AD
Capability of securely moving data from i4Q solution to cloud level (SOPHIA).	P2_BP01 - P2_BP02	i4Q - DATA TRANSFER: The system should be able of securely moving data from i4Q solution to cloud level (SOPHIA) once the analysis have been done.	PC2r16	6-i4Q_SH
Building a self-diagnosis interface available for the customer.	P2_BP01 - P2_BP02	SOPHIA PLATFORM: The system should provide a self-diagnosis "maintenance interface" for the customer, that contains some outputs from the i4Q solutions (e.g., lifetime estimation of the principal components, suggested processing parameters, etc.).	PC2r17	12-i4Q_AD, 18-i4Q_QD
Building a self-diagnosis interface available for Biesse support.	P2_BP01 - P2_BP02	SOPHIA PLATFORM: The system should provide a self-diagnosis "maintenance interface" for Biesse support, that contains the information available for the customer and all the other outputs from the i4Q solutions (e.g., confidential data, outputs from experimental algorithms, etc.).	PC2r18	12-i4Q_AD, 18-i4Q_QD

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Identify the limits and improvements required at the end of i4Q project, that need to be overcome for future development.	P2_BP01 - P2_BP02	OTHER: At the end of i4Q project, all the involved partners have to identify the limits and improvements that need to be overcome for future development in ascending order of importance.	PC2r19	22-i4Q_LCP

Table 8. Gathered requirements from Pilot 2

2.3.3 Pilot 3: White Goods Product Quality

2.3.3.1 Main Challenges

The main challenge of the Whirlpool (WHR) use case is virtualizing some manual testing operations. This virtualization relies on the hypothesis that product conformity on all (or a subset) performance parameters can be inferred by the analysis of data gathered along the production line. i4Q contribution is identified in the realization of three new software modules (or combination of i4Q solutions) that will:

1) perform a pseudo machine learning (supervised and non-supervised) from historic data to identify prediction mechanisms that correlate, with a specific degree of confidence, the data associated with each specific product under production with its conformity potential. The supervised machine learning will be assisted by an extensive availability of proven correlations already studied and experimented in Whirlpool (for example factors influencing energy Design of Experiments and results are reported in **Figure 7**).

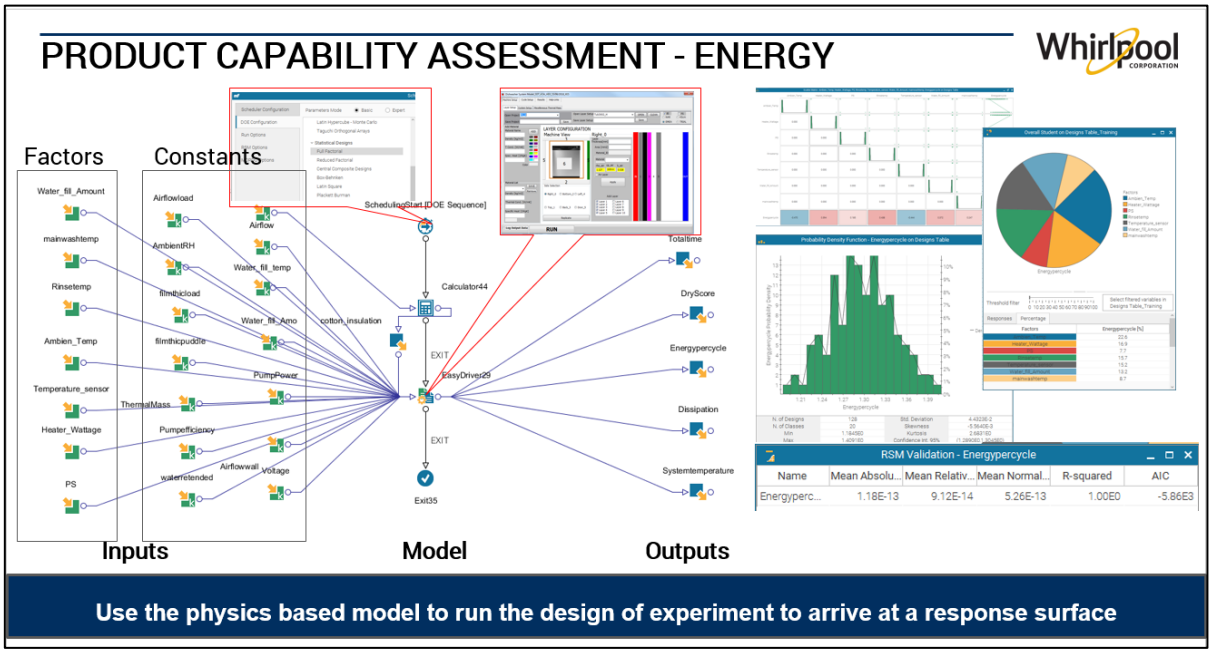

Figure 7. Logic of correlating input factors to product performances

2) embed the inferring algorithm in a system that will be used in production: after the final phase of production (End of life test) all the relevant data gathered during assembly will be evaluated and a prediction on the conformity of the product under test on all (or a subset) of its performance parameters and the results of this stored

3) analyse each Virtual Test results and, according to some rules (to be both imposed by User and supported by learning) will trigger the alert to the decision tree that will act according to the existing BP

4) provide a Data Visualization and Analytical tool that will support the Quality Task Force in decision processes.

The secondary challenge of WHR use case is related to the high degree of integration of i4Q solution into the existing architecture based on Google Cloud Platform in both direction (data in, results out).

2.3.3.2 Table of Requirements

Table 9 shows the collected requirements of Pilot 3. The first column lists the optimisation and stakeholder requirements of Pilot 3 regarding the i4Q RIDS. Then, the requirements are assigned to the corresponding business processes from D1.3. In the third column the requirements-IDs of the derived system requirements are named. These IDs can be found in the lists in the Requirements Analysis (Section 3) where the system requirements are listed according to the i4Q Solutions.

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
A system able to predict the product conformity by examining data collected along the production line, integrating the WHR Google Cloud Platform and performing virtual tests should be provided.	P3_BP01	The system shall predict the product conformity.	PC3r1,	1-i4Q_DQG, 2-i4Q_QE, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA
	P3_BP02	The system shall perform virtual tests for all the products resulting from the manufacturing process.	PC3r2	10-i4Q_DA, 16-i4Q_DT
	P3_BP03	The system shall be integrated with WHR Google Cloud Platform to access input data.	PC3r3	9-i4Q_DIT
A human-adjustable system that can examine the state of the virtual test results and decide whether to scale the alert process based on the decision tree should be provided.	P3_BP01	The systems shall perform analysis based on Artificial Intelligence and Machine Learning to develop a Data Distribution Service (DDS) performing Threshold and Importance analyser.	PC3r4	8-i4Q_DR, 12-i4Q_AD, 19-i4Q_PA
	P3_BP02	The system shall be trained with the use of historical data to develop a DDS performing Threshold and Importance analyser.	PC3r5	10-i4Q_DA
	P3_BP03	The system shall generate an alert for non-conformity situations to perform Threshold and Importance analyser.	PC3r6	11-i4Q_BDA
The storage of the results and outcomes of the Virtual Test integrated with	P3_BP01	The system shall store input data from GCP in an internal repository to store results according to provided format (to perform Store	PC3r7	8-i4Q_DR, 10-i4Q_DA

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
the WHR Legacy System (GCP) should be performed by a Virtual Test Module that connects to the GCP and stores the results according to the intended format.		Product Conformity result from Virtual Test).		
	P3_BP02	The system shall store output/results from analyses in an internal repository (to perform Store Product Conformity result from Virtual Test).	PC3r8	7-i4Q_DRG, 8-i4Q_DR
The decision-making process after the alert for non-conformity should be assisted by a flexible, human-friendly analytical tool that is able to correlate both the virtual test result and all other data available in GCP. Data visualization and analysis is needed.	P3_BP01	The system shall visualize the results of the analysis in an ad-hoc dashboard (integrated virtual test results and WHR Google Cloud Platform). Basic functionality such as: Historical data	PC3r9	12-i4Q_AD
	P3_BP02	The tool shall be user-friendly and can be used by the multi-functional Quality teams.	PC3r10	12-i4Q_AD
All data generated by new modules shall be adhering to provided ontology Material-Process-Functions-Quality (MPFQ) (developed in H2020-QU4LITY)	P3_BP01	The existing MPFQ Model should be evaluated and embedded, and the data should be mapped (harmonized) on it.	PC3r11	7-i4Q_DRG

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Evaluate and embed MPFQ model into i4Q to harmonize the data.				

Table 9. Gathered requirements from Pilot 3

2.3.4 Pilot 4: Aeronautics and Aerospace Metal Parts Quality

2.3.4.1 Main Challenges

Factor main challenges are related with obtaining the strict data quality management requirements included in Standard AS9100 - Quality Systems - Aerospace - Model for Quality Assurance in Design, Development, Production, Installation and Servicing (AS9100), for being an aerospace industry supplier and in that way improving its manufacturing quality assurance system, so specialised areas within an aerospace quality management system are: acquisition, traceability, configuration management, product documentation and control of work performed outside the supplier's facilities.

Currently it does not have manufacturing lines qualification system based on a continuous process validation to certificate its manufacturing quality level and cannot guarantee the inalterability of product and process data.

To evolve towards manufacturing with zero-defects eliminating the efficiency failures caused by:

- the state of the cutting lubricant,
- minimize the breakage of the cutting tools due to lack of cutting lubricant or due to the blockage of cooling channels of the tools,
- facilitate diagnosis and evaluation of breakage incidents,
- ensure that the tools work within their optimum range,
- predict equipment damage, and
- implement an efficient inspection of all manufactured parts, particularly complex parts.

For solving those efficiency failures there will be to address next specific challenges:

1. **Digitize the factory** to read and collect all the information in production chain in real time by means of proper sensors and cameras, to evaluate production decisions based upon data analytics and simulation, visualize products performing in their environments in real-time and connect separate processes for improved tracking and monitoring and gain control over its complex processes.
2. **Analyse all collected data**, to alert on product and process deviations. It will be used sensors to measure the properties of the cutting lubricant (pH, concentration of salts, bacterial level, size of metal particles, etc.) to facilitate the diagnosis and evaluation of

incidents in tool breaks. With real-time measurement of the temperature of the cutting zone, for instance, it will be ensured that the equipment works within the optimum range, raising the efficiency of the system, set-up times and the number of incidents will be reduced.

3. **Use of AI algorithms** that will recommend parameter reconfiguration. The real-time analysis of the temperature and vibration of different machine sites (head, cannon, motors, etc.) will predict future failures.
4. **Data Integration and Transformation** for assuring its manufacturing data quality (accuracy, precision, integrity, consistency, and reliability) and to ensure the reliability of all the raw industrial data to its aerospace and aeronautics sectors customers.

2.3.4.2 Table of Requirements

Table 10 shows the collected requirements of Pilot 4. The first column lists the optimisation and stakeholder requirements of Pilot 4 regarding the i4Q RIDS. Then, the requirements are assigned to the corresponding business processes from D1.3. In the third column the requirements-IDs of the derived system requirements are named. These IDs can be found in the lists in the Requirements Analysis (Section 3) where the system requirements are listed according to the i4Q Solutions.

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Collect data from quality related sensors (time-stamped).	P4-BP01	The system shall be able to collect and store time-stamped data from all sensors related to part quality.	PC4r1	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT
Part quality detection.	P4-BP01	The system shall be able to collect and store time-stamped images associated to the dimensional and attributes of the part.	PC4r2	8-i4Q_DR
Gather information from human source and take it into account for analysis.	P4-BP01	The system shall be able to collect and store all quality part measurements data, scraps, tool changes, etc. inputted by the operator.	PC4r3	8-i4Q_DR, 9-i4Q_DIT
Current measuring	P4-BP01	The system must be able to collect and save all part measurement data provided	PC4r4	8-i4Q_DR, 9-i4Q_DIT

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
machines data gathering.		by measurement equipment automatically in digital format.		
Algorithm for predicting quality defects.	P4-BP01	The system should be able to predict and correct the detected deviations by automatically modifying parameters of the CNC machine and by analysing all collected data by users and measurement equipment.	PC4r5	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD
Algorithm for predicting quality defects.	P4-BP02	i4Q solutions should be able to predict tool wear through algorithms and data collected during manufacturing.	PC4r6	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD
Algorithm for predicting quality defects.	P4-BP01	i4Q shall be capable to predict when the deviation of part measurements or attributes will occur by algorithms and data collected during manufacturing.	PC4r7	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD
Extract valuable info from existing data.	P4-BP01	The system should allow communication with other existing databases.	PC4r8	8-i4Q_DR, 9-i4Q_DIT
Interface adaptability to end user.	P4-BP01	The user interface shall adopt localization aspects: decimal/thousands separator, interface languages. Spanish shall be one the localizations available.	PC4r9	12-i4Q_AD

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Collect data from status sensors (time-stamped).	P4-BP02	The system shall be able to collect and store time-stamped data from all sensors related to work environment.	PC4r10	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT
Trouble visual anticipation.	P4-BP02	The system shall be able to collect and store associated to the machine, tool, production order and part.	PC4r11	8-i4Q_DR
Trouble visual anticipation.	P4-BP01, P4-BP02	The data should be time-stamped, and the data capture frequency must be configurable to number of cycles.	PC4r12	8-i4Q_DR
Keep optimal working/cutting conditions.	P4-BP02	The system shall learn and be able to establish critical working ranges.	PC4r13	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 19-i4Q_PA
Monitoring the working conditions.	P4-BP02	The system shall be able to collect and save vibration data produced by the tool according to a certain number of cycles.	PC4r14	8-i4Q_DR, 15-i4Q_IM, 18-i4Q_QD, 21-i4Q_LRT
Gather information from human source and take it into account for analysis.	P4-BP02	The system should be able to collect and save online data/comments manually inputted by the user.	PC4r15	8-i4Q_DR, 9-i4Q_DIT
Avoid loses and corrupts of data due to communication failure.	P4-BP02	The system shall store sensor data in offline mode in case the connection with other solutions (Repository) is broken.	PC4r16	9-i4Q_DIT

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
An algorithm to relate the alarm and message generated on all CNC machines to all data collected from sensors.	P4-BP02	The system must be able to communicate with the machines to read, collect and save all warnings and alarms that the CNC machine issues and should be able to relate them to all data captured from the sensors to anticipate problems.	PC4r17	8-i4Q_DR, 18-i4Q_QD, 19-i4Q_PA
Extract valuable info from existing data.	P4-BP02	The system should allow communication with other existing databases.	PC4r18	8-i4Q_DR, 9-i4Q_DIT
Assure traceability of data.	P4-BP02	The system shall allow to associate information with the production order (such as customer, industrial sector, etc).	PC4r19	8-i4Q_DR
Possibility to do human analysis; for analysis itself and machine learning.	P4-BP02	The system should allow to filter historical information taking into account different criteria (e.g., machines, zones, dates, ...) of both information collected and autonomous decisions.	PC4r20	10-i4Q_DA, 12-i4Q_AD
Interface adaptability to end user.	P4-BP02	The user interface shall adopt localization aspects: decimal/thousands separator, interface languages. Spanish shall be one the localizations available.	PC4r21	12-i4Q_AD
Possibility to do human analysis; for analysis itself	P4-BP02	Data capture, decision-making actions, and other intervals shall be configurable.	PC4r22	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
and machine learning				
Possibility for Displaying a single signal so the user can view it on ral time for human analysis.	P4-BP02	The interface should allow you to display a specific (selectable) signal in real time remotely. For example, the temperature, flow sensor, or camera).	PC4r23	12-i4Q_AD
Early error detection	P4-BP02	The system should determine by itself (AI learning) the proper/warning/error ranges of some data sensors.	PC4r24	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD
Grant usability over time, adapting to company's needs	P4-BP02	The system shall allow the load of master data and operational data (e.g., calendars, working timetables, etc).	PC4r25	12-i4Q_AD
Create a Map of the plant: instance sections, machines (types, properties, sensors, ranges)	P4-BP02	The system shall include a digital layout of the plant: instance sections, machines (types, properties, sensors, ranges). In addition, it shall be editable over time for evolving as company evolves.	PC4r26	15-i4Q_IM, 16-i4Q_DT

Table 10. Gathered requirements from Pilot 4

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

2.3.5.1 Main Challenges

In the i4Q project the two main objectives of the RiaStone Pilot case are:

a. To add to the already existing factory systems, a new and innovative system that will enable the capabilities of in-line, in real-time inspection and continuous monitoring of

the quality conformity of the incoming raw matter received from RiaStone´s 3rd party suppliers.

b. To integrate into one single central data analytics system, the data originated in the i4Q future raw matter analyses system, with the data originated from the systems implemented in the previous H2020 BOOST4.0 project, the data originated from Zero-Defects Manufacturing (ZDM) systems implemented in the currently running H2020 Qu4lity project, as well as data originated in other factory data sources such as Quality Control data, product traceability data, Scada System data, and ERP and MES data

The fulfilling of these two objectives will allow RiaStone to leverage with data other essential actions for the promotion of the factory's overall production effectiveness (OPE):

- to be able to reject substandard raw materials that might be delivered by its suppliers and continuously monitor the prime matters that are delivered into the production line and
- to integrate horizontally the systems' data that is dispersed through several different production management, and production assistance & monitoring systems, that currently reside in vertical separated data silos.

To achieve these objectives RiaStone faces the need to address the following challenges:

1. To be able to implement an accurate and efficient spectroscopy-based measuring system that enables the Realtime, in-line measurement of 100% of incoming Prime matters.
2. To be able to implement data management tools that can integrate 100% of the available production data.
3. To be able to extract business value from the data collected in the factory, after its transformed into information.

2.3.5.2 Table of Requirements

Table 11 shows the collected requirements of Pilot 5. The first column lists the optimisation and stakeholder requirements of Pilot 5 regarding the i4Q RIDS. Then, the requirements are assigned to the corresponding business processes from D1.3. In the third column the requirements-IDs of the derived system requirements are named. These IDs can be found in the lists in the Requirements Analysis (Section 3) where the system requirements are listed according to the i4Q Solutions.

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Capability to inspect the raw matter delivered by 3rd parties at download duct ports.	P5_BP01	During the Raw Matter delivery process, the spectrometric testing system shall perform Kubelka-munk readings and Reflectance readings on Polyvinyl alcohol (PVA) in parts pr million (ppm) and water (%),	PC5r1	18-i4Q_QD

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
		during the complete 90minute delivery process @1 second intervals, delivering the test results to i4Q^{QD} tool.		
Capability to inspect the raw matter delivered by the storage silo @dispensing tray.	P5_BP01	During the Raw Matter Storage Silo dispensing process, the spectrometric testing system shall perform Kubelka-munk readings and Reflectance readings on PVA (ppm) and water (%), @1 second intervals, delivering the test results to i4Q^{QD} tool.	PC5r2	18-i4Q_QD
Capability to inspect the raw matter sample delivered by 3rd parties for the purposes of Quality Control (QC).	P5_BP01	During the Raw Matter delivery process, one of the delivery raw matter samples shall be tested by the spectrometric testing system, which will perform one (1) Kubelka-munk reading and Reflectance reading on PVA and water contents of the sample, delivering the test results to i4Q^{QD} tool, which will confirm to the RiaStone QC that the supplier delivered sample is effectively part of the delivered lot.	PC5r3	18-i4Q_QD
Realtime/proactive analysis on the raw matter's composition and granulometry.	P5_BP01	Realtime/proactive analysis on the raw matter's composition and granulometry shall be performed continuously by using the i4Q^{DA}, i4Q^{BDA}, i4Q^{AD} and i4Q^{QD}.	PC5r4	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 18-i4Q_QD
Realtime data collection, transformation,	P5_BP01	Realtime data collection, transformation, integration and storage of e.g., Spectrometry +	PC5r5	1-i4Q_DGQ, 7-i4Q_DRG, 8-

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
integration and storage.		granulometry analysis results, chemometric benchmarking data (enables mapping raw matter composition to specific quantities of constituents), purchase order, cargo bill should be realised through the deployment of $i4Q^{DIT}$, the $i4Q^{DQG}$ and $i4Q^{DR}$.		i4Q_DR, 9-i4Q_DIT
Realtime data integration and transformation of all data coming from the production line and Quality Assurance.	P5_BP02	Realtime data integration and transformation of all data coming from the production line and Quality Assurance should be managed through the deployment of the $i4Q^{DIT}$.	PC5r6	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT
Quality issues/defects root cause analysis.	P5_BP02	Quality issues/defects root cause analysis shall be realised using integrated data from production processes by the application and integration of several i4Q solutions, such as the $i4Q^{DA}$, $i4Q^{BDA}$ and $i4Q^{AD}$. There is also the possibility to use $i4Q^{DT}$ and $i4Q^{QE}$.	PC5r7	2-i4Q_QE, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 16-i4Q_DT
Proactive production quality optimization.	P5_BP02	Proactive quality optimization shall be performed through the deployment of the $i4Q^{PQ}$, $i4Q^{LRT}$ and $i4Q^{DA}$.	PC5r8	10-i4Q_DA, 17-i4Q_PQ, 21-i4Q_LRT

Table 11. Gathered requirements from Pilot 5

2.3.6 Pilot 6: Automatic Advanced Inspection of Automotive Plastic Parts

2.3.6.1 Main Challenges

The main challenge in pilot 6 for a company dedicated to the manufacture of injected parts for the automotive sector like FARP is to reach zero defects in production to reduce the number of

rejections, both internal and external, with the aim of speeding up the subsequent stages of assembling.

To reach this objective, the following challenges shall also be met:

- The standardization of the use of the solution in any production ecosystem regardless of the manufacturer of injection moulding machine, sensors, equipment and so on with their corresponding process data format to be extracted and collected by the system.
- Security in the collection of data to the cloud or to the system to not allow intrusions by external attacks.
- Select the necessary parameters to establish the inspection conditions and to be able to relate them to the quality of the final part.
- Minimize the number of rejects in production (zero defects).
- The system is capable of being installed in any area considering the environmental conditions.
- The solution does not affect significantly the production speed and the productivity of the machine is affected.
- The system can inspect several types of parts with different geometries in the same inspection line.
- The system knows how to identify, not only the defective part, but also to correlate it with the process parameterization to speed up decision-making.
- Data that will be used for model training is quite imbalanced (few NOK parts compared to OK parts). Some small-scale trials will be performed at AIMPL before upscaling the process at FARP. Moreover, NOK parts can be shuffled and restart the process, as much as needed.
- Lack of rheological properties of the material can be highly corelated with OK-NOK condition. This event should be assessed during the inspection.

2.3.6.2 Table of Requirements

Table 12 shows the collected requirements of pilot 6. The first column lists the optimisation and stakeholder requirements of pilot 6 regarding the i4Q RIDS. Then, the requirements are assigned to the corresponding business processes from D1.3. In the third column the requirements-IDs of the derived system requirements are named. These IDs can be found in the lists in the Requirements Analysis (Section 3) where the system requirements are listed according to the i4Q Solutions.

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
The quality control device shall never make mistakes.	P6_BP6-02	Quality inspection 100 % detection performance for quality inspection (If not achievable at least zero	PC6r1	18-i4Q_QD

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
		false positive rate shall be provided.)		
Adaptability to different environmental conditions should be provided.	P6_BP6-01, P6_BP6-02	Since the environmental conditions (e.g., lightness, temperature, etc) can vary from day-to-day the process should not be affected by environmental factors	PC6r2	18-i4Q_QD
Dataflow from machines to database shall be established.	P6_BP6-01, P6_BP6-02	Data pipeline should be established to be able to use the data for other objectives.	PC6r3	7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA, 12-i4Q_AD
Capability of securely moving data from factory level to cloud level.	P6_BP6-01, P6_BP6-02	Secure transfer shall be provided.	PC6r4	4-i4Q_TN, 6-i4Q_SH
Feature selection should reduce data flow load without affecting performance.	P6_BP6-01	Feature selection should be done in a way that will reduce data flow load but not affect parameter optimization performance.	PC6r5	7-i4Q_DRG, 9-i4Q_DIT, 17-i4Q_PQ, 22-i4Q_LCP
Additional data requirement (Material compound data, environmental data, material flow viscosity data).	P6_BP6-01	Additional sensors (rheometer, thermometer, humidity sensor, etc) should be adaptable.	PC6r6	9-i4Q_DIT, 18-i4Q_QD
Standardize the solution independently of the equipment	P6_BP6-01, P6_BP6-02	The i4Q solution should be able to work independent to the model, size, brand, etc. of the plastic injection machines.	PC6r7	15-i4Q_IM

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
that is going to be used.				
Quality assurance and ensuring the improvement of part quality by using Parameter optimization	P6_BP6-01, P6_BP6-02	By using the machine monitoring parameters of the injection machine with different machine learning methods, the quality of the parts produced from the machine shall be increased as well as the faulty piece number decreased.	PC6r8	18-i4Q_QD, 22-i4Q_LCP
Inspected part's maximum dimension should be flexible.	P6-BP6-02	The part that the device can examine should be flexible since the parts being produced come in different shapes and sizes.	PC6r9	18-i4Q_QD
Integration of the visual inspection device to the production lane.	P6-BP6-02	Integration of the device into the production lane should not have an impact on production rate/speed.	PC6r10	18-i4Q_QD
Capability to mapping part-label data correctly.	P6_BP6-01, P6_BP6-02	All parts that pass-through inspection shall be correctly labelled since this data is going to have an impact on parameter optimization.	PC6r11	3-i4Q_BC, 8-i4Q_DR, 9-i4Q_DIT
Automation of device's visual inspection start-up phase for each part.	P6-BP6-02	Visual inspection device should do the initialization process automatically for each different part.	PC6r12	18-i4Q_QD
Historical image data should be managed in the data repository.	P6-BP6-02	Image data should be stored in proper way.	PC6r13	7-i4Q_DRG, 8-i4Q_DR

Project Objectives/Goals, Stakeholder Requirements	Assigned (Business-) Process from D1.3	System Requirement Description	ID	i4Q Solutions that are connected/ mapped to this Req.
Easy access to machine status and shop floor details.	P6-BP6-01	General manufacturing environment should be followed remotely to be able to manage production workload efficiently.	PC6r14	15-i4Q_IM, 16-i4Q_DT
Optimization procedure should be converted to autonomous to improve injection machine performance and Overall Equipment Effectiveness (OEE).	P6-BP6-01	Injection machine parameters should be optimized using analytical solution.	PC6r15	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD, 19-i4Q_PA
Acceptance tests for initial production of the injection machine or new machines which needs certification after certain successful test requires a lot of effort and takes long time. New machines also require process flow optimization and requires to make a lot of production trials causes waste material and workload.	P6-BP6-01	Process qualification or machine certification can be done by successfully predicting product quality without manual test and inspection which takes a lot of time and effort.	PC6r16	17-i4Q_PQ, 21-i4Q_LRT, 22-i4Q_LCP

Table 12. Gathered requirements from Pilot 6

2.4 Further knowledge and expertise

In the literature, requirements for the smart factory or Industry 4.0 oriented companies were found, e.g., wireless connection, connection to IIoT devices, cyber security around an automated production line, modularity of the machines, low cost of implementation and low complexity of implementation. The design requirements that were chosen are e.g., the use of the existing PLC and MES, the cost of the PLC, the simplicity of key exchange, authenticity and confidentiality (Mantravadi et al. 2020, p. 11).

In addition, the i4Q Consortium was asked about further requirements for i4Q RIDS and smart factories in general. The results are shown in the following **Table 13**.

Requirement-ID	General requirements
TUBr1	Data analytics and data-driven approaches should support the complete digital transformation of process related data.
TUBr2	Automatic traceability of defects should be clear, consistent and continuous labelling of all components and products throughout the value-adding process.
TUBr3	Industrial partners should use data acquisition, processing, storage and accessing technologies.
FARPr1	An automated defect detection system to eliminate defects on the visual side of the part should give the same performance for every production shift on every environmental condition (day-light, vibration, etc).
FARPr2	Part quality prediction algorithms should be introduced to optimize production parameters accordingly.
FARPr3	The stored image data should be recorded during the defect detection process and offers production managers, but also customers, the possibility of real-time monitoring.
IBMr1	The development of edge computing platform should be addressing a broad set of current and future requirements from industrial and manufacturing use cases. The edge platform is expected to address a wide range of aspects as defined by i4Q. IBM's contributions will address aspects of enabling intelligent data processing at the manufacturing floor by bringing AI/ML to the edge close to where the data is being generated. Having these capabilities at the edge will significantly improve the quality, reliability, and efficiency in manufacturing.
IBMr2	The development of blockchain based infrastructure should be addressing data trust and traceability in industrial and manufacturing use cases. The blockchain platform is expected to address cornerstone issues of data reliability to enable smart processing by analysis components, as well as establishing trust among

Requirement-ID	General requirements
	partners. Having these capabilities will significantly enhance the quality, reliability, and trust in manufacturing data.
AIMPr1	The i4Q solution should be adapted to a variety of different machine types (injection machine makers, year of manufacturing, format of the data process to collect...).
AIMPr2	The i4Q Solution should synchronise all data in the process, the process data of the injection moulding machine and any additional sensors and correlate them with the artificial image data.
ITIr1	Improve the reliability and quality of data exchange in the plant by deploying a new generation of private infrastructure based on 5G networks. These networks should offer a highly scalable and independent architecture that increases traffic capacity and network efficiency compared to 4th generation technologies.
ITIr2	Improvement in communication latency should be achieved through various techniques and standardised mechanisms, such as Time Sensitive Networks (TSN), to achieve wireless communication have a latency similar to wired communications.
ITIr3	Integrate the software-defined networking paradigm into a Wireless Personal Area Network (WPAN) environment with Time Slotted Channel Hopping and Media Access Control (TSCH MAC). This allows to implement dynamic and fully centralized resource provisioning, increasing flexibility and scalability as well as allowing node mobility while reducing management complexity.
TIAGr1	IEE 802.1 TSN (deterministic wired communication) should be integrating into a wide collection of machines and increase the use of deterministic communication into industry.

Table 13. Elicited general requirements

2.5 Ethics and Security

All activities in the i4Q project follow the General Data Protection Regulation (GDPR) of the European Union.

2.5.1 General Ethics

The ethical behaviour of each project participant must be considered in every action according to the guidelines of the GDPR. The project follows the key ethical research principles regarding Informed Consent, Protection from harm, Deception, Confidentiality, Withdrawal. In general, research activities should be compliant with the principles of dignity, freedom, equality, solidarity, citizens' rights, and justice.

2.5.2 Data Ethics

Data which is collected during the project is evaluated regarding sensitive content before operational use. To ensure such activities this is considered in T1.5 Data Management Plan where specific guidelines are developed for operational use throughout the project duration. Based on the guideline's additional requirements for date collection and usage are derived.

2.5.2.1 Personal Data

Personal data collected in the project will relate to voluntary project participants as informants or pilot/demonstration participants. Personal data will be collected during the project and will include data such as (but not limited to) name, occupation, gender, age group, education, geographic area. Actions will be taken to ensure that those handling subjects' identifiable information are made fully aware of their responsibilities and obligations to respect confidentiality in compliance with humanitarian standards, best practices, and legal requirements under the GDPR. Further all personal data that is used during the project will be anonymized to protect personal rights and identification.

2.5.2.2 Data Exchange

The basic approach of i4Q will be to anonymize all data collected. If some of the information shared between the Partners from within the EU with the Israeli and Turkish partners should contain (sensitive) personal data, this would constitute a transfer of personal data to third countries under the GDPR. Any transfer of personal data that are undergoing processing or are intended for processing after transfer to a third country requires a legal basis.

2.5.3 Data Security

Data used during the project is continuously analysed and classified in different types of data and/or information with the aim of developing regulations for intellectual or industrial property, trade secrecy or data protection purposes. These activities include collateral aspects such as the ownership of generated data or cyber security measures and other potential topics which may impact the data protection. Further, security aspects will be addressed in work package (WP) 3 Manufacturing Data Quality and WP 4 Manufacturing Data Analytics for Manufacturing Quality Assurance.

3. Requirements Analysis

3.1 Requirement's analysis method

The requirements analysis already started during the technical discussions when interactions and feasibility were discussed. For further requirements analysis, the requirements listed in the templates are analysed in terms of language criteria and wording, also the syntax for well-formed requirements ISO/IEC/IEEE 29148 (ISO/IEC/IEEE 29148:2018, pp. 10ff) should be adapted to all requirements so that they are understandable and comprehensible in any context. In addition, it is checked whether it is a requirement or another statement. The next step is to analyse the requirements with respect to duplication, clustering, possible conflicts, (inter-)dependencies, interactions, and priorities. During this analysis, further clarification with the technical partners is necessary to obtain complete, consistent, feasible, and comprehensible sets of requirements for all pilot use cases and all i4Q Solutions (RIDS). Therefore, a *solutions requirements template* is set up (Appendix II) that includes all gathered requirements for each i4Q Solution. The solution providers are asked to comply the requirements that were mapped to their solutions. Which means that the requirement is going to be considered in the further solution development and possible to be fulfilled by the named solution. If the mapped requirement cannot be considered in the further solution development and is not possible to be fulfilled by the named solution, the feedback from the solution providers should be “not comply”. In this case, it could be useful to transfer the requirement to another solution. If there are open questions or uncertainties about how to fulfil the requirement and whether it can be considered in further solution development, the requirement remains open until this is clarified further in the process.

The requirements are clustered twice. First into the type of requirement and second in the classification. The types of requirements are based on ISO/IEC/IEEE 29148 (ISO/IEC/IEEE 29148:2018, pp. 15f) and adjusted to the current status of the project where the requirements are gathered in the first version and a detailed clustering is not yet useful. The types of requirements are listed and explained in **Table 14**. With these types of requirements, the main attributes of requirements are covered. Ethics aspects are considered and documented in deep detail in the Data Management Plan of Task 1.5 (see Section 2.4).

Type	Keywords/examples	Description
Functional/Technical Req.	Function/specification of system or component	"Describe the function of a system, process or product or a task to be performed by the system. The requirement should be expressed quantitatively. There can be more than one technical requirement associated with a single function, functional requirement or task."
Interface Req.	Electrical interfaces of the system, mechanical interfaces of the system, software	Interface requirements are the definition of how the system is required to interact with external systems, or how system elements

Type	Keywords/examples	Description
	interfaces, interaction with human users	within the system, including human elements, interact with each other.
Usability and Quality Req.	Longevity, appearance, style, corporate design, user-friendly, personalization, cultural requirements, handling of the tool	The requirement shall address the i4Q Solutions regarding quality and usability.
Security Req.	Integrity, reliability, privacy, availability, robustness, accessibility	The requirements shall address the data quality and security. If necessary, safety requirements could be included.
Guidelines Req.	Hardware and software documentation, installation and maintenance manuals, training materials, installation software	Guidelines should help users during the usage of a system/solution.

Table 14. Requirements Type attributes with descriptions (cf. ISO/IEC/IEEE 29148:2018, pp. 15f)

The focus of the requirements classification (**Table 15**) is on the handling of manufacturing data. Since the requirements are in a mostly generic stage in the first version, more than one class can be assigned. The main needs and expectations may be found through this classification. The classification can also be used for the i4Q Solutions.

Class	Description
Data Acquisition & Transformation	Recording Data from different sources e.g., sensors, simulation models, open-source data sets and transform data in usable formats in tabular structure containing feature information.
Data Storage & Transfer	Establishment of data base system with pipeline connection to data sources and software solutions.
Data Analytics	Pre-processing of data, usage generic algorithms
Data Visualization	Appropriate visualization of analysis results
Data Guidelines	Document that provides standards and references for processes and actions regarding manufacturing data.

Table 15. Requirements Classification with descriptions (cf. ISO/IEC/IEEE 29148:2018, pp. 15f)

The sets of requirements for the i4Q Solutions (RIDS) should be validated and kept up to date as the project progresses. To verify and determine the degree of fulfilment of the requirements later in the project, requirements should be formulated and documented in a measurable and testable form. Traceability of the system and software requirements to stakeholder requirements is

developed through the templates and is available throughout the requirements engineering process.

The following sub-sections first describe the results of mapping the requirements to the i4Q Solutions. Then, the main functions/services of the i4Q Solutions are described and the complete sets of requirements and required data are provided. In Section 4 the overall interrelationships and interfaces of the requirements will be described including several quantitative and qualitative analysis results. Furthermore, it will be explained how the system modelling will support the deeper requirements analysis for the second version of this deliverable.

3.2 Mapping of requirements to i4Q solutions

The elicited requirements that were described above are now mapped to the i4Q Solutions. In **Table 16** the mapping of the literature requirements (see Section 2.2) to i4Q Solutions is depicted. All the pilot requirements of Section 2.3 are included in the lists of requirements for all 24 i4Q Solutions in Section 3.3.

	i4Q Solutions that will meet or build on these basic requirements in a broader sense																				
Req. ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Lit1															X	X		X				
Lit2				X																		
Lit3								X														
Lit4																X						
Lit5									X						X			X				
Lit6								X	X													
Lit7																			X			
Lit8				X				X	X						X	X						
Lit9								X														
Lit10																						
Lit11																		X				
Lit12								X														
Lit13			X					X	X													
Lit14									X						X	X		X	X			
Lit15								X														
Lit16																			X			
Lit17																						
Lit18															X							
Lit19								X	X				X	X	X			X				

	i4Q Solutions that will meet or build on these basic requirements in a broader sense																					
Req. ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Lit20																						
Lit21																X						
Lit22								X														
Lit23																						
Lit24					X	X		X														
Lit25			X		X	X		X														
Lit26					X	X		X														
Lit27													X	X								
Lit28				X	X	X																
Lit29				X	X	X																
Lit30																						
Lit31									X				X	X	X	X		X				
Lit32																						
Lit33															X							
Lit34															X	X						
Lit35															X				X			
Lit36				X				X								X						

Table 16. Requirements derived from literature and mapped to i4Q Solution

3.3 Specification of requirements according to i4Q solutions

In this section the elicited requirements are specified according to the IoT-based RIDS which consist of the 22 i4Q Solutions. There are 17 software tools and 5 guidelines that are segmented into i4Q Solutions for Manufacturing Data Quality, i4Q Solutions for Manufacturing Data Analytics and i4Q Solutions for Rapid Manufacturing Line Qualification and Reconfiguration. The templates used for gathering pilot-specific requirements and the feedback from the solution providers for each solution are attached in Appendix I and II.

i4Q Solutions for Manufacturing Data Quality

3.3.1 i4Q^{DQG} Data Quality Guidelines

3.3.1.1 Main functions/services

This is a document that contains guidelines around data quality management in production. It will contain a "terminology and definitions" section to clarify key terms. The key concepts are:

- Data, information, and (explicit, implicit, tacit) knowledge
- Data and information quality
    - Data quality => technical view
    - Information quality => application view
- Data and information life cycle
- Evolutional Data Quality according to Liu and Chi approach (Liu, L. and Chi, L., 2002)
- Total Data Quality Management

Data quality characteristics, a suitable data life cycle model, and data quality management procedures will be identified.

The Data Quality Guideline bases on contents identified within the context of the use cases and the technical partners' components. These are relevant aspects to consider:

- Data and information flows (i.e., what one does with data and information)
- Relevant quality characteristics identified by partners
- Relevant factors that influence data and information quality
- Existing measures to manage data quality-related factors
- Existing strategies to apply measures

These inputs will be complemented with related contents in literature.

3.3.1.2 Requirements for i4Q^{DQG}

Table 17 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The guideline should be easy to operationalize.	BIBA1r1	Usability and Quality req	1-i4Q_DQG	ok	Guidelines
The guideline should cover long-term and short-term measures to improve data quality.	BIBA1r2	Guidelines req	1-i4Q_DQG	ok	Guidelines

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The guideline should focus on information, not on database quality improvements.	BIBA1r3	Guidelines req	1-i4Q_DQG	ok	Guidelines
The guideline should use a data life cycle model to define its scope.	BIBA1r4	Guidelines req	1-i4Q_DQG	ok	Guidelines
The system shall predict the product conformity.	PC3r1	Functiona/ Technical req	1-i4Q_DQG, 2-i4Q_QE, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA	tbc*1	Data Acquisition & Transformation, Data Analytics
Realtime data collection, transformation, integration, and storage of e.g., Spectrometry + granulometry analysis results, chemometric benchmarking data (enables mapping raw matter composition to specific quantities of constituents), purchase order, cargo bill should be realised through the deployment of i4Q_DIT, the i4Q_DQG and i4Q_DR.	PC5r5	Functional/ Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	tbc*2	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Realtime data integration and transformation of all data coming from the production line and Quality Assurance should be managed through the deployment of the i4Q_DIT.	PC5r6	Functional/ Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	tbc*3	Data Acquisition & Transformation, Data Storage & Transfer, Guidelines

Table 17. i4Q^{DQG} System requirements mapped to i4Q Solution

Comment to tbc*1, tbc*2, tbc*3:

"Need to know specific relevance for this solution component".

3.3.2 i4Q^{QE} QualiExplore for Data Quality Factor Knowledge

3.3.2.1 Main functions/services

QualiExplore is a small software tool to organize and visualize factors that influence data quality. It grounds on the Evolutional Data Quality approach suggested by Liu and Chi (Liu, L. and Chi, L., 2002):

Collection Quality > Organization Quality > Presentation Quality > Application Quality

This approach assumes that data quality is cumulative, i.e., application quality depends on the quality of all preceding steps. Each of the four quality concepts has various factors influencing the respective quality. We assume that a production environment has more than 100 factors – e.g., technical, personal, organizational, methodological, social, cultural, and political ones.

In a first step, QualiExplore users indicate what they are interested in, e.g., goals, data sources, and quality characteristics.

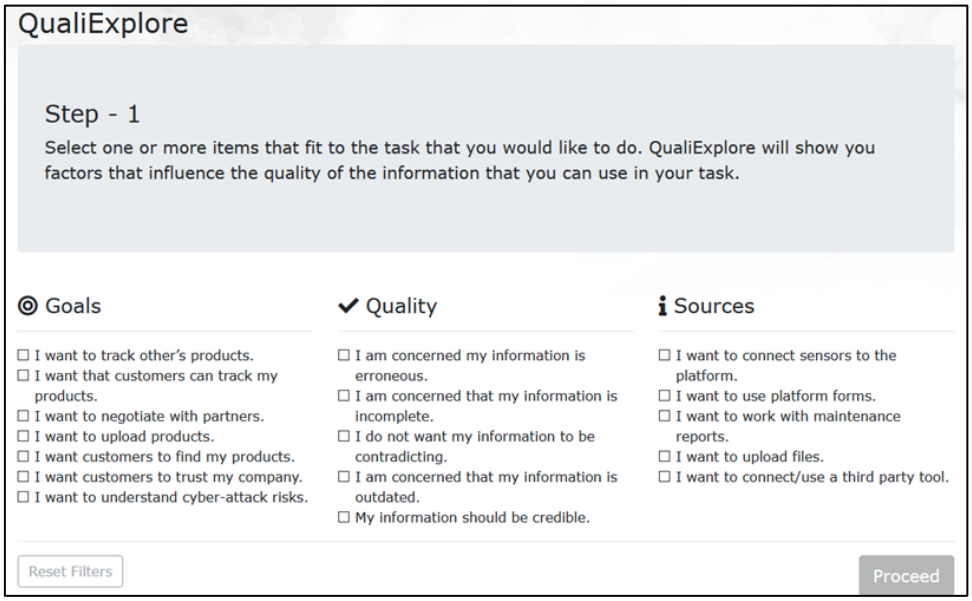

Figure 8. QualiExplore filters for data quality (NIMBLE example)

The second step filters the factors according to the interests and visualizes them in a tree-structure. Coloured flags indicate matches; red flags should be investigated by the user and green ones where already investigated.

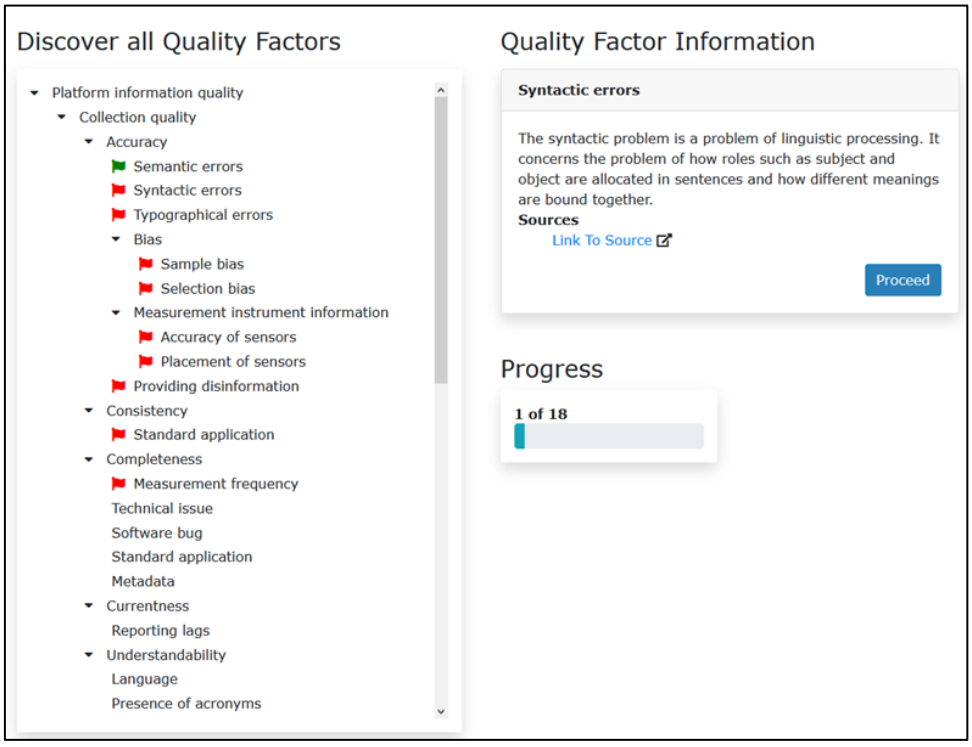

Figure 9. QualiExplore view for data quality factors (NIMBLE example)

While the left side visualizes the quality factors, the right side explains a factor. There is a button to mark a factor description "read" (green flag) and a progress bar to indicate how many factors the user already covered among the matching ones.

We plan to improve this tool with the following features:

- Semantic knowledge base for data quality factors
- Graphical editing environment to simplify customization
- Integration of a digital assistant (chatbot or voice assistant)

3.3.2.2 Requirements for i4Q[QE]

Table 18 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
QualiExplore shall be accessible via a website (it is a web-based solution).	BIBA 2r1	Functional/ Technical req, Usability and Quality req	2-i4Q_QE	ok	Data Visualization, Guidelines
QualiExplore users shall be able to create, edit, and delete factor descriptions.	BIBA 2r2	Functional/ Technical req, Usability and Quality req	2-i4Q_QE	ok	Data Visualization, Guidelines
QualiExplore users shall be able to filter factors (to reduce cognitive load).	BIBA 2r4	Functional/ Technical req, Usability and Quality req	2-i4Q_QE	ok	Data Visualization, Guidelines
QualiExplore shall use terminology used in other i4Q solutions (coherence).	BIBA 2r6	Usability and Quality req	2-i4Q_QE	ok	Data Visualization, Guidelines
Other i4Q solutions might integrate QualiExplore as a HTML/Javascript widget (usability/ease of access).	BIBA 2r7	Interface req, Usability and Quality req	2-i4Q_QE	ok	Data Visualization, Guidelines
QualiExplore factor descriptions shall be intelligible and relevant.	BIBA 2r3	Usability and Quality req, Guidelines req	2-i4Q_QE	ok	Data Visualization, Guidelines

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
QualiExplore contents should adopt acknowledged terminology from standards and literature (credibility).	BIBA 2r5	Guidelines req	2-i4Q_QE	ok	Data Visualization, Guidelines
The system shall predict the product conformity.	PC3r 1	Functional/Technical req	1-i4Q_DQG, 2-i4Q_QE, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA	tbc*1	Data Acquisition & Transformation, Data Analytics
Quality issues/defects root cause analysis shall be realised using integrated data from production processes by the application and integration of several i4Q solutions, such as the i4Q_DA, i4Q_BDA and i4Q_AD. There is also the possibility to use i4Q_DT and i4Q_QE.	PC5r 7	Functional/Technical req	2-i4Q_QE, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 16-i4Q_DT	tbc*2	Data Analytics, Data Visualization

Table 18. i4Q^{QE} System requirements mapped to i4Q Solution

Comment to tbc*1, tbc*2:

"Need to know specific relevance for this solution component".

3.3.3 i4Q^{BC} Blockchain Traceability of Data

3.3.3.1 Main functions/services

This solution provides easy, trusted and traceable access to data coming from many different sources. This solution shall enhance the level of trust in the platform by employing a blockchain based data service, to support data traceability in the data that flows directly to the blockchain, thus serving as a single point of truth, preserving provenance and supporting non-repudiation. Information stored on the blockchain cannot be tampered with or erased and can be proved to be authentic. The underlying blockchain platform shall use Hyperledger Fabric, which is an open-source project implementing a permissioned blockchain network. Smart contracts shall be provided to govern the actions that take place upon the arrival of new data, and to ensure that

the required participants in the network approve incoming transactions. The Representational State Transfer (REST) interfaces provided shall enable the invocation of transactions to add data to the blockchain and a query mechanism to retrieve data previously stored in the blockchain.

3.3.3.2 Requirements for i4Q[BC]

Table 19 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
No specific requirements from additional i4Q solutions. Collaborative work is needed to establish data models and interfaces so that other solutions may use this service, which is envisioned as part of the underlying infrastructure.	IBM3r2	Interface req	3-i4Q_BC, *others*	ok	Data Acquisition & Transformation, Data Storage & Transfer
All parts that pass-through inspection shall be correctly labelled since this data is going to have an impact on parameter optimization.	PC6r11	Functional/ Technical req	3-i4Q_BC, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer

Table 19. i4Q[BC] System requirements mapped to i4Q Solution

The literature requirement (Lit13, see **Table 6**) "Data outcome of every step of the workflow should be specified and the levels should be stored in a global factory-wide database" of Azevedo and Almeida is merge to this i4Q Solution by the technical providers (Azevedo and Almeida 2011, p. 756).

The literature requirement (Lit25, see **Table 6**) "Cryptographic method should be resistant to computational attacks" of Mantravadi et al. is merge to this i4Q Solution by the technical providers (Mantravadi et al. 2020, p. 12).

3.3.4 i4Q^{TN} Trusted Networks with Wireless & Wired Industrial Interfaces

3.3.4.1 Main functions/services

i4Q^{TN} Trusted Networks is a group of communication technologies such as TSN for wired communications, and wireless access networks (Wireless Sensors Technologies (WSN), low-power wide-area network (LPWAN), ad-hoc connections...) configured and optimized to improve reliability of the communication infrastructure and therefore the integrity and reliability of data collected in the floor plant. Depending on the use case requirements, i4Q^{TN} provides a robust and cost-effective solution to connect devices, sensors, and machines to other management, data analysis, storage, or visualization systems that need this collected data.

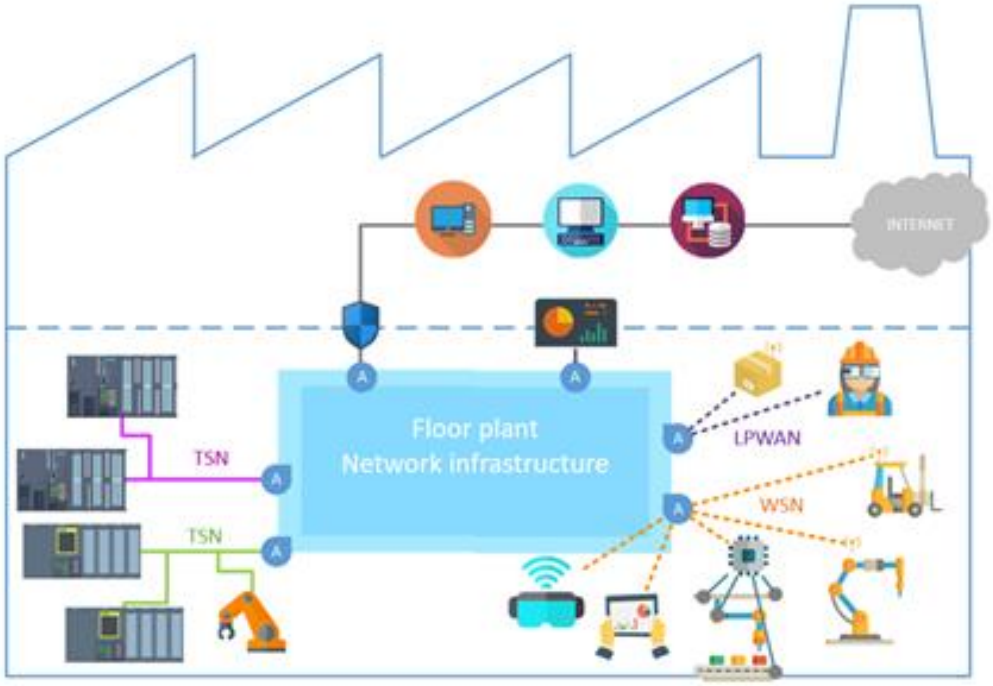

Figure 10. Network Infrastructure

The wireless solutions based on Wireless Sensor Networks, and LoRaWAN for long range requirements, are envisaged to merge and implement state of the art techniques to enhance the quality of service and robustness in these types of networks, with the introduction of Software Defined Networks (SDN) and adaptative mechanisms.

3.3.4.2 Requirements for i4Q^{TN}

Table 20 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Reliability, robustness, availability, and easy scalability of plant communication networks should allow the network to be able to interconnect a large number of mobile devices.	ITI 4r1	Functional /Technical req, Interface req	4-i4Q_TN	ok	Data Acquisition & Transformation, Data Storage & Transfer
Ultra-Reliable and Low Latency Communications (URLLC) should be achieved through the use of synchronized and deterministic mechanism.	ITI 4r2	Functional /Technical req	4-i4Q_TN	ok	Data Acquisition & Transformation, Data Storage & Transfer
A dynamic and fully centralize resource provisioning shall be integrated into a WPAN network based in TSCH MAC.	ITI 4r3	Functional /Technical req	4-i4Q_TN	ok	Data Acquisition & Transformation, Data Storage & Transfer
Node mobility in WPAN networks shall be improved by using SDN mechanisms to manage data flow changes on the network.	ITI 4r4	Functional /Technical req	4-i4Q_TN	ok	Data Acquisition & Transformation, Data Storage & Transfer
This solution should provide deterministic wired communication that converges real-time control traffic with regular best-effort traffic on one single network.	TIA G4r 1	Functional /Technical req	4-i4Q_TN	ok	Data Storage & Transfer
WISH: a clear use case where the usability of deterministic Ethernet (TSN) should be demonstrated.	TIA G4r 2	Usability and Quality req	4-i4Q_TN	ok	Data Storage & Transfer
While moving any data from the CNC to another repository, the system shall guarantee the	PC 1r1 1	Security req	4-i4Q_TN, 6-i4Q_SH, 22-i4Q_LCP	ok	Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
security of the data against any type of intrusion.					
The system shall be able to collect and store time-stamped data from all sensors related to part quality.	PC 4r1	Functional /Technical req Interface req	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall be able to collect and store time-stamped data from all sensors related to work environment.	PC 4r10	Functional /Technical req	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
Secure transfer shall be provided.	PC 6r4	Security req	4-i4Q_TN, 6-i4Q_SH	ok	Data Storage & Transfer

Table 20. i4Q^{TN} System requirements mapped to i4Q Solution

3.3.5 i4Q^{CSG} Cybersecurity Guidelines

3.3.5.1 Main functions/services

This is a document that will contain a set of recommendations to enable multilayer cyber security features in IIoT, i4Q^{CSG} includes an architecture and methodology to provision signed certificates with Hardware Security Module (HSM) and trusted material to devices with or without a Trusted Platform Module (TPM).

The recommendations follow the security standard 62443 to distribute digital identities using security hardware.

3.3.5.2 Requirements for i4Q^{CSG}

Table 21 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more

information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The cybersecurity guidelines shall provide trust mechanism based on 62443 standard.	IKER5r1	Guidelines req	5-i4Q_CSG	ok	Guidelines
The cybersecurity guidelines should describe security mechanism both for an IACS (Industrial Automation & Control Systems) topology and for individual components.	IKER5r2	Guidelines req	5-i4Q_CSG	ok	Guidelines

Table 21. i4Q^{CSG} System requirements mapped to i4Q Solution

3.3.6 i4Q^{SH} IIoT Security Handler

3.3.6.1 Main functions/services

This is a piece of software that distributes trust using x509 certificates and asymmetric cryptography. Once the trust is distributed, every module will have a digital identity that will use to provide security between different endpoints using asymmetric cryptography considering different trust policies, adjusting security and safety policies at different levels.

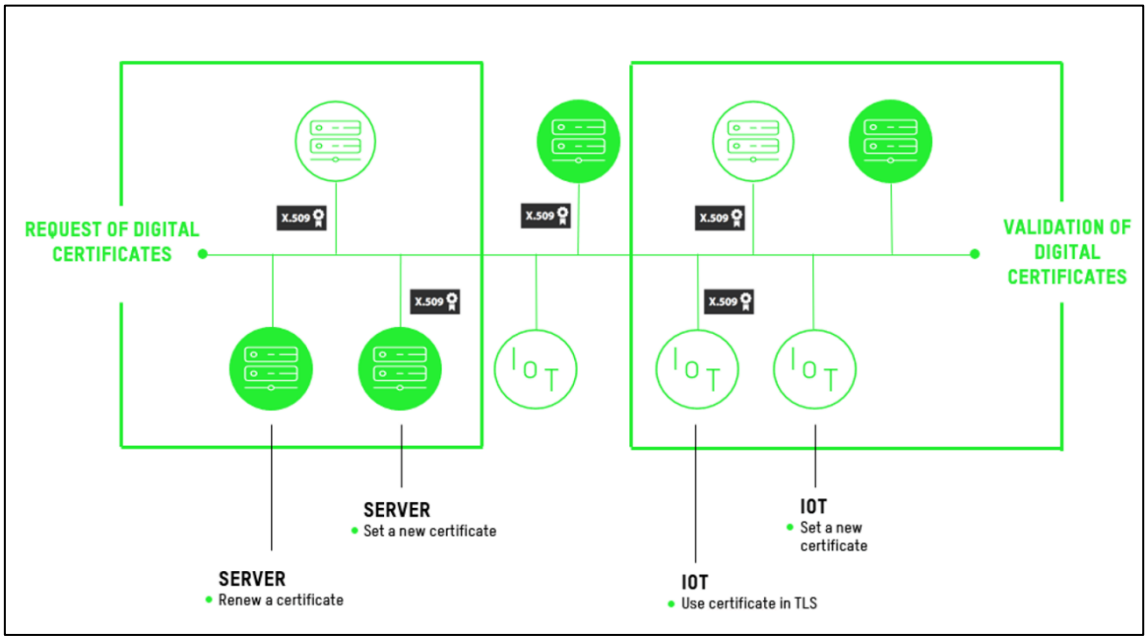

Figure 11. Digital Identity Life Cycle

i4Q[SH] also exposes cryptography operations supported by a HSM, that other modules can consume to ensure the trustability and privacy of data.

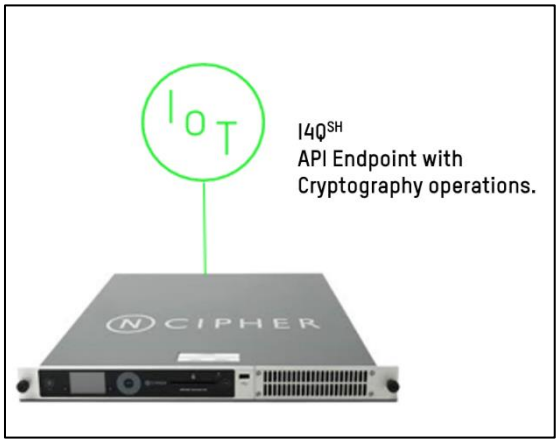

Figure 12. Secure module endpoint

3.3.6.2 Requirements for i4Q[SH]

Table 22 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
When new i4Q module is set up, the i4Q_SH shall provide trust in terms of a digital identity with x509 certificates.	IKER6r1	Functional/ Technical req, Security req	6-i4Q_SH	ok	Data Storage & Transfer
An i4Q module shall store the digital identity in a secure way. If the i4Q module cannot store the digital identity it should use the cryptography operations of the i4Q_SH.	IKER6r2	Functional/ Technical req, Security req	6-i4Q_SH	ok	Data Storage & Transfer
When an i4Q module communicates with another i4Q module it should cipher the communication using the provided trust.	IKER6r3	Functional/ Technical req, Security req	6-i4Q_SH	ok	Data Storage & Transfer
When a i4Q module stores data in a secure way it shall use the provided trust to cipher the communication.	IKER6r4	Functional/ Technical req, Security req	6-i4Q_SH	ok	Data Storage & Transfer
i4Q_SH shall provide cryptography operations supported by one HSM.	IKER6r5	Functional/ Technical req, Security req	6-i4Q_SH	ok	Data Storage & Transfer
While moving any data from the CNC to another repository, the system shall guarantee the security of the data against any type of intrusion.	PC1r11	Security req	4-i4Q_TN, 6-i4Q_SH, 22-i4Q_LCP	tbc*1	Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
i4Q - DATA TRANSFER: The system should be able of securely moving data from i4Q solution to cloud level (SOPHIA) once the analysis have been done.	PC2r16	Security req	6-i4Q_SH	tbc*2	Data Storage & Transfer
Secure transfer shall be provided.	PC6r4	Security req	4-i4Q_TN, 6-i4Q_SH	tbc*3	Data Storage & Transfer

Table 22. i4Q[SH] System requirements mapped to i4Q Solution

3.3.7 i4Q[DRG] Guidelines for building Data Repositories for Industry 4.0

3.3.7.1 Main functions/services

This is a document that will contain guidelines to build data repositories in the industry 4.0 paradigm. This document is targeted to the system administration and development team of a manufacturing company disposed to transition to such paradigm. Presenting our experience in a well-structured document should serve as a reference and starting point for future projects concerning this matter. The goal for the document is to pass on the knowledge gathered on the build process of one of these repositories, giving advice to follow and presenting errors to avoid. Some possible topics to be treated are:

- Project planning.
- Architecture design.
- Data processing (Normalization, encryption, etc.)
- Performance.
- Software alternatives.
- Implementation details.
- Integration with other technologies.
- Transition from legacy systems.

Any other relevant topics will be identified and treated in order to get the most complete reference possible.

3.3.7.2 Requirements for i4Q[DRG]

Table 23 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
A technical document describing the whole process of the repository creation shall be provided. It will be as intuitive and complete as possible, to serve as a guide for future implementations. It will take some input from i4Q_DR.	ITI 7r1	Guidelines req, Usability and Quality req	7-i4Q_DRG, 8-i4Q_DR	ok	Guidelines
When storing the data collected from the sources listed above, the system shall guarantee their safety through robust approaches (redundancy, error correction coding, etc.).	PC 1r12	Functional/Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer
i4Q - DATA REPOSITORY: The system should be able to provide a data repository in which the CNC can store the main data (for example axes torque during the test cycles) every 2 ms.	PC 2r3	Functional/Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer, Data Acquisition & Transformation

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The system shall store output/results from analyses in an internal repository (to perform Store Product Conformity result from Virtual Test).	PC 3r8	Functional/Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer
The existing MPFQ Model should be evaluated and embedded, and the data should be mapped (harmonized) on it.	PC 3r11	Functional/Technical req	7-i4Q_DRG	ok	Data Storage & Transfer
Realtime data collection, transformation, integration and storage of e.g., Spectrometry + granulometry analysis results, chemometry benchmarking data (enables mapping raw matter composition to specific quantities of constituents), purchase order, cargo bill should be realised through the deployment of i4Q_DIT, the i4Q_DQG and i4Q_DR.	PC 5r5	Functional/Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Realtime data integration and transformation of all data coming from the production line and Quality Assurance should be managed through the deployment of the i4Q_DIT.	PC 5r6	Functional/Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer, Guidelines
Data pipeline should be established to be able to use the data for other objectives.	PC 6r3	Functional/Technical req	7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Acquisition & Transformation, Data Storage & Transfer
Feature selection should be done in a way that will reduce data flow load but not affect parameter optimization performance.	PC 6r5	Usability and Quality req	7-i4Q_DRG, 9-i4Q_DIT, 17-i4Q_PQ, 22-i4Q_LCP	ok	Data Acquisition & Transformation, Data Visualization
Image data should be stored in proper way.	PC 6r13	Functional/Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer

Table 23. i4Q^{DRG} System requirements mapped to i4Q Solution

3.3.8 i4Q^{DR} Data Repository

3.3.8.1 Main functions/services

The objective of this solution is to create a suitable storage system for the collected data. This system or repository will oversee receiving, storing, and serving the data in a proper way to the other components in the architecture. It will provide the proper tools for administrators to consult and transform the information contained inside it, as well as ways for data scientist to use this

data in their experimentation. These tools will be provided through a suitable user interface. The solution will also oversee the data protection, serving as a secure system for the information by means of encryption, both in flight and at rest. The result of this task will be an efficient repository, ready to provide its service to the rest of the components present in the system.

3.3.8.2 Requirements for i4Q[DR]

Table 24 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
The desired performance levels shall be achieved, being able to process the incoming data and requests in a reasonable time. To do so, some factors as scalability or even outsourcing some processing tasks to public clouds shall be taken into account.	ITI8r1	Functional /Technical req	8-i4Q_DR	ok	Data Storage & Transfer
The repository shall be able to hold all the necessary information and to store the full size of the incoming data.	ITI8r2	Functional /Technical req	8-i4Q_DR	ok	Data Storage & Transfer
The repository shall communicate successfully with the other components of the system and provide the necessary channels and interfaces to make the information transmission feasible.	ITI8r3	Interface req	8-i4Q_DR	ok	Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
The repository shall store the data in an optimized way. A data model shall be designed to organize all the information suitably (from the volume, data processing, machine learning, etc. points of view).	ITI8r4	Functional /Technical req	8-i4Q_DR	ok	Data Storage & Transfer
The necessary security mechanisms shall be implemented to ensure the protection of private data (encryption) and the human access to it (authentication, authorization).	ITI8r5	Security req	8-i4Q_DR	ok	Data Storage & Transfer
When storing the data collected from the sources listed above, the system shall guarantee their safety through robust approaches (redundancy, error correction coding, etc.).	PC1r12	Functional /Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer
i4Q - DATA REPOSITORY: The system should be able to provide a data repository in which the CNC can store the main data (for example axes torque during the test cycles) every 2 ms.	PC2r3	Functional /Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer, Data Acquisition & Transformation
The systems shall perform analysis based on Artificial Intelligence and Machine Learning to develop a DDS performing Threshold and Importance analyzer.	PC3r4	Functional /Technical req	8-i4Q_DR, 12-i4Q_AD, 19-i4Q_PA	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
The system shall store input data from GCP in an internal repository to store results according to provided format (to perform Store Product Conformity result from Virtual Test).	PC3r7	Functional /Technical req	8-i4Q_DR, 10-i4Q_DA	ok	Data Storage & Transfer, Data Analytics
The system shall store output/results from analyses in an internal repository (to perform Store Product Conformity result from Virtual Test).	PC3r8	Functional /Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer
The system shall be able to collect and store time-stamped data from all sensors related to part quality.	PC4r1	Functional /Technical req	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall be able to collect and store time-stamped images associated to the dimensional and atributes of the part.	PC4r2	Functional /Technical req	8-i4Q_DR	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall be able to collect and store all quality part measurements data, scraps, tool changes, etc.. inputted by the operator.	PC4r3	Functional /Technical req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
The system must be able to collect and save all part measurement data provided by measurement equipment automatically in digital format.	PC4r4	Functional /Technical req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system should allow communication with other existing databases.	PC4r8	Interface req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall be able to collect and store time-stamped data from all sensors related to work enviroment.	PC4r10	Functional /Technical req	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall be able to collect and store associated to the machine, tool, production order and part.	PC4r11	Functional /Technical req	8-i4Q_DR	ok	Data Storage & Transfer
The data should be time-stamped and the data capture frequency must be configurable to number of cycles.	PC4r12	Functional /Technical req	8-i4Q_DR	ok	Data Storage & Transfer
The system shall be able to collect and save vibration data produced by the tool according to a certain number of cycles.	PC4r14	Functional /Technical req	8-i4Q_DR, 15-i4Q_IM, 18-i4Q_QD,	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
			21-i4Q_LRT		
The system should be able to collect and save online data/comments manually inputted by the user.	PC4r15	Functional /Technical req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system must be able to communicate with the machines to read, collect and save all warnings and alarms that the CNC machine issues and should be able to relate them to all data captured from the sensors in order to anticipate problems.	PC4r17	Functional /Technical req	8-i4Q_DR, 18-i4Q_QD, 19-i4Q_PA	ok	Data Analytics
The system should allow communication with other existing databases.	PC4r18	Interface req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall allow to associate information with the production order (such as customer, industrial sector, etc).	PC4r19	Functional /Technical req	8-i4Q_DR	ok	Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
Realtime data collection, transformation, integration and storage of e.g. Spectrometry + granulometry analysis results, chemometry benchmarking data (enables mapping raw matter composition to specific quantities of constituents), purchase order, cargo bill should be realised through the deployment of i4Q_DIT, the i4Q_DQG and i4Q_DR.	PC5r5	Functional /Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics
Realtime data integration and transformation of all data coming from the production line and Quality Assurance should be managed through the deployment of the i4Q_DIT.	PC5r6	Functional /Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer, Guidelines
Data pipeline should be established to be able to use the data for other objectives.	PC6r3	Functional /Technical req	7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Acquisition & Transformation, Data Storage & Transfer
All parts that pass-through inspection shall be correctly labelled since this data is going to have an impact on parameter optimization.	PC6r11	Functional /Technical req	3-i4Q_BC, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
Image data should be stored in proper way.	PC6r13	Functional /Technical req	7-i4Q_DRG, 8-i4Q_DR	ok	Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
Injection machine parameters should be optimized using analytical solution.	PC6r15	Functional /Technical req	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD	ok	Data Analytics

Table 24. i4Q^{DR} System requirements mapped to i4Q Solution

i4Q Solutions for Manufacturing Data Analytics

3.3.9 i4Q^{DIT} Data Integration and Transformation Services

3.3.9.1 Main functions/services

The main functions of this solution are a) to clean and process the input data so that they will be ready for further analysis/ modelling and b) to provide a framework for fusing the different types of data derived from the various sensors involved in the pilots. It will interact with other solutions to receive data, as well as provide them in other formats. This solution, that will be a distributed server-based platform, will contain other microservices for conducting all the preparation and decision-making actions; Some of these microservices are:

- Data cleaning
- Sensor signals filtering
- Feature extraction
- Early fusion of heterogeneous data
- Late fusion of results

3.3.9.2 Requirements for i4Q^{DIT}

Table 25 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system

requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Data from the data repository/ pilots should be drawn.	CERTH9r1	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation
This solution should be able to connect with other microservices.	CERTH9r2	Interface req	9-i4Q_DIT	ok	Data Acquisition & Transformation
Data preparation actions on input data shall be performed.	CERTH9r3	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation
Group integration actions shall be performed according to the nature of data that will be combined.	CERTH9r4	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation
Early fusion of input data and late fusion of results should be performed.	CERTH9r5	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation
When the CNC is active, the system shall connect to the CNC via the FapiCorbaLib interface to (1) periodically read and store relevant processing parameters and (2) write in dedicated parameters the suggestions for improved process.	PC1r1	Functional / Technical req, Interface req	9-i4Q_DIT, 10-i4Q_DA	ok	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
When the system requires to retrieve old CNC parameters content, the system shall connect to the Mongo DB installed on the CNC and query the required data.	PC1r2	Functional / Technical req, Interface req	9-i4Q_DIT	Tbc*1	Data Acquisition & Transformation, Data Storage & Transfer
During the milling process, the system shall connect to the CNC USB port where the accelerometer is plugged in, to retrieve with a streaming connection all the available time domain vibration signals.	PC1r3	Functional / Technical req, Interface req	9-i4Q_DIT, 10-i4Q_DA	ok	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics
During or after the execution of PartProgram files, the system shall connect with the CNC via Windows protocols (to be identified) to retrieve the current PartProgram file from a dedicated folder.	PC1r4	Functional / Technical req, Interface req	9-i4Q_DIT	Tbc*2	Data Acquisition & Transformation
After the execution of test movements, the system shall connect with the CNC via Windows protocols (to be identified) to retrieve the recorded files from a dedicated folder.	PC1r5	Functional / Technical req, Interface req	9-i4Q_DIT	ok	Data Acquisition & Transformation
During the milling process, the system shall compute the FFT analysis of all the available time domain vibration signals.	PC1r6	Functional / Technical req	9-i4Q_DIT	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
After retrieving the current PartProgram file and while it is still active, the system shall parse its content to read the information (stored in the first lines) characterizing the current milling process.	PC1r7	Functional / Technical req	9-i4Q_DIT	Tbc*3	Data Acquisition & Transformation, Data Storage & Transfer
While retrieving the information from the sources listed above, the system shall be able to compute the differences between the various time references systems and synchronize the timestamps for all retrieved data.	PC1r8	Functional / Technical req	9-i4Q_DIT, 22-i4Q_LCP	ok	Data Acquisition & Transformation
While analysing the information retrieved from the sources listed above, the system shall be able to compute new features providing insight on the recorded process (e.g., FFT binning).	PC1r9	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Analytics
While analysing the information retrieved from the sources listed above, the system shall be able to filter the information from errors linked to the physical limitations of available signals.	PC1r10	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
During the execution of a part program, the system shall be able to determine if chatter is taking place from the analysis of the current processing parameters and the computed FFT.	PC1r16	Functional / Technical req	9-i4Q_DIT, 18-i4Q_QD	Tbc*4	Data Analytics
i4Q - READ DATA: The system should be able to read the BIESSE CNC parameters every 2 milliseconds.	PC2r2	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation
i4Q - READ DATA: In case a data repository will not be provided, the system should be able to read data from the Biesse Raw Log File every 2 milliseconds, located on machine pc.	PC2r4	Functional / Technical req, Interface req	9-i4Q_DIT	ok	Data Acquisition & Transformation
i4Q - DATA SYNCHRONIZATION: When data are read from different sources (for example BIESSE CNC and data repository) and therefore with different sample frequency and different trigger of acquisition, the system shall synchronize and align the data.	PC2r5	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation
i4Q ALGORITHMS: Once an algorithm is established, the system should provide a "user	PC2r9	Usability and Quality req	9-i4Q_DIT	Tbc*5	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
interface" where can be defined the machine setup to perform test cycle, according to the constraints defined in the "administration interface".					
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert the needed data (for example torque, micro-marker values, …).	PC2r10	Functional / Technical req, Usability and Quality req	9-i4Q_DIT, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics, Data Visualization
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to define the data acquisition parameters (for example sampling frequency, resolution, …).	PC2r11	Functional / Technical req	9-i4Q_DIT, 21-i4Q_LRT, 22-i4Q_LCP	Tbc*[6]	Data Analytics, Data Visualization
i4Q ALGORITHMS: When change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, …), the system shall scale the output data from the algorithms and/or the thresholds of the algorithms within constraint conditions.	PC2r13	Functional / Technical req, Usability and Quality req	9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The system shall predict the product conformity.	PC3r1	Functional / Technical req	1-i4Q_DQG, 2-i4Q_QE, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA	Tbc*[7]	Data Acquisition & Transformation, Data Analytics
The system shall be integrated with WHR Google Cloud Platform to access input data.	PC3r3	Interface req	9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall be able to collect and store time-stamped data from all sensors related to part quality.	PC4r1	Functional / Technical req, Interface req	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall be able to collect and store all quality part measurements data, scraps, tool changes, etc. inputted by the operator.	PC4r3	Functional / Technical req, Usability and Quality req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system must be able to collect and save all part measurement data provided by measurement equipment automatically in digital format.	PC4r4	Functional / Technical req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The system should allow communication with other existing databases.	PC4r8	Interface req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Storage & Transfer, Data Acquisition & Transformation
The system shall be able to collect and store time-stamped data from all sensors related to work environment.	PC4r10	Functional / Technical req	4-i4Q_TN, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system should be able to collect and save online data/comments manually inputted by the user.	PC4r15	Functional / Technical req, Usability and Quality req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system shall store sensor data in offline mode, in case the connection with other solutions (Repository) is broken.	PC4r16	Functional / Technical req	9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer
The system should allow communication with other existing databases.	PC4r18	Interface req	8-i4Q_DR, 9-i4Q_DIT	ok	Data Storage & Transfer, Data Acquisition & Transformation
Realtime data collection, transformation, integration and storage of e.g., Spectrometry + granulometry analysis results, chemometry benchmarking data (enables mapping raw	PC5r5	Functional / Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
matter composition to specific quantities of constituents), purchase order, cargo bill should be realised through the deployment of i4Q_DIT, the i4Q_DQG and i4Q_DR.					
Realtime data integration and transformation of all data coming from the production line and Quality Assurance should be managed through the deployment of the i4Q_DIT.	PC5r6	Functional / Technical req	1-i4Q_DGQ, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer, Guidelines
Data pipeline should be established to be able to use the data for other objectives.	PC6r3	Functional / Technical req	7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Acquisition & Transformation, Data Storage & Transfer
Feature selection should be done in a way that will reduce data flow load but not affect parameter optimization performance.	PC6r5	Usability and Quality req	7-i4Q_DRG, 9-i4Q_DIT, 17-i4Q_PQ, 22-i4Q_LCP	ok	Data Acquisition & Transformation, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Additional sensors (rheometer, thermometer, humidity sensor, etc) should be adaptable.	PC6r6	Functional / Technical req, Interface req	9-i4Q_DIT, 18-i4Q_QD	Tbc*8	Data Acquisition & Transformation, Data Analytics
All parts that pass-through inspection shall be correctly labelled since this data is going to have an impact on parameter optimization.	PC6r11	Functional / Technical req	3-i4Q_BC, 8-i4Q_DR, 9-i4Q_DIT	ok	Data Acquisition & Transformation, Data Storage & Transfer

Table 25. i4Q^{DIT} System requirements mapped to i4Q Solution

No comment to tbc*1, tbc*2 , tbc*3, tbc*4, tbc*5 , tbc*6, tbc*7, tbc*8 :

3.3.10 i4Q^{DA} Services for Data Analytics

3.3.10.1 Main functions/services

The main functions of this solution are the provision of Data Analytics services, supported by the integration of several state-of-the-art tools, methods, and libraries, ranging from Big Data Processing and Analytics to Machine Learning, Data Mining and Deep Learning. The services will be provisioned through two main channels: i) Open Application Programming Interfaces (APIs) like RESTFul-based, pub-sub, socket-based for the collection of the necessary data to execute the selected services and for the provision of results coming from the Data Analytics services, or ii) Deployment bundles with the necessary tools, methods, and libraries to deploy and run the selected services on premises or on cloud environments.

- Deep Learning (TensorFLow, Keras, PyTorch)
- Machine Learning & Data Mining (Scikit Learn, Spark MLLib, Weka on Spark, etc.)
- Big Data Processing (Spark, Flink, Storm, etc.)

3.3.10.2 Requirements for i4Q^{DA}

Table 26 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more

information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Since multiple simulations will need to be run (either in edge or in cloud), it would be beneficial that i4Q_EW, i4Q_AI, i4Q_DA should have the ability to handle i4Q_DT simulations.	IKER 10r1	Functional / Technical req, Interface req	10-i4Q_DA, 13-i4Q_AI, 14-i4Q_EW, 16-i4Q_DT, 19-i4Q_PA	tbc*1	Data Analytics
A user access to Data Analytics Services shall be provided: (Registration and login/ download of a containerized deployment bundle).	UNI10r1	Usability and Quality req	10-i4Q_DA	ok	Data Analytics
Data access shall be provided: the i4Q Data Repository or other types of repositories should be accessible/data connectors should be available to connect selected data sources.	UNI10r2	Interface req	10-i4Q_DA	ok	Data Analytics, Data Storage & Transfer
Data selection functionality should be provided (user selects input data for the desired service).	UNI10r3	Usability and Quality req	10-i4Q_DA	ok	Data Analytics, Data Visualization
Security: Data storage and exchange should be secured. (non-functional)	UNI10r4	Security req	10-i4Q_DA	ok	Data Analytics, Data Storage & Transfer
Scalability to 10s of nodes: Solution should be scalable to any type of environment (cloud, on-premises). (non-functional)	UNI10r5	Usability and Quality req	10-i4Q_DA	ok	Data Analytics, Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Results shall be provided: provide the results through web service/bundle or in the i4Q_AD.	UNI10r6	Functional /Technical req, Usability and Quality req	10-i4Q_DA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
When the CNC is active, the system shall connect to the CNC via the FapiCorbaLib interface to (1) periodically read and store relevant processing parameters and (2) write in dedicated parameters the suggestions for improved process.	PC1r1	Functional /Technical req, Interface req	9-i4Q_DIT, 10-i4Q_DA	tbc*2	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics
During the milling process, the system shall connect to the CNC USB port where the accelerometer is plugged in, to retrieve with a streaming connection all the available time domain vibration signals.	PC1r3	Functional /Technical req, Interface req	9-i4Q_DIT, 10-i4Q_DA	tbc*3	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics
i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict the component degradation under investigation within one day, by analysis performed in time and frequency domain. This goal requires an interaction with the following "i4Q ALGORITHMS" group of goals.	PC2r6	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
i4Q ALGORITHMS: When change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, ...), the system shall scale the output data from the algorithms and/or the thresholds of the algorithms within constraint conditions.	PC2r13	Functional /Technical req, Usability and Quality req	9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	tbc*4	Data Analytics
The system shall predict the product conformity.	PC3r1	Functional /Technical req	1-i4Q_DQG, 2-i4Q_QE, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA	ok	Data Acquisition & Transformation, Data Analytics
The system shall perform virtual tests for all the products resulting from the manufacturing process.	PC3r2	Functional /Technical req	10-i4Q_DA, 16-i4Q_DT	ok	Data Analytics
The system shall be trained with the use of historical data to develop a DDS performing Threshold and Importance analyser.	PC3r5	Functional /Technical req	10-i4Q_DA	ok	Data Analytics
The system shall store input data from GCP in an internal repository to store results according to provided format (to perform Store Product Conformity result from Virtual Test).	PC3r7	Functional /Technical req	8-i4Q_DR, 10-i4Q_DA	tbc*5	Data Storage & Transfer, Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The system should be able to predict and correct the detected deviations by automatically modifying parameters of the CNC machine and by analysing all collected data by users and measurement equipment.	PC4r5	Functional /Technical req, Usability and Quality req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
i4Q solutions should be able to predict tool wear through algorithms and data collected during manufacturing.	PC4r6	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
i4Q shall be capable to predict when the deviation of part measurements or attributes will occur by algorithms and data collected during manufacturing.	PC4r7	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
The system shall learn and be able to establish critical working ranges.	PC4r13	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 19-i4Q_PA	tbc*6	Data Analytics
The system should allow to filter historical information, taking into account different criteria (e.g., machines, zones, dates, etc) of both information collected and autonomous decisions.	PC4r20	Functional /Technical req	10-i4Q_DA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
Data capture, decision-making actions, and other intervals shall be configurable.	PC4r22	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
The system should determine by itself (AI learning) the	PC4r24	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD	ok	Data Analytics,

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
proper/warning/error ranges of some data sensors.					Data Visualization
Realtime/proactive analysis on the raw matter's composition and granulometry shall be performed continuously by using the i4Q_DA, i4Q_BDA, i4Q_AD and i4Q_QD.	PC5r4	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 18-i4Q_QD	ok	Data Analytics, Data Visualization
Quality issues/defects root cause analysis shall be realised using integrated data from production processes by the application and integration of several i4Q solutions, such as the i4Q_DA, i4Q_BDA and i4Q_AD. There is also the possibility to use i4Q_DT and i4Q_QE.	PC5r7	Functional /Technical req	2-i4Q_QE, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 16-i4Q_DT	ok	Data Analytics, Data Visualization
Proactive quality optimization shall be performed through the deployment of the i4Q_PQ, i4Q_LRT and i4Q_DA.	PC5r8	Functional /Technical req	10-i4Q_DA, 17-i4Q_PQ, 21-i4Q_LRT	ok	Data Analytics
Injection machine parameters should be optimized using analytical solution.	PC6r15	Functional /Technical req	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD	tbc*7	Data Analytics

Table 26. i4Q[DA] System requirements mapped to i4Q Solution

No comment to tbc*1, tbc*2 , tbc*3, tbc*4, tbc*5 , tbc*6, tbc*7

3.3.11 i4Q^{BDA} Big Data Analytics Suite

3.3.11.1 Main functions/services

As in the case of the i4Q^{DA}, the Big Data Analytics Suite main function is to deliver on-demand deployment bundles that are easily configurable, deployable, and executed. This Suite will be able to provide custom-built deployment bundles that can contain all the necessary tools, methods, libraries, and code to deploy and run the selected Data Analytics tasks in a panoply of environments, from centralized, distributed on-premises or Cloud. This solution will be supported by containerization technologies such as Kubernetes or Docker.

3.3.11.2 Requirements for i4Q^{BDA}

Table 27 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
User access to i4Q_BDA should be provided (Registration and login/Download of containerized deployment Bundle).	UNI11r1	Interface req	11-i4Q_BDA	ok	Data Analytics, Data Storage & Transfer
Bundle configuration: the user of i4Q_BDA should be able to define desired tools, methods, libraries, and technologies, as well as the target deployment infrastructure Cloud/Edge. This should be fully coordinated with i4Q_AI and i4Q_EW.	UNI11r2	Functional / Technical req, Interface req	11-i4Q_BDA, 13-i4Q_AI, 14-i4Q_EW	ok	Data Analytics, Data Storage & Transfer
i4Q_BDA should provide an interface that contains the tools/methods required to provide the best solution.	UNI11r3	Functional / Technical req,	11-i4Q_BDA	ok	Data Analytics,

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
		Usability and Quality req			Data Storage & Transfer
Security: Data storage and exchange should be secured. (non-functional)	UNI11r4	Security req	11-i4Q_BDA	ok	Data Analytics, Data Storage & Transfer
Data access: the i4Q_DR or other types of repositories should be accessible/data connectors should be available to connect selected data sources.	UNI11r5	Interface req	11-i4Q_BDA	ok	Data Analytics, Data Storage & Transfer
The solution should provide an open API with all the methods and algorithms available.	UNI11r6	Functional / Technical req	11-i4Q_BDA	ok	Data Analytics, Data Storage & Transfer
Scalability to 10s of nodes: Solution should be scalable to any type of environment (cloud, on-premises). (non-functional)	UNI11r7	Usability and Quality req	11-i4Q_BDA	ok	Data Analytics, Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Part quality prediction systems for plastic injection process shall be realised: Besides of injection machine parameters, environmental parameters such as temperature or humidity as well as material parameters, compounds chemical properties and material flow parameters are very important to predict part quality. Rheometer sensor should be investigated to measure viscosity to include analytic platform, some material properties should be measured or gathered from material suppliers.	FARP11r1	Functional / Technical req	11-i4Q_BDA	ok	Data Analytics, Data Acquisition & Transformation
Before the execution of a part program, the system shall be able to foresee the final workpiece quality (surface roughness) from the analysis of the defined processing parameters.	PC1r13	Functional / Technical req	11-i4Q_BDA, 21-i4Q_LRT	ok	Data Analytics
During the execution of a part program, the system shall be able to foresee the final workpiece quality (surface roughness) from the analysis of the current processing parameters.	PC1r14	Functional / Technical req	11-i4Q_BDA, 18-i4Q_QD	ok	Data Analytics
During the execution of a part program, the system shall be able to suggest processing parameters (axis and spindle speed overrides) that improve	PC1r15	Functional / Technical req	11-i4Q_BDA, 17-i4Q_PQ	tbc*1	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
the final workpiece quality (surface roughness).					
Before the execution of a part program, the system shall be able to foresee if chatter will take place from the analysis of the foreseen processing parameters and the knowledge of previous chatter conditions on the same machine.	PC1r17	Functional / Technical req	11-i4Q_BDA, 21-i4Q_LRT	ok	Data Analytics
During the execution of a part program, the system shall be able to suggest processing parameters (axis and spindle speed overrides) that remove or reduce the impact of chatter vibrations.	PC1r18	Functional / Technical req	11-i4Q_BDA, 17-i4Q_PQ	tbc*2	Data Analytics
The system shall be able to detect trends in the data collected from the sources listed above as well as in the computed features.	PC1r19	Functional /Technical req	11-i4Q_BDA	ok	Data Analytics
The system shall be able to correlate the computed trends with the degradation of specific components (failure modes).	PC1r20	Functional /Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 18-i4Q_QD, 21-i4Q_LRT	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected degradation of specific components (failure modes).	PC1r21	Functional /Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT	tbc*3	Data Analytics
i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict the component degradation under investigation within one day, by analysis performed in time and frequency domain. This goal requires an interaction with the following "i4Q ALGORITHMS" group of goals.	PC2r6	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA	ok	Data Analytics
i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict an offline remaining lifetime estimation within one day.	PC2r7	Functional / Technical req	11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA	ok	Data Analytics
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert the needed data (for example torque, micro-marker values, etc).	PC2r10	Functional / Technical req, Usability and Quality req	9-i4Q_DIT, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
i4Q ALGORITHMS: For each established algorithm, the system should provide an uncertainty analysis with a confidence level of 95 %. With the aim to define the reliability of the developed algorithms to identify machine problems.	PC2r12	Usability and Quality req	11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics
i4Q ALGORITHMS: When change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, ...), the system shall scale the output data from the algorithms and/or the thresholds of the algorithms within constraint conditions.	PC2r13	Functional / Technical req, Usability and Quality req	9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	tbc*4	Data Analytics
The system shall predict the product conformity.	PC3r1	Functional / Technical req	1-i4Q_DQG, 2-i4Q_QE, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA	ok	Data Acquisition & Transformation, Data Analytics
The system shall generate an alert for non-conformity situations to perform Threshold and Importance analyser.	PC3r6	Functional / Technical req	11-i4Q_BDA	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The system should be able to predict and correct the detected deviations by automatically modifying parameters of the CNC machine and by analysing all collected data by users and measurement equipment.	PC4r5	Functional / Technical req, Usability and Quality req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
i4Q solutions should be able to predict tool wear through algorithms and data collected during manufacturing.	PC4r6	Functional / Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
i4Q shall be capable to predict when the deviation of part measurements or attributes will occur by algorithms and data collected during manufacturing.	PC4r7	Functional / Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
The system shall learn and be able to establish critical working ranges.	PC4r13	Functional / Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 19-i4Q_PA	tbc*5	Data Analytics
Data capture, decision-making actions, and other intervals shall be configurable.	PC4r22	Functional / Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	tbc*6	Data Analytics, Data Visualization
The system should determine by itself (AI learning) the proper/warning/error ranges of some data sensors.	PC4r24	Functional / Technical req	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD	ok	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Realtime/proactive analysis on the raw matter's composition and granulometry shall be performed continuously by using the i4Q_DA, i4Q_BDA, i4Q_AD and i4Q_QD.	PC5r4	Functional / Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 18-i4Q_QD	ok	Data Analytics, Data Visualization
Quality issues/defects root cause analysis shall be realised using integrated data from production processes by the application and integration of several i4Q solutions, such as the i4Q_DA, i4Q_BDA and i4Q_AD. There is also the possibility to use i4Q_DT and i4Q_QE.	PC5r7	Functional / Technical req	2-i4Q_QE, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 16-i4Q_DT	ok	Data Analytics, Data Visualization
Data pipeline should be established to be able to use the data for other objectives.	PC6r3	Functional / Technical req	7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA, 12-i4Q_AD	tbc*7	Data Acquisition & Transformation, Data Storage & Transfer

Table 27. i4Q^{BDA} System requirements mapped to i4Q Solution

No comment to tbc*1, tbc*2, tbc*3, tbc*4, tbc*5, tbc*6, tbc*7

3.3.12 i4Q^{AD} Analytics Dashboard

3.3.12.1 Main functions/services

This solution has the main function of providing visual analytics tools and methods to the i4Q project. The i4Q Analytics Dashboard can be used via a Web Application or through the provision of a deployment bundle that can be deployed on premises or on the cloud, and will be based on state-of-the-art visual analytics tools, such as Apache Superset, Grafana or Jupyter Notebooks.

3.3.12.2 Requirements for i4Q^{AD}

Table 28 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
User access to Analytics Dashboard should be provided (Registration and login/ download of a containerized deployment bundle).	UNI12r1	Usability and Quality req	12-i4Q_AD	ok	Data Visualization, Data Storage & Transfer
Data access: the i4Q_DR or other types of repositories should be accessible/data connectors should be available to connect selected data sources.	UNI12r2	Interface req	12-i4Q_AD	ok	Data Visualization, Data Storage & Transfer
Configurable Data selection functionality should be integrated (user selects data for visualization).	UNI12r3	Usability and Quality req	12-i4Q_AD	ok	Data Visualization
Security: Data storage and exchange should be secured. (non-functional)	UNI12r4	Security req	12-i4Q_AD	ok	Data Visualization, Data Storage & Transfer
Results of i4Q_DA and i4Q_BDA shall be provided and presented in i4Q_AD (connection to i4Q_DA and i4Q_BDA).	UNI12r5	Functional/ Technical req, Interface req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	ok	Data Visualization, Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Stability, capability and performance (quality output) of manufacturing processes shall be monitored just-in-time and visualized in a dashboard solution.	TUB 12r1	Functional/ Technical req, Usability and Quality req	12-i4Q_AD, 17-i4Q_PQ	ok	Data Analytics, Data Visualization
During all the improved BPs, the system shall display collected information as well as generated one (adapted parameters, FFT, suggestions, degrading components) through its dashboard.	PC1r 22	Functional/ Technical req, Interface req	12-i4Q_AD	ok	Data Visualization
i4Q ALGORITHMS: When a machine problem will be intercepted, the system will send the result to Sophia platform in ascending order of priority (medium in case of preventive maintenance or high in case of machine stop). The message could contain the following information: suspected component; type of problem; priority; …	PC2r 14	Functional/ Technical req, Interface req	12-i4Q_AD	tbc*1	Data Visualization, Data Storage & Transfer
i4Q ALGORITHMS: The system should provide a "user interface" to collect feedback from hotliner or field, with the aim to increase the reliability of the i4Q algorithms	PC2r 15	Usability and Quality req	12-i4Q_AD	tbc*2	Data Visualization
SOPHIA PLATFORM: The system should provide a self-diagnosis "maintenance interface" for the customer, that contains some outputs from the i4Q solutions (e.g., lifetime estimation of the principal	PC2r 17	Usability and Quality req	12-i4Q_AD, 18-i4Q_QD	ok	Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
components, suggested processing parameters, …).					
SOPHIA PLATFORM: The system should provide a self-diagnosis "maintenance interface" for Biesse support, that contains the information available for the customer and all the other outputs from the i4Q solutions (e.g., confidential data, outputs from experimental algorithms, ...).	PC2r 18	Usability and Quality req	12-i4Q_AD, 18-i4Q_QD	ok	Data Visualization
The systems shall perform analysis based on Artificial Intelligence and Machine Learning to develop a DDS performing Threshold and Importance analyser.	PC3r 4	Functional/ Technical req	8-i4Q_DR, 12-i4Q_AD, 19-i4Q_PA	ok	Data Analytics
The system shall visualize the results of the analysis in an ad-hoc dashboard (integrated virtual test results and WHR Google Cloud Platform). Basic functionality such as: Historical data	PC3r 9	Functional/ Technical req	12-i4Q_AD	ok	Data Visualization
The tool shall be user-friendly and can be used by the multi-functional Quality teams.	PC3r 10	Usability and Quality req	12-i4Q_AD	ok	Data Visualization
The system should be able to predict and correct the detected deviations by automatically modifying parameters of the CNC machine and by analysing all collected data by users and measurement equipment.	PC4r 5	Functional/ Technical req Usability and Quality req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	tbc*3	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
i4Q solutions should be able to predict tool wear through algorithms and data collected during manufacturing.	PC4r 6	Functional/ Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	tbc*[4]	Data Analytics, Data Visualization
i4Q shall be capable to predict when the deviation of part measurements or attributes will occur by algorithms and data collected during manufacturing.	PC4r 7	Functional /Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	tbc*[5]	Data Analytics, Data Visualization
The user interface shall adopt localization aspects: decimal/thousands separator, interface languages. Spanish shall be one the localizations available.	PC4r 9	Usability and Quality req	12-i4Q_AD	tbc*[6]	Data Visualization
The system shall learn and be able to establish critical working ranges.	PC4r 13	Functional/ Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 19-i4Q_PA	tbc*[7]	Data Analytics
The system should allow to filter historical information taking into account different criteria (e.g., machines, zones, dates, etc) of both information collected and autonomous decisions.	PC4r 20	Functional/ Technical req	10-i4Q_DA, 12-i4Q_AD	ok	Data Analytics, Data Visualization
The user interface shall adopt localization aspects: decimal/thousands separator, interface languages. Spanish shall be one the localizations available.	PC4r 21	Usability and Quality req	12-i4Q_AD	tbc*[8]	Data Visualization
Data capture, decision-making actions, and other intervals shall be configurable.	PC4r 22	Functional/Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD	tbc*[9]	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The interface should allow you to display a specific (selectable) signal in real time remotely. For example, the temperature, flow sensor, or camera).	PC4r 23	Usability and Quality req	12-i4Q_AD	ok	Data Visualization
The system shall allow the load of master data and operational data (e.g., calendars, working timetables, etc).	PC4r 25	Functional/Technical req, Usability and Quality req	12-i4Q_AD	tbc*[10]	Data Visualization
Realtime/proactive analysis on the raw matter's composition and granulometry shall be performed continuously by using the i4Q_DA, i4Q_BDA, i4Q_AD and i4Q_QD.	PC5r 4	Functional/Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 18-i4Q_QD	ok	Data Analytics, Data Visualization
Quality issues/defects root cause analysis shall be realised using integrated data from production processes by the application and integration of several i4Q solutions, such as the i4Q_DA, i4Q_BDA and i4Q_AD. There is also the possibility to use i4Q_DT and i4Q_QE.	PC5r 7	Functional/Technical req	2-i4Q_QE, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 16-i4Q_DT	Ok	Data Analytics, Data Visualization
Data pipeline should be established to be able to use the data for other objectives.	PC6r 3	Functional/Technical req	7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA, 12-i4Q_AD	tbc*[11]	Data Acquisition & Transformation, Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Injection machine parameters should be optimized using analytical solution.	PC6r 15	Functional/Technical req	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD	tbc*12	Data Analytics

Table 28. i4Q^{AD} System requirements mapped to i4Q Solution

No comment to tbc*2, tbc*3, tbc*4, tbc*5, tbc*6, tbc*7, tbc*8, tbc*9, tbc*10, tbc*11

Comment to tbc*1:

"[UNI]: not comply; If it is to send info to other platforms, the Analytics dashboard will not be the responsible solution for this transfer".

3.3.13 i4Q^{AI} AI Models Distribution to the Edge

3.3.13.1 Main functions/services

Management of AI-based workloads in a hybrid cloud edge manufacturing environment. A policy-based distribution mechanism shall be put in place to ease the process of model distribution to the correct edge nodes; aided by a discovery component keeping up-to-date information of system components. The AI model distribution shall be coordinated with the workload deployment mechanism to ensure that the right set of AI models is made available for the edge workload that using them.

3.3.13.2 Requirements for i4Q^{AI}

Table 29 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
i4Q_AI, i4Q_EW, and i4Q_IM shall be fully coordinated to create a consistent platform to service the data analytics services such as i4Q_PQ i4Q_QD.	IBM13r1	Functional/ Technical req, Interface req	13-i4Q_AI, 14-i4Q_EW, 15-i4Q_IM	ok	Data Acquisition & Transformation, Data Storage & Transfer
Since multiple simulations will need to be run (either in edge or in cloud), it would be beneficial that i4Q_EW, i4Q_AI, i4Q_DA should have the ability to handle i4Q_DT simulations.	IKER13r1	Functional/ Technical req, Interface req	10-i4Q_DA, 13-i4Q_AI, 14-i4Q_EW, 16-i4Q_DT, 19-i4Q_PA	ok	Data Analytics
Bundle configuration: the user of i4Q_BDA should be able to define desired tools, methods, libraries, and technologies, as well as the target deployment infrastructure Cloud/Edge. This should be fully coordinated with i4Q_AI and i4Q_EW.	UNI13r1	Functional/Technical req, Interface req	11-i4Q_BDA, 13-i4Q_AI, 14-i4Q_EW	ok	Data Analytics, Data Storage & Transfer

Table 29. i4Q^{AI} System requirements mapped to i4Q Solution

3.3.14 i4Q^{EW} Workloads Placement and Deployment

3.3.14.1 Main functions/services

Deploy and execution of AI workloads on the edge computing environment are required in smart manufacturing facilities. This solution shall enable workloads to execute efficiently on the edge, including placement and deployment services. Target deployment environment may be very heterogeneous and dynamic; thus, deployment needs to take a variety of criteria into consideration. Interfaces and capabilities to run different workloads on different devices shall be pursued. Deployment shall be based on well-known orchestrators, such as Kubernetes.

3.3.14.2 Requirements for i4Q^{EW}

Table 30 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further,

the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Bundle configuration: the user of i4Q_BDA should be able to define desired tools, methods, libraries and technologies, as well as the target deployment infrastructure Cloud/Edge. This should be fully coordinated with i4Q_AI and i4Q_EW.	UNI14r1	Functional/Technical req, Interface req	11-i4Q_BDA, 13-i4Q_AI, 14-i4Q_EW	ok	Data Analytics, Data Storage & Transfer
i4Q_AI, i4Q_EW, and i4Q_IM shall be fully coordinated to create a consistent platform to service the data analytics services such as i4Q_PQ i4Q_QD.	IBM14r1	Functional/Technical req, Interface req	13-i4Q_AI, 14-i4Q_EW, 15-i4Q_IM	ok	Data Acquisition & Transformation, Data Storage & Transfer
Since multiple simulations will need to be run (either in edge or in cloud), it would be beneficial that i4Q_EW, i4Q_AI, i4Q_DA should have the ability to handle i4Q_DT simulations.	IKER14r1	Functional/Technical req, Interface req	10-i4Q_DA, 13-i4Q_AI, 14-i4Q_EW, 16-i4Q_DT, 19-i4Q_PA	ok	Data Analytics
i4Q ARCHITECTURE: Define the right edge/cloud architecture	PC2r1	Functional/Technical req	14-i4Q_EW	ok	Data Acquisition & Transformation, Data Storage & Transfer

Table 30. i4Q^{EW} System requirements mapped to i4Q Solution

3.3.15 i4Q^{IM} Infrastructure Monitoring

3.3.15.1 Main functions/services

Infrastructure monitoring solution will observe the manufacturing processes in order to predict possible failures and provide alerts or take corrective actions. In general, the solution will perform prediction of harmful events as well as detection of these failures and will provide alerts in both cases.

3.3.15.2 Requirements for i4Q^{IM}

Table 31 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
i4Q_AI, i4Q_EW, and i4Q_IM shall be fully coordinated to create a consistent platform to service the data analytics services such as i4Q_PQ i4Q_QD.	IBM 15r1	Functional/ Technical req, Interface req	13-i4Q_AI, 14-i4Q_EW, 15-i4Q_IM	ok	Data Acquisition & Transformation, Data Storage & Transfer
Relevant data should be collected in order to have the necessary information in order to agile the decision making and correlate this data with quality data to identify quickly the problem in order to solve it.	AIM P15r 1	Functional/ Technical req	15-i4Q_IM	ok	Data Acquisition & Transformation, Data Analytics
Historical data from sensors should be available in order to build the solution.	CER TH1 5r1	Functional/ Technical req	15-i4Q_IM	ok	Data Acquisition & Transformation, Data Analytics

Requirement definition (related to the solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The solution should be able to manage and provide alerts.	CERTH15r2	Functional/ Technical req	15-i4Q_IM	ok	Data Analytics, Data Visualization
The solution should be able to access the edge environment.	CERTH15r3	Interface req	15-i4Q_IM	ok	Data Analytics, Data Storage & Transfer
The solution should successfully detect failures in the processes it monitors.	CERTH15r4	Functional/ Technical req	15-i4Q_IM	ok	Data Analytics, Data Visualization
The system shall be able to correlate the computed trends with the degradation of specific components (failure modes).	PC1r20	Functional/ Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 18-i4Q_QD, 21-i4Q_LRT	tbc*1	Data Analytics
Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected degradation of specific components (failure modes).	PC1r21	Functional/ Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT	tbc*2	Data Analytics
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert machine condition and other constraints required for the data recording (test cycles).	PC2r8	Functional/ Technical req	15-i4Q_IM	tbc*3	

Requirement definition (related to the solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The system shall be able to collect and save vibration data produced by the tool according to a certain number of cycles.	PC4r 14	Functional/ Technical req	8-i4Q_DR, 15-i4Q_IM, 18-i4Q_QD, 21-i4Q_LRT	tbc*4	Data Analytics
The system shall include a digital layout of the plant: instance sections, machines (types, properties, sensors, ranges). In addition, it shall be editable over time for evolving as company evolves.	PC4r 26	Functional/ Technical req, Usability and Quality req	15-i4Q_IM, 16-i4Q_DT	tbc*5	Data Analytics, Data Visualization, Guidelines
The i4Q solution should be able to work independent to the model, size, brand, etc. of the plastic injection machines.	PC6r 7	Functional/ Technical req, Usability and Quality req	15-i4Q_IM	ok	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics
General manufacturing environment should be followed remotely to be able to manage production workload efficiently.	PC6r 14	Functional/ Technical req	15-i4Q_IM, 16-i4Q_DT	ok	Data Analytics

Table 31. i4Q^{IM} System requirements mapped to i4Q Solution

No comment to tbc*1, tbc*2, tbc*3, tbc*4, tbc*5

The literature requirement (LIT1, see **Table 6**) "predictive machine maintenance should use live data" of Pfirrmann et al. is merge to this i4Q Solution by the technical providers. (Pfirrmann et al. 2019, S. 3067).

3.3.16 i4Q^{DT} Digital Twin simulation services

3.3.16.1 Main functions/services

The Digital Twin simulation services solution provides a connected 3D production simulation environment. It enables virtual validation/visualisation and productivity optimisation. It will make use of both pre-existing data and simulated data (virtual sensors) obtained with the developed model. It will also make use of data from different factory levels (small cell to entire factory).

3.3.16.2 Requirements for i4Q^{DT}

Table 32 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Flexible enough Digital Twin model template (UI) with the minimum possible dependencies on the type of input data and manufacturing/asset plant shall be developed.	IKER 16r1	Functional/ Technical req	16-i4Q_DT	ok	Data Analytics
The output visualization of the Digital Twin should be depicted in a general way to be able to provide simulation results to other components in the least constrained way possible.	IKER 16r2	Functional/ Technical req	16-i4Q_DT	ok	Data Analytics, Data Visualization
Since multiple simulations will need to be run (either in edge or in cloud), it would be beneficial that i4Q_EW, i4Q_AI, i4Q_DA should have the ability to handle i4Q_DT simulations.	IKER 16r3	Functional/ Technical req, Interface req	10-i4Q_DA, 13-i4Q_AI, 14-i4Q_EW, 16-i4Q_DT, 19-i4Q_PA	ok	Data Analytics
The system shall be able to correlate the computed trends with the degradation of specific components (failure modes).	PC1r 20	Functional/ Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 18-i4Q_QD, 21-i4Q_LRT	tbc*1	Data Analytics
Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected	PC1r 21	Functional/ Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT	tbc*2	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
degradation of specific components (failure modes).					
The system shall perform virtual tests for all the products resulting from the manufacturing process.	PC3r2	Functional/ Technical req	10-i4Q_DA, 16-i4Q_DT	ok	Data Analytics
The system shall include a digital layout of the plant: instance sections, machines (types, properties, sensors, ranges). In addition, it shall be editable over time for evolving as company evolves.	PC4r26	Functional/ Technical req, Usability and Quality req	15-i4Q_IM, 16-i4Q_DT	ok	Data Analytics, Data Visualization, Guidelines
Quality issues/defects root cause analysis shall be realised using integrated data from production processes by the application and integration of several i4Q solutions, such as the i4Q_DA, i4Q_BDA and i4Q_AD. There is also the possibility to use i4Q_DT and i4Q_QE.	PC5r7	Functional/Technical req	2-i4Q_QE, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 16-i4Q_DT	tbc*3	Data Analytics, Data Visualization
General manufacturing environment should be followed remotely to be able to manage production workload efficiently.	PC6r14	Functional/ Technical req	15-i4Q_IM, 16-i4Q_DT	ok	Data Analytics
Injection machine parameters should be optimized using analytical solution.	PC6r15	Functional/ Technical req	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ,	tbc*4	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
			18-i4Q_QD, 19-i4Q_PA		

Table 32. i4Q^{DT} System requirements mapped to i4Q Solution

Comment to tbc*1

"It may depend on the knowledge needed to build the DT".

Comment to tbc*3

"It is still not clear the need of a DT in this context".

Comment to tbc*2, tbc*4

„[IKER]: not comply; This may be more related with the solution i4Q_PA, which is not in the list of column O, however a DT would be needed and a detailed model would be needed ".

i4Q Solutions for Rapid Manufacturing Line Qualification and Reconfiguration

3.3.17 i4Q^{PQ} Data-driven Continuous Process Qualification

3.3.17.1 Main functions/services

i4Q^{PQ} provides a tool for achieving and ensuring process stability and product quality. Based on process data such as product quality, machine parameters, systematic influences, and interdependencies, an algorithm is developed. This algorithm can predict process stability and product quality. Therefore, it enables the process owner to get a deeper understanding how chances in the machine parameters will change the output of the process. As a result, e.g., the ramp-up time for a manufacturing process is reduced. By monitoring each step of the manufacturing process the product quality is predicted. If critical parameters change over time and pass a warning threshold, the process owner is informed and enabled to adjust the parameters to save setting before products with insufficient quality features are produced. The monitoring tool will be implemented as a dashboard solution.

3.3.17.2 Requirements for i4Q^{PQ}

Table 33 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more

information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
The time to process approval during ramp-up phase shall be reduced through stable processes with available process data acquired from simulated data or predecessor process, full access to process related data sources, sufficient data quality and quantity is needed for algorithm modelling.	TUB 17r 1	Functional/ Technical req	17-i4Q_PQ	ok	Data Analytics, Data Acquisition & Transformation
In-line continuous process validation after process reconfiguration should be possible through data-driven continuous process qualification, full access to process related data sources, sufficient data quality and quantity is needed for algorithm modelling.	TUB 17r 2	Functional/ Technical req, Interface req	17-i4Q_PQ	ok	Data Analytics, Data Acquisition & Transformation
Stability, capability, and performance (quality output) of manufacturing processes shall be monitored just-in-time and visualized in a dashboard solution.	TUB 17r 3	Functional/ Technical req, Usability and Quality req	12-i4Q_AD, 17-i4Q_PQ	ok	Data Analytics, Data Visualization
During the execution of a part program, the system shall be able to suggest processing parameters (axis and spindle speed overrides) that improve the final workpiece quality (surface roughness).	PC1 r15	Functional/ Technical req	11-i4Q_BDA, 17-i4Q_PQ	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
During the execution of a part program, the system shall be able to suggest processing parameters (axis and spindle speed overrides) that remove or reduce the impact of chatter vibrations.	PC1 r18	Functional/ Technical req	11-i4Q_BDA, 17-i4Q_PQ	ok	Data Analytics
Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected degradation of specific components (failure modes).	PC1 r21	Functional/ Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT	ok	Data Analytics
Proactive quality optimization shall be performed through the deployment of the i4Q_PQ, i4Q_LRT and i4Q_DA.	PC5 r8	Functional/ Technical req	10-i4Q_DA, 17-i4Q_PQ, 21-i4Q_LRT	tbc*1	Data Analytics
Feature selection should be done in a way that will reduce data flow load but not affect parameter optimization performance.	PC6 r5	Usability and Quality req	7-i4Q_DRG, 9-i4Q_DIT, 17-i4Q_PQ, 22-i4Q_LCP	tbc*2	Data Acquisition & Transformation, Data Visualization
Injection machine parameters should be optimized using analytical solution.	PC6 r15	Functional/ Technical req	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD	ok	Data Analytics
Process qualification or machine certification can be done by successfully predicting product quality without manual test and inspection which takes a lot of time and effort.	PC6 r16	Functional/ Technical req, Guidelines req	17-i4Q_PQ, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics, Guidelines

Table 33. i4Q[PQ] System requirements mapped to i4Q Solution

Comment to tbc*[1]

"Seems very similar to 18-i4Q_QD".

Comment to tbc*[2]

"Depending on used algorithm and data a feature selection is not advised. Please specify performance".

3.3.18 i4Q[QD] Rapid Quality Diagnosis

3.3.18.1 Main functions/services

This solution will function as a microservice. The main function is to monitor the manufacturing line and diagnose possible causes of failures. To ensure the function of the manufacturing line, the following aspects should be monitored by i4Q[QD]:

- Evaluation of data
- Product quality
- Process condition
- Maintenance actions
- Machine reconfiguration

3.3.18.2 Requirements for i4Q[QD]

Table 34 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
This microservice should have different modules for each function it performs, e.g., detection, decision and decision making.	CERTH 18r1	Functional/ Technical req	18-i4Q_QD	ok	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
The solution should interact with other solutions for monitoring and receiving input.	CERTH 18r2	Interface req	18-i4Q_QD	ok	Data Analytics, Data Storage & Transfer
The solution should store the information it receives.	CERTH 18r3	Functional/ Technical req	18-i4Q_QD	ok	Data Analytics, Data Storage & Transfer
This microservice should be able to produce key performance indices (KPIs).	CERTH 18r4	Functional/ Technical req	18-i4Q_QD	ok	Data Analytics, Data Visualization
During the execution of a part program, the system shall be able to foresee the final workpiece quality (surface roughness) from the analysis of the current processing parameters.	PC1r14	Functional/ Technical req	11-i4Q_BDA, 18-i4Q_QD	ok	Data Analytics
During the execution of a part program, the system shall be able to determine if chatter is taking place from the analysis of the current processing parameters and the computed FFT.	PC1r16	Functional/ Technical req	9-i4Q_DIT, 18-i4Q_QD	ok	Data Analytics
The system shall be able to correlate the computed trends with the degradation of specific components (failure modes).	PC1r20	Functional/ Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 18-i4Q_QD, 21-i4Q_LRT	tbc*1	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict the component degradation under investigation within one day, by analysis performed in time and frequency domain. This goal requires an interaction with the following "i4Q ALGORITHMS" group of goals.	PC2r6	Functional/ Technical req	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA	tbc*2	Data Analytics
i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict an offline remaining lifetime estimation within one day.	PC2r7	Functional/ Technical req	11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA	tbc*3	Data Analytics
SOPHIA PLATFORM: The system should provide a self-diagnosis "maintenance interface" for the customer, that contains some outputs from the i4Q solutions (e.g., lifetime estimation of the principal components, suggested processing parameters, …).	PC2r17	Usability and Quality req	12-i4Q_AD, 18-i4Q_QD	ok	Data Visualization
SOPHIA PLATFORM: The system should provide a self-diagnosis "maintenance interface" for Biesse support, that contains the information available for the customer and all the other	PC2r18	Usability and Quality req	12-i4Q_AD, 18-i4Q_QD	ok	Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
outputs from the i4Q solutions (e.g., confidential data, outputs from experimental algorithms, ...).					
The system shall be able to collect and save vibration data produced by the tool according to a certain number of cycles.	PC4r14	Functional/ Technical req	8-i4Q_DR, 15-i4Q_IM, 18-i4Q_QD, 21-i4Q_LRT	tbc*4	Data Analytics
The system must be able to communicate with the machines to read, collect and save all warnings and alarms that the CNC machine issues and should be able to relate them to all data captured from the sensors in order to anticipate problems.	PC4r17	Functional/ Technical req	8-i4Q_DR, 18-i4Q_QD, 19-i4Q_PA	ok	Data Analytics
The system should determine by itself (AI learning) the proper/warning/error ranges of some data sensors.	PC4r24	Functional/ Technical re	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD	ok	Data Analytics, Data Visualization
During the Raw Matter delivery process, the spectrometric testing system shall perform Kubelka-munk readings and Reflectance readings on PVA (ppm) and water (%), during the complete 90minute delivery process @1 second intervals, delivering the test results to i4Q_QD tool.	PC5r1	Functional/ Technical req	18-i4Q_QD	tbc*5	Data Acquisition & Transformation, Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
During the Raw Matter Storage Silo dispensing process, the spectrometric testing system shall perform Kubelka-munk readings and Reflectance readings on PVA (ppm) and water (%), @1 second intervals, delivering the test results to i4Q_QD tool.	PC5r2	Functional/ Technical req	18-i4Q_QD	tbc*[6]	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics
During the Raw Matter delivery process, one of the delivery raw matter samples shall be tested by the spectrometric testing system, which will perform one (1) Kubelka-munk reading and Reflectance reading on PVA and water contents of the sample, delivering the test results to i4Q_QD tool, which will confirm to the Riastone QC that the supplier delivered sample is effectively part of the delivered lot.	PC5r3	Functional/ Technical req	18-i4Q_QD	tbc*[7]	Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics
Realtime/proactive analysis on the raw matter's composition and granulometry shall be performed continuously by using the i4Q_DA, i4Q_BDA, i4Q_AD and i4Q_QD.	PC5r4	Functional/ Technical req,	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 18-i4Q_QD	ok	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
Quality inspection %100 detection performance for quality inspection (If not achievable at least zero false positive rate shall be provided.)	PC6r1	Functional/ Technical req, Usability and Quality req	18-i4Q_QD	tbc*[8]	Data Analytics
Since the environmental conditions (e.g. lightness, temperature, etc) can vary from day-to-day the process should not be affected by environmental factors	PC6r2	Functional/ Technical req	18-i4Q_QD	tbc*[9]	Data Acquisition & Transformation, Data Analytics
Additional sensors (rheometer, thermometer, humidity sensor, etc) should be adaptable.	PC6r6	Functional/ Technical req, Interface req	17-i4Q_PQ, 18-i4Q_QD	ok	Data Acquisition & Transformation, Data Analytics
By using the machine monitoring parameters of the injection machine with different machine learning methods, the quality of the parts produced from the machine shall be increased as well as the faulty piece number decreased.	PC6r8	Usability and Quality req	18-i4Q_QD, 22-i4Q_LCP	ok	Data Analytics, Guidelines
The part that the device can examine should be flexible since the parts being produced come in different shapes and sizes.	PC6r9	Usability and Quality req	18-i4Q_QD	tbc*[10]	Data Acquisition & Transformation, Data Analytics
Integration of the device into the production lane should not have an impact on production rate/speed.	PC6r10	Functional/ Technical req, Usability and Quality req	18-i4Q_QD	tbc*[11]	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
Visual inspection device should do the initialization process automatically for each different part.	PC6r12	Functional/ Technical req	9-i4Q_DIT, 18-i4Q_QD	ok	Data Analytics
Injection machine parameters should be optimized using analytical solution.	PC6r15	Functional/ Technical req	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD	ok	Data Analytics

Table 34. i4Q^{QD} System requirements mapped to i4Q Solution

No comment to tbc*[2], tbc*[3], tbc*[4], tbc*[5], tbc*[6], tbc*[7], tbc*[8], tbc*[9], tbc*[10], tbc*[11]

3.3.19 i4Q^{PA} Prescriptive Analysis Tools

3.3.19.1 Main functions/services

The Prescriptive Analysis Tool provides mainly simulations as a service. It exploits the Digital Twin developed to test different configuration parameters and analyze the effect small changes can produce in the production. It makes use of manufacturing resources, production planning and process condition. The prescriptive analysis will come from exhaustive simulation with no specific optimization algorithm implemented.

3.3.19.2 Requirements for i4Q^{PA}

Table 35 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
An efficient and flexible enough communication with other i4Q solutions, particularly with i4Q_DT should be ensured.	IKER 19r1	Interface req	19-i4Q_PA	ok	Data Analytics, Data Visualization
An interface should be provided that allows the definition of the scenarios to be simulated and the criteria to evaluate the simulation results and provide a prescriptive analysis.	IKER 19r2	Functional/ Technical req, Usability and Quality req	19-i4Q_PA	ok	Data Analytics, Data Visualization
Since multiple simulations will need to be run (either in edge or in cloud), it would be beneficial that i4Q_EW, i4Q_AI, i4Q_DA should have the ability to handle i4Q_DT simulations.	IKER 19r3	Functional/ Technical req, Interface req	10-i4Q_DA, 13-i4Q_AI, 14-i4Q_EW, 16-i4Q_DT, 19-i4Q_PA	ok	Data Analytics
Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected degradation of specific components (failure modes).	PC1r 21	Functional/ Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict the component degradation under investigation within one day, by analysis performed in time and frequency domain. This goal requires an interaction with the following "i4Q ALGORITHMS" group of goals.	PC2r6	Functional/ Technical req	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA	tbc*1	Data Analytics
i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict an offline remaining lifetime estimation within one day.	PC2r7	Functional/ Technical req	11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA	tbc*2	Data Analytics
The systems shall perform analysis based on Artificial Intelligence and Machine Learning to develop a DDS performing Threshold and Importance analyzer.	PC3r4	Functional/ Technical req	8-i4Q_DR, 12-i4Q_AD, 19-i4Q_PA	tbc*3	Data Analytics
The system shall learn and be able to establish critical working ranges.	PC4r13	Functional/ Technical req	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 19-i4Q_PA	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected / mapped to this Req.	Status	Classification
The system must be able to communicate with the machines to read, collect and save all warnings and alarms that the CNC machine issues and should be able to relate them to all data captured from the sensors in order to anticipate problems.	PC4r17	Functional/ Technical req	8-i4Q_DR, 18-i4Q_QD, 19-i4Q_PA	tbc*4	Data Analytics
Injection machine parameters should be optimized using analytical solution.	PC6r15	Functional/ Technical req	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD, 19-i4Q_PA	ok	Data Analytics

Table 35. i4Q^{PA} System requirements mapped to i4Q Solution

Comment to tbc*1, tbc*2 & tbc*3

"[IKER]: In order to use i4Q_PA, i4Q_DT is needed, at least as is has been conceived by now, PC2 has no requirements for this solution".

Comment to tbc*4

"[IKER]: Read, collect and save are indeed out of the scope of i4Q_PA. Only the part of anticipating problems would be covered by this solution. Maybe we need to split this requirement?".

3.3.20 i4Q^{LRG} Manufacturing Line Reconfiguration Guidelines

3.3.20.1 Main functions/services

This tool provides a multi-media guide to reconfiguration the manufacturing line. To do so, it considers the results obtained when calibrating the parameters of the machine. Based on this information, this guideline will ensure long-term productivity. In addition, it will reduce the reconfiguration efforts of the manufacturing line.

3.3.20.2 Requirements for i4Q[LRG]

Table 36 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
An interactive and intuitive guide for users about Manufacturing Line reconfiguration should be provided. No specific requirements from additional i4Q solutions.	UPV20r1	Guidelines req, Usability and Quality req	20-i4Q_LRG	ok	Guidelines
A technical document of the manufacturing line (it will be intuitive) should be provided.	UPV20r2	Guidelines req, Usability and Quality req	20-i4Q_LRG	ok	Guidelines
This solution should store historical query data to facilitate its use to the end-user.	UPV20r3	Functional/ Technical req, Usability and Quality req	20-i4Q_LRG	tbc*1	Guidelines, Data Storage & Transfer, Data Visualization

Table 36. i4Q[LRG] System requirements mapped to i4Q Solution

Comment to tbc*1

„The documentation should include sample queries to facilitate its use to the end-user".

3.3.21 i4Q[LRT] Manufacturing Line Reconfiguration Toolkit

3.3.21.1 Main functions/services

The objective of this toolkit is to increase productivity and reduce the efforts for manufacturing line reconfiguration through AI. This tool consists of a set of services that will allow us to analyse and simulate different scenarios. This will provide the best configuration for the modules and parameters of the manufacturing line.

3.3.21.2 Requirements for i4Q^{LRT}

Table 37 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Relevant data shall be collected in order to have the necessary information to speed up the decision-making process of the production line, taking into account quality.	UPV 21r1	Functional /Technical req	21-i4Q_LRT	ok	Data Acquisition & Transformation
The toolkit should be able to connect with other i4Q solutions and communicate successfully with the other components of the system.	UPV 21r2	Interface req	21-i4Q_LRT	ok	Data Acquisition & Transformation, Data Storage & Transfer
A database of the production line data shall be collected from other i4Q solution and maintained in order to train the AI.	UPV 21r3	Functional /Technical req	21-i4Q_LRT	ok	Data Acquisition & Transformation, Data Storage & Transfer
A study of the machinery, cell or manufacturing line shall be carried out in order to find out the points of analysis.	UPV 21r4	Functional /Technical req	21-i4Q_LRT	ok	Data Acquisition & Transformation, Data Storage & Transfer
Before the execution of a part program, the system shall be able to foresee the final workpiece quality (surface roughness) from the analysis of the defined processing parameters.	PC1r 13	Functional /Technical req	11-i4Q_BDA, 21-i4Q_LRT	ok	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
Before the execution of a part program, the system shall be able to foresee if chatter will take place from the analysis of the foreseen processing parameters and the knowledge of previous chatter conditions on the same machine.	PC1r17	Functional /Technical req	11-i4Q_BDA, 21-i4Q_LRT	ok	Data Analytics
The system shall be able to correlate the computed trends with the degradation of specific components (failure modes).	PC1r20	Functional /Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 18-i4Q_QD, 21-i4Q_LRT	ok	Data Analytics
Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected degradation of specific components (failure modes).	PC1r21	Functional /Technical req	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT	ok	Data Analytics
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert the needed data (for example torque, micro-marker values, …).	PC2r10	Functional /Technical req, Usability and Quality req	9-i4Q_DIT, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics, Data Visualization
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to define the data acquisition parameters (for	PC2r11	Functional /Technical req	9-i4Q_DIT, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics, Data Visualization

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
example sampling frequency, resolution, …).					
i4Q ALGORITHMS: For each established algorithm, the system should provide an uncertainty analysis with a confidence level of 95 %. With the aim to define the reliability of the developed algorithms to identify machine problems.	PC2r12	Usability and Quality req	11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics
i4Q ALGORITHMS: When change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, …), the system shall scale the output data from the algorithms and/or the thresholds of the algorithms within constraint conditions.	PC2r13	Functional /Technical req, Usability and Quality req	9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics
The system shall be able to collect and save vibration data produced by the tool according to a certain number of cycles.	PC4r14	Functional /Technical req	8-i4Q_DR, 15-i4Q_IM, 18-i4Q_QD, 21-i4Q_LRT	ok	Data Analytics
Proactive quality optimization shall be performed through the deployment of the i4Q_PQ, i4Q_LRT and i4Q_DA.	PC5r8	Functional /Technical req	10-i4Q_DA, 17-i4Q_PQ,	tbc*1	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
			21-i4Q_LRT		
Process qualification or machine certification can be done by successfully predicting product quality without manual test and inspection which takes a lot of time and effort.	PC6r16	Functional /Technical req, Guidelines req	17-i4Q_PQ, 21-i4Q_LRT, 22-i4Q_LCP	ok	Data Analytics, Guidelines

Table 37. i4Q^{LRT} System requirements mapped to i4Q Solution

Comment to tbc*1 :

„In addition, the system suggests processing parameters that reduce the rate of vibration and reconfigures the production line.“

3.3.22 i4Q^{LCP} Manufacturing Line Data Certification Procedure

3.3.22.1 Main functions/services

This solution consists of a guideline and a related digital assistant. The **guideline** describes the certification procedure based on standards and further guidelines is developed. i4Q^{LCP} will support standardization and implementation of data processes in manufacturing lines considering the Service Oriented Architecture (SoA) and the state with implemented i4Q solution. Based on this information, a workflow is developed and transferred into a procedure. The procedure contains all necessary steps a company needs to perform to ensure the full functionality of all i4Q solutions. The guideline and procedure are the standard audit document for ensuring long term functionality and ensure stable and performant processes and product quality. The **digital assistant** is a so-called conversational AI. It supports users via natural language communication during the audit. The assistant will provide, for instance, information about audit steps and it will allow users to monitor audit progress. The assistant integrates the functionality of the QualiExplore i4Q^{QE} (3.3.2.) solution and may also interact with other i4Q solutions relevant to an audit. The digital assistant incorporates the information described in the guideline. This concerns workflows and checklists. Since building the assistant relies on training data, it will require example conversations.

3.3.22.2 Requirements for i4Q^{LCP}

Table 38 shows the system requirements of the pilots in relation to the i4Q Solutions. In the first column, a detailed description about the specific requirement is listed. The second column contains the requirement's ID. Then the type of system requirements is mentioned beside. Further, the next column lists the associated i4Q Solutions. To achieve a clear vision of the solution provider's opinion, the next column notes the status of each relationship between the system requirement and i4Q Solutions. In case, the requirement needs "to be clarified" (tbc), more information is executed under the table. The last column shows the classification of the requirements.

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
An audit procedure for manufacturing resources (machine, cell or manufacturing line) shall be developed to ensure the accuracy and reliability of data from the manufacturing process.	TUB22 r1	Guidelines req	22-i4Q_LCP	ok	Guidelines
Knowledge shall be transferred to the employees through training according to guidelines and applied standards.	TUB22 r2	Guidelines req, Usability and Quality req	22-i4Q_LCP	ok	Guidelines
While retrieving the information from the sources listed above, the system shall be able to compute the differences between the various time references systems and synchronize the timestamps for all retrieved data.	PC1r8	Functional/ Technical req	9-i4Q_DIT, 22-i4Q_LCP	tbc*1	Data Acquisition & Transformation
While moving any data from the CNC to another repository, the system shall guarantee the security of the data against any type of intrusion.	PC1r11	Security req	4-i4Q_TN, 6-i4Q_SH, 22-i4Q_LCP	tbc*2	Data Storage & Transfer

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert the needed data (for example torque, micro-marker values, …).	PC2r10	Functional/ Technical req, Usability and Quality req	9-i4Q_DIT, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	tbc*3	Data Analytics, Data Visualization
i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to define the data acquisition parameters (for example sampling frequency, resolution, …).	PC2r11	Functional/Technical req	9-i4Q_DIT, 21-i4Q_LRT, 22-i4Q_LCP	tbc*4	Data Analytics, Data Visualization
i4Q ALGORITHMS: For each established algorithm, the system should provide an uncertainty analysis with a confidence level of 95 %. With the aim to define the reliability of the developed algorithms to identify machine problems.	PC2r12	Usability and Quality req	11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	tbc*5	Data Analytics
i4Q ALGORITHMS: When change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, …), the system shall scale the output data from the algorithms and/or the thresholds of the algorithms within constraint conditions.	PC2r13	Functional/Technical req, Usability and Quality req	9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP	tbc*6	Data Analytics

Requirement definition (related to the i4Q solution)	ID	Type of requirement	i4Q Solutions connected/ mapped to this Req.	Status	Classification
OTHER: At the end of i4Q project, all the involved partners have to Identify the limits and improvements that need to be overcome for future development in ascending order of importance.	PC2r19	Guidelines req	22-i4Q_LCP	ok	Guidelines
Feature selection should be done in a way that will reduce data flow load but not affect parameter optimization performance.	PC6r5	Usability and Quality req	7-i4Q_DRG, 9-i4Q_DIT, 17-i4Q_PQ, 22-i4Q_LCP	tbc*7	Data Acquisition & Transformation, Data Visualization
By using the machine monitoring parameters of the injection machine with different machine learning methods, the quality of the parts produced from the machine shall be increased as well as the faulty piece number decreased.	PC6r8	Usability and Quality req	18-i4Q_QD, 22-i4Q_LCP	tbc*8	Data Analytics, Guidelines
Process qualification or machine certification can be done by successfully predicting product quality without manual test and inspection which takes a lot of time and effort.	PC6r16	Functional/ Technical req, Guidelines req	17-i4Q_PQ, 21-i4Q_LRT, 22-i4Q_LCP	tbc*9	Data Analytics, Guidelines

Table 38. i4Q[LCP] System requirements mapped to i4Q Solution

Comment to tbc*2, tbc*3, tbc*4, tbc*5, tbc*6, tbc*7, tbc*8, tbc*9:

"The guideline will not work with data or provide detailed information how analysis is performed. However, it is a guidance which leads how i4Q Solution are implemented, established, and maintained. Detailed Information will be more specific in upcoming standards."

4. Overall Context Description

4.1 Description of the overall interrelationships and interfaces of the requirements

The sets of requirements for the pilots and solutions are shown in Section 2.3 (Pilots) and Section 3.3 (Solutions). To describe the overall context and interrelations of these requirements, several quantitative and qualitative analysis results will be presented.

Before these analyses were performed, all requirements which were not complied by the solution providers were deleted from these lists. The requirements which should be clarified later are counted in those analyses. It must be said that this represents the status of requirements elicitation. This document presents the first version of "Requirement's analysis and functional specifications" and will be updated during the next 5 months until the second version will be submitted in M9 in deliverable D1.9. To get an impression of what is needed and required by the partners - especially the pilot providers and solutions providers - the following diagrams and analysis results will give an overview.

4.1.1 Requirements: Classification

The classification into *Data Acquisition & Transformation, Data Storage & Transfer, Data Analytics, Data Visualization and Data Guidelines* is explained in Section 3.1. **Figure 12, Table 39** and **Table 40** provide an overview of the classification related to the pilots. Further, the number of requirements that are found for each class and their related solutions are shown.

Main findings:

- The requirements of the six pilots match almost all these classes, only the data guidelines were not mapped to Pilot 1 and Pilot 3 (**Figure 12**). This demonstrates the comprehensive needs of the pilots regarding the i4Q RIDS.
- The heat map of the requirements classification related to the pilots (**Table 39**) show where the main challenges currently are. Pilot 4 has many data storage and transfer requirements which correlates to their main challenges in digitization of manufacturing data. Overall, pilots name data analytics requirements the most. Since there are several analytical solutions in i4Q RIDS, there are still some aspects to clarify, which requirement fits best to the solutions.
- Throughout the requirements, i4Q Solutions are mapped to several classes. The mapping of solutions to these classes shows that the solution providers do not intend to meet all the assigned classes (**Table 40**).
- **Table 39** shows that all classes are assigned multiple times. Data Analytics is seen as the class with most interrelations. This fits to the heat map which shows that the analytical part is required the most.
- *Data Acquisition and Transformation* is mainly performed by 9-i4Q_DIT (see Section 4.1.4).
- *Data Storage and Transfer* is mainly performed by 8-i4Q_DR (see Section 4.1.4).
- *Data Analytics* is the main class, most i4Q solutions are mapped here, also because analytics is a wide field with several applications. Functions and services of the i4Q solutions are in some cases overlapping. Therefore, some cases follow different strategies

to fulfil the requirements, which leads to further clarification. In this class there are also the most interdependencies between the solutions.

- *Data Visualization* is mainly performed by i4Q_AD which has 28 requirements at the moment. There will be upcoming requirements when the data analytics solutions will be specified.
- There are five *Data Guidelines* planned in i4Q Project. These guidelines will probably fit for all the pilots even they are not all connected to this class yet. Requirements are mainly defined by the guideline providers, only few requirements are collected from pilot providers so far.

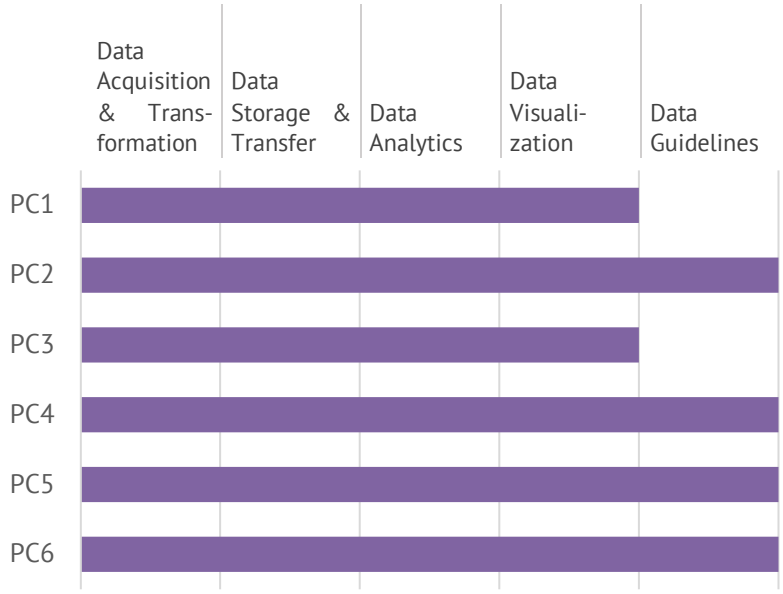

Figure 13. Pilots that named requirements mapped to the Classification

	Data Aquisition & Transformation	Data Storage & Transfer	Data Analytics	Data Visualization	Data Guidelines	Σ
PC1	7	6	12	1	0	26
PC2	5	4	7	7	1	24
PC3	2	4	6	2	0	14
PC4	9	12	10	11	1	43
PC5	5	5	6	2	1	19
PC6	8	5	11	1	2	27
Σ	**36**	**36**	**52**	**24**	**5**	**153**

Table 39. Frequency of pilot requirements mapped to the Classification

Class	i4Q Solutions																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Data Acquisition & Transformation				X					X					X	X							
Data Storage & Transfer			X	X		X		X						X	X							
Data Analytics									X	X	X		X	X	X	X	X	X	X		X	
Data Visualization											X	X			X	X	X	X	X		X	
Data Guidelines	X	X			X		X													X		X

Table 40. i4Q Solutions mapped to the Classification

Since the solution mapping has sometimes weaker edges between the classes, comments that were gathered are outlined as follows:

- Data Guidelines in Solution 2-i4Q_QE: i4Q_QE uses a static knowledge base. Therefore, it is similar to a guideline. Though it also visualizes the knowledge.
- Data Analytics in Solution 13-i4Q_AI and 14-i4Q_EW: This is the closest class for these services, there is not data analytics per se, but enabling technologies.
- Data Visualization in Solution 19: Visualization is not one of the objectives of i4Q_PA, but it will be needed.

4.1.2 Requirements: Type

Five different types of requirements are explained in Section 3.1. Throughout, one or two types are assigned to each requirement. **Figures Figure** 13 and Figure 14 present the distribution over these types of requirements for all six pilots (**Figure 13**) and 22 i4Q Solutions (**Figure 14**). All types of requirements are assigned multiple times. The most often type is "functional/technical req." which is reasonable in this project with a technical background. In this first version of requirements the functional and technical requirements are listed in one type because most of the requirements are related to both as they are in a generic form.

Main findings:

- The focus is on *functional/technical requirements*. They can be found in every pilot and almost every solution. Functional/technical requirements will be analysed and specified in further requirements elicitation for all pilots and solutions. In the second version of this deliverable (D1.9), this type may be separated into two, functional *and* technical.
- The largest number of *functional/technical requirements* was collected for 8-i4Q_DR, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD and 18-i4Q_BDA. These are currently the i4Q solutions with the clearest functionalities for customer (pilot) usage.

- There are already some *interface requirements* gathered. But as the function structure of the solutions is not ready yet, the interfaces will be specified in further process and modelled in SysML models (see Section 4.2).
- *Usability and quality requirements* can be found in almost every solution. For i4Q QualiExplore for Data Quality Factor Knowledge, i4Q Analytics Dashboard and i4Q Manufacturing Line Data Certification Procedure (2-i4Q_QE, 12-i4Q_AD, 22-i4Q_LCP) most usability and quality requirements is elicited. This makes sense, as these three solutions will be developed user-friendly for operators and managers to support the data management in manufacturing.
- *Security requirements* were not mentioned by many pilot providers so far. This will change in further process as all pilots have security standards in their factories.
- The largest amount of *security requirements* can be found in i4Q IIoT-Security Handler (6-i4Q_SH). There are many points to be clarified what this solution will exactly provide for the pilots.
- *Guideline's requirements* are very few and often combined with *usability and quality requirements* as guidelines should be easy and helpful to use.

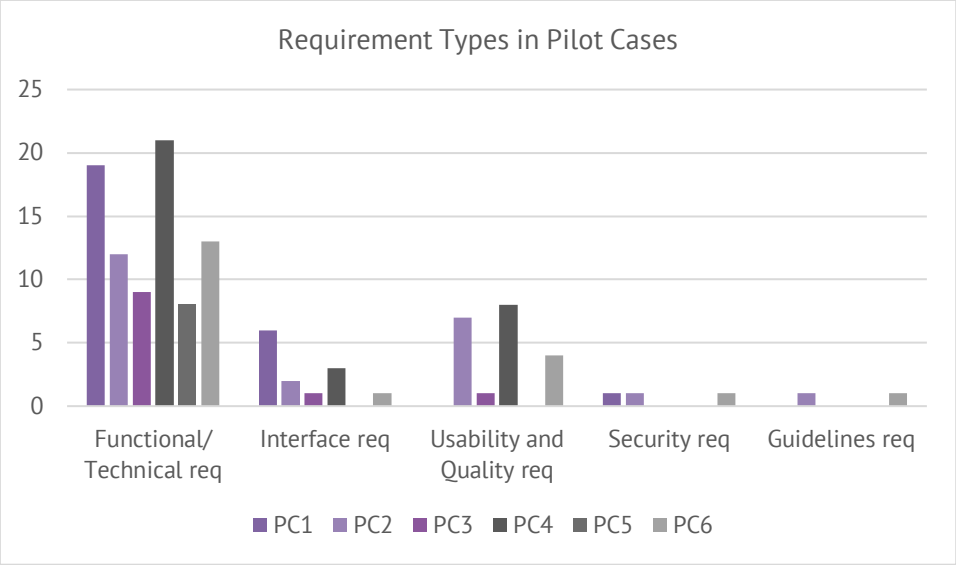

Figure 14. Frequency of requirements per Type of requirement

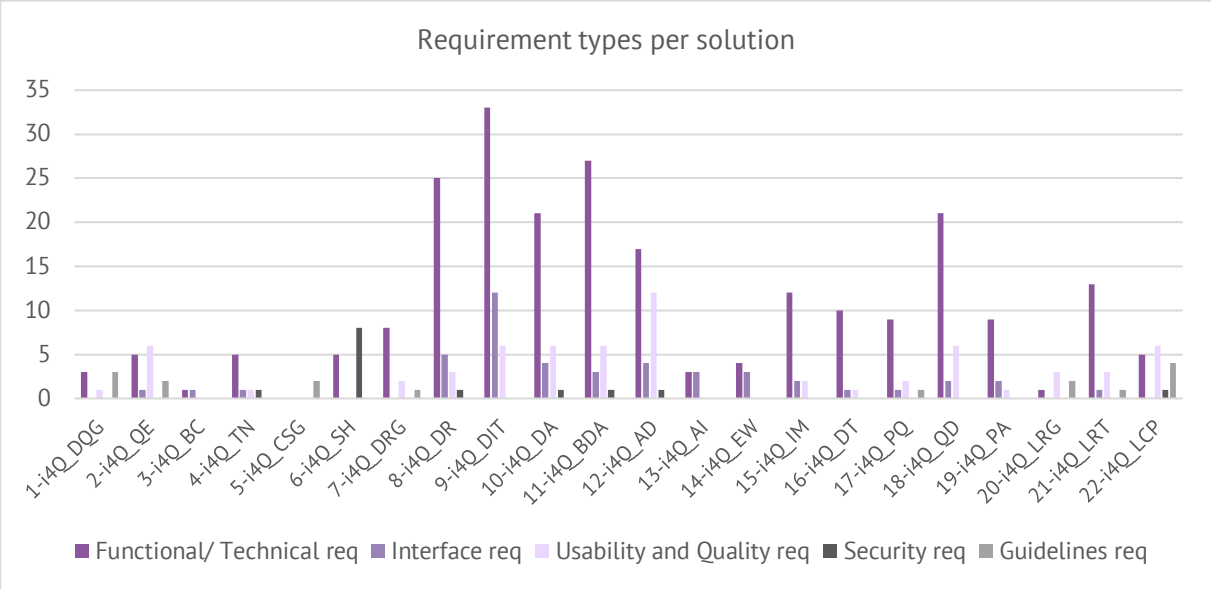

Figure 15. Frequency of type of requirements per i4Q Solution

4.1.3 Requirements: Priority & Difficulty

The overall assignment of priorities and difficulties is shown in **Figure 16**. The requirements without an assessment were mostly gathered with the *further requirements template*. All assessed requirements are pilot-specific requirements.

Main findings:

- The requirements assessed were predominantly rated as high priority. Since in this first version of the requirements elicitation mainly generic requirements were collected, it is understandable that these are important - high priority - requirements.
- The difficulty was predominantly rated between nominal and difficult. Considering the complexity of the 22 different i4Q Solutions and the connections between them, as well as the implementation in six different pilot use cases, the general assessment could be "difficult". However, the requirements collected are diverse and, in some cases, even easy to meet.

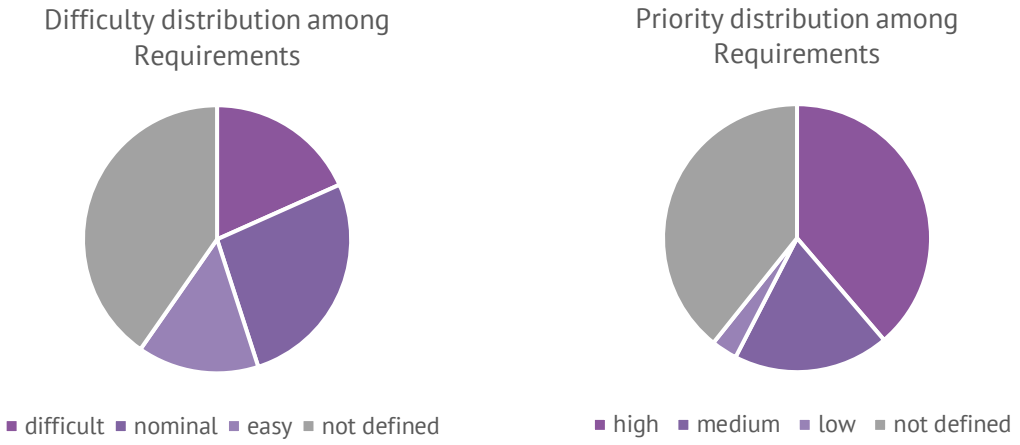

Figure 16. Assessment of requirements in terms of priority (left) and difficulty (right)

4.1.4 Requirements: mapping to i4Q Solutions

Figure 17 shows how many requirements are elicited for each i4Q Solution and how often they were assigned by the pilots. This gives an orientation of how concrete the needs and requirements for each solution currently are.

Main findings:

- The five guideline solutions (1-i4Q_DQG, 5-i4Q_CSG, 7-i4Q_DRG, 20-i4Q_LRG, 22-i4Q_LCP) have less requirements than other solutions. This is reasonable in this early stage of the project. Also, the guidelines will fit to all pilot cases and have mainly generic and pilot-unspecific requirements.
- For the structural solutions such as i4Q Blockchain Traceability of Data, i4Q Trusted Networks with Wireless & Wired Industrial Interfaces, i4Q IIoT-Security Handler, i4Q AI-Models Distribution to the Edge, i4Q Workloads Placement and Deployment (3-i4Q_BC, 4-i4Q_TN, 6-i4Q_SH, 13-i4Q_AI, 14-i4Q_EW), there are only few requirements in this first version. This could be explained by many open issues in the use and application of these solutions. This should be clarified later in the process when more requirements will be added.
- The integration of the functionality of the i4Q QualiExplore (2-i4Q_QE) into i4Q Manufacturing Line Data Certification Procedure (22-i4Q_LCP) and the interaction of them with other audit-relevant i4Q Solutions is not included yet. Other interface requirements are also still missing and will be later integrated in the SysML models.
- i4Q Data Repository (29), i4Q Data Integration and Transformation Services (39) and i4Q Big Data Analytics Suite (32) solutions (8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA) have the most requirements mapped, which are mainly complied. This shows how important and clear the need of data acquisition and storage is for all pilot cases. There are some duplicates or similarities in these requirements but nevertheless the usage can be foreseen, even though the quality and quantity of data is not yet finally specified.
- The main solution for data visualization is the i4Q Analytics Dashboard (12-i4Q_AD). This solution has 28 requirements assigned and will be used by all the pilots. In this solution the usability is important and the well working connection to the data repository and all analytical solutions should be ensured. There are several aspects to be clarified later in process.
- There are some doubts about the usage of i4Q Digital Twin Simulation Services (16-i4Q_DT) in pilot case 2 and 3. During the technical discussions for requirements elicitation and business process modelling, i4Q_DT was not assigned to these pilots. The requirements templates indicate that i4Q_DT is needed and closely linked with i4Q_PA. Additionally, the DT solution is maybe not used in PC4 although this was planned in D1.3.

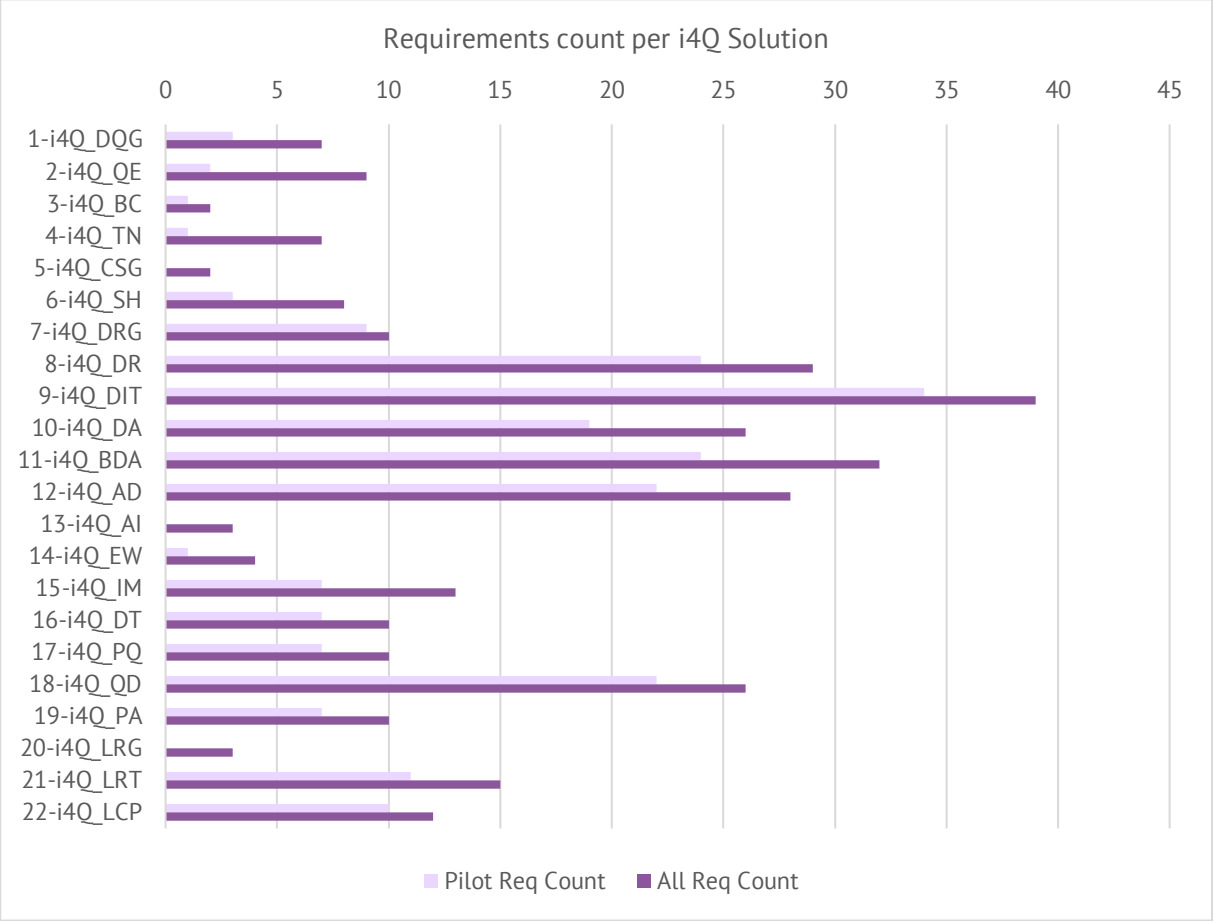

Figure 17. Frequency of requirements per i4Q Solution

4.1.5 Requirements: Interrelationships and interdependencies

In Section 2.3 and Section 3.3 the connections of requirements to i4Q Solutions were listed. **Table 41** gives a first idea of how these solutions should be developed in synergies. This could be used as an input for WP 2. In **Table 41** the 15 pilot-specific requirements with four or more connections to i4Q Solutions are listed.

Main findings:

- The listed requirements are mostly assigned to the class **Data Analytics.**
- Interface risks should be found early and reduced in product development process.
- Synergies of different analytical solutions shall be found and used.
- Synchronization between developers is important and must be done via clear communication, e.g., via functional structures and SysML models for each i4Q Solution.
- SysML will support the further modelling of the functions, requirements and interrelationships of the pilots and solutions (see Section 4.2).

Req. ID	Requirement Description	Connections	Connections to i4Q Solutions
PC1r20	The system shall be able to correlate the computed trends with the degradation of specific components (failure modes).	5	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 18-i4Q_QD, 21-i4Q_LRT
PC1r21	Before the execution of a part program, the system shall be able to suggest processing parameters that reduce the rate and/or the impact of the detected degradation of specific components (failure modes).	6	11-i4Q_BDA, 15-i4Q_IM, 16-i4Q_DT, 17-i4Q_PQ, 19-i4Q_PA, 21-i4Q_LRT
PC2r6	i4Q ALGORITHMS: When data are read from the sources (for example BIESSE CNC and/or data repository), the system shall predict the component degradation under investigation within one day, by analysis performed in time and frequency domain. This goal requires an interaction with the following "i4Q ALGORITHMS" group of goals.	4	10-i4Q_DA, 11-i4Q_BDA, 18-i4Q_QD, 19-i4Q_PA
PC2r10	i4Q ALGORITHMS: Once an algorithm is established, the system should provide an "administration interface" to insert the needed data (for example torque, micro-marker values, ...).	4	9-i4Q_DIT, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP
PC2r13	i4Q ALGORITHMS: When change the machine model or the boundary conditions of the test (for example, temperature conditions, customer operating pressure, ...), the system shall scale the output data from the algorithms and/or the thresholds of the algorithms within constraint conditions.	5	9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA, 21-i4Q_LRT, 22-i4Q_LCP
PC3r1	The system shall predict the product conformity.	5	1-i4Q_DQG, 2-i4Q_QE, 9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA
PC4r13	The system shall learn and be able to establish critical working ranges.	4	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 19-i4Q_PA

Req. ID	Requirement Description	Connections	Connections to i4Q Solutions
PC4r14	The system shall be able to collect and save vibration data produced by the tool according to a certain number of cycles.	4	8-i4Q_DR, 15-i4Q_IM, 18-i4Q_QD, 21-i4Q_LRT
PC5r4	Realtime/proactive analysis on the raw matter's composition and granulometry shall be performed continuously by using the i4Q_DA, i4Q_BDA, i4Q_AD and i4Q_QD.	4	10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 18-i4Q_QD
PC5r5	Realtime data collection, transformation, integration and storage of e.g., Spectrometry + granulometry analysis results, chemometry benchmarking data (enables mapping raw matter composition to specific quantities of constituents), purchase order, cargo bill should be realised through the deployment of i4Q_DIT, the i4Q_DQG and i4Q_DR.	4	1-i4Q_DQG, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT
PC5r6	Realtime data integration and transformation of all data coming from the production line and Quality Assurance should be managed through the deployment of the i4Q_DIT.	4	1-i4Q_DQG, 7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT
PC5r7	Quality issues/defects root cause analysis shall be realised using integrated data from production processes by the application and integration of several i4Q solutions, such as the i4Q_DA, i4Q_BDA and i4Q_AD. There is also the possibility to use i4Q_DT and i4Q_QE.	5	2-i4Q_QE, 10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD, 16-i4Q_DT
PC6r3	Data pipeline should be established to be able to use the data for other objectives.	5	7-i4Q_DRG, 8-i4Q_DR, 9-i4Q_DIT, 11-i4Q_BDA, 12-i4Q_AD
PC6r5	Feature selection should be done in a way that will reduce data flow load but not affect parameter optimization performance.	4	7-i4Q_DRG, 9-i4Q_DIT, 17-i4Q_PQ, 22-i4Q_LCP
PC6r15	Injection machine parameters should be optimized using analytical solution.	6	8-i4Q_DR, 10-i4Q_DA, 12-i4Q_AD, 16-i4Q_DT, 17-i4Q_PQ, 18-i4Q_QD

Table 41. Pilot-specific requirements with four or more connections to i4Q Solutions

4.1.6 Requirements for Data Quality

Data Quality is an essential part for usage of any kind of data analytic system and is described in ISO 8000. Therefore, requirements for data quality are needed to ensure the full functionality of i4Q Solutions related to data analytics. At the current state of the project and T1.4 most of the pilot providers describe the available data in the requirements elicitation document in an unspecific manner like e.g., CNC parameters, time series, and various flat file formats. Data quality is not directly addressed. This is also the case for the requirements elicitation document of the i4Q Solution developers. To achieve the best possible project outcome the data quality related requirements of pilot providers and i4Q Solution developers will be iteratively refined in the next steps of requirements analysis. Additionally, concepts how data quality can be achieved, ensured, and monitored is part of i4Q[DQG] and i4Q[QE].

4.2 Model in SysML – System Requirements (Outlook)

4.2.1 OMG Systems Modelling Language SysML

SysML The **OMG Systems Modeling Language™** (**OMG SysML®**)[3] is a general-purpose graphical modeling language for specifying, analyzing, designing, and verifying complex systems that may include hardware, software, information, personnel, procedures, and facilities.

In particular, the language provides graphical representations with a semantic foundation for modeling system requirements, behavior, structure, and parametrics, which is used to integrate with other engineering analysis models.

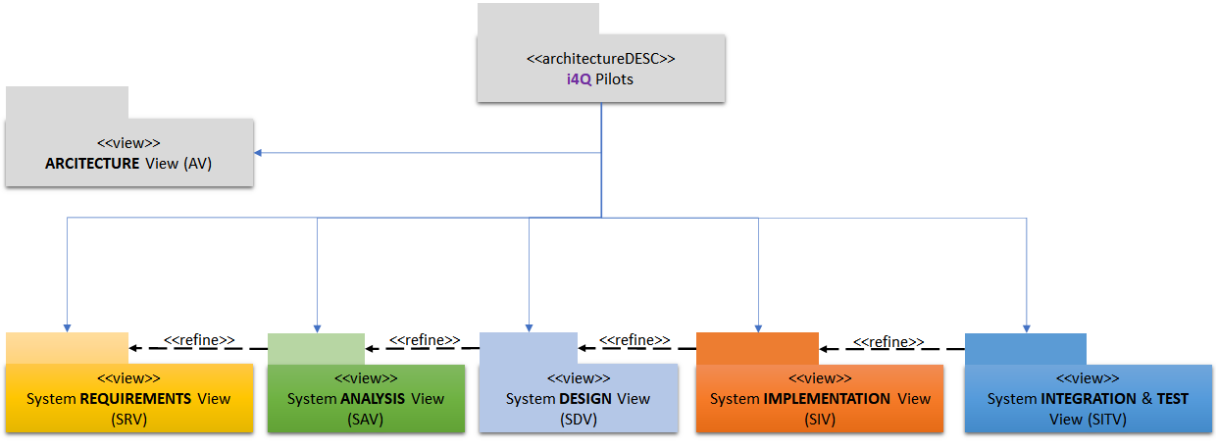

Figure 18. SysML Views/Layers

The SysML Diagram Views/Layers are:

- System **ARCITECTURE** View (**AV**) – The SysML Package diagrams in this layer illustrate how the System Architecture is organized into complementary Views and Viewpoints,

[3] https://sysml.org/

consistent with international standards (ISO/IEC/IEEE 42010:2011) and Model-Based Systems Engineering (MBSE)4 best practices.

- System **REQUIREMENTS** View (S**R**V) – This layer specifies the **Functional** Requirements and the **Non-Functional** Requirements (NFRs) of the subject System-of-interest, that must be satisfied by Unit, Integration, and System Test Cases (TCs).
- System **ANALYSIS** View (S**A**V) – This layer specifies the high-level functions, logical components, and logical data of the subject System-of-interest. In general, the System Analysis *satisfies* the *Requirement «view»*, and in turn it is refined by the *System Design «view»*.
- System **DESIGN** View (S**D**V) – This layer specifies the low-level (detailed) functions, physical components, and physical data of the subject System-of-interest. In general, the System Design *refines* the *System Analysis «view»*, and in this manner transitive refines System Requirements traceability.
- System **IMPLEMENTATION** View (S**I**V) – This layer specifies the construction of the physical Software Components, Hardware Components, and Mechanical Components that implement the subject physical System-of-interest.
- System **INTEGRATION** & **TEST** View (S**IT**V) - This layer specifies the System Test Cases must exhaustively test the System Design and Implementation using black-box and white-box Test Cases at the Unit, Integration, and System levels.

SysML Modelling Language will be used in i4Q Pilots to analyse their requirements gathered and classified in this deliverable (Section 2.3), and afterwards refine them during the following phases of the project, in fact in D1.9 document, specifically using its above defined diagrams, that provide a transition from traditional processes that are document-based and code-centric to more efficient and effective processes that are model-based (or model-driven). All the processes defined in SysML revolves around the requirements of a system. Section 4.2.2 shows some examples for SysML modelling for Pilot 4.

[4] https://mbseworks.com/

4.2.2 Example of Pilot 4: Aeronautics and Aerospace Metal Parts Quality

*4.2.2.1 Requirements Diagram for Business Process - P4-BP**01** – In-line product quality control*

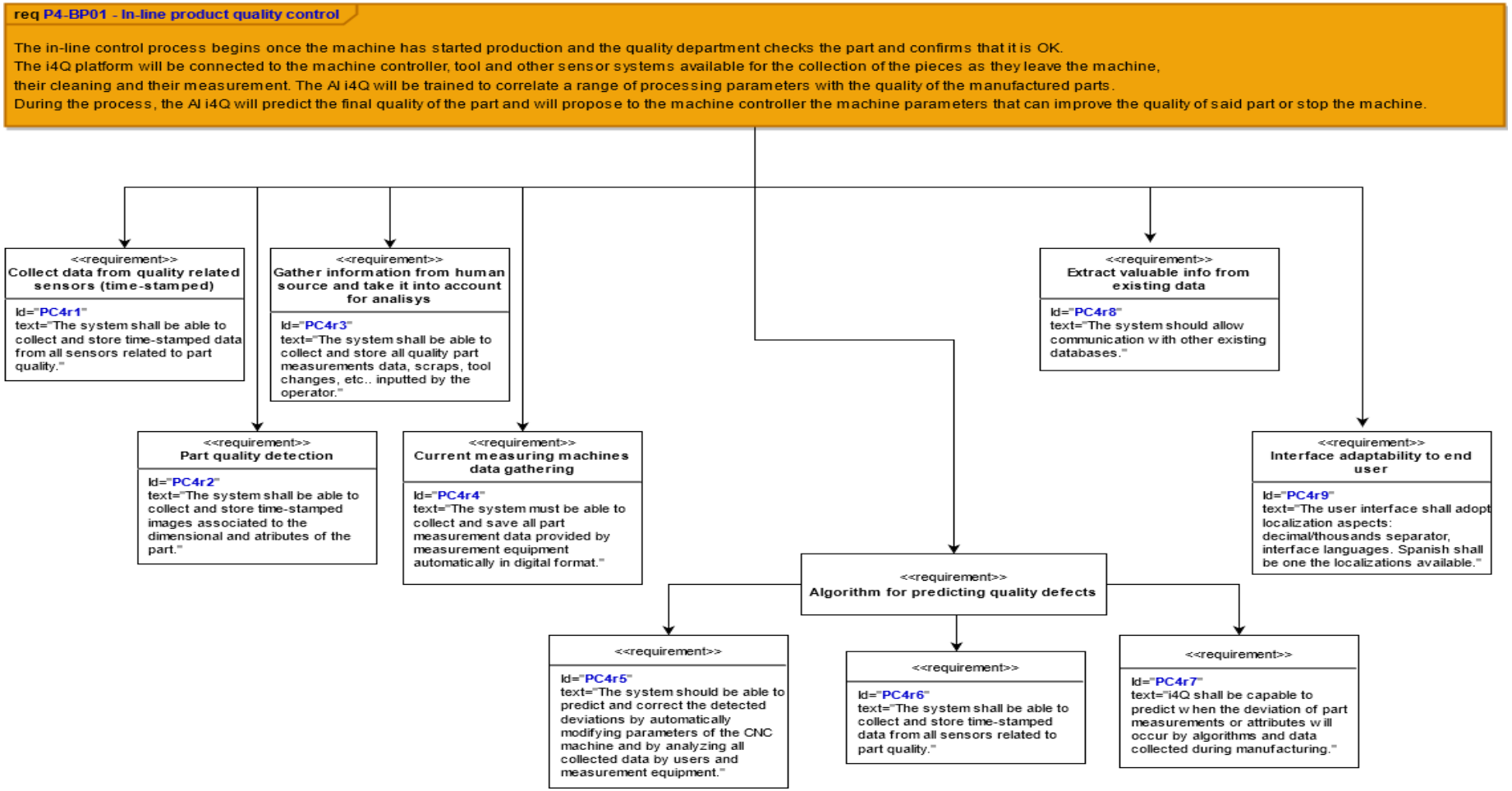

Figure 19. SysML Requirements Diagram – FACTOR – P4-BP01

*4.2.2.2 Requirements Diagram for Business Process - P4-BP**02** - Automatic online correction of the CNC machining process*

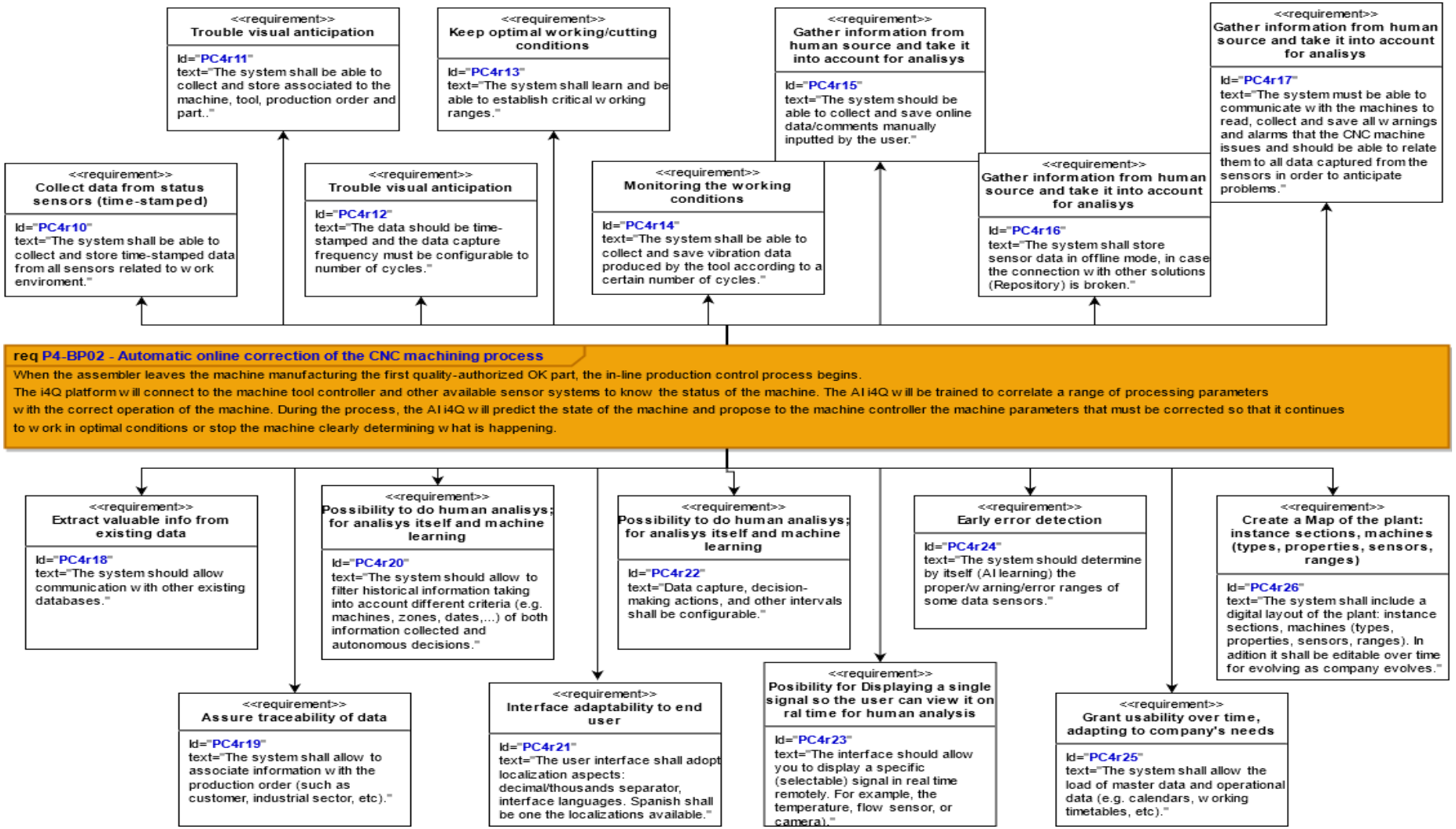

Figure 20. SysML Requirements Diagram – FACTOR – P4-BP02

5. Conclusions

Deliverable D1.4 gives an overview of the requirements engineering in i4Q project. In this first version of the "Requirements Analysis and Functional Specifications" the complex and extensive process was started gathering requirements from all 24 partners who have different starting points, various needs, and expectations for the 22 i4Q Solutions. A suitable requirements elicitation and analysis procedure was developed according to ISO/IEC/IEEE 29148 (ISO/IEC/IEEE 29148:2018-11), ISO/IEC/IEEE 12207 (ISO/IEC/IEEE 12207:2017-11) and ISO/IEC/IEEE 15288 (ISO/IEC/IEEE 15288:2015-05-15). These standards are used as the basis for collecting factories' requirements for Smart Manufacturing in the context of quality control and adapted to the i4Q approach. Additionally, the process is performed with respect to the standards VDI 2221 (VDI 2221-1:2019-11 and VDI 2221-2:2019-11) and VDI 2206 (VDI 2206:2004-06) which describe the design of technical products and systems (VDI 2221) as well as a design methodology for mechatronic systems (VDI 2206). The system limitations of the requirements engineering in the i4Q Project are focused on stakeholder, system, and software requirements which all contribute to fulfil the i4Q business requirements, e.g., the realization of Zero-Defect-Manufacturing through the set of i4Q Solutions.

To clarify and itemise the project task and to obtain an information base consisting of requirements, several sources for requirements elicitation were used. These sources, consisting of the pilot providers, technical partners, the solution providers, and a literature review provide a first version of requirements for the i4Q RIDS. This interdisciplinary i4Q approach combines stakeholder interests, requirements of end-users in factories, and technical providers of software solutions at the same time. These two perspectives are matched during requirements engineering to elicit complete sets of requirements for each i4Q Solution. This deliverable represents the first version and an interim result of the definition of the requirements and specifications of each i4Q Solution that should be developed during the project.

In Section 2, first, the methodology of requirements elicitation procedure and the state-of-the-art analysis was presented with its list of resulting requirements from literature. Then, the six pilots that define as end-users the context of use in i4Q Project were presented with their main challenges regarding i4Q RIDS and the corresponding lists of stakeholder and system requirements. These requirements were mainly gathered during pilot specific technical discussions between end-users and solution providers which were also useful for deliverable D1.3 in which the AS-IS and TO-BE scenarios were described. These stakeholder requirements were recursively transformed into functional, system, and software requirements and mapped to the i4Q Solutions by the technical partners. Finally, further knowledge and expertise were added including the connection to the ethics aspects that are mainly gathered in D1.6 Data Management Plan.

In Section 3 the elicited requirements were mapped to the 22 i4Q Solutions to analyse them and prepare the information base for the function structures. First, the requirements analysis method was described. Then, the results for each i4Q Solutions were presented by describing the main functions/services and the assigned requirements, from the pilots and the solution providers, combined in lists of requirements for the 22 i4Q Solutions.

In Section 4 the results of the first version of requirements are evaluated. The main needs for the further requirements elicitation and analysis and functional specifications are discussed. The clustering of requirements and the quantitative and qualitative results are presented. Some i4Q Solutions have already large lists of requirements which contain several doublings or similarities because e.g., the needs in data acquisition and data storage are similar. In data analytical solutions there are several connections between solutions, these dependencies should be considered in the further product development process in order to avoid risks and benefit from synergies. The requirements are mainly functional/technical requirements, security and interface requirements have been considered less, here more specific requirements should be added later. There are still many open aspects regarding the requirements that should be clarified later in process.

The use of the open-source system modelling language SysML[5] is presented, which provides the following system diagrams: system ARCHITECTURE view, system REQUIREMENTS view, system ANALYSIS view, system DESIGN view, system IMPLEMENTATION view and system INTEGRATION & TEST view. For the next iterations of requirements elicitation and analysis the procedures will be adjusted to derive more detailed and specific requirements and include additional information. The open-source system modelling language SysML will be used to describe, visualize, and document complex structures of requirements interfaces and (inter-)dependencies. This forms the basis for the functional specifications. The second version of this document (deliverable D1.9) will provide a detailed definition of the system and software requirements as well as the functional specification.

[5] https://sysml.org/

References

AS9100, Quality Systems - Aerospace - Model for Quality Assurance in Design, Development, Production, Installation and Servicing (https://www.sae.org/standards/content/as9100/)

Azevedo, Américo; Almeida, António (2011): Factory Templates for Digital Factories Framework. In: *Robotics and Computer-Integrated Manufacturing* 27 (4), pp. 755–771. DOI: 10.1016/j.rcim.2011.02.004.

Barton, David; Gönnheimer, Philipp; Schade, Florian; Ehrmann, Christopher; Becker, Jürgen; Fleischer, Jürgen (2019): Modular smart controller for Industry 4.0 functions in machine tools. In: *Procedia CIRP* 81, pp. 1331–1336. DOI: 10.1016/j.procir.2019.04.022.

Günther, Lisa C.; Colangelo, Eduardo; Wiendahl, Hans-Hermann; Bauer, Christian (2019): Data quality assessment for improved decision-making: a methodology for small and medium-sized enterprises. In: *Procedia Manufacturing* 29 (8), pp. 583–591. DOI: 10.1016/j.promfg.2019.02.114.

ISO/IEC/IEEE 12207:2017-11, Systems and software engineering - Software life cycle processes (ISO/IEC/IEEE 12207:2017-11)

ISO/IEC/IEEE 15288:2015-05-15, Systems and software engineering - System life cycle processes (ISO/IEC/IEEE 15288:2015-05-15)

ISO/IEC/ IEEE 29148:2018-11, Systems and software engineering - Life cycle processes - Requirements engineering (ISO/IEC/ IEEE 29148:2018-11)

ISO/IEC/IEEE 42010:2011, Systems and software engineering — Architecture description (ISO/IEC/IEEE 42010)

Kuhn, Marlene; Funk, Felix; Franke, Jörg (2021): Blockchain architecture for automotive traceability. In: *Procedia CIRP* 97, pp. 390–395. DOI: 10.1016/j.procir.2020.05.256.

Liu, L.; Chi, L., 2002. Evolutional Data Quality: A Theory-Specific View. In *ICIQ,* pp. 292-304.

Mamledesai, Harshavardhan; Soriano, Mario A.; Ahmad, Rafiq (2020): A Qualitative Tool Condition Monitoring Framework Using Convolution Neural Network and Transfer Learning. In: *Applied Sciences* 10 (20), pp. 7298. DOI: 10.3390/app10207298.

Mantravadi, Soujanya; Schnyder, Reto; Moller, Charles; Brunoe, Thomas Ditlev (2020): Securing IT/OT Links for Low Power IIoT Devices: Design Considerations for Industry 4.0. In: *IEEE Access* 8, pp. 200305–200321. DOI: 10.1109/ACCESS.2020.3035963.

MBSE - https://mbseworks.com/

Pfirrmann, D.; Voit, M.; Eckstein, M. (2019): QUALITY CONTROL OF A MILLING PROCESS USING PROCESS DATA MANAGEMENT IN THE AEROSPACE INDUSTRY. In: *MM SJ* 2019 (04), pp. 3067–3070. DOI: 10.17973/MMSJ.2019_11_2019052.

SysML - www.sysml.org

Unver, Berna; Kabak, Özgür; Topcu, Y. Ilker; Altinisik, Armagan; Cavusoglu, Ozcan (2020): A decision support system for proactive failure prevention: a case in a leading automotive company. In: *JEIM* 33 (5), pp. 845–880. DOI: 10.1108/JEIM-09-2019-0264.

VDI 2221-1:2019-11, Design of technical products and systems, Part 1: Model of product design (VDI 2221-1:2019-11)

VDI 2221-2:2019-11, Design of technical products and systems, Part 2: Configuration of individual product design processes (VDI 2221-2:2019-11)

VDI 2206:2004-06, Design methodology for mechatronic systems (VDI 2206:2004-06)

Wan, Shan; Li, Dongbo; Gao, James; Roy, Rajkumar; Tong, Yifei (2017): Process and knowledge management in a collaborative maintenance planning system for high value machine tools. In: *Computers in Industry* 84 (1), pp. 14–24. DOI: 10.1016/j.compind.2016.11.002.

Yang, Helin; Alphones, Arokiaswami; Zhong, Wen-De; Chen, Chen; Xie, Xianzhong (2020): Learning-Based Energy-Efficient Resource Management by Heterogeneous RF/VLC for Ultra-Reliable Low-Latency Industrial IoT Networks. In: *IEEE Trans. Ind. Inf.* 16 (8), pp. 5565–5576. DOI: 10.1109/TII.2019.2933867.

Appendix I

Example of the structural information gathering of pilot requirements:

Pilot	Improvement need/goal optimization need/goal project objectives/goals	Assigned (Business-)Process from D1.3	Data Quality		Requirement definition (related to the i4Q solution)
			Provided data (format, quantity, data source)	Expected data from i4Q-Solutions	
PC1	Capability to read/write FIDIA CNC parameters through FapiCorbaLib	P1_BP01, P1_BP02, P1_BP03	CNC parameters (various formats) from FapiCorbaLib library	Correct reading confirmation	When the CNC is active, the system shall connect to the CNC via the FapiCorbaLib interface to (1) periodically read and store relevant processing parameters and (2) write in dedicated parameters the suggestions for improved process.

ID	Type of requirement		Priority	Difficulty	i4Q Solutions that are connected/mapped to this Requirement	Classification		
PC1r1	Functional/Technical req	Interface req	high	easy	9-i4Q_DIT, 10-i4Q_DA	Data Acquisition & Transformation	Data Storage & Transfer	Data Analytics

Table 42. Requirements elicitation template for Pilots

Appendix II

Example of the structural information gathering after mapping the requirements to the i4Q Solutions:

Solution	Improvement or Optimization need/goal Project objectives/goals	Assigned (Business-)Process from D1.3	Data Quality		Requirement definition (related to the i4Q solution)
			Provided data (format, quantity, data source)	Expected data from i4Q-Solutions	
18-i4Q_QD	Capability to inspect the raw matter sample delivered by 3rd parties for the purposes of Quality Control	P5_BP01	Spectrometering test results regarding the Water % and PVA ppm, contents in each raw matter delivery.	System reading Data comparison against the readings obtained from Requirement 1, confirming that the samples and the raw matter being delivered are part of the same lot	During the Raw Matter delivery process, one of the delivery raw matter samples shall be tested by the spectrometric testing system, which will perform one (1) Kubelka-munk reading and Reflectance reading on PVA and water contents of the sample, delivering the test results to i4Q_QD tool, which will confirm to the RiaStone QC that the supplier delivered sample is effectively part of the delivered lot.

ID	Version	Type of requirement	Prio	Difficulty	Additional information, comments	i4Q Solutions connected/ mapped to this Req.	Classification			Solution Provider	
										Comply / Not comply / To be clarified	Comments
PC5r3	v1	Functional / Technical req	high	nominal	PC5r1, PC5r2, PC5r3 meet RiaStone's vision of their actual needs to install spectrometry and granulometry sensing hardware capable of obtaining raw material composition data. RiaStone does not have a concrete idea of how to couple these requirements with the i4Q req. because it is still unclear what the i4Q project can effectively bring to RiaStone.	18-i4Q_QD	Data Acquisition & Transformation	Data Storage & Transfer	Data Analytics	to be clarified	

Table 43. i4Q Solutions requirements template