D1.8 – Demonstration Scenarios and Monitoring KPIs Definition v2

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	D1.8 – Demonstration scenarios and monitoring KPIs definition v2		
WORK PACKAGE	WP1 – Industrial Scenarios and Requirements Analysis		
DATE OF DELIVERY	CONTRACTUAL: Sept. 2021	ACTUAL	Sept. 2021
NATURE	Report	DISSEMINATION LEVEL	Public
LEAD BENEFICIARY	CERTH		
RESPONSIBLE AUTHOR	Beatriz Andres		
CONTRIBUTIONS FROM	2-ENG, 4-ITI, 5-KBZ, 6-EXOS, 8-BIBA, 9-UPV, 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 has as preceding documents: • D1.3. is focused on the definition of AS IS and TO BE scenarios for all the pilots involved in the application and demonstration of the i4Q solutions. Moreover, D1.3 includes the mapping between TO-BE scenarios and the i4Q solutions. Further iterations. • This document has no further iterations. D1.3 provide inputs for: • D1.9 Requirements Analysis and Functional Specification v2 • D2.3 Report on Business Viewpoint • D2.4 Report on Usage Viewpoint • D2.5 Functional Specifications • D2.6 Technical Specifications • D6.1 Pilot 1: FIDIA - Smart Quality in CNC Machining • D6.2 Pilot 2: BIESSE - Diagnostics and IoT Services • D6.3 Pilot 3: WHIRLPOOL - White Goods Product Quality • D6.4 Pilot 4: FACTOR - Aeronautics and Aerospace Metal Parts Quality • D6.5 Pilot 5: RIASTONE - Advanced In-line Inspection for incoming Prime Matter Quality Control • D6.6 Pilot 6: FARPLAS - Automatic Advanced Inspection of Automotive Plastic Parts		

	• D9.9 Short Interim Management Report v2 (in order to provide the full list of KPI baseline values)
EXTERNAL ANNEXES/ SUPPORTING DOCUMENTS	None
READING NOTES	None
ABSTRACT	Deliverable 1.8 "Demonstration Scenarios and monitoring KPIs definition v2" is the second part of the result of Task 1.3 "Use cases scenarios and KPIs". This Deliverable 1.8 see the in-depth setting up the most suitable Key Performance Indicators (KPIs) required to quantitatively evaluate the results obtained by setting up i4Q based solutions. The definition of the KPIs and its measurement will enable to compare the performance between the As-Is business processes and the To-Be business processes defined in D1.3 "Demonstration Scenarios and Monitoring KPIs Definition". Moreover, within the context of D1.8, the performance measures to establish the starting point (KPIs baseline values) for the implementation of their industrial use cases were defined and will be listed in full detail in D9.9. Finally, this deliverable will give all the inputs required to put in place a KPIs dashboard enabling to understand how, data reliability, product quality and manufacturing quality, will be impacted by i4Q. The KPIs dashboard will be exploited for the evaluation of i4Q pilots. The ISO 22400 "Automation systems and integration KPIs for manufacturing operations management" will be followed for defining, implementing and visualizing the Pilots KPIs. The monitoring KPIs deliverable is a reference document focused on stablishing the KPIs baseline values of the current situation (which will be fully listed in D9.9), and As-Is scenarios, of the pilots participating in i4Q project. For doing this, the KPIs dashboard is described and represented. Based on the As-Is scenarios, the top-level problems and improvements associated to the industrial pilots will be defined. Then, the To-Be scenarios are determined of each use case. In this regard, the companies determine the improvements that are expected in their business processes after the implementation of i4Q based solutions, by formulating a set of objectives to achieve. The KPIs definition are identified to monitor the extent into which the i4Q solutions improve the use case business processes. Therefore, D1.8 (alongside D9.9) serves as the reference for guidance of KPIs baseline values for the project pilots, and for monitoring the performance achieved within the i4Q project by using the KPIs dashboard.

Document History

VERSION	ISSUE DATE	STAGE	DESCRIPTION	CONTRIBUTOR
0.1	24-May-2021	ToC	Table of contents and sections allocation to partners	UPV
0.1	24-May-2021	Draft	Working versions	(ALL) Pilot 1. FIDIA, CESI, ITI Pilot 2. BIES, ENG, TIAG Pilot 3. WHI, ENG Pilot 4. FACT, EXOS, UPV Pilot 5. RIAS, UNI, KB Pilot 6. FARP, ITI, AIMP
0.2	21-Jul-2021	Draft	Content revision of some parts indicated by UPV	EXOS
0.2	23-Aug-2021	Draft	Reviewing of several sections	EXOS UPV
0.2	06-Sep-2021	Draft	KPIs measurement	ALL
0.2	06-Sep-2021	Draft	Reviewing all sections	UPV
0.3	07-Sep-2021	1st Draft	Internal Review	BIBA and BIESSE
0.4	15-Sep-2021	Draft	Contributors Review	ALL
0.5	15-Sep-2021	Draft	Task 1.3 Viceleader Review	EXOS
0.6	21-Sep-2021	Draft review	Task 1.3 Leader Review	UPV
1.0	22-Sep-2021	2nd Draft	Pre-final version sent to CERTH for the final quality check	UPV
2.0	30-Sep-2021	Final doc	Final quality check and issue of final doc	CERTH

Disclaimer

Copyright message

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS/ACRONYMS

AsIs_PxBPy	AS-IS Pilot x Business Process y
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
D1.3.	Demonstration Scenarios and Monitoring KPIs Definition
D1.4.	Deliverable - Requirements Analysis and Functional Specification
D1.8.	Demonstration Scenarios and Monitoring KPIs Definition v2
D1.9.	Deliverable - Requirements Analysis and Functional Specification v2
dd:hh	Day and hour when the KPI is measured
DOA	Description of Action
DSS	Decision Support System
IoT	Internet of Things
ISO 22400	International Organization for Standardization "Automation systems and integration KPIs for manufacturing operations management"
KPI	Key Performance Indicator
KPIixk	KPI *k* of To-Be business process *y* of Pilot *x*
MES	Manufacturing Execution System
N/A	Not Available Data (to be measured)
OEE	Overall Equipment Effectiveness
Oxyz	Objective *z* defined for each To-Be business process *y* in each Pilot *x*
PCxry	Pilot case "x" requirement "y"
Pilot 1	Smart Quality in CNC Machining [FIDIA, ITI, CESI]
Pilot 2	Diagnostics and IoT Services [BIES, ENG, TIAG]
Pilot 3	White Goods Product Quality [WHI, ENG]
Pilot 4	Aeronautics and Aerospace Metal Parts Quality [FACT, EXOS, UPV]
Pilot 5	Advanced In-line Inspection for incoming Prime Matter Quality Control [RIAS, UNI, KBZ]
Pilot 6	Automatic Advanced Inspection of Automotive Plastic Parts [FARP, ITI, AIMP]
RIDS	Reliable Industrial Data Services
RMS	Root-Mean-Square
SMART objectives	specific, measurable, achievable, realistic, and time-bound objectives
T1.3	Use cases scenarios and KPIs
T1.4	Requirements Analysis and Functional Specification
TBD	To Be Defined
To-Be_Px_BPy	To be state of business process "y" in pilot "x"
UI	User Interface
WP	Work Package

S/N	Serial number
1-i4Q_DQG	i4Q Data Quality Guidelines
2-i4Q_QE	i4Q QualiExplore for Data Quality Factor Knowledge
3-i4Q_BC	i4Q Blockchain Traceability of Data
4-i4Q_TN	i4Q Trusted Networks with Wireless & Wired Industrial Interfaces
5-i4Q_CSG	i4Q Cybersecurity Guidelines
6-i4Q_SH	i4Q IIoT Security Handler
7-i4Q_DRG	i4Q Guidelines for building Data Repositories for Industry 4.0
8-i4Q_DR	i4Q Data Repository
9-i4Q_DIT	i4Q Data Integration and Transformation Services
10-i4Q_DA	i4Q Services for Data Analytics
11-i4Q_BDA	i4Q Big Data Analytics Suite
12-i4Q_AD	i4Q Analytics Dashboard
13-i4Q_AI	i4Q AI Models Distribution to the Edge
14-i4Q_EW	i4Q Edge Workloads Placement and Deployment
15-i4Q_IM	i4Q Infrastructure Monitoring
16-i4Q_DT	i4Q Digital Twin simulation services
17-i4Q_PQ	i4Q Data-driven Continuous Process Qualification
18-i4Q_QD	i4Q Rapid Quality Diagnosis
19-i4Q_PA	i4Q Prescriptive Analysis Tools
20-i4Q_LRG	i4Q Manufacturing Line Reconfiguration Guidelines
21-i4Q_LRT	i4Q Manufacturing Line Reconfiguration Toolkit
22-i4Q_LCP	i4Q Manufacturing Line Data Certification Procedure

Executive summary

The deliverable D1.8 "Demonstration scenarios and monitoring KPIs definition v2" seeks in depth and defines in detail the KPIs required to quantitatively evaluate the results obtained by setting up i4Q-based solutions. The definition of the KPIs and their measurement will enable to compare the performance between the As-Is business processes and the To-Be business processes defined in D1.3 "Demonstration Scenarios and Monitoring KPIs Definition".

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

The purpose of this document is to take i4Q pilots' KPIs from the DOA, review them and decide whether they are useful enough to compare the As-Is business processes and the To-Be business processes defined in D1.3. Moreover, within the context of D1.8, the performance measures to establish the starting point (KPIs baseline values) for the implementation of their industrial use cases were defined and will be listed in full detail in D9.9.

Finally, this deliverable will give all the inputs required to put in place a KPIs dashboard enabling to understand how data reliability, product quality and manufacturing quality will be impacted by i4Q. This KPIs dashboard will be exploited for the evaluation of i4Q pilots. The ISO 22400 "Automation systems and integration KPIs for manufacturing operations management", will be followed for defining, implementing and visualizing the Pilots' KPIs.

The KPIs dashboard will enable to make a comparative analysis of the status of the main business processes performed before and after i4Q solutions' implementation in each use case.

The deliverable reflects the approach taken to help the industrial pilots become aware of the i4Q technical capabilities and potentiality. Hence, it includes:

- The KPIs Definition, Implementation and Visualization Methodology according to the ISO 22400 "Automation systems and integration KPIs for manufacturing operations management".
- The pilot's KPIs definition and baseline measurement.
- The KPIs dashboard tool selection and implementation, to visualize and record the baseline values.

In summary, main results from deliverable D1.8 are grouped in 3 categories:

- The list of KPIs defined to measure the impact of i4Q solutions implementation.
- The baseline values measured and recorded for its comparison once the i4Q solutions are implemented (which are going to be fully listed in D9.9).
- The KPIs Dashboard for record and visualization.

The D1.8 main actions are:

- Describe the methodology to define the KPIs.
- Define the i4Q pilots' objectives to achieve when implementing the To-Be business processes.
- Determine and describe the KPIs that will allow the i4Q pilots to measure the degree of achievement of the previously defined objectives.
- Record a first measure of the KPIs defined, for its use on the baseline KPI values (to be listed in detail in D9.9).
- Select a dashboard tool and implement it, to record and visualize the baseline values and the future KPI values, once the future To-Be scenarios are implemented.

Document structure

Section 1: Introduction: Provides an introduction to this deliverable, including a general overview and the outline of its purpose, scope, and context.

Section 2: KPIs Definition, Implementation and Visualization Methodology: Describes the methodology used to define, implement and visualize the KPIs. The ISO 22400 "Automation systems and integration KPIs for manufacturing operations management" is taken as a reference document.

Section 3: Key Performance Indicators Definition: Provides a detailed description of each of the KPIs selected to measure the i4Q solutions impact on the i4Q pilots. First, the objectives to achieve with the implementation of the To-Be business processes defined in the D1.3 are defined. Then, the KPIs to measure the objectives achievement are described according to the methodology defined in Section 2.

Section 4: KPIs Dashboard: Establishes the dashboard tool selection, the KPIs dashboard tool implementation and the KPIs baseline values record and visualization in the KPIs dashboard tool.

Section 5: Conclusions: Provides a summary of the document, emphasising the most important aspects of user scenario characterisation.

1. Introduction

Deliverable D1.8, Demonstration Scenarios and Monitoring KPIs Definition v2, aims at creating the starting point of i4Q project towards the pilot-driven implementations, providing direct input from the use cases. D1.8 is inserted in Work Package 1 that aims at establishing main features of industrial scenarios to be addressed in the i4Q project, by implementing the IoT-based Reliable Industrial Data Services (RIDS).

The use cases compound a representative sample of the industry requiring manufacturing data quality and manufacturing process quality. Moreover, a set of needs and problems that are common on each of the sectors to which the use cases belong, have been identified. In order to deal with the problems and needs found in each use case, the set of 22 i4Q solutions (17 software tools and 5 guidelines) have been considered. The 22 i4Q solutions have been mapped to meet the use cases' needs, with the aim of managing huge amount of industrial data coming from cheap cost-effective, smart, and small size interconnected factory devices for supporting manufacturing online monitoring and control (see D1.3 and D1.4).

Taking as a base the D1.1, D1.3 and D1.4, the first part of the deliverable D1.8 sets up the most suitable Key Performance Indicators (KPIs) required to quantitatively evaluate the results obtained by setting up i4Q based solutions. To this extent, the Pilots have formulated a set of specific, measurable, achievable, realistic, and time-bound (SMART) objectives. The second part of D1.8 conducts an in-depth analysis of all the current systems of the demonstration scenarios, to establish the starting point (KPIs baseline values) which is going to be listed in detail per pilot in D9.9. This activity will give all the inputs required to put in place a KPIs dashboard enabling to understand how, data reliability, product quality and manufacturing quality, will be impacted by i4Q. The KPIs dashboard will be exploited for the evaluation of i4Q pilots. The ISO 22400 Automation systems and integration KPIs for manufacturing operations management will be followed for defining, implementing and visualising the Pilots KPIs.

This deliverable (alongside D9.9) defines and measures the KPI baseline values for each of the industrial scenarios to be targeted by i4Q RIDS. With the participation of most project partners (Universities and Research Centres, IT developers, and Industrial partners), this task seeks to set up the most suitable Key Performance Indicators (KPIs) required to evaluate quantitatively the results obtained by setting up i4Q based solutions. Moreover, the starting point KPIs baseline values are measured by each of the Pilot partners:

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

D1.8 is developed by means of collaboration between consortium members, providing pilot information and data, as well as their estimation about all the procedures taken into account during the creation of this document. This deliverable followed the presented set of steps:

- The KPIs Definition, Implementation and Visualization Methodology.
- Describe the methodology to define the KPIs according to the ISO 22400 Automation systems and integration KPIs for manufacturing operations management.
- Define the i4Q pilots' SMART objectives to achieve when implementing the To-Be business processes.
- Determine and describe the KPIs that will allow the i4Q pilots to measure the degree of achievement of the previously defined objectives.
- The pilot's KPIs definition and baseline measurement.
- The baseline values measured and recorded for its comparison once the i4Q solutions are implemented.
- Record a first measure of the KPIs defined, for its use on the baseline KPI values.
- Select a Dashboard tool and implement it, to visualize and record the baseline values and the future KPI values once the future To-Be scenarios are implemented.
- Establishes the dashboard tool selected, the KPIs dashboard tool implementation and the KPIs baseline values record and visualization in the KPIs dashboard tool.
- Telco's every 2 weeks between all i4Q project partners to follow up the progress of work.
- Telco's between industrial pilots and technical developers to get feedback about the KPIs definition and measurement.
- Telco's to align the functional requirements of T1.4 with the T1.3.
- Conclusions that provide a summary of the document, emphasising the most important aspects of user scenario characterisation.

2. KPIs Definition, Implementation and Visualization Methodology

According to the ISO 22400 "Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 1: Overview, concepts and terminology", a KPI is a **quantifiable level of achieving a critical objective**. The KPIs are derived directly from, or through an aggregation function of, physical measurements, data and/or other KPIs. Moreover, a good KPI has certain criteria which ensure its usefulness in achieving various goals in the manufacturing operation. The criteria are listed below, along with the process for performing each individual measurement:

- **Aligned**: the KPI is aligned to the degree to which the KPI affects change in relevant higher-level KPIs, where alignment implies a high ratio of the percent improvement (assuming positive impact) in important higher-level metrics to the percent improvement in a KPI.
- **Balanced**: the extent to which a KPI is balanced within its chosen set of KPIs.
- **Standardized**: the KPI is standardized to the extent to which a standard for the KPI exists and that standard is correct, complete, and unambiguous; the standard can be plant-wide, corporate-wide, or industry-wide.
- **Valid**: the KPI is valid to the extent of the syntactic (i.e. grammar) and semantic (i.e. meaning) compliance between the operational definition of the KPI and the standard definition. If no standard exists, then validity is zero.
- **Quantifiable**: the KPI is quantifiable to the extent to which the value of the KPI can be numerically specified; there is no penalty for the presence of uncertainty, as long as the uncertainty can also be quantified.
- **Accurate**: the KPI is accurate to the extent to which the measured value of the KPI is close to the true value, where a departure from the true value can be affected by poor data quality, poor accessibility to the measurement location, or the presence of substandard measurement devices and methods.
- **Timely**: the KPI is timely to the extent it is computed and accessible in real-time, where real-time depends on the operational context.
- **Predictive**: the KPI is predictive to extent to which a KPI is able to predict non-steady-state operations.
- **Actionable**: the KPI is actionable to the extent to which a team responsible for the KPI has the knowledge, ability, and authority to improve the actual value of the KPI within their own process.
- **Trackable**: the KPI is trackable to the extent to which the appropriate steps to take to fix a problem are known, documented, and accessible, where the particular problem is indicated by particular values or temporal trends of the KPI.
- **Relevant**: the KPI is relevant to the extent to which the KPI enables performance improvement in the target operation, demonstrates real-time performance, allows the accurate prediction of future events, and reveals a record of the past performance valuable for analysis and feedback control.
- **Correct**: the KPI is correct to the extent that, compared to the standard definition (if one exists), the calculation required to compute the value of the KPI compared to the standard definition (if one exists) has no errors with respect to the standard definition.

- **Complete**: the KPI is complete to the extent that, compared to the standard definition (if one exists), the definition of the KPI, and the calculation required to compute the value of the KPI, covers all parts, and no more, of the standard definition.
- **Unambiguous**: the KPI is unambiguous to the extent that the syntax (i.e. grammar) and semantics (i.e. meaning) in the definition of the KPI lacks ambiguity or uncertainty.
- **Automated**: the KPI is automated to the extent that KPI collection, transfer, computation, implementation, and reporting are automated.
- **Buy-in**: the KPI has buy-in to the extent that the team responsible for the target operation, as well as teams responsible for both upper and lower level KPIs, are willing to support the use of the KPI and perform the tasks necessary to achieve target values for the KPI; includes difficulty of obtaining official approval by management for the KPI.
- **Documented**: the KPI is documented to the extent that the documented instructions for implementation of a KPI are up-to-date, correct, complete, and unambiguous, including instructions on how to compute the KPI, what measurements are necessary for its computation, and what actions to take for different KPI values.
- **Comparable**: the KPI is comparable to the extent that means are defined to reference supporting measurements over a period of time, and a normalizing factor to express the indicator in absolute terms with appropriate units of measure.
- **Understandable**: the KPI is understandable to the extent that the meaning of the KPI is comprehended by team members, management, and customers, particularly with respect to corporate goals.
- **Inexpensive**: the KPI is inexpensive to the extent that the cost of measuring, computing, and reporting the KPI is low.

This section, describes the methodology used to define, implement and visualize the KPIs. The ISO 22400 "Automation systems and integration KPIs for manufacturing operations management" is taken as a reference document. In this regard, the following subsections are described: subsection 2.1 KPIs definition methodology, subsection 2.2. KPIs implementation methodology, and subsection 2.3 KPIs visualization tool.

2.1 KPIs Definition Methodology

In order to characterise and define the KPIs, a top-down methodology has been considered, so that the strategic decisions have helped to formalize the objectives to be achieved in each of the To-Be business processes defined in the D1.3, and the objectives are converted/mapped into a set of KPIs. These sets are used as target values comparing the As-Is and To-Be business processes' performance. The To-Be **business processes** are the *set of activities performed with a set of resources*, including i4Q solutions, *to realize an objective within a specified timeline*. An **improvement method** requires an understanding of the objective through which a set of KPIs has to be managed. This set of KPIs depends on selection criteria that will enable the objective to be realized. The **monitoring of performance** is specific to identified objectives of the enterprise, and KPIs are most useful when their values can be used to *identify trends relative to certain operational objectives*.

The ISO 22400 is followed to define each of the KPIs of this deliverable D1.8. KPI specifications are expressed using the structure in Table 1 and are in accordance with ISO 22400-1 and ISO 22400-2 "Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions". The structure in

Table 1 identifies KPI descriptive elements in the left column and gives a description of each element in the right column.

Name	Name of the KPI
ID	A user defined unique identification of the KPI in the user environment. The KPI *k* of To-Be business process *y* of Pilot *x* is represented as KPI_{xyk}
Description	A brief description of the KPI_{xyk}
Objective	KPI_{xyk} will allow to measure the achievement of the objective *z* defined for each To-Be business process *y* in each Pilot *x*, O_{xyz} Objectives to be realized with use of performance indicators are determined. An improvement method requires an understanding of the objective through which a set of KPI_{xyk} has to be managed. This set of KPI_{xyk} depends on selection criteria that will enable the objective O_{xyz} to be realized. The KPIs KPI_{xyk} are used to assess the progress or extent of compliance with regard to important objectives O_{xyz} or critical success factors within a company.
Units of measure	The basic unit or dimension in which the KPI_{xyk} is expressed
Data source	The source/s from which the pilot is going to obtain the data needed to calculate the mathematical formula of the KPI_{xyk} before and after i4Q solutions implementation. When specifying the data source after i4Q, the pilots have proposed interim i4Q solutions from which information will be extracted ,and KPIs measured.
Math. Formula	The mathematical formula of the KPI_{xyk} specified in terms of elements
Measurement Timing	A KPI_{xyk} can be calculated either in • real-time - after each new data acquisition event • on demand - after a specific data selection request • periodically - done at a certain interval, e.g. once per day
Evaluation Timing	KPI_{xyk} Evaluation Frequency* *Evaluation frequency can coincide with the measurement timing
Trend	Is the information about the improvement direction of the x KPI_{xyk}, • higher is better • lower is better • stable is better
Range	Specifies the upper and lower logical limits of the KPI_{xyk}
Responsible for Measurement	Responsible is the group typically measuring this KPI_{xyk}. The groups used in this part of ISO 22400 are: • Operators – personnel responsible for the direct operation of the equipment • Supervisors – personnel responsible for directing the activities of the operators

	• Management – personnel responsible for the overall execution of production
Audience	Audience is the user group typically using this KPI_{xyk}. The user groups used in this part of ISO 22400 are: • Operators – personnel responsible for the direct operation of the equipment • Supervisors – personnel responsible for directing the activities of the operators • Management – personnel responsible for the overall execution of production
Decision	Decision to be taken when the KPI_{xyk} is out of the limits

Table 1. Structure of KPI_{xyk} description

2.2 KPIs Implementation Methodology

Table 2 identifies KPI_{xyk} measurement elements in the left column and gives a description of each element in the right column.

Business Process	Business process *y* of Pilot *x* to which the KPI_{xyk} refers
KPI Name	Name of the KPI_{xyk}
KPI Code	A user defined unique identification of the KPI_{xyk} in the user environment. The KPI *k* of To-Be business process *y* of Pilot *x* is represented as KPI_{xyk}
KPI Units	The basic unit or dimension in which the KPI_{xyk} is expressed
Data	Number results of the different data to be computed in the KPI_{xyk} Value (mathematical formula)
KPI Value	Number result of the KPI_{xyk} mathematical formula
KPI Measurement Datetime	(dd:hh)

Table 2. Structure of KPIxyk measurement

2.3 KPIs Visualization Tool

In order to have valuable information about the performance between the As-Is and To-Be business processes of the i4Q Pilots and to be able to quantitatively evaluate the results obtained by the implementation of i4Q-based solutions, it is necessary firstly to **periodically collect all the parameters of each KPI** to be measured and secondly to **represent this information in graphical form** that allows it to be monitored in an intuitive way over time, this latter point is the objective of KPIs Visualization Tools.

To provide a graphical representation of the KPIs, metrics and measures used to check the performance of i4Q Solutions, i4Q will use Dashboards that use charts and graphs to show the evolution of KPIs over time, that is, a KPIs dashboard provides a combined tool for monitoring and analysis in a single way, allowing i4Q Pilots to easily see trends and be alerted to KPIs that have values out of minimum and maximum values.

3. Key Performance Indicators Definition

In this section, each of the six Pilots of i4Q defines a set of KPIs, which will allow them to monitor the As-Is and the To-Be business process defined in deliverable D1.3 Demonstration Scenarios and Monitoring KPIs Definition:

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

3.1 Pilot 1: Smart Quality in CNC Machining

3.1.1 Objectives and KPIs definition for Business Process 1 of Pilot 1 (To-Be_P1_BP01)

The two objectives that FIDIA aims to achieve with the implementation of *To-Be_P1_BP01 Ensure final surface quality*, are defined next:

- *P1_BP01_O1 (O_{111})*: Roughness of the surface of the parts produced by milling machine tools should always be under 5 micrometers.
- *P1_BP01_O2 (O_{112})*: The difference between the real processing time (Measured Processing Time) and the theoretical processing time (Expected Processing time) should be less than 10%.

The i4Q solutions are expected to achieve these quality objectives both:

- before the process, by predicting and measuring the final roughness and proposing processing parameters that improve such roughness, and
- during the process, by predicting the final roughness and proposing spindle and feed override that improve such roughness.

In this subsection, the KPIs defined to monitor the Business Process 1 of Pilot 1 To-Be_P1_BP01, are presented next:

- *KPI_{111}*: Final surface roughness
- *KPI_{112}*: Processing time

Name	Final surface roughness
ID	KPI_{111}
Description	Surface roughness of the parts produced by milling machine tools (hereinafter roughness), is a component of the parts surface texture. Roughness is quantified by the deviations in the direction of the normal vector of a manufactured surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth.
Objective	KPI_{111} will allow to measure the achievement of P1_BP01_O1 (O_{111})
Units of measure	Micrometres (μm)

Name	Final surface roughness
ID	KPI_{111}
Data source	The Arithmetical mean deviation of the assessed profile will be directly measured by a Rugosimeter. After i4Q --> **18-i4Q_QD** should predict the final surface roughness during the process and then the **21-i4Q_LRT** should optimise the process parameters to improve surface roughness (at the end measured by the Rugosimeter). **9-i4Q_DIT** should be able to access process data.
Math. Formula	*KPI_{111} = Final surface roughness directly measured by a Rugosimeter*
Measurement Timing	After each part completion
Evaluation Timing	Immediately after each part completion and removal from the machine tool workspace.
Trend	The lower, the better
Range	0.5 µm-5 µm
Responsible for Measurement	Both before and after i4Q, the KPI will be measured by the equipment operator by with a Rugosimeter.
Audience	Both before and after i4Q, the KPI will be used by quality inspection department operators.
Decision	By comparing this indicator with the acceptable range, it is possible to determine when to propose a reconfiguration of the machine parameters.

Table 3. KPI_{111} definition: Final surface roughness

Name	Processing time deviation
ID	KPI_{112}
Description	The processing time deviation compares the actual time required by the machine tool to complete a part (Measured Processing Time) with the theoretical one (Expected Processing Time). These times can be different since the operator (and, in future, i4Q solutions) can override the processing parameters.
Objective	KPI_{112} will allow to measure the achievement of P1_BP01_O2 (O_{112})
Units of measure	Percentage (%)
Data source	A dedicated CNC parameter can be used to access the measured processing time, while the expected processing time is provided by the Computer-Aided Manufacturing (CAM) used to create the part program and will be manually added to the part program header for easier automatic retrieval by **18-i4Q_QD /21-i4Q_LRT** solutions.
Math. Formula	*KPI_{112} = Processing Time Deviation = 100 * Measured Processing time/Expected Processing Time*
Measurement Timing	Measured Processing Time: Immediately after each part completion

	Expected Processing Time: when the part program is generated by the CAM
Evaluation Timing	Measured Processing Time: Immediately after each part completion Expected Processing Time: since when the part program is generated by the CAM to the process completion
Trend	The lower, the better
Range	Between 50% and 110%
Responsible for Measurement	Both before and after i4Q, the KPI can be collected from the CNC by an operator. After i4Q, the KPI can be collected from the CNC by any connected i4Q solution
Audience	Both before and after i4Q, the KPI will be used by the equipment operator.
Decision	This indicator is usable to evaluate if a reconfiguration of the machine parameters is acceptable. If the estimated KPI_{112} is greater than 110%, the relevant parameters reconfiguration is not acceptable.

Table 4. KPI_{112} definition: Processing time

3.1.2 Objectives and KPIs definition for Business Process 2 of Pilot 1 (To-Be_P1_BP02)

The two objectives that FIDIA aims to achieve with the implementation of *To-Be_P1_BP02 Chatter detection and avoidance* are defined next, as part of the identification and removal of the Chatter vibrations:

- *P1_BP02_O1* (O_{121}): Maximum value of Chatter root-mean-square (RMS) of velocity during the process (in the time domain) must be reduced of 75% respect to the base value

  The maximal RMS amplitude of velocity vibrations at the detected chatter frequencies should be reduced by i4Q solutions compared to ex ante situation. Namely, the maximum value of such RMS of velocity along the whole machining process.

- *P1_BP02_O2* (O_{122}): Chatter identification time has to be lower than 60s.

  The Chatter identification time should be fast enough to not cause a degradation of a significant part of the total part surface.

In this subsection, the KPIs defined to monitor the Business Process 2 of Pilot 1 To-Be_P1_BP02 are presented next:

- KPI_{121}: Maximal Chatter RMS
- KPI_{122}: Chatter identification time

Name	Max Chatter RMS (in the time domain)
ID	KPI_{121}
Description	The root-mean-square (RMS) of the velocity amplitude of a vibrating machine is an indicator of the vibration energy in the machine. The higher the vibration energy, the higher the root-mean-square velocity amplitude. Max Chatter RMS is the maximum value of such RMS of

	velocity along the whole machining process.
Objective	KPI_{121} will allow to measure the achievement of P1_BP02_O1 (O_{121})
Units of measure	m/s
Data source	Before i4Q, the Chatter RMS (and its maximal value) can be read from the USB accelerometer SW suite After i4Q, the Chatter RMS should be detected by **18-i4Q_QD** solution, while **9-i4Q_DIT** solution should be able to access process/accelerometers data in real-time.
Math. Formula	The standard deviation of vibration velocity at identified chatter frequencies is the square root of the variance of the vibration. KPI_{121} = *Max Chatter RMS* for all the demo machine natural chatter frequencies
Measurement Timing	After the process end
Evaluation Timing	After the process end
Trend	The lower, the better
Range	N/A (depend on the selected process)
Responsible for Measurement	Before i4Q, the data to compute the Max Chatter RMS can be recorded and then collected from the USB accelerometer SW suite by an operator. After i4Q, the Max Chatter RMS will be computed directly by the i4Q solutions.
Audience	Both before and after i4Q, the KPI will be used by equipment operator.
Decision	The Max Chatter RMS in the time domain will be used to determine the effectiveness of the proposed parameters adaptions for Chatter removal. If it is too high, it means that the Chatter is not efficiently removed.

Table 5. KPI_{121} definition: Max Chatter RMS in the time domain

Name	Chatter identification time
ID	KPI_{122}
Description	The Chatter identification time is the actual time required to assess the presence of Chatter and notify it.
Objective	KPI_{122} will allow to measure the achievement of the P1_BP02_O2 (O_{122})
Units of measure	Seconds (s)
Data source	Before i4Q: USB SW suite recordings After i4Q: i4Q solutions (**9-i4Q_DIT** / **18-i4Q_QD**)
Math. Formula	KPI_{122} = *Timestamp of chatter presence notification – Timestamp of chatter vibration appearance*
Measurement Timing	Real time

Evaluation Timing	Real time
Trend	The lower, the better
Range	1 s – 5 min
Responsible for Measurement	Before i4Q solutions deployment, the KPI will be computed by an operator. After i4Q solutions deployment, the KPI will be computed by the i4Q **RIDS**.
Audience	The KPI will be used by the machine operators
Decision	This indicator is usable to evaluate the effectiveness of chatter detection solution (whether the operator or the i4Q solutions). If it is too high, it means that the chatter detection solution is not fast enough to react to chatter presence.

Table 6. KPI_{122} definition: Chatter identification time

3.1.3 Objectives and KPIs definition for Business Process 3 of Pilot 1 (To-Be_P1_BP03)

The objective that FIDIA aims to achieve with the implementation of *To-Be_P1_BP03 Evaluation of machine tool condition* is defined next, as part of the provision of support to the maintenance operator in the determination of the machine tool components whose degradation is affecting the surface quality of the parts produced by the milling machine tools:

- *P1_BP03_O1* (O_{131}): Failed Component Identification Times should be reduced at least by 50%.

In this subsection, the KPI defined to monitor the Business Process 3 of Pilot 1 To-Be_P1_BP03 is presented:

- KPI_{131} definition: Failed Component Identification Time ratio

Name	Failed Component Identification Time
ID	KPI_{131}
Description	This KPI computes the time required by an operator to identify the machine tool component that is causing a quality degradation of produced parts and its failure mode.
Objective	KPI_{131} will allow to measure the achievement of the P1_BP03_O1 (O_{131})
Units of measure	Seconds (s)
Data source	Failed Component Identification Time will be directly measured by an operator both before and after i4Q. After i4Q- **15-i4Q_IM/11-i4Q_BDA** should predict in-process the incipient failure and concerned component, and then the **21-i4Q_LRT** should propose alternative process parameters to reduce specific component degradation rate. **9-i4Q_DIT** should be able to access and process data.
Math. Formula	*KPI_{131} = Failed Component Identification Time = Timestamp of failure component identification time – Timestamp of machine tool analysis*

	begin
Measurement Timing	Immediately after machine tool maintenance
Evaluation Timing	On demand by the machine tool customer
Trend	The lower, the better
Range	1-8 hours
Responsible for Measurement	The KPI will be directly measured by an operator both before and after i4Q.
Audience	Before and after i4Q, the KPI will be used by FIDIA maintenance department operators.
Decision	This indicator is usable to evaluate the effectiveness of the maintenance procedure, including the contribute provided by i4Q solution in identifying the defective components.

Table 7. KPI_{131} definition: Failed Component Identification Time

3.2 Pilot 2: Diagnostics and IoT Services

3.2.1 Objectives and KPIs definition for Business Processes 1 of Pilot 2 (To-Be_P2_BP01)

The objectives that BIESSE aims to achieve with the implementation of *To-Be_P1_BP01 Diagnostic of axis movement and torque monitoring*, are defined next:

- *P2_BP01_O1* (O_{211}): Monitoring the machine axes status, through the analysis in time and frequency domain of the transmission signals (torque, acceleration, speed, position, jark, etc...), with the aim to improve the diagnostic capability, increase the machine reliability, reduce production waste and downtime.
- *P2_BP01_O2* (O_{212}): Monitoring the position repeatability of the machine axes, through a time domain analysis of micro-marker signals (reference position of the axes during the calibration), with the aim of identifying drifts in advance, that in the case of an axis associate to a tool magazine, can generate failed tool changes or component breakages.

In this subsection, the KPIs defined to monitor the Business Process 1 of Pilot 2 To-Be_P2_BP01 are presented next:

- KPI_{211}: Effectiveness
- KPI_{212}: Diagnostics of the Bearing in the Ball Screw transmission
- KPI_{213}: Diagnostics of Incorrect Rack Pitch
- KPI_{214}: Diagnostics of Backlash
- KPI_{215}: Diagnostics of Cleanliness of the Rack
- KPI_{216}: Diagnostics of Gantry Error
- KPI_{217}: Occurrence of Axes Torque Errors
- KPI_{218}: Micro-Marker Trend
- KPI_{219}: Occurrence of Micro-Marker Errors

Most of the KPIs defined by the Pilot 2 require an analysis of the torque data (KPI212 , KPI213, KPI214, ...), different algorithms will be implemented according to the type of problem under diagnosis. This is the reaosn why we associeted the KPI name according to the type of problem under diagnosis.

Name	Effectiveness
ID	KPI_{211}
Description	The effectiveness is the ratio of the number of Completed Programs (CP) to the number of all Started Programs (SP), where a program is the machining cycle to produce a piece.
Objective	KPI_{211} will allow to measure the achievement of O_{211} and O_{212}
Units of measure	Ratio of completed programs (%)
Data source	Completed Programs (CP) Started Programs (SP) Before i4Q --> statistical data from the machine After i4Q --> statistical data from the machine and the following i4Q solutions, including **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** should predict premature or normal physiological degradation of the components and to avoid unexpected breakage.
Math. Formula	KPI_{211}= Effectiveness = $(CP / SP) * 100$
Measurement Timing	CP and SP are measured in real-time and then the effectiveness is computed at the of the day.
Evaluation Timing	Effectiveness is evaluated at the end of the day
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Sophia platform After i4Q --> Sophia platform
Audience	Before and after i4Q --> Management personnel responsible for the overall execution of production
Decision	Customer and BIESSE sides: This indicator is usable for the manager level to make an analysis of machine reliability

Table 8. KPI_{211} definition: Effectiveness

Name	Diagnostics of the Bearings in the Ball Screw transmission ($DBBS_j$)
ID	KPI_{212}
Description	Frequency domain analysis to diagnose the bearings in the ball screw transmission in the j-th axis under investigation. The types of defects could be located on the internal ring, external ring, rolling element, cage, etc.
Objective	KPI_{212} will allow to measure the achievement of O_{211}

Units of measure	Torque unit (in CNC the torque is given in % referred to maximum value available from the driver)
Data source	The parameters that should be elaborated to calculate the KPI_{212} Torque (T_j) Velocity (v_j) Acceleration (a_j) Frequency (f_j) Sample frequency (Sf) Before i4Q --> BIESSE CNC After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-i4Q_DR**. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	$KPI_{212} = DBBS_j\ (f_j) = g_f\ (T_j, v_j, a_j, Sf)$ g_f *means a generic frequency domain algorithm (to be defined)* $j=\{1,2,\ldots,m\}$ *m axes under investigation*
Measurement Timing	All data sources are measured periodically (test cycle), and when specific value is required for evaluation the measure timing will be on demand. $DBBS_j$ is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	$DBBS_j$ is evaluated in real time
Trend	The lower, the better
Range	Min: TBD Max: TBD Range will be defined through a statistical analysis when the algorithm will be available in machine for test.
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.

Decision	This indicator is feedback for the technical department to make an analysis of machine performance. This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components (e.g., Bearings) or maintenance. This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms and feedback from the machine operator and Biesse support.

Table 9. KPI_{212} definition: Diagnostics of the Bearing in the Ball Screw transmission

Name	Diagnostics of Incorrect Rack Pitch ($DIRP_j$)
ID	KPI_{213}
Description	Time domain analysis to diagnose the incorrect rack pitch of the rack and pinion transmission in the j-th axis under investigation.
Objective	KPI_{213} will allow to measure the achievement of P2_BP01_O1
Units of measure	Torque unit (in CNC the torque unit is given in % referred to maximum value available from the driver)
Data source	Torque (T_j) Position (p_j) Velocity (v_j) Before i4Q --> current enterprise data source After i4Q --> i4Q After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-i4Q_DR**. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	$KPI_{213} = DIRP_j = g_t(T_j, v_j, p_j)$ g_t *means a generic time domain algorithm (to be defined)* $j=\{1,2,\ldots,m\}$ *m axes under investigation*
Measurement Timing	All data sources are measured on demand and/or periodically (test cycle) and then the $DIRP_j$ is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	$DIRP_j$ is evaluated in real time
Trend	The lower, the better
Range	Min: TBD

	Max: TBD Range will be defined through a statistical analysis when the algorithm will be available in machine for test.
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.
Decision	BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance. This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components or maintenance (e.g., Retune the rack pitch). This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms and feedback from the machine operator and Biesse support.

Table 10. KPI_{213} definition: Diagnostics of Incorrect Rack Pitch

Name	Diagnostics of Backlash (DB_j)
ID	KPI_{214}
Description	Time domain analysis to diagnose the backlash of the rack and pinion transmission in the j-th axis under investigation.
Objective	KPI_{214} will allow to measure the achievement of P2_BP01_O1
Units of measure	Torque unit (in CNC the torque is given in % which refers to the maximum value available from the driver)
Data source	Torque (T_j) Position (p_j) Velocity (v_j) Acceleration (a_j) Jerk (J_j) Before i4Q --> current enterprise data source After i4Q --> i4Q After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-**

	i4Q_DR. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	$KPI_{214} = DB_j = g_t(T_j, p_j, v_j, a_j J_j)$ g_t *means a generic time domain algorithm (to be defined)* $j=\{1,2,\ldots,m\}$ *m axes under investigation*
Measurement Timing	All data sources are measured on demand and/or periodically (test cycle) and then the DB_j is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	DB_j is evaluated in real time
Trend	The lower, the better
Range	Specifies the upper and lower logical limits of the KPI Min: TBD Max: TBD Range will be defined through a statistical analysis when the algorithm will be available in machine for test.
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.
Decision	BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance. This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components or maintenance (e.g., Adjust the pinion position to give the proper backlash). This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms and feedback from the machine operator and Biesse support.

Table 11. KPI_{214} definition: Diagnostics of Backlash

Name	Diagnostics of Cleanliness of the Rack (DCR_j)
ID	KPI_{215}
Description	Time domain analysis to diagnose the cleanliness of the rack of the rack and pinion transmission in the j-th axis under investigation.
Objective	KPI_{215} will allow to measure the achievement of P2_BP01_O1
Units of measure	Torque unit (in CNC the torque is given in % referred to maximum value available from the driver)
Data source	Torque (T_j) Acceleration (a_j) Before i4Q --> current enterprise data source After i4Q --> i4Q After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-i4Q_DR**. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	$KPI_{215} = DCR_j = g_t(T_j, a_j)$ g_t *means a generic time domain algorithm (to be defined)* $j=\{1,2,\ldots,m\}$ *m axes under investigation*
Measurement Timing	All data sources are measured on demand and/or periodically (test cycle) and then the DCR_j is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	DCR_j is evaluated in real time
Trend	The lower, the better
Range	Min: TBD Max: TBD Range will be defined through a statistical analysis when the algorithm will be available in machine for test.
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from

	Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.
Decision	BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance; This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components or maintenance (e.g., Clean the rack). This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms and feedback from the machine operator and Biesse support.

Table 12. KPI_{215} definition: Diagnostics of Cleanliness of the Rack

Name	Diagnostics of Gantry Error (DGE)
ID	KPI_{216}
Description	Time domain analysis to diagnose the gantry error of a transmission with gantry motor (i.e., incorporates dual linear motors and dual linear encoders) in the X axis.
Objective	KPI_{215} will allow to measure the achievement of P2_BP01_O1
Units of measure	Position unit [mm]
Data source	Emergency Position of the first motor in gantry (EP_x) Emergency Position of the second motor in gantry (EP_{Xs}) Position (p) Before i4Q --> current enterprise data source After i4Q --> i4Q After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-i4Q_DR**. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	$KPI_{216} = DGE = \lvert EP_X - EP_{Xs} \rvert$
Measurement Timing	All data sources are measured on demand and/or periodically (test cycle) and then the DGE is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	DGE is evaluated in real time
Trend	The lower, the better
Range	Min: 0

	Max: 2
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.
Decision	BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance; This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components or maintenance (e.g., Square the beam). This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms and feedback from the machine operator and Biesse support.

Table 13. KPI_{216} definition: Diagnostics of Gantry Error

Name	Occurrence of Axes Torque Errors (OATE)
ID	KPI_{217}
Description	The occurrence of axes torque errors is the ratio of the Number of Axes Torque Errors (NATE) to the Hours of Machine Work (HMW)
Objective	KPI_{217} will allow to measure the achievement of P2_BP01_O1
Units of measure	1/h
Data source	Number of Axes Torque Errors (NATE) Hours of Machine Work (HMW) Before i4Q --> current enterprise data source After i4Q --> current enterprise data source After i4Q- **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** should predict premature or normal physiological degradation of the components and to avoid unexpected breakage.
Math. Formula	KPI_{217} = OATE = NATE / HMW
Measurement Timing	NATE and HMW are measured in real-time and then the OATE is computed at the of the day.
Evaluation Timing	OATE is evaluated at the end of the day

Trend	The lower, the better
Range	Min: 0 Max: TBD
Responsible for Measurement	Before i4Q --> N/A After i4Q --> The KPI will be computed by an expert operator
Audience	Before i4Q --> N/A After i4Q --> Technical Supervisors and Management from Biesse side
Decision	CUSTUMER AND BIESSE SIDE: This indicator is usable as indicator for the manager level to make an analysis of machine reliability BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance; This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters or to replace the machine damaged components.

Table 14. KPI_{217} definition: Occurrence of Axes Torque Errors

Name	Micro-Marker Trend (MMT)
ID	KPI_{218}
Description	Time domain analysis of the micro-marker trend
Objective	KPI_{218} will allow to measure the achievement of P2_BP01_O2
Units of measure	mm (for linear axes) rad (for rotating axes)
Data source	Micro-Marker data (MM): reference position of the axis during the calibration Encoder Motor Ratio (EMR) Timestamp (t) Before i4Q --> current enterprise data source After i4Q --> i4Q After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-i4Q_DR**. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	KPI_{218}= MMT= g (MM, EMR, t) g means a generic time domain algorithm

Measurement Timing	All data sources are measured during axes calibration and then the MMT is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	MMT trend is evaluated in real time
Trend	Close to zero, the better
Range	Min: - 1/2*EMR Max: + 1/2*EMR
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.
Decision	BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance; This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components or maintenance (e.g., Retune the homing position of the axis). This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms and feedback from the machine operator and Biesse support.

Table 15. KPI_{218} definition: Micro-Marker Trend

Name	Occurrence of Micro-Marker Errors (OMME)
ID	KPI_{219}
Description	The occurrence of micro-marker errors is the ratio of the Number of Micro-Marker Errors (NMME) to the Hours of Machine Work (HMW)
Objective	KPI_{219} will allow to measure the achievement of P2_BP01_O2
Units of measure	1/h
Data source	Number of Micro-Marker Errors (NMME) Hours of Machine Work (HMW) Before i4Q --> current enterprise data source

	After i4Q --> current enterprise data source After i4Q- **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** should predict premature or normal physiological degradation of the components and to avoid unexpected breakage.
Math. Formula	KPI_{219} = OMME = NMME/HMW
Measurement Timing	NMME and HMW are measured in real-time and then the OMME is computed at the of the day.
Evaluation Timing	OMME is evaluated at the end of the day
Trend	The lower, the better
Range	Min: 0 Max: TBD
Responsible for Measurement	Before i4Q --> N/A After i4Q --> The KPI will be computed by an expert operator
Audience	Before i4Q --> N/A After i4Q --> Technical Supervisors and Management from Biesse side
Decision	CUSTUMER AND BIESSE SIDE: This indicator is usable as indicator for the manager level to make an analysis of machine reliability BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance; This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters or to replace the machine damaged components.

Table 16. KPI_{219} definition: Occurrence of Micro-Marker Errors

3.2.2 Objectives and KPIs definition for Business Processes 2 of Pilot 2 (To-Be_P2_BP02)

The objectives that BIESSE aims to achieve with the implementation of *To-Be_P1_BP02 Electrospindle Monitoring*, are defined next:

- *P2_BP02_O1* (O_{221}): Reduce the failed tool changes or component breakage through the monitoring of the time required by the electro-spindle to perform the lock and unlock operations during the tool change.

In this subsection, the KPIs defined to monitor the Business Process 2 of Pilot 2 To-Be_P2_BP02 are presented next:

- KPI_{221}: Occurrence of Lock Tool Errors
- KPI_{222}: Occurrence of Unlock Tool Errors
- KPI_{223}: Lock Tool Trend
- KPI_{224}: Unlock Tool Trend

Name	Occurrence of Lock Tool Errors (OLTE)
ID	KPI_{221}
Description	The occurrence of lock tool errors is the ratio of the Number of Lock Tool Errors (NLTE) to the Number of Lock Tool (NLT)
Objective	KPI_{221} will allow to measure the achievement of P2_BP02_O1
Units of measure	[%]
Data source	Number of Lock Tool Errors (NLTE) Number of Lock Tool (NLT) Before i4Q --> current enterprise data source After i4Q --> current enterprise data source and the following i4Q solutions, including **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** should predict premature or normal physiological degradation of the components and to avoid unexpected breakage.
Math. Formula	KPI_{221} = OLTE = NLTE/NLT
Measurement Timing	NLTE and NLT are measured in real-time and then the OLTE is computed at the of the day.
Evaluation Timing	OLTE is evaluated at the end of the day
Trend	The lower, the better
Range	Min: 0 % Max: 100 %
Responsible for Measurement	Before i4Q --> N/A After i4Q --> The KPI will be computed by an expert operator
Audience	Before i4Q --> N/A After i4Q --> Technical Supervisors and Management from Biesse side
Decision	CUSTUMER AND BIESSE SIDE: This indicator is usable as indicator for the manager level to make an analysis of machine reliability BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance; This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters or to replace the machine damaged components.

Table 17. KPI_{221} definition: Occurrence of Lock Tool Errors

Name	Occurrence of Unlock Tool Errors (OUTE)
ID	KPI_{222}

Description	The occurrence of unlock tool errors is the ratio of the Number of Unlock Tool Errors (NUTE) to the Number of Unlock Tool (NUT)
Objective	KPI_{221} will allow to measure the achievement of P2_BP02_O1
Units of measure	[%]
Data source	Number of Unlock Tool Errors (NUTE) Number of Unlock Tool (NUT) Before i4Q --> current enterprise data source After i4Q --> current enterprise data source and the following i4Q solutions, including **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** should predict premature or normal physiological degradation of the components and to avoid unexpected breakage.
Math. Formula	KPI221 = OUTE = NUTE/NUT
Measurement Timing	NUTE and NUT are measured in real-time and then the OUTE is computed at the of the day.
Evaluation Timing	OUTE is evaluated at the end of the day
Trend	The lower, the better
Range	Min: 0 % Max: 100 %
Responsible for Measurement	Before i4Q --> N/A After i4Q --> The KPI will be computed by an expert operator
Audience	Before i4Q --> N/A After i4Q --> Technical Supervisors and Management from Biesse side
Decision	CUSTUMER AND BIESSE SIDE: This indicator is usable as indicator for the manager level to make an analysis of machine reliability BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance. This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters or to replace the machine damaged components.

Table 18. KPI_{222} definition: Occurrence of Unlock Tool Errors

Name	Lock Tool Trend (LTT)
ID	KPI_{223}
Description	Time domain analysis of the lock tool trend
Objective	KPI_{223} will allow to measure the achievement of P2_BP02_O1

Units of measure	Seconds (s)
Data source	Time for Lock Tool (TLT) Timestamp (t) Number of Tool Holder (NTH) Before i4Q --> current enterprise data source After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-i4Q_DR**. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	$KPI_{223} = LTT = g\ (TLT, t, NTH)$ g means a generic time domain algorithm
Measurement Timing	All data sources are measured during axes calibration and then the LTT is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	LLT is evaluated in real time
Trend	It's desirable to have constant value close to the target one. Remarkable positive or negative trend from the target suggest the probability that failed tool changes or component breakage may occur
Range	Min: 0 Max: 3.01
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.
Decision	BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance. This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components (e.g., Replace the pressure multiplier) or maintenance. This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms

	and feedback from the machine operator and Biesse support.

Table 19. KPI_{223} definition: Lock Tool Trend

Name	Unlock Tool Trend (UTT)
ID	KPI_{224}
Description	Time domain analysis of the unlock tool trend
Objective	KPI_{224} will allow to measure the achievement of P2_BP02_O1
Units of measure	[s]
Data source	Time for Unlock Tool (TUT) Timestamp (t) Number of Tool Holder (NTH) Before i4Q --> current enterprise data source After i4Q - The required data sources should be defined by **21-i4Q_LRT/11-i4Q_BDA/10-i4Q_DA** and collected according to **9-i4Q_DIT/8-i4Q_DR**. The algorithms should be defined in the **15-i4Q_IM/11-i4Q_BDA/10-i4Q_DA** while the process data should be visualized by **12-i4Q_AD**.
Math. Formula	KPI_{224} = *UTT = g (TUT, t, NTH)* g means a generic time domain algorithm
Measurement Timing	All data sources are measured during axes calibration and then the UTT is computed in real time. The machine conditions during the test cycle are defined in the pilot requirements **PC2r8** and **PC2r9**.
Evaluation Timing	UTT is evaluated in real time
Trend	It's desirable to have constant value close to the target one. Remarkable positive or negative trend from the target suggest the probability that failed tool changes or component breakage may occur
Range	Min: 0 Max: 3.01
Responsible for Measurement	Before i4Q --> N/A After i4Q --> i4Q The algorithms responsible for measurement will be developed in the pilot requirements **PC2r6**, **PC2r12** and **PC2r13.**
Audience	Before i4Q --> N/A After i4Q --> Customer and Technical Supervisors/Management from Biesse side by the interface defined in the pilot requirements **PC2r17** and **PC2r18**.

Decision	BIESSE SIDE: This indicator is feedback for the technical department to make an analysis of machine performance. This indicator is usable for Biesse support to propose a reconfiguration of the machine parameters, to replace the machine damaged components (e.g., Replace the pressure multiplier) or maintenance. This indicator is usable for i4Q solutions to tune algorithms and thresholds through a correlation between outputs from the algorithms and feedback from the machine operator and Biesse support.

Table 20. KPI_{224} definition: Unlock Tool Trend

3.3 Pilot 3: White Goods Product Quality

3.3.1 Objectives and KPIs definition for Business Processes 1 of Pilot 3 (To-Be_P3_BP01)

The objectives that WHIRPOOL aims to achieve with the implementation of *To-Be_P3_BP01 Full production product conformity automatic assessment*, are defined next:

- P3_BP01_O1 (O_{311}): Eliminate non-conform product to reach the market by filtering them at factory or internal logistic level.
- P3_BP01_O2 (O_{312}): Increase the products quality and process quality by a 100% through the use of data information and analytical tools.

In order to have a better understanding of the KPI Involved in WHR use case, the KPIs have been grouped in three families: Business Process Impact, Business Process Efficiency, Business process Effectiveness.

In this section we are describing the KPIs commonly used in Whirlpool to assess and measure product Quality as directly linked with the objective O_{311}. WHR policies have already in place a system of KPI which is used to monitor and keep track of quality along the product lifetime. The KPIs defined to monitor the Business Process 1 of Pilot 3 To-Be_P3_BP01 are presented next:

Business Process Impact related KPIs: In simpler word the strategy is to move the detection of failures from consumer home, to ZHQ and finally to the production line: this can help meet customer expectations more effectively to achieve higher customer satisfaction and allows for a fully controlled improvement of product and production process.

- KPI_{311}: FPY - First Pass Yield
- KPI_{312}: Q-LOSS, to measure the overall quality of the product (not only assembly) but also reliability of some component
- KPI_{313}: 1MIS - First Month in Service, is an index of customer dissatisfaction.
- KPI_{314}: 1-2-star percentage

Business Process Efficiency KPIs: Other than measuring the impact of the BP_01 on business, we are also expecting the process itself to improve in terms of efficiency, and thus use less resources (human, capital, and time). These KPI are not yet in place since the improvement of this specific business process is not yet performed in a Kaizen style but more as a step improvement. However, three main indicators will be used to measure the result of i4Q on BP efficiency:

- KPI_{315}: BP Cost reduction
- KPI_{316}: Ramp up time
- KPI_{317}: Time to Market Change

Name	FPY - First Pass Yield
ID	KPI_{311}
Description	It is a measure of finished goods (FG) produced without any reprocessing. Ratio between distinct serial numbers (S/N) – i.e. each single product has a serial number associated, and the data gathered are related to products having a S/N without any repairs and the total number of distinct S/N produced during the same time interval. FPY is expressed as a percentage ranging from 0 to 100%. It is used to measure factory effectiveness in quality. It measures how good are the production and assembly processes in producing good parts without reworking. Measurements and tests performed during production are limited in terms of time, so they have always to be related to a specific period of time (shift, day, week, month, etc)
Objective	To achieve a state of production without need for repairs, incomplete products, and quality issues. Reduce reworks, scrap, and incomplete products at the end of the assembly lines. P3_BP01_O01
Units of measure	Percentage %
Data source	(S/N: serial number) Reworked S/N + Incomplete S/N + Scrapped S/N: Total number of distinct serial numbers (S/N) that have been sent to the repair station Complete S/N + Scrapped S/N: Total number of distinct serial numbers (S/N) that enter the assembly line Before i4Q --> current enterprise data source - Factory legacy system After i4Q --> current enterprise data source - Factory legacy system **10-i4Q_DA, 16-i4Q_DT, 15-i4Q_IM, 12-i4Q_AD**, combined in an integrated will impact to the overall Quality monitoring and improving process.
Math. Formula	$FPY = 1 - \frac{(Reworked\ S/N\ + Incomplete\ S/N\ +\ Scrapped\ S/N}{Complet\ S/N\ +\ Scarpped\ S/N}$
Measurement Timing	FPY is usually measured for each shift. Can be grouped by day, week, month.
Evaluation Timing	FPY is usually evaluated by day, week, month, year
Trend	Generally, the higher the better. However, in a first phase for a particular group of problem FPY is expected to decrease. After it has been stabilized is expected to grow again. For the specific timeframe of i4Q we are interested in Its decrease. The KPI above mentioned are not always moving in the same direction,

	especially when improvement actions take place: 1) FPY is expected to increase when Improvement on product and process are in place, 2) FPY is expected to decrease if an improvement on measurement system is placed (e.g.: new gauge station, new measuring procedures, change in acceptance limits etc.) A decrease in FPY should reflect, after a given period of time (usually several months) to a decrease of 1MIS 1st Month in Service (KPI 313 described in **Table 23**)
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> MES After i4Q --> MES
Audience	Before i4Q --> Operators, Supervisors, Management After i4Q --> Operators, Supervisors, Management
Decision	FPY is a measure of efficiency of the assembly line. The plant should use FPY to find permanent solutions to root causes that negatively impact FPY. The scope of the plant is to maximize FPY. FPY can be impacted by the adoption of improved, more accurate measurement and detection system along the production line: in this case, the more filtering capacity is applied to production line the more FPY is expected to lower. In a stabilized period however, the Improvement action of the plant will tend to improve It again by reducing the potential causes of defects at design stages and thanks to process improvement.

Table 21. KPI_{311} definition: FPY - First Pass Yield

Name	Q-LOSS
ID	KPI_{312}
Description	Measurement describes the frequency of units with defects which may cause a service call in the market. Measurement is a weighted average of A, B, and C defects with assigned weights of 1, 0,5 and 0,1, respectively (2 B defects are equivalent to 1 A defect and 10 C defects are equivalent to 1 A defect). Measurement is based on statistical process control, 3% of finished goods are chosen based on sampling strategy by the quality department. Improvement initiatives need to ensure that measurement strictness is kept, more discovered defects might reduce the number of customer complaints. Zero Hours Test (ZHT) team is to record a defect weight following only

	the guidelines for defect assignment established at the central level. To measure the overall quality of the product (not only assembly) but also reliability of some component. It is based on the result of intensive testing conducted on sample production (3%) and on the combination of three different severity of defects (A- defect, B-Defect, C-Defect in order of severity). The scope of Q-loss Is to monitor overall product quality and product conformity and avoid large numbers of potentially faulty or defective appliances to reach the market.
Objective	Monitor defects which might cause customer complaints P3_BP01_O01
Units of measure	Parts per million (ppm)
Data source	Number of identified A, B, C defects found during ZHT No. of units tested: Number of units tested into ZHT lab. Before i4Q --> current enterprise data source - Factory legacy system After i4Q --> current enterprise data source - - Factory legacy system **10-i4Q_DA, 16-i4Q_DT, 15-i4Q_IM, 12-i4Q_AD**, combined in an integrated will impact to the overall Quality monitoring and improving process.
Math. Formula	$QLoss = \frac{(Nº\ of\ A\ defects) + (0{,}5 \cdot Nº\ of\ B\ defects) + (0{,}1 \cdot Nº\ of\ C\ defects)}{Nº\ of\ units\ tested} \cdot 1000000$
Measurement Timing	Q Loss is usually measured for each shift. Can be grouped by day, week, and month.
Evaluation Timing	Q Loss is usually evaluated by day, week, month, year
Trend	The lower the better. However, in case of an improvement of measurement system, Q-loss can be seen growing (more defects found before they reach the market). After it has stabilized Is expected to lower again. For the specific timeframe of i4Q we are interested in its increase: i4Q will contribute as an improvement of filtering capacity. The KPI above mentioned are not always moving in the same direction, especially when improvement action are in place: Q-LOSS is expected to decrease if the filtering capacity is moving backward in the value chain (e.g.: a test performed in ZHT is implemented on 100% production on line or at supplier home)
Range	Min: 0 ppm Max: 1Million ppm
Responsible for Measurement	Before i4Q --> Quality Area Managers After i4Q --> Quality Area Managers
Audience	Before i4Q --> Operators, Supervisors, Management After i4Q --> Operators, Supervisors, Management

Decision	If Q Loss is increasing specific actions are taken by multifunctional teams in order to analyse specific problems and deploy solution either on product level (redesign), procurement, or process (fabrication or assembly)

Table 22. KPI_{312} definition: Q-LOSS

Name	First month in service
ID	KPI_{313}
Description	First month in service (1MIS) is an index of customer dissatisfaction. Measurement describes the number of Service interventions for pieces produced during a specific period of production (typically a month). Usually, the first reliable data is available after 4 months from production, but data with a 6-month maturity is considered to be more representative. 3-month rolling average is used for more reliable business reviews. Two events that occurred in the same product are counted separately if the second call was made at least 7 days after the first call. 1MIS is expressed in parts per million (ppm). The minimum possible value of 1MIS is 0 ppm. Organization should clearly outline actions to decrease 1MIS. First Month in Service to measure the incidence of service call received from the market in the first month of appliance operation, which is believed to be the significant period for failures depending on production to appear.
Objective	Measure the service incident rate on products during the first month of life. Verify the impact of actions aimed at improving quality including prevention, detection, and containment. P3_BP01_O01
Units of measure	Parts per million (ppm)
Data source	Number of identified A, B, C defects found during ZHT (Zero Hour Test – statistical check done after production in ZHT lab) Number of units tested: Number of units tested into ZHTlab. Before i4Q --> current enterprise data source - Factory legacy system After i4Q --> current enterprise data source - - Factory legacy system **10-i4Q_DA, 16-i4Q_DT, 15-i4Q_IM, 12-i4Q_AD**, combined in an integrated will impact to the overall Quality monitoring and improving process.
Math. Formula	$1MIS = \frac{Nº\ products\ prodiced\ in\ period\ p\ which\ failled\ in\ 1\ month}{Nº\ of\ products\ produced\ in\ period\ p} \cdot 1000000$
Measurement Timing	1MIS is measured monthly.

Evaluation Timing	1MIS is evaluated by month, quarter, year
Trend	The lower the better. The higher the FPY (cfr. KPI_{311} First Pass Yield) in this introduction phase should allow a contextual decrease of defects found in the market (represented by 1MIS)
Range	Min: 0 ppm Max: 1Million ppm
Responsible for Measurement	Before i4Q --> Quality Area Managers After i4Q --> Quality Area Managers
Audience	Before i4Q --> Supervisors, Management After i4Q --> Supervisors, Management
Decision	If 1MIS is increasing specific actions are taken by multifunctional teams in order to analyse specific problems and deploy solution on improving quality including prevention, detection, and containment.

Table 23. KPI_{313} definition: 1-MIS

Name	1-2 Rating Star
ID	KPI_{314}
Description	It is composed by the % of negative reviews (1&2 stars) visible on a list of selected retailers' websites it is the periodical evaluation of the number of negative feedbacks reported by consumers in the trade partners and retailer's websites
Objective	Measure the customer perception on Whirlpool products. P3_BP01_O01
Units of measure	%
Data source	Number of 1- and 2-star ratings Before i4Q --> Selected Retailers Websites After i4Q --> Selected Retailers Websites **10-i4Q_DA, 16-i4Q_DT, 15-i4Q_IM, 12-i4Q_AD**, combined in an integrated will impact to the overall Quality monitoring and improving process.
Math. Formula	$12\ star = \frac{Nº\ of\ reviews\ rated\ with\ 1\ and\ 2\ stars}{Nº\ of\ total\ review} \cdot 100$
Measurement Timing	12STAR is measured monthly.
Evaluation Timing	12STAR is evaluated by month, quarter, year
Trend	The lower the better.
Range	Min: 0 % Max: 100%

Responsible for Measurement	Before i4Q --> Central Quality After i4Q --> Central Quality
Audience	Before i4Q --> Supervisors, Management After i4Q --> Supervisors, Management
Decision	If 12STAR is increasing specific actions are taken by multifunctional teams in order to analyse specific problems and deploy solution on improving quality including prevention, detection, and containment

Table 24. KPI314 definition: 1-2 Rating Star

Name	BP (Business Process) Cost reduction
ID	KPI_{315}
Description	Ratio between cumulated cost avoidance of physical test avoided thank to Virtual test introduction and actual cost. Reduction of expenses and capital by using a massive conformity test execution 50% reduction TCQ (Total Cost of Quality - from 120k€/year factory to 60K€/year factory)
Objective	Measure the efficiency of BP. P3_BP01_O2
Units of measure	%
Data source	Factory cost reporting. Before i4Q --> Factory cost reporting (120k€/year) After i4Q --> Estimate by Quality Managers and Business Process experts **10-i4Q_DA, 16-i4Q_DT, 15-i4Q_IM, 12-i4Q_AD**, combined in an integrated will impact to the overall Quality monitoring and improving process.
Math. Formula	*BPCostReduction =1 - (Forecasted BP Cost/Previous BP cost)*
Measurement Timing	This KPI will be measured before i4Q introduction (AS-IS) and after i4Q introduction (TO-BE)
Evaluation Timing	This KPI will be evaluated at project end after M36. (so very difficult to be actualized and reported in a deliverable)
Trend	The higher the better
Range	Min: 20% Max: 50%
Responsible for Measurement	Before i4Q --> not used After i4Q --> i4Q team, Central Quality
Audience	Before i4Q --> not relevant

	After i4Q --> Central Quality
Decision	If BP Cost Reduction is not achieving the required reduction (or it's increasing) the Central Quality team will evaluate whether the new cost is acceptable considering the Improvement in business impact. This evaluation will be used for exploitation strategy as well.

Table 25. KPI_{315} definition: BP Cost Reduction

Name	Ramp-up time
ID	KPI_{316}
Description	The time to move from Pilot Production of new model to complete regime production at target quality level and cost
Objective	Measure the effectiveness of Quality conformity process during a NPI (New Product Introduction). P3_BP01_O02
Units of measure	Days
Data source	NPI Project Management post audit (internal audit done on sample NPI project to evaluate how the project performed) Before i4Q --> Project Management Post-audit documentation After i4Q --> Project Management Post-audit documentation **10-i4Q_DA, 16-i4Q_DT, 15-i4Q_IM, 12-i4Q_AD**, combined in an integrated will impact to the overall Quality monitoring and improving process.
Math. Formula	$Ramp - up\ time = Date_{regime} - Date_{pilot}$
Measurement Timing	This KPI will be measured after each NPI project conclusion. It's not possible presently to know whether a NPI project will be conclude in the DIsh factory during the i4Q project execution.
Evaluation Timing	Ramp-up-time will be evaluated at NPI project conclusion
Trend	The lower the better
Range	Min: 0 days (ramp up is immediate and the quality level and cost are released at target the day of start production) Max: undefined (a project could never reach the given target)
Responsible for Measurement	Before i4Q --> NPI project manager After i4Q --> NPI project manager
Audience	Before i4Q --> Management After i4Q --> Management
Decision	If Ramp-up time is increasing or not decreasing, some correction at business process, organization and tool are evaluated by management

Table 26. KPI_{316} definition: Ramp-up Time

Name	TTM Time to Market Change
ID	KPI_{317}
Description	Time to Introduce a new model or platform in the market. It is measured as days between the New Product Introduction project start and the effective availability of new product in the market. The knowledge created by the correlation analysis may lead to a better product development, pushing to redesign process control levels and tolerances chain, arriving also to review the approach to systematic quality data gathering (CPM Critical Parameter Management) focusing only on what is really impacting the final product quality. >10% decrease time-to-market (from average 300 days to 270 days)
Objective	Measure the effectiveness of NPI (New Product Introduction) business process P3_BP01_O2
Units of measure	Days
Data source	NPI Project Management post audit Before i4Q --> Project Management Post-audit documentation After i4Q --> Project Management Post-audit documentation **10-i4Q_DA, 16-i4Q_DT, 15-i4Q_IM, 12-i4Q_AD**, combined in an integrated will impact to the overall Quality monitoring and improving process.
Math. Formula	$TTM = DATE_{ProjectStop} - DATE_{ProjectStart}$
Measurement Timing	This KPI will be measured after each NPI project conclusion
Evaluation Timing	TTM will be measured after each NPI project conclusion
Trend	The lower the better
Range	Min: 0 days (theoretical - a very small project not requiring any activity or a NPI process ultra-optimized could allow a direct introduction of new product in the market instantaneously) Max: Undefined (not all the NPI project get to a conclusion)
Responsible for Measurement	Before i4Q --> NPI project manager After i4Q --> NPI project manager
Audience	Before i4Q --> Management After i4Q --> Management
Decision	If TTM is increasing or not decreasing, some correction at business process, organization and tools are evaluated by management

Table 27. KPI_{317} definition: Time to Market

3.4 Pilot 4: Aeronautics and Aerospace Metal Parts Quality

3.4.1 KPIs definition for Business Processes 1 of Pilot 4 (To-Be_P4_BP01)

The objective that FACTOR aims to achieve with the implementation of *To-Be_P4_BP01 In-line product quality control*, is defined next:

- P4_BP01_O1 (O_{411}): Eliminate the parts that are manufactured with defects, rising the quality ratio.
- P4_BP01_O1 (O_{411}): Eliminate machine stops due to faulty parts. Machine stops is another source of waste due to the time spent on fixing a machine when a quality issue appears.

In this subsection, the KPIs / KPI defined to monitor the Business Process 1 of Pilot 4 To-Be_P4_BP01 are/is presented.

- KPI_{411} Quality ratio
- KPI_{412} Machines stops due to Quality issues

Name	Quality ratio
ID	KPI_{411}
Description	The quality ratio is the relationship between the good quantity (GQ) and the produced quantity (PQ). The **quality ratio** measures the number of good parts that have been produced without defects and they are ready to be delivered over the total manufactured parts, therein is an indicator of the waste that the manufacturer produces.
Objective	KPI_{411} will allow to measure the achievement of the objective P4_BP01_O1 by measuring the **ratio of the good quality parts related to the total parts** and finally achieving, in an ideal scenario, the goal of zero-defect manufacturing, therefore, rising the quality ratio to 100%. KPI_{411} will allow to measure the achievement of the objective P4_BP01_O2, given that the OEE value is the result of multiplying quality ratio by effectiveness and availability, if the quality ratio rises, maintaining the rest of the parameter's constant, the value of the OEE will rise.
Units of measure	quality ratio (%)
Data source	OK Parts or good quantity **(GQ)** Total produced quantity **(PQ)** Before i4Q --> Manual Data inputted in an excel file and M.E.S. After i4Q --> **15-i4Q_IM** should check that the measurements are between the ranges of the quality specifications, if it doesn't, the solution should count the NOK parts and calculate the quality ratio. The data will be sent to **7-i4Q_DR** and **9-i4Q_DIT** will take the data and calculate historical Quality Ratio.

Math. Formula	KPI_{411} = GQ / PQ
Measurement Timing	Before i4Q: One part of every different launch* is measured every hour, the result of this measure is extrapolated to the production of the last hour, if this part is OK, last hour's production is considered OK, if it isn't, the whole production of the last hour is considered NOK and sent to quality department for a further analysis or analyzed by the operator himself. ALL these parts are considered NOK. These values are always inputted manually to an Excel Spreadsheet. After i4Q: Quality ratio measured **real time** by 15-i4Q_IM**. All parts should be measured and if NOK parts are detected, the system should count them as NOK and interpretate the real time Quality Ratio value; **9-i4Q_DIT** should calculate the historical quality ratio. *A launch is a production of a different model or order; the parts are different among the different launches. **Every time that a part is produced, the value should be updated.
Evaluation Timing	Quality ratio is evaluated in real time by **10-i4Q_DA,** other solutions as **11-i4Q_BDA or 16-i4Q_DT** can take this data to build the algorithms. Managers will evaluate the data on demand.
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Machine Operator/ Quality management / Supervisors After i4Q --> **15-i4Q_IM**
Audience	Before i4Q --> Machine Operator/ Quality management / Supervisors/ Production Management After i4Q --> • 12-i4Q_AD, 10-i4Q_DA, 11-i4Q_BDA. 16-i4Q_DT. • Data analysts: Quality Management/ Production Management. • Operators, assemblers, and plant floor personel.
Decision	This indicator is usable as real-time indicator for the operator level to reconfigure the machine parameters This indicator is usable as indicator for the manager level to make a study of the machine parameters and determine whether change the production allocation or similar decisions. This indicator is usable for i4Q solution propose a reconfiguration of the

	machine parameters, stop the machine if the number of unvalidated parts rises or continuously improve the process until achieving a 100 % of quality ratio.

Table 28. KPI_{411} definition: Quality ratio

Name	Machines stops due to Quality issues
ID	KPI_{412}
Description	When the measurements of the parts are not within the tolerances of the geometry dimensions, the machine is stopped and adjusted to reduce the scrap. The KPI_{412} measures the number of stops that a machine is stopped because the parts are not being well machined.
Objective	Since quality ratio depends on the good quantity over the total produced quantity, reducing the parts that are not well machine will improve the quality value of the OEE. Therefore, KPI_{412} will allow to measure the achievement of the objective P4_BP01_O1, given that the OEE value is the result of multiplying quality ratio by effectiveness and availability, if quality ratio is raised, keeping the rest of the parameters constant, the OEE will rise. KPI_{412} will allow to measure the achievement of the objective P4_BP02_O2 reducing the number of stops will mean that the total time that a machine is stopped will be lower. If the stops because of quality issues is improved, availability will be improved as well.
Units of measure	Number of stops because of quality issues (Counter)
Data source	Number of stops (quality issues) **(NS_Q)** Before i4Q --> Manual Data inputted in an excel file and M.E.S. After a machine is stopped, the operator justifies the stop by selecting quality issues. (Not measuring intensively). After i4Q --> **15-i4Q_IM/18-i4Q_QD** should count every stop due to quality issues by an isolated counter and extract the real time value of the KPI. **9-i4Q_DIT** should be able to access this data and calculate historical KPI values.
Math. Formula	$KPI_{412} = NS_Q$
Measurement Timing	Before i4Q: One part of every different *launch** is measured every hour, the result of this measure is extrapolated to the production of the last hour, if this part is OK, last hour's production is considered OK, if it isn't, the whole production of the last hour is considered NOK and the machine is stopped to reduce scrap. The problem is analyzed and solved by human effort. After i4Q: Every time that the dimensions don't fit the tolerances, **15-i4Q_IM/18-i4Q_QD** should compute the stop as a stop because of quality issues and

	9-i4Q_DIT should have a counter of the historical stops. **A launch is a production of a different model or order; the parts are different among the different launches.*
Evaluation Timing	Number of stops due to quality issues is measured real time* by **10-i4Q_DA.** Managers will evaluate the data on demand. *Update the KPI after each stop.
Trend	The lower, the better
Range	Min: 0 Max: Will be defined later
Responsible for Measurement	Before i4Q --> Machine Operator/ Quality management / Supervisors After i4Q --> • 15-i4Q_IM/18-i4Q_QD/9-i4Q_DIT • Supervisor / Quality Management
Audience	Before i4Q --> Quality management, operations management After i4Q --> • *12-i4Q_AD,* 10-i4Q_DA, 11-i4Q_BDA. 16-i4Q_DT • Data analysts: Quality Management/ Production Management • Operators, assemblers, and plant floor personel.
Decision	This indicator is usable as a real-time indicator for the operator level to reconfigure the machine parameters This indicator is usable for the manager level to make a study of the machine parameters and determine whether change the production allocation, tools or similar decisions. This indicator is usable for the i4Q solution propose a reconfiguration of the machine parameters, stop the machine if the number of unvalidated parts rises, or continuously improve the process until achieving a 100 % of quality.

Table 29. KPI_{412} definition: Number of stops due to quality issues

3.4.2 Objectives and KPIs definition for Business Processes 2 of Pilot 4 (To-Be_P4_BP02)

The objectives that FACTOR aims to achieve with the implementation of *To-Be_P4_BP02 Automatic online correction of the CNC machining process*, are defined next:

- *P4_BP02_O1 (O_{421})*: the **Overall Equipment Effectiveness (OEE)** is calculated by the product of quality ratio (P4_BP01_O1), availability (P4_BP02_O2), and effectiveness (P4_BP02_O3). The objective of P4_BP02_O1 is to **rise the final value of the OEE**. Since P4_BP02_O2 is the result of multiplying the values of the other main objectives, a further description of each one is addressed in its respective sections.
- *P4_BP02_O2 (O_{422})*: lower the time that a machine is stopped. Being the availability the time that a machine is running divided over the total time that the machine should have been running, the objective is to avoid non-expected stops of the machine, rising the time that the machine is producing final goods, rising then the availability value.
- *P4_BP02_O3 (O_{423})*: rise the final **effectiveness value of the OEE,** which is the ratio between the number of machined parts divided by the theoretical part that should have been machined.

In this subsection, the KPIs defined to monitor the Business Process 2 of Pilot 4, To-Be_P4_BP02: Automatic online correction of the CNC machining process, are presented:

- *KPI_{421}*: Overall Equipment Effectiveness
- *KPI_{422}*: Availability
- *KPI_{423}*: Effectiveness
- *KPI_{424}*: Machines stops due to Maintenance operations
- *KPI_{425}*: Machines stops due to tool breakages

Name	Overall Equipment Effectiveness
ID	KPI_{421}
Description	Overall Equipment effectiveness represents the availability of a work unit (see KPI_{422}), the effectiveness of the work unit (see KPI_{423}) and the quality ratio (see KPI_{411}). Overall Equipment Effectiveness integrates the aforementioned KPIs in a single indicator.
Objective	KPI_{421} will allow to measure the achievement of P4_BP02_O1, P4_BP02_O2, P4_BP01_O1 and P4_BP02_O3 Combined with KPI_{411}, KPI_{422} and KPI_{423}, the KPI_{421} will measure and improve the OEE.
Units of measure	%
Data source	Quality Ratio **(QR)** Availability **(AVA)** Effectiveness **(EFF)** Before i4Q --> enterprise data source via the Manufacturing Execution System (M.E.S) and further analysis. The calculation is done automatically. The data source of the 3 parameters is explained in its own KPIs. After i4Q --> **15-i4Q_IM** should check in real time* the status of the machine and report the results to **9-i4Q_DIT** which should calculate the OEE with the historical data.

	*OEE can be updated every minute.
Math. Formula	OEE = Quality Ratio (QR) * Availability (AVA) * Effectiveness (EFF)
Measurement Timing	Before i4Q --> OEE is measured automatically and in real time by the M.E.S. but a further and deep analysis has to be made to have real data. After i4Q --> **9-i4Q_DIT** should calculate the OEE in real time. It will also be calculated by the M.E.S.
Evaluation Timing	Overall Equipment Effectiveness is evaluated nn real time by **10-i4Q_DA;** other solutions, like **11-i4Q_BDA or 16-i4Q_DT** can also evaluate the results. Overall Equipment Effectiveness is evaluated on demand, daily, weekly, quarterly and annually by management board.
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Manufacturing Execution System (MES) and management. After i4Q --> • 15-i4Q_IM, 9-i4Q_DIT. • M.E.S. and operations management
Audience	Before i4Q --> Production Managers, quality managers, decision making responsible and operators After i4Q --> • *12-i4Q_AD,* 10-i4Q_DA, 11-i4Q_BDA. 16-i4Q_DT • Production Managers, quality managers, decision making managers. • Operators, assemblers, and plant floor personel.
Decision	This indicator is usable as a real-time indicator for the operator level to understand how production is performing. This indicator is usable for the manager level to make a study of the overall production and identify weak points over the production dependencies. This indicator is usable for i4Q solution to understand whether the production is being improved or not. This KPI will mean the basic objective for the i4Q solution. If other KPI is being improved but OEE is not, the changes that the solution is proposing are not meeting the success criteria.

Table 30. KPI_{421} definition: Overall equipment effectiveness

Name	Availability
ID	KPI_{422}

Description	Availability is a ratio that shows the relation between the actual production time (APT), which Is the time that the machine has been producing and the planned busy time (PBT) for a work unit, which is the total time that the machine should have been producing.
Objective	KPI_{422}will allow achieving the Objective P4_BP01_O1 and P4_BP02_O2 by analyzing **how much time the machine is producing final goods** over the total time that the machine should have been producing. If the availability is raised, while the other parameters of the OEE keep constant, the OEE value will rise.
Units of measure	%
Data source	Actual Production Time **(APT)** Planned busy time **(PBT)** Before i4Q --> enterprise data source via the Manufacturing Execution System (M.E.S) with already existing sensors and further analysis. After i4Q --> **15-i4Q_IM** should check in real time the status of the machine and calculate the availability in real time within a determined time ranges or launches; the data should be reported to **7-i4Q_DR and 9_i4Q_DIT** to enable the calculation of historical availability and OEE.
Math. Formula	KPI_{422} = APT / PBT
Measurement Timing	Before i4Q --> Availability is measured automatically and in real time by the M.E.S. but a further analysis has to be made to have real data. After i4Q --> Availability measured real time, **15-i4Q_IM** should report the actual status of availability and **9-i4Q_DIT** should calculate the historical results.
Evaluation Timing	Availability is evaluated in real time by **10-i4Q_DA;** other solutions, like **11-i4Q_BDA or 16-i4Q_DT** can also evaluate the results. Availability is evaluated on demand, daily, weekly, quarterly and annually by management board.
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Manufacturing Execution System (MES) and operations management. After i4Q --> • 15-i4Q_IM, 9-i4Q_DIT, • M.E.S. and operations management
Audience	Before i4Q --> Manager, operator After i4Q --> • *12-i4Q_AD,* 10-i4Q_DA, 11-i4Q_BDA. 16-i4Q_DT

	• Production Managers, quality managers, decision making managers. • Operators, assemblers, and plant floor personel.
Decision	This indicator is usable as a real-time indicator for the operator level to know the production status, the most critical machines and launches and where are resources being wasted. This indicator is usable as an indicator for the manager level to study where the time is being wasted and why and allocate resources. This indicator is usable for the i4Q solution to know whether the changes are making a positive impact or slowing down the production by rising stopped time.

Table 31. KPI_{422} definition: Availability

Name	Effectiveness
ID	KPI_{423}
Description	Effectiveness represents the relationship between the planned target cycle and the actual cycle expressed as the planned runtime per item (PRI) multiplied by the produced quantity (PQ) divided by the actual production time (APT).
Objective	This $KPI\text{-}_{423}$ will allow achieving the Objective P4_BP02_O3 by analyzing **how much efficient the process of machining is being performed,** measuring the number of parts that the machine has produced with the theorical number of parts that the machine should have produced. The OEE depends on effectiveness, while other parameters keep constant, rising this KPI will mean a higher OEE, which is the final objective.
Units of measure	%
Data source	Planned runtime per item **(PRI)** Actual Production Time **(APT)** Produced quantity **(PQ)** Before i4Q --> enterprise data source via the Manufacturing Execution System (M.E.S) with already existing sensors. The theorical planned runtime per item (PRI) is done manually. After i4Q --> i4Q solutions can be filled by the M.E.S.
Math. Formula	Effectiveness = (PRI * PQ)/ APT
Measurement Timing	Before i4Q --> Effectiveness is measured automatically and in real time by the M.E.S. A further analysis has to be made to have real data. After i4Q --> **15-i4Q_IM** should get the production time per part and calculate the real time effectiveness; the real time value should be

	provided to **9-i4Q_DIT** that will calculate the Effectiveness value over determined time ranges and launches.
Evaluation Timing	Effectiveness is evaluated in real time by **10-i4Q_DA and 15-i4Q_IM;** other solutions, like **11-i4Q_BDA or 16-i4Q_DT** can also evaluate the results. Overall Equipment Effectiveness is evaluated on demand, daily, weekly, quarterly and annually by management board.
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Manufacturing Execution System (MES) and management. After i4Q --> Real time: **15-i4Q_IM** and M.E.S.
Audience	Before i4Q --> Manager, operator After i4Q --> • 12-i4Q_AD, 10-i4Q_DA, 11-i4Q_BDA. 16-i4Q_DT • Production Managers, quality managers, decision making managers.
Decision	This indicator is usable as a real-time indicator for the operator level to reconfigure the machine parameters. This indicator is usable as an indicator for the manager level to visualize if production can be improved and if machines are running as expected. This indicator is usable for the i4Q solution propose a reconfiguration of the machine parameters.

Table 32. KPI_{423} definition: Effectiveness

Name	Machines stops due to Maintenance operations
ID	KPI_{424}
Description	A main goal of the implementation of i4Q is to prevent issues, identify potential problems that can happen in a short period of time and taking actions to avoid them or alerting, reducing the maintenance operations that are performed after a problem happens. The time that a machine is stopped is a waste that can be solved by anticipating problems.
Objective	KPI_{424} will allow to measure the achievement of the objective P4_BP01_O1, given that the OEE value is the result of multiplying quality ratio by effectiveness and availability, if the time that a machine is stopped because of maintenance operations, the overall time that the machine is stopped will lower, rising the availability and then the OEE. KPI_{424} will allow to measure the achievement of the objective P4_BP02_O2 Reducing the number of stops will mean that the total time that a machine is stopped will be lower. If the stops because of maintenance operations is improved, availability will be improved as

	well.
Units of measure	Number of stops because of maintenance operations (Counter)
Data source	Number of stops (quality issues) **(NS_M)** Before i4Q --> Value inputted by the maintenance department in the M.E.S. (Not measuring intensively). After i4Q --> **18-i4Q_QD** should determine if the cause of the stop is due to maintenance operations, show the data in real time and deploy it to **9-i4Q_DIT**, that will use this data to calculate the historical KPI value
Math. Formula	$KPI_{424} = NS_M$
Measurement Timing	Before i4Q: Stops due to maintenance operations are measured real time by the MES. After i4Q: **18-i4Q_QD** should extract the value in real time.
Evaluation Timing	With the real time value provided by **18-i4Q_QD**, the solution **9-i4Q_DIT**, **10-i4Q_DA, 11-i4Q_BDA should evaluate the value also in real time.** Managers will evaluate the data on demand.
Trend	The lower, the better
Range	Min: 0 Max: Will be defined later
Responsible for Measurement	Before i4Q --> Machine Operator/ Quality management / Supervisors After i4Q --> **18-i4Q_QD and 9-i4Q_DIT**
Audience	Before i4Q --> Manager After i4Q --> • 12-i4Q_AD, 10-i4Q_DA, 11-i4Q_BDA. 16-i4Q_DT • Production Managers, quality managers, decision making managers.
Decision	This indicator is usable as a real-time indicator for the operator level to reconfigure the machine parameters in order to avoid problems related with maintenance. This indicator is usable for the manager level to make a study of the machine parameters and determine whether change the production allocation, tools or similar decisions. This indicator is usable for the i4Q solution propose a reconfiguration of the machine parameters, stop the machine if the number of unvalidated parts rises, or continuously improve the process until achieving a 100 % of availability.

Table 33. KPI_{424} definition: Number of stops due to maintenance operations

Name	Machines stops due to tool breakages
ID	KPI_{425}
Description	A main goal of the implementation of i4Q is to prevent tool breakages, if a tool is arriving to its final production time and it is not performing well, i4Q should change the parameters to return to normal operations or stop the production and alert before quality issues take place.
Objective	KPI_{424} will allow to measure the achievement of the objective P4_BP01_O1. If a tool is broken, the machine process is not well performed and quality parts are lowered; reducing the times that a tool is broken will reduce the non-quality parts, rising then the quality ratio. KPI_{424} will allow to measure the achievement of the objective P4_BP01_O1, given that the OEE value is the result of multiplying quality ratio by effectiveness and availability, if the time that a machine is stopped because of tool breakages it will raise the quality ratio, the availability because of a higher production time and the effectiveness. KPI_{424} will allow to measure the achievement of the objective P4_BP02_O2. Reducing the number of stops will mean that the total time that a machine is stopped will be lower. If the stops because of tool breakages is improved, availability will be improved as well. KPI_{424} will allow to measure the achievement of the objective P4_BP02_O3. Every time that a machine is started, it has a warm up period, where the effectiveness is not the optimal. Reducing the times that a machine is stopped will mean a reduction of that time, raising the overall effectiveness.
Units of measure	Number of stops because of tool breakages
Data source	Number of stops (quality issues) **(NS_{TB})** Before i4Q --> Value inputted by the operator in the M.E.S. (Not measuring intensively). After i4Q --> **15-i4Q_IM** should alert every time that a stop because of potential tool breakage is about to happen; if the problem is solved by changing the tool, the stop will not be computed as a stop because of tool breakage but if the tool finally breaks and the machine is stopped, **18-i4Q_QD** will interpretate the stop as a stop due to tool breakage.
Math. Formula	$KPI_{425} = NS_{TB}$
Measurement Timing	Stops due to maintenance operations are measured real time by the MES. After i4Q: **18-i4Q_QD** should extract the value in real time.
Evaluation Timing	With the real time value provided by **18-i4Q_QD**, the solution **9-i4Q_DIT, 10-i4Q_DA, 11-i4Q_BDA should evaluate the value also in real time.** Managers will evaluate the data on demand.

Trend	The lower, the better
Range	Min: 0 Max: Will be defined later ~~Infinite~~
Responsible for Measurement	Before i4Q --> Machine Operator/ Quality management / Supervisors After i4Q --> **15-i4Q_IM and 18-i4Q_QD**
Audience	Before i4Q --> Manager After i4Q --> • 12-i4Q_AD, 10-i4Q_DA, 11-i4Q_BDA. 16-i4Q_DT • Data analysts: Quality Management/ Production Management • Maintenance Department personel • Operators, assemblers, and plant floor personel.
Decision	This indicator is usable as a real-time indicator for the operator level to reconfigure the machine parameters in order to avoid problems related with maintenance. This indicator is usable for the manager level to make a study of the machine parameters and determine whether change the production allocation, tools or similar decisions. This indicator is usable for the i4Q solution propose a reconfiguration of the machine parameters, stop the machine if the tool breakage can take place soon and alert to perform a change with enough time to interfere as less as possible in the production.

Table 34. KPI_{425} definition: Number of stops due to tool breakages

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

3.5.1 Objectives and KPIs definition for Business Processes 1 of Pilot 5 (To-Be_P5_BP01)

The objectives that RIASTONE aims to achieve with the implementation of To-Be_P5_BP01 Data collection and analysis for raw matter quality control, are defined next:

- P5_BP01_O1 (O_{511}): To diagnose quality issues related to raw matter parameter variations, and raw matter quality ratio.
- P5_BP01_O2 (O_{512}): To reduce the "post-isostatic press" scrap rate caused by raw matter's composition variations

Both objectives will be attained by setting up a process for collecting, storing and analyzing raw matter composition and granulometry data, the process will have as an end goal to find significant variations on these parameters that could lead to defects in the pieces produced with the analyzed raw matter batches.

The main goal is to analyze raw matter's composition data, in order to continuously probe its quality and effects on the overall final product quality. Further, comparison analyses between the quality of raw matter upon its arrival and its quality upon production line feeding will enable a better understanding of the changes that occur during storage as well as strategies to mitigate quality issues in the future.

The process itself will be materialized through the installation of a spectrometer, a polarized light source, and a sensing probe directly in the dispensing trays that feed raw matter to the production process, it is expected that data collection and analysis will be achieved during i4Q.

In this subsection, the KPIs defined to monitor the Business Process 1 of Pilot 5 To-Be_P5_BP01: Data collection and analysis for raw matter quality control are presented:

- KPI_{511}: Raw Matter Composition ratio
- KPI_{512}: Post-Isostatic Press Scrap rate

Name	Raw Matter Composition ratio
ID	KPI_{511}
Description	The raw matter composition ratio is the correlation between the measured composition values (MC), and the theoretical benchmark values (BC). This raw matter composition ratio compares the measured variations in composition and granulometry of the raw matter being used in the production (real-time) against a benchmark for accepted variations in the aforementioned parameters
Objective	P5_BP01_O2
Units of measure	This KPI is measured in relative %
Data source	Measured Composition (MC) - Spectrometry/Granulometry sensors data Benchmark Composition (BC) - Laboratory analysis data/ historical composition data (to be acquired) Before i4Q --> N/A After i4Q --> Spectrometry/Granulometry sensor data
Math. Formula	Raw Matter Composition ratio = |MC / BC| < "X" (TBD) where X is the accepted variation regarding BC
Measurement Timing	Raw Matter composition is measured at a sampling cycle rate of ~1 second
Evaluation Timing	Raw Matter Composition validation in the same standard cycle rate of ~1 second, identical to the measurement sampling rate Every time the product is dispensed into the dispensing tray
Trend	Exact values to be defined, namely: • total measurement period

	Note: as a general rule the lower the "X", the better
Range	Upper and lower logical limits of the KPI Min: 0% Max: 100% Note: there will be a % grading of the 100%, that will trigger alarms with different severities and mitigation actions
Responsible for Measurement	The responsible personnel for Quality Measurement are the Quality Supervisors – personnel responsible for directing the activities of the operators regarding quality related events As-Is Before i4Q --> Quality Supervisors To Be After i4Q --> **10-i4Q_DA, 11-i4Q_BDA 12-i4Q_AD**
Audience	The Audience (Work Group) using this KPI as part of ISO 22400 are: • Quality Supervisors – personnel responsible for directing the activities of the operators regarding quality related events • Production Management – personnel responsible for the overall execution of production, and contract management relations with 3rd parties Before i4Q --> Quality Supervisors / Production Management After i4Q --> i4Q solution / Production Management
Decision	@Production Line level, this KPI is usable as real-time indicator for the operator level to reconfigure the machine parameters, or even the production line configuration, depending of the alarm/event severity. @Management Level this KPI is usable as a measurement of raw matter "Deficient Quality" indicator, that will enable price promotion/demotion mechanism towards the 3rd party raw matter supplier

Table 35. KPI_{511} definition: Raw Matter Composition ratio

Name	Post-Isostatic Press Scrap rate
ID	KPI_{512}
Description	The Post-Isostatic Press Scrap rate is the relationship between the conformant quantity (CQ), and the produced quantity (PQ). The Post-Isostatic Press Scrap rate represents the quality ratio of the isostatic press stage of the production process, and is primarily influenced by the raw matter composition variations
Objective	P5_BP01_O2
Units of measure	This KPI is measured in relative %
Data source	• The source or sources from which the enterprise is going to obtain the data needed to calculate the math. Conformant Quantity (CQ) - submillimetre computer

	vision-based quality control data after the Iso-pressing and fettling process • Produced Quantity (PQ) - Quantity control data after the Iso-pressing and fettling process Before i4Q --> current Pressing process Quality Control report After i4Q --> **i4Q solution / Production Management Dashboard**
Math. Formula	The mathematical formula of the KPI specified in terms of elements is: Post-Isostatic Press Scrap rate = |CQ / PQ| < "X" (TBD)
Measurement Timing	Product Conformity (CQ) is measured in real-time, @ a standard cycle rate of ~1 second
Evaluation Timing	Conformant Quantity (CQ) is periodically evaluated at the end of each 8-hour operational shift. Every time the product is dispensed into the dispensing tray
Trend	Exact values to be defined, namely: • total measurement period Note: as a general rule the lower the "X", the better
Range	Upper and lower logical limits of the KPI: Min: 0% Max: 100% Note: there will be a % grading of the 100%, that will trigger alarms with different severities and mitigation actions
Responsible for Measurement	The responsible personnel for this KPI are the Shift Supervisors – personnel responsible for directing the activities of the operators regarding production related events As-Is Before i4Q --> Quality Supervisors To Be After i4Q --> **10-i4Q_DA, 11-i4Q_BDA 12-i4Q_AD, 18-i4Q_QD**
Audience	The Audience (Work Group) using this KPI as part of ISO 22400 are: • Shift Supervisors – personnel responsible for directing the activities of the operators regarding production related events Before i4Q --> Shift Supervisors After i4Q --> 8-i4Q_DR, 12-i4Q_AD
Decision	At Production Line level, this KPI is usable as real-time indicator for the shift manager and the operators to reconfigure the machine parameters, or even the production line configuration, depending of the alarm/event severity.

Table 36. KPI_{512} definition: Quality ratio

3.5.2 Objectives and KPIs definition for Business Processes 2 of Pilot 5 (To-Be_P5_BP02)

The objectives that RIASTONE aims to achieve with the implementation of To-Be_P5_BP02 Final product QC causal relation analysis, are defined next:

Within i4Q it is expected that data correlation and analytics methods are developed and deployed in order to analyze the causal relations between data collected and analyzed during the production process and final products' QC process data. Further, a systematic data collection process on the final QC stage is essential.

- P5_BP02_O1 (O_{521}): To increase the cause-defect detection ratio, by performing a causal analysis between the final quality ratio and variations in the production stage parameters (e.g., it is known that the density of the glazing liquid will lead to the appearance of specific defects in quality control, such as drops or holes in the final glazing).
- P5_BP02_O2 (O_{522}): To increase the quality ratio by predicting future defects and alert the operators/managers accordingly.

In this subsection, the KPIs defined to monitor the Business Process 2 of Pilot 5 To-Be_P5_BP02: Final product QC causal relation analysis are presented:

- KPI_{521}: Quality ratio
- KPI_{522}: Cause-Defect detection ratio

Name	Quality ratio
ID	KPI_{521}
Description	The quality ratio is the ratio between the conformant quantity (CQ) Vs the produced quantity (PQ) The quality ratio KPI will measure the overall quality of the production process
Objective	KPI521 will enable the measure of achievement of the Objective P5_BP02_O1
Units of measure	This KPI is measured in relative %
Data source	conformant quantity (CQ) - Final Quality Control report (Excel file) produced quantity (PQ) - Final Quality Control report (Excel File) Before i4Q --> current report (not built for machine ingestion and interpretation) After i4Q --> **12-i4Q_AD, 18-i4Q_QD**
Math. Formula	The mathematical formula of the KPI specified in terms of elements *Quality ratio = |CQ / PQ| < "X" (TBD)*
Measurement Timing	Product Conformity (CQ) is measured in real-time, a standard cycle rate of ~1 second
Evaluation Timing	Conformant Quantity (CQ) is periodically evaluated at the end of each 8-hour operational shift

Trend	Is the information about the improvement direction, higher is better or lower is better • Note: as a general rule the lower the "X", the better
Range	Specifies the upper and lower logical limits of the KPI Min: 98% Max: 100%
Responsible for Measurement	The responsible personnel for Quality Measurement are the Quality Supervisors – personnel responsible for directing the activities of the operators regarding quality related events As-Is Before i4Q --> Quality Supervisors To Be After i4Q --> i4Q solution
Audience	The Audience (Work Group) using this KPI as part of ISO 22400 are: • Quality Supervisors – personnel responsible for directing the activities of the operators regarding quality related events • Production Management – personnel responsible for the overall execution of production Before i4Q --> Quality Supervisors / Production Management After i4Q --> i4Q solution / Production Management
Decision	@Production Line level, this KPI is usable as real-time indicator for the operator level to reconfigure the Glazing Mixer/ Glazing Tunnel machine parameters, or even the production line configuration, depending of the alarm/event severity.

Table 37. KPI_{521} definition: Quality ratio

Name	Cause-Defect detection ratio
ID	KPI_{522}
Description	The Cause-defect ratio is the relationship between the defects with detected cause (DC) and the total number of defects (DT)
Objective	KPI_{522} will enable the measure of achievement of the Objective P5_BP02_O2
Units of measure	This KPI is measured in relative %
Data source	defects with cause (DC) - i4Q causal analysis results defects total (DT) - Final Quality Control reports (Excel File) Before i4Q --> manual correlation between causes and effects (empirical) After i4Q --> **10-i4Q_DA, 11-i4Q_BDA, 12-i4Q_AD. 18_i4Q_QD**
Math. Formula	Cause-Defect detection ratio = DC / DT
Measurement Timing	Cause-Defect Detection Ratio is periodically evaluated at the end of each

	8-hour operational shift
Evaluation Timing	The Evaluation Frequency coincides with the measurement Timing
Trend	For this specific KPI the Higher the KPI_{522}, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	The responsible personnel for Quality Measurement are the Quality Supervisors – personnel responsible for directing the activities of the operators regarding quality related events As-Is Before i4Q --> Quality Supervisors To Be After i4Q --> i4Q solution
Audience	The Audience (Work Group) using this KPI as part of ISO 22400 are: • Quality Supervisors – personnel responsible for directing the activities of the operators regarding quality related events • Production Management – personnel responsible for the overall execution of production, Before i4Q --> Quality Supervisors / Production Management After i4Q --> i4Q solution / Production Management
Decision	At Management Level this KPI is usable as a measurement of cause-effect detection capabilities, lower values will indicate that further process refinements are necessary.

Table 38. KPI_{522} definition: Cause-Defect detection ratio

3.6 Pilot 6: Automatic Advanced Inspection of Automotive Plastic Parts

3.6.1 Objectives and KPIs definition for Business Processes 1 of Pilot 6 (To-Be_P06_BP01)

The objectives that FARPLAS aims to achieve with the implementation of To-Be Business Process 1 of Pilot 6 *To-Be_P06_BP01 Autonomous parameter optimization for the injection process*, are defined next:

- P6_BP01_O1 (O_{611}): Reducing the Cycle Time in the Injection Process

This objective aims to reduce cycle time of the Injection process by automatically optimizing the Injection machine parameters as part of the i4Q solution. This solution will replace the manual the optimizing the injection parameters, which results in wasted time and resources with a much more efficient automatic parameter optimization solution.

- P6_BP01_O2 (O_{612}): Reducing Scrap Rate

With this objective Farplas aims to achieve significant reduction in scrap produced by plastic injection process by replacing the trial-based parameter optimizing process which produces scrap on each trial with i4Q solution.

In this subsection, the KPIs defined to monitor the Business Process 1 of Pilot 6 To-Be_P06_BP01 Autonomous parameter optimization for the injection process are presented:

- KPI_{611}: Cycle time (referred to the units of time needed to produce one part)
- KPI_{612}: Unplanned Stop Time
- KPI_{613}: Overall equipment effectiveness index
- KPI_{614}: Quality Ratio
- KPI_{615}: Availability
- KPI_{616}: Effectiveness
- KPI_{617}: Wasted good amount

Name	Cycle time (referred to the units of time needed to produce one part)
ID	KPI_{611}
Description	The average production time spend on each part. This indicator calculated by dividing the addition of time spend on production (PT) and unplanned stop time (UST) by the quantity of produced parts per day (PQ).
Objective	P6_BP01_O1
Units of measure	Time units(sec) / part produces
Data source	Before i4Q: • Collected from SAP and Injection Data After i4Q: • Collected from SAP and Injection Data
Math. Formula	KPI_{611} = PT+UST / PQ
Measurement Timing	Real-time
Evaluation Timing	End of the day
Trend	The lower, the better
Range	Min: 0 Max: PT+UST
Responsible for Measurement	Before i4Q --> Machine Operator After i4Q --> Big Data System
Audience	Before i4Q --> Operator and Process engineer After i4Q --> **9-i4Q_DIT, 10-i4Q_DA, 12-i4QAD**
Decision	This indicator is usable to evaluate the effectiveness if i4Q solutions. If this parameter is below the expected value, i4Q solution was not effective.

Table 39. KPI_{611} definition: Cycle time

Name	Unplanned Stop Time
ID	KPI_{612}
Description	Time spent on manual optimization of Injection process parameters
Objective	P6_BP01_O1
Units of measure	Time Unit (sec)
Data source	Machine activity log sheet and Production planning sheet Before i4Q --> OEE Sheet from SAP After i4Q --> OEE Sheet from SAP
Math. Formula	KPI_{612} = Time spent on manual optimization of Injection process parameters
Measurement Timing	Realtime
Evaluation Timing	End of the day
Trend	The lower, the better
Range	Min: 0 Max: 86.400 sec.
Responsible for Measurement	Before i4Q --> Machine Operator and Process engineer After i4Q --> SAP
Audience	Before i4Q --> Operator and Process engineer After i4Q --> i4Q solution, Operator and Process engineer
Decision	This indicator is usable for i4Q solution propose a reconfiguration of the machine parameters.

Table 40. KPI_{612} definition: Unplanned stop Time

Name	Overall equipment effectiveness index (OEE)
ID	KPI_{613}
Description	The OEE index represents the availability of a work unit. The effectiveness of the work unit, and the quality factors integrated in single indicator
Objective	P6_BP01_O1 P6_BP01_O2
Units of measure	%
Data source	Before i4Q --> OEE sheet from SAP After i4Q --> OEE sheet from SAP
Math. Formula	*KPI_{613} = Performance * Availability * Quality*

Measurement Timing	periodically, real-time
Evaluation Timing	End of day
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Process engineer After i4Q --> SAP
Audience	Before i4Q --> Operator and Process engineer After i4Q --> Operator and Process engineer
Decision	This indicator is usable for i4Q solution propose a reconfiguration of the machine parameters. If this parameter increased less than 10% the i4Q solution was not effective.

Table 41. KPI_{613} definition: OEE

Name	Quality ratio
ID	KPI_{614}
Description	The quality ratio is the relationship between the good quantity (GQ) and the produced quantity (PQ)
Objective	P6_BP01_O1 P6_BP01_O2
Units of measure	%
Data source	Before i4Q --> OEE sheet from SAP After i4Q --> OEE sheet from SAP
Math. Formula	$KPI_{614} = 100 * GQ / PQ$
Measurement Timing	Periodically
Evaluation Timing	End of day
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Process engineer After i4Q --> SAP
Audience	Before i4Q --> Operator and Process engineer After i4Q --> Operator and Process engineer
Decision	This indicator is used for calculating OEE.

Table 42. KPI_{614} definition: Quality ratio

Name	Availability
ID	KPI_{615}
Description	Availability is ratio that shows the relation between the actual product time (APT) and the planned busy time (PBT) for a work unit.
Objective	P6_BP01_O1 P6_BP01_O2
Units of measure	%
Data source	Before i4Q --> OEE sheet from SAP After i4Q --> OEE sheet from SAP
Math. Formula	$KPI_{615} = 100 * APT / PBT$
Measurement Timing	Periodically
Evaluation Timing	End of day
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Process engineer After i4Q --> SAP
Audience	Before i4Q --> Operator and Process engineer After i4Q --> Operator and Process engineer
Decision	This indicator is used for calculating OEE.

Table 43. KPI_{615} definition: Availability

Name	Effectiveness (Performance)
ID	KPI_{616}
Description	Effectiveness represents the percentage ratio between the actual working time (AWT) and production time (APT)
Objective	P6_BP01_O1 P6_BP01_O2
Units of measure	%
Data source	Before i4Q --> OEE sheet from SAP After i4Q --> OEE sheet from SAP

Math. Formula	$KPI_{616} = PT * 100 / AWT$
Measurement Timing	Periodically
Evaluation Timing	End of day
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Process engineer After i4Q --> SAP
Audience	Before i4Q --> Operator and Process engineer After i4Q --> Operator and Process engineer
Decision	This indicator is used for calculating OEE.

Table 44. KPI_{616} definition: Effectiveness

Name	Wasted good amount
ID	KPI_{617}
Description	The wasted goods amount describes the wasted material per day. It's calculated by summation of total weight of scrap parts.
Objective	P6_BP01_O2
Units of measure	gram
Data source	Before i4Q --> SAP After i4Q --> SAP
ath. Formula	KPI_{617} = Wasted good amount = Scrap Weight
Measurement Timing	periodically
Evaluation Timing	End of day
Trend	The lower, the better
Range	Min: 0 Max: unlimited
Responsible for Measurement	Before i4Q --> Process engineer After i4Q --> SAP and Process engineer
Audience	Before i4Q --> Process engineer After i4Q --> Process engineer
Decision	This indicator is usable for i4Q solution propose a reconfiguration of the machine parameters. If this parameter does not decrease more than 50% the i4Q solution was not effective.

Table 45. KPI_{617} definition: Wasted good amount

3.6.2 Objectives and KPIs definition for Business Processes 2 of Pilot 6 (To-Be_P06_BP02)

The objectives that FARPLAS aims to achieve with the implementation of *To-Be_P6_BP02 Automatic Quality Inspection*, are defined next:

- P6_BP02_O1 (*O_{621}*): Reducing Cycle Time in the Quality Control Process

This objective aims to reduce the time of the quality control process and increase the accuracy as part of the i4Q solution. This solution will replace the visual quality control process with a much more efficient automatic quality control solution.

In this subsection, the KPIs defined to monitor the Business Process 2 of Pilot 6 To-Be_P6_BP02 Automatic Quality Inspection are presented:

- *KPI_{621}*: Injection Cycle Time
- *KPI_{622}*: Overall equipment effectiveness index

Name	Injection Cycle Time
ID	KPI_{621}
Description	Total cycle time of the injection process.
Objective	P6_BP02_O1
Units of measure	Time(sec)
Data source	Before i4Q → OEE sheet from SAP and Injection Data After i4Q → OEE sheet from SAP and Injection Data
Math. Formula	N/A
Measurement Timing	Real-time
Evaluation Timing	Real-time
Trend	The lower, the better
Range	Min: 0 Max: 300 sec
Responsible for Measurement	Before i4Q --> Injection machine and SAP After i4Q --> SAP and i4Q Solution
Audience	Before i4Q --> Operator and QA After i4Q --> Process engineer
Decision	This indicator is usable for i4Q solutions purposes **18-i4Q_QD** . If this parameter does not decrease 15% the **18-i4Q_QD** solution was not effective.

Table 46. KPI_{621} definition: Injection cycle time

Name	Overall equipment effectiveness index
ID	KPI_{622}
Description	The OEE index represents the availability of a work unit. the effectiveness of the work unit, and the quality factors integrated in single indicator. OOE calculated by multiplying Performance, Availability and Quality
Objective	P6_BP02_O1
Units of measure	%
Data source	Before i4Q --> OEE sheet from SAP After i4Q --> OEE sheet from SAP
Math. Formula	*OEE = Performance * Availability * Quality*
Measurement Timing	periodically, real-time
Evaluation Timing	End of day
Trend	The higher, the better
Range	Min: 0% Max: 100%
Responsible for Measurement	Before i4Q --> Process engineer After i4Q --> SAP
Audience	Before i4Q --> Operator and Process engineer After i4Q --> Process engineer
Decision	This indicator is usable for i4Q solution propose a reconfiguration of the machine parameters. If this parameter increased less than 10% the i4Q solution was not effective.

Table 47. KPI_{622} definition: Overall equipment effectiveness index

4. KPIs Dashboard

4.1 Dashboard Tool Selection

In order to fulfil the objectives of this deliverable, different tools have been evaluated that allow both the collection of the data of the numerical values of the KPIs of the Pilots.

Based on these numerical values it will be done a graphical representation of them that allow their analysis both to see their state at the present moment and to see their evolution over the time, that allows predicting future values, and in this way to know if they are within the correct margins or are outside the margins, altering the production systems.

Several KPIs Dashboards tools has been evaluated, from simple free dashboards that allow you to track a limited number of KPIs, dashboards that follow strict methodologies such as the 'Balanced Scorecard' or ones that come as part of a more extensive Business Intelligence (BI) solution. Most tools have a similar set of basic features such as integrations, full-screen modes, and all the graphs. However, features such as additional analytics tools, KPI reports, and optional manual data entry will prove beneficial as you grow your performance tracking.

Taking into account all the before considerations, Microsoft Excel has been selected because it is a tool that fulfils all the objectives pursued in the collection of the KPIs of the i4Q Pilots, with the following fundamental characteristics:

- MS Excel allows reading/loading of text files in .txt and .csv formats (among others), which are some of the common formats in which the information is generated by MES production control systems.
- It has a huge set of statistical formulas to analyze KPIs data.
- MS Excel has graphic tools that allow the visual representation of the KPIs facilitating the interpretation of the data and decision making.
- MS Excel has a very useful macro programming interface.
- And finally, it is a universally known tool, accessible to everyone and easy to use.

4.2 KPIs Dashboard Tool IMPLEMENTATION

Once the KPIs have been defined and the initial starting values have been established, the collection of KPIs in excel files is started.

The KPIs have been collected in the following MS Excel files:

- i4Q-Pilot**01-FIDIA**_KPIsDashboard.xlsx
- i4Q-Pilot**02-BIESSE**_KPIsDashboard.xlsx
- i4Q-Pilot**03-WHIRPOOL**_KPIsDashboard.xlsx
- i4Q-Pilot**04-FACTOR**_KPIsDashboard.xlsx
- i4Q-Pilot**05-RIASTONE**_KPIsDashboard.xlsx
- i4Q-Pilot**06-FARPLAS**_KPIsDashboard.xlsx

The strategy followed for the collection of the KPIs is as follows:

- First sheet is a summary of the KPIs collected within the context of D1.8, thus making it easier to identify the KPIs and the key information to be entered in the Excel sheets. The fields it contains are the following:

- Business Process Oder number, BP description and BP Code.
- KPI Identification and KPI Name.
- Units of measure and Math. Formula.
- Timing Measurement and Timing Evaluation.
- Trend and Range.

- A separate sheet for each KPI containing the data and the formulas that operate on these data and the Dashboard graphs. The nomenclature used in the separate sheets containing each of the KPI values is identified as follows:

  PilotNumber_BusinesProcessNumber-KPINumber

  For example: **P4_BP02 - KPI421** would be:

  - P4: Pilot number 4 – FACTOR
  - BP02: Business Process number 02
  - KPI421: Overall Equipment Effectiveness

Each KPI spreadsheet contains the following information:

- KPI **Baseline** Value.
- Data/Hour.
- Range LOW.
- Range HIGH.
- KPI **Current** Value: value calculated by the formula corresponding to each KPI.
- Date / Hour: the date and the hour have been separated because in most of the KPIs the measurement of the same with respect to the hour is very significant.
- Formula: contains the parameters/values used by the formula to calculate "KPI Current" value of the KPI. Those parameters/values are information that is directly input by each Pilot.

For each KPI sheet, a graphical representation of the evolution of the KPI data over time is made to see its evolution and improvement with respect to the initial values and after the implementation of i4Q Solutions.

Figure 1. Example of i4Q Pilot FACTOR`s KPI (**P4_BP02 - KPI421**) - Overall Equipment Effectiveness

Initially it has been decided to use MS Excel "Combination Charts" for the Dashboards because it let i4Q Pilots represent two different data tables that are related to each other, in which there would be a primary x-axis and y-axis and an additional secondary y-axis to help provide broader understanding in one chart, and in that way these charts will give a comparative analysis of the two graphs of different categories and also for the mixed type of data, thereby enabling Pilots to view and highlight higher and lower values within the charts. These "Combination Charts" are the best feature that enables to summarize large data sets with multiple data tables and illustrate the numbers in a systematic manner in one chart.

These MS Excel spreadsheets with the KPIs will be complementary to the i4Q AD - Analytics Dashboard solution in which advanced tools will be used for the treatment of large volumes of big data information.

In WP6 - EVALUATE: Piloting and Demonstrating - **Phase-1 - Pilot implementation definition, planning and KPI validation criteria**, the high-level scenarios in T1.3 - Use Cases Scenarios and KPIs will be complemented.

The Pilots/Industrial Users will iterate again on the KPIs' MS Excel files, continuing to collect the requirements in terms of specific KPI values and validation criteria to be evaluated. Collecting this information throughout the project, which will be refined as the project progresses, for the definition of precise validation methods and procedures to univocally determine the real values of these KPIs. These methods will be used for a first evaluation of the KPIs, in order to allow comparison of the results and analysis of improvements at the end of the project.

Due to the confidential nature of the KPI data, each i4Q pilot partner will be responsible for the MS Excel spreadsheet that collects their KPIs, throughout the project.

5. Conclusions

This deliverable seeks in depth and defines in detail the methodology used to define KPIs required to quantitatively evaluate the results obtained by setting up i4Q based solutions. To define the KPIs the pilots have formulated the set of objectives to achieve when implementing the To-Be business processes, previously reported in D1.3. Once defined the objectives, each pilot has described the KPIs to measure the degree of achievement of the previously defined objective.

The ISO 22400 Automation systems and integration KPIs for manufacturing operations management is be followed for defining, implementing and visualizing the Pilots KPIs.

A summary of the defined KPIs is depicted next, including the i4Q solutions and enterprise legacy systems that are prompt to be used for the KPI measurement:

		Data sources After i4Q solutions implementation	
Pilot	**KPIixk**	**i4Q Solutions**	**Enterprise Legacy Systems**
Pilot 1	KPI_{111}: Final surface roughness	9-i4Q_DI / 18-i4Q_QD / 21-i4Q_LRT	Rugosimeter
	KPI_{112}: Processing time	18-i4Q_QD / 21-i4Q_LRT	CAM
	KPI_{121}: Max Chatter RMS in the time domain	9-i4Q_DI / 18-i4Q_QD	
	KPI_{122}: Chatter identification time		
	KPI_{131}: Failed Component Identification Time	9-i4Q_DI / 11-i4Q_BDA / 15-i4Q_IM / 21-i4Q_LRT	
Pilot 2	KPI_{211}: Effectiveness	5-i4Q_IM / 10-i4Q_DA,11-i4Q_BDA	Statistical data from the machine
	KPI_{212}: Diagnostics of the Bearing in the Ball Screw transmission	8-i4Q_DR / 9-i4Q_DIT / 10-i4Q_DA / 11-i4Q_BDA / 12-i4Q_AD / 15-i4Q_IM / 21-i4Q_LRT	
	KPI_{213}: Diagnostics of Incorrect Rack Pitch		
	KPI_{214}: Diagnostics of Backlash		
	KPI_{215}: Diagnostics of Cleanliness of the Rack		
	KPI_{216}: Diagnostics of Gantry Error		
	KPI_{217}: Occurrence of Axes Torque Errors	10-i4Q_DA / 11-i4Q_BDA / 15-i4Q_IM	
	KPI_{218}: Micro-Marker Trend	8-i4Q_DR / 9-i4Q_DIT / 10-i4Q_DA / 11-i4Q_BDA / 12-i4Q_AD / 15-i4Q_IM / 21-i4Q_LRT	
	KPI_{219}: Occurrence of Micro-Marker Errors	10-i4Q_DA / 11-i4Q_BDA / 15-i4Q_IM	
	KPI_{221}: Occurrence of Lock Tool Errors		
	KPI_{222}: Occurrence of Unlock Tool Errors		
	KPI_{223}: Lock Tool Trend	8-i4Q_DR / 9-i4Q_DIT / 10-i4Q_DA / 11-i4Q_BDA / 12-i4Q_AD / 15-i4Q_IM / 21-i4Q_LRT	
	KPI_{224}: Unlock Tool Trend		
Pilot 3	KPI_{311}: FPY - First Pass Yield	10-i4Q_DA / 12-i4Q_AD / 15-i4Q_IM / 16-i4Q_DT	Factory Legacy System
	KPI_{312}: Q-LOSS		
	KPI_{313}: 1-MIS		
	KPI_{314}: 1-2 Rating Star		Selected Retailers Websites
	KPI_{315}: BP Cost Reduction		Quality Managers and Business Process experts
	KPI_{316}: Ramp-up Time		Project Management Post-audit
	KPI_{317}: Time to Market		

		Data sources After i4Q solutions implementation	
Pilot	**KPIixk**	**i4Q Solutions**	**Enterprise Legacy Systems**
			documentation
Pilot 4	KPI_{411}: Quality ratio	7-i4Q_DR / 9-i4Q_DIT / 15-i4Q_IM	
	KPI_{412}: Number of stops due to quality issues	9-i4Q_DIT / 15-i4Q_IM / 18-i4Q_QD	
	KPI_{421}: Overall equipment effectiveness	9-i4Q_DIT / 15-i4Q_IM	
	KPI_{422}: Availability		
	KPI_{423}: Effectiveness		
	KPI_{424}: Number of stops due to maintenance operations	9-i4Q_DIT / 18-i4Q_QD	
	KPI_{425}: Number of stops due to tool breakages	15-i4Q_IM / 18-i4Q_QD	
Pilot 5	KPI_{511}: Raw Matter Composition ratio	10-i4Q_DA / 11-i4Q_BDA / 12-i4Q_AD	
	KPI_{512}: Quality ratio	10-i4Q_DA / 11-i4Q_BDA / 12-i4Q_AD / 18-i4Q_QD	
	KPI_{521}: Quality ratio	12-i4Q_AD / 18-i4Q_QD	
	KPI_{522}: Cause-Defect detection ratio	10-i4Q_DA / 11-i4Q_BDA / 12-i4Q_AD / 18-i4Q_QD	
Pilot 6	KPI_{611}: Cycle time	8-i4Q_DR / 11-i4Q_BDA / 12-i4Q_AD	SAP and Injection Data
	KPI_{612}: Unplanned stop Time		OEE Sheet from SAP
	KPI_{613}: OEE		
	KPI_{614}: Quality ratio		
	KPI_{615}: Availability		
	KPI_{616}: Effectiveness		
	KPI_{617}: Wasted good amount		
	KPI_{621}: Injection cycle time		
	KPI_{622}: Overall equipme		

Table 48. Summary of defined KPIs

D1.8 (alongside D9.9) also records a first measure of the KPIs defined, for its use on the KPI baseline values, which will enable to compare the performance between the As-Is business processes (baseline values) and the To-Be business processes.

Therefore, this document (in combination with D9.9) serves as the reference for guidance of KPIs baseline values for the project pilots, and for monitoring the performance achieved within the i4Q project, by using the KPIs dashboard. The KPIs dashboard will enable to make a comparative analysis of the status of the main business processes performed before and after i4Q solutions implementation in each use case.

This document is not without limitations due to some of the KPIs are defined as algorithms that have to be defined in the i4Q solutions; and there is not still closed how are they going to be measured. The pilots have made a first approximation on the solutions where they are going to measure the KPIs, once the i4Q solutions are implemented. This could be a future research line that will be covered in WP6 - EVALUATE: Piloting and Demonstrating.

As part of WP1, Task 1.3 "Use cases scenarios and KPIs" is parallelly tackled on Task 1.4 "Requirements Analysis and Functional Specification", which is already on going taking the results of this deliverable as a direct input, and Task 2.3 “Business Viewpoint”. Future activities

tasks to be developed in terms of KPIs will help the preparation of the test cases validation of WP6, in Tasks 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6).

References

Hertweck, P., Moßgraber, J., Kontopoulos, E., Mitzias, P., Hellmund, T., Karakostas, A., ... & Kompatsiaris, I. (2018). The Backbone of Decision Support Systems: The Sensor to Decision Chain. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM), 10*(4), 65-87.

E. Kamateri, G. Meditskos, S. Symeonidis, S. Vrochidis, I. Kompatsiaris, W. Minker. (2019). Knowledge-based Intelligence and Strategy Learning for Personalised Virtual Assistance in the Healthcare Domain. Semantic Technologies for Healthcare and Accessibility Applications (SyMpATHY). Special session in the 13th International Conference on Advances in Semantic Processing (SEMAPRO), 2019.

ISO 22400 (2014) Automation systems and integration KPIs for manufacturing operations management.

D1.1. Project Vision Guide

D1.3. Demonstration Scenarios and Monitoring KPIs Definition

D1.4. Requirements Analysis and Functional Specification