AUTOWARE

Wireless Autonomous, Reliable and Resilient Production Operation Architecture for Cognitive Manufacturing

D1.2b Data-driven digital manufacturing requirements and KPIs

Document Owner	**SQS**		
Contributors	SFKL, JSI, TEKN, IMEC, SMC		
Reviewers	INNO		
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Project partners

Software Quality Systems	SQS
Asociación de Empresas Tecnológicas Innovalia	INNO
Technologie Initiative SmartFactoryKL e.V.	SmartFactory
Jozef Stefan Institute	JSI
TTTech Computertechnik AG	TTT
Consiglio Nazionale Delle Ricerche	CNR
imec	imec
Robovision	Robovision
Universidad Miguel Hernández	UMH
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.	FhG
Blue Ocean Robotics	BOR
Fundación Tekniker	Tekniker
SMC Pneumatik GmbH	SMC

Executive Summary

This public deliverable (D1.2b) updates the AUTOWARE use case needs and their Key Performance Indicators (KPIs) presented by D1.2a in M6. It has been constructed from the AUTOWARE Task T1.3 "Cognitive Digital Automation Requirement Elicitation & Technical and Business KPI Specification" second phase four months in the project. This task address stakeholders' coordination for the collection, update and negotiation of suitable indicators and requirements to deal with digital cognitive solutions for autonomous manufacturing, which will support the implementation of the AUTOWARE solution.

An appropriate set of business and technical requirements for the definition of the AUTOWARE framework has been derived from the methodology given in D1.1 "Use case scenarios and requirement elicitation framework". Moreover, in order to properly monitor and control the requirements, proper KPIs have been identified and a suitable framework has been proposed to gather and synthesize relevant information.

As a final outcome, business and technical requirements are taken into account in the design of the AUTOWARE manufacturing architecture. The information presented here serves as a basis for continuous KPI-based impact assessment and evaluation of requirements in order to validate and demonstrate the applicability of AUTOWARE innovations.

Keywords

Business process modelling, Challenges, KPIs, Manufacturing, Methodology, Requirements, Use case scenarios.

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Acronyms

3GPP	3rd Generation Partnership Project:
BPI	Business Performance Indicator
CAD	Computer-Aided Design
DoA	Description of Action
ERP	Enterprise Resource Planning
ETSI	European Telecommunications Standards Institute
FoF	Factories of the Future
IEC	International Electrotechnical Commission
IIRA	Industrial Internet Reference Architecture
ISO	International Standardization Organization
IT	Information Technology
KPI	Key Performance Indicator
LTE	Long Term Evolution
MES	Manufacturing Execution System
M2M	Machine-to-Machine
MOM	Manufacturing Operations Management
OEE	Overall Equipment Effectiveness
OT	Operational Technology
PPP	Public Private Partnership
QR	Quick Response
RAMI 4.0	Reference Architecture Model Industrie 4.0
ROS	Robot Operating System
SCADA	Supervisory Control And Data Acquisition
SME	Small and Medium-sized Enterprise
SMI	Service Measurement Index
TPI	Total Performance Index
TPM	Total Productive Maintenance
WP	Work Package

1. Introduction

1.1 Purpose and scope

The successful introduction of flexible, reconfigurable and self-adaptive industrial environments relies upon fulfilling the ecosystem stakeholder needs. Thus, the ultimate objective of this public deliverable is to identify what requirements and Key Performance Indicators (KPIs) are involved in reaching flexible and reconfigurable manufacturing systems. In order to realize that, the AUTOWARE (Wireless Autonomous, Reliable and Resilient Production Operation Architecture for Cognitive Manufacturing) use case needs and their KPIs have been obtained through carefully designed questionnaires and structured interviews, which have allowed us to classify the use case owners' goals and necessities according to different business and technological layers.

Different manufacturing environments, which pose the requirements of industrial deployment both from large and small businesses, have been analysed. In particular, a survey method has been applied to gather information about operational processes, capacities and needs of the following use case scenarios:

- **Neutral experimental facilities** where integrating, testing, and validating the AUTOWARE components in an operational environment. Specifically, these infrastructures are focused on:
    - Modular production processes (**SmartFactory^{KL}**, Section 4.1).
    - Reconfigurable workcells (**JSI**, Section 4.2).
    - Collaborative robotics environments (**Tekniker**, Section 4.3).
- **Industrial production lines**, where paper recycling and machinery sectors are respectively involved:
    - Industrial cognitive automation for the recycling industry (**STORA**, see Section 0), where automation is applied in visual inspection, selection and separation of paper recycling.
    - Manufacturer of pneumatic automation products (**SMC**, Section 0), where the level of automation is low as the assembly is still performed by operators, since a human-like sensitivity has been required.

Based on the proposed approach in D1.1 "Use case scenarios and requirement elicitation framework", a scenario-driven requirements engineering methodology is used to identify the necessities of all the use cases. Specifically, the data collection has involved use case owners and technology providers, and the principal steps in requirements gathering process have included:

1. Discovering: the **elicitation** process represents the first phase to specify use case characteristics and requirements in AUTOWARE. As a starting point, the document D1.1 presented the use case descriptions, including general business objectives to be achieved. Thus, taking into account these descriptions, an analysis of the gap between current (AS-IS) and future (TO-BE) situations allowed us to extract an initial list of unstructured requirements and KPIs from each scenario.
2. **Analysis**: the overall goal of this step is to understand and clarify the elicited requirements applied in the pilot use cases. During this process, the reasons for the needs of the end users are investigated, identifying heterogeneous viewpoints coming from different stakeholders involved.
3. **Specification** report: as a result of the previous process, the needs of the use cases are adapted and classified to be schematically documented.
4. **Validation** phase in which requirements changes are tracked and evaluated

* This process is considered a two iteration methodology, which includes a second verification and validation phase which results are included in this deliverable.

It is necessary to note that, as the scope of the AUTOWARE ecosystem has broadened in the first half of the project, the requirements engineering process have continued and, in this second phase, the results of deliverable D1.2a report have been updated between M18 and M21.

Along this process, requirements are structured and prioritized according to their nature (i.e., level of abstraction and relate goals), which allow us to evaluate the effort required to meet the expectations.

Prior to presenting the collected requirements and measurement indicators, a KPI-based approach is proposed, through which a list of relevant instruments for measuring and benchmarking future manufacturing systems from both business and technical perspectives. For such purpose, a method for identifying and organizing KPIs, which is particularly suited to new manufacturing business models' evaluation, is defined in this deliverable. Furthermore, based on the resulting list of prioritized needs and KPIs identified for each use case scenario, a generalisation of them will be generated. Finally as part of this reflection, an initial preview of the results obtained thanks to the survey on Digitalization and Certification Levels launched with the aim of enhancing the SME engagement strategy is presented, a more detailed report will be presented as part of the lessons learned in the final version of deliverable D1.4b Guidelines on M36.

1.2 Contributions to other WPs and deliverables. Document structure

In Work Package 1 ("Scenario, KPIs & Reference Model"), the AUTOWARE consortium will define requirements, indicators and provide a suitable framework to be used for all technical developments (WP2, WP3, WP4), setting the foundation for piloting phases (WP5). Indeed, WP5 will assess the technical feasibility of the systems proposed. The project plan is shown in Figure 1.

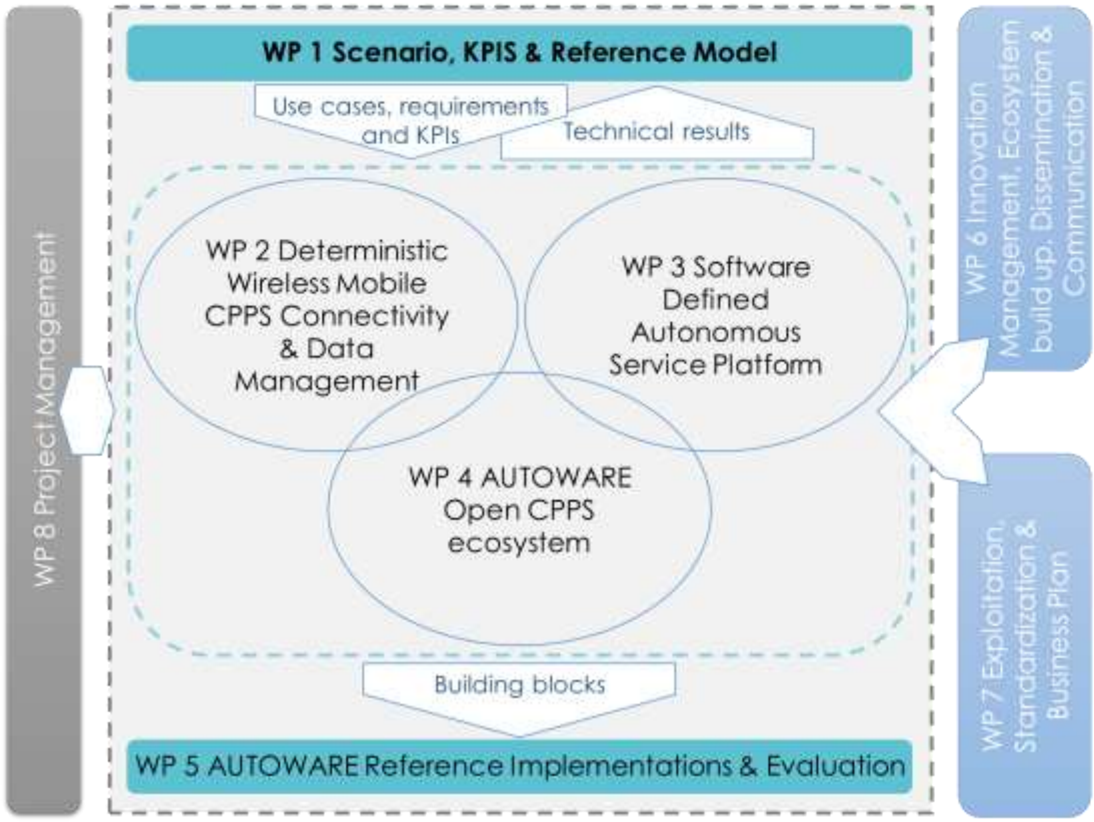


Figure 1. Work plan for AUTOWARE.

The requirement engineering processes and the description of use case scenarios given in deliverable D1.1, which was the main outcome of T1.1 and T1.2, lay the foundation of the analysis of requirements and KPIs. In this point, the present document focuses on the activities of the T1.3 "Cognitive Digital Automation Requirement Elicitation & Technical and Business KPI Specification", which according to the Description of the Action (DoA), have the following objective: to generate individual requirements that cover functional, technical, non-functional and business categories. After that, T1.4 will identify the appropriate solutions to meet the defined technical and business requirements.

In addition, requirements and KPIs specified in this deliverable are an important basis for the technical work packages WP2, WP3 and WP4, which aim at implementing and integrating solutions for realizing the use cases and fulfilling the defined requirements, which will be validated by the WP5 by performing KPI measurements.

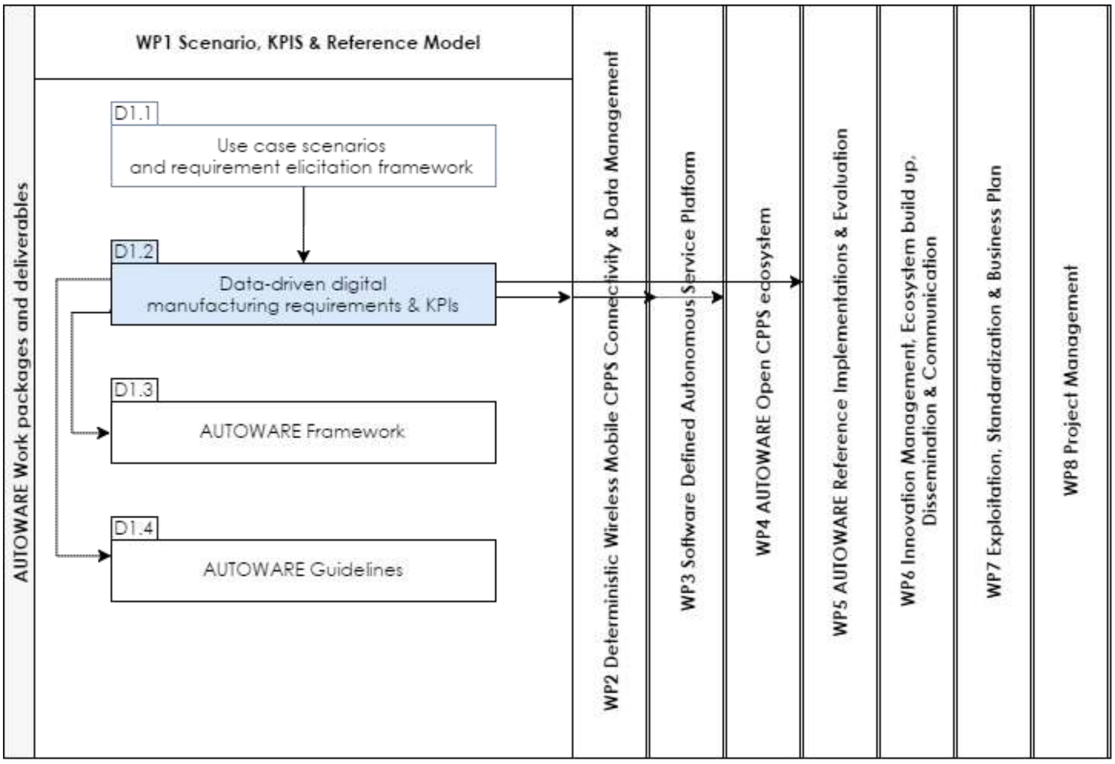


Figure 2. Contributions to other WPs and deliverables.

The remainder of this deliverable is organized as follows:

1. Chapter 0 is concerned with the definition of the methodology for determining performance indicators in AUTOWARE.
2. Chapter 2 and 3 present the AUTOWARE reference models for technological layers and business dimensions, and the KPI definition methodology proposed.
3. Updated structured requirements and KPIs for each use case are presented in Chapters 0 to 0, identifying the final list of requirements and KPIs defined to measure technical and business performance of the use cases.
4. Chapter 7 presents the clustering of the requirements and KPIs based on business goals defined for Industry 4.0 general categories, AUTOWARE technological areas and Reference Architecture enablers.
5. In Chapter 8, the results are generalised in a set of requirements and KPIs which provide insight into a general advanced manufacturing use case.
6. Finally, conclusions are outlined in Chapter 0.

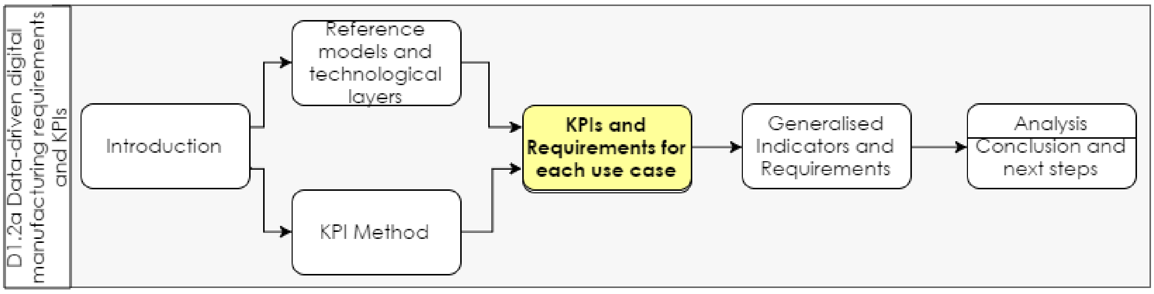


Figure 3. Deliverable structure.

1.3 Target audience

This deliverable is intended to be a guideline for the AUTOWARE project partners; however, it could be also interesting for manufacturing SMEs since it aims at gathering changing needs of manufacturing businesses.

2. Reference models and technological layers

With regard to existing reference models related to automation systems and manufacturing operations, the ANSI/ISA-95 and, later, the IEC 62264 standards define hierarchical models (Figure 4) that have been largely used as a reference for manufacturing systems, as well as for specifying interoperable interfaces to connect enterprise systems and control operations. However, instead of hierarchical architectures, the industry is moving toward flexible structures, where functions are distributed throughout multiple IT networks and interact across different control levels. In this way, as a representative example, the Reference Architecture Model Industrie 4.0 (RAMI 4.0) is a metamodel that integrates the production system life cycle with a functional control hierarchy, by combining different standards, such as the IEC 62264 or the IEC TS 62832 standard "for the Digital Factory", which defines a framework to specify a factory using digital representation of assets. RAMI 4.0 is especially focused on the process and manufacturing industries, unlike other reference architectures, such as the Industrial Internet Reference Architecture (IIRA) or the SmartM2M (ETSI TR 103 375), in which manufacturing is just one of the applicable sector (a vertical domain). A thorough review of current manufacturing standards is given in [1], which states that "existing manufacturing standards are far from being sufficient for the service-oriented smart manufacturing ecosystem". Emerging technologies upon which future smart manufacturing systems will rely are described below.

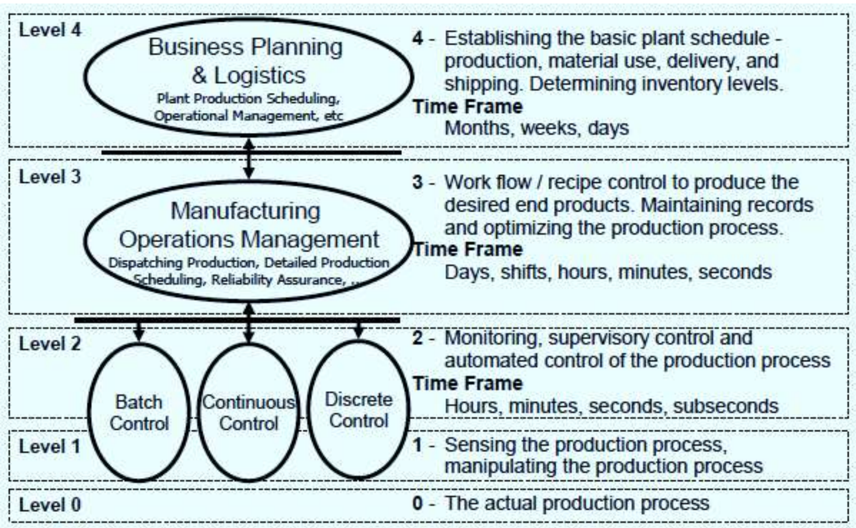


Figure 4. The IEC 62264 control hierarchy [2].

2.1 AUTOWARE technological layers

Different emerging technological fields upon which future smart manufacturing systems will rely are considered by AUTOWARE. In fact, the questionnaires used for gathering technical requirements and KPIs are organized into the following six technological categories (layers):

- **Orchestration & Digital Twin**
  - Since smart manufacturing relates to coordinate and optimize digital and physical processes, this layer covers the digitalisation of the physical systems (digital twin), and the dynamic orchestration of technical manufacturing processes [3].
- **Cloud and Simulation**
  - This part focuses on the importance of cloud-based software for analytics applications, as well as Modelling and Simulation of production processes. This also involves storing historical data and results.
- **Information Processing**
  - Big Data Analytics solutions have to be able to optimize planning and scheduling decisions in the increasing data-intensive applications by processing operational sensor data through Machine Learning and Data Mining techniques.
- **Data Distribution and Fog Computing**
  - This layer focuses on the management of large amounts of data through smart distribution policies. Moreover, Fog Computing is considered to enable more efficient processing, analysis and storing of the data, thereby reducing the delay in communication between the cloud and the machines.
- **Industrial Communications and Control**
  - The essence of this layer is the support of latency-sensitive applications. Therefore, it covers real-time machine-to-machine (M2M) communications between wireless and wired devices (e.g. sensors, actuators, etc.), as well as the connection between cell equipment and production systems at the MOM level.
- **Security and Certification**
  - With the convergence of Operational Technology (OT) and Information Technology (IT) systems, manufacturers raise concerns about security and confidentiality risks because data is now exchanged between multiple networks. Regarding certification-related aspects, they are a priority in manufacturing scenarios.

This classification expands on some general ideas of the technology trends in industrial systems identified in oneM2M [4], namely, data management and analytics, real-time command and control, connectivity and security.

Questionnaires are based on the combined expertise of the technological partners. Figure 5 shows the layered structure and identifies the technology providers responsible for each layer. Although manufacturing applications are diverse, this approach allows us to organize the requirements for each use case, making the data more easily understandable and comparable.

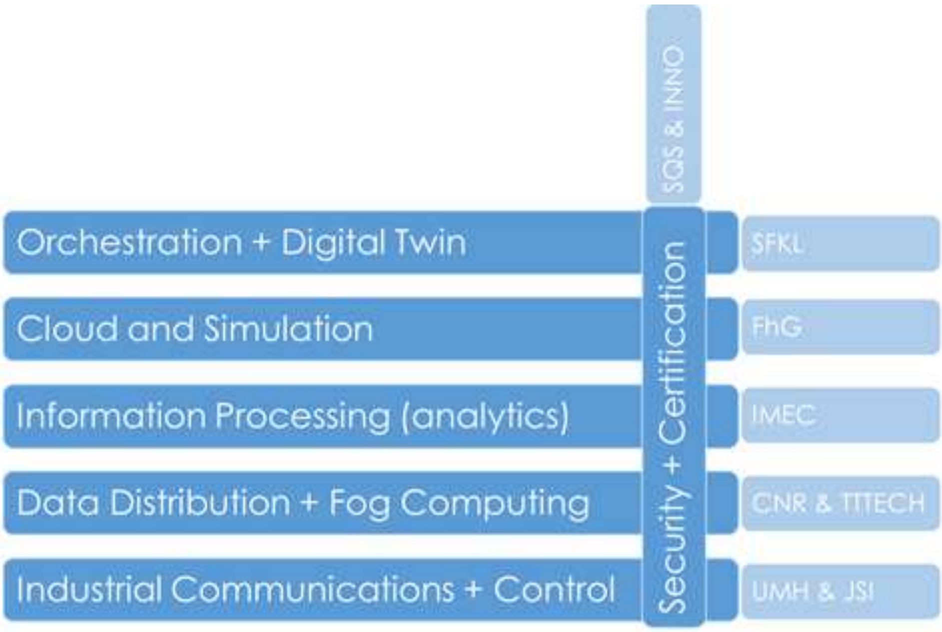


Figure 5. Layered structure for requirements collection.

This classification has been added to the template proposed in D1.1 for specifying the requirements, as shown in Figure 6.

Requirement name	
Type	Business/Technical, Functional/Non-Functional
Priority	"High", "Medium" and "Low"
Purpose and description	Please specify why this requirement is relevant
Application area	To contextualise the requirement, please refer to which business or technological area/s the requirement belongs to.
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	Please describe which actors, conditions and even limitations are expected to be relevant in the requirement.

Figure 6. Template for requirement specification.

2.2 Business dimensions

From the business point of view, we will be analysing the expected impact in the objectives previously defined by the use case owners. Industry 4.0 improvement areas are generally related to time (e.g., reduced time to market) and cost savings (e.g., efficiency boost) in the manufacturing process. Business Performance Indicators (BPIs) can be extracted by using the following the complementary perspectives proposed in the FITMAN project [5]:

- **Cost:** The costs associated with operating the organization's supply chain processes. E.g., inventory cost, production/service cost, transportation cost, total resource cost.
- **Efficiency:** The extent to which the organization's resources (e.g. time, use/maintenance of facilities) are exploited. E.g., manufacturing cycle time, overall efficiency.
- **Flexibility:** The extent to which an organization's supply chain supports changes in product or service offerings (i.e., features, volume, and speed) in response to marketplace changes (i.e., competitors, legislation, and technological innovation). E.g., response time to new demands, responsiveness to customer requests, delivery lead-time flexibility (adapting lead-time to the dynamic needs of customers, production/service flexibility (time required to add new products/services to existing operations).
- **Sustainability:** The extent of usage of an environmental resource. E.g., awareness to environmental sustainability, waste generated during production/service operations, utility use (e.g., energy, water), carbon footprint…

  From another point of view, this dimension also focuses on social factors related to sustainability, such as, quality of life, human development or equity.
- **Quality:** The degree to which the outcome of the process fulfils customer's needs and requirements. E.g., percentage of mistaken deliveries, product/service quality, customer complaints, customer satisfaction.
- **Innovation:** The extent to which the organization introduces new processes, products, or services. E.g., time-to-market, range of products/services offered to customers, new products/services under development, success rate of new products/services.

3. Method to define Performance Indicators in AUTOWARE

3.1 Introduction

The effectiveness of AUTOWARE innovations need to be assessed by clear KPIs. There are numerous definitions of the KPI concept; for example, according to [6], performance measurement is "the process of quantifying action, where measurement is the process of quantification and action leads to performance". In such a context, business, technical and organisational decisions should be based on efficiency and effectiveness criteria.

An overview of the state-of-the-art methodologies for defining significant assessment instruments is given below.

3.2 KPIs in manufacturing industry

In the industrial automation arena, "digitized performance data persists beyond the shop-floor whiteboard and supports normalized calculations and reporting, allowing KPIs across previously siloed functions, plants, and business units to be shared and benchmarked for consistency and best-practice sharing" [7]. According to [8], performance management in manufacturing systems involves:

1) An awareness of current situation,
2) a clear view of the desired situation,
3) the identification of improvement potentials, and
4) the complete achievement of improvement goal.

KPIs can be applied to individual devices, processes or whole plants. For example, functional performance, availability and energy consumption metrics are good examples of possible KPIs in manufacturing production lines. One of the most widely used KPI in this industry today comes from the Total Productive Maintenance (TPM) concept coined by Nakajima [9], which provided a quantitative metric called Overall Equipment Effectiveness (OEE) for measuring productivity of manufacturing equipment. Specifically, OEE is a function of availability, performance rate and quality rate, so that an OEE score of 100% indicates that only good parts are being manufactured, without downtime, as fast as possible. This KPI, is included, for example, in the ISO 22400 standard, released in 2014, which defines a framework for defining and using indicators for Manufacturing Operations Management (MOM, level 3 at IEC 62264).

The ISO 22400 specifies a list of 34 KPIs [10] that are associated to machines and workers involved in production automation systems and that, therefore, should be considered in product development, when implementing Manufacturing Execution Systems (MES), etc.

KPIs provided by ISO 22400 include different related criteria, which can be categorised in six types as follows:

- Efficiency
- Quality
- Capacity
- Environmental
- Inventory management
- Maintenance

There are several frameworks focused on specific industries. For example, the ISO/IEC 25010 standard is generally used in requirements elicitation and software quality evaluation, as it defines a terminology for specifying, measuring and evaluating software product quality.

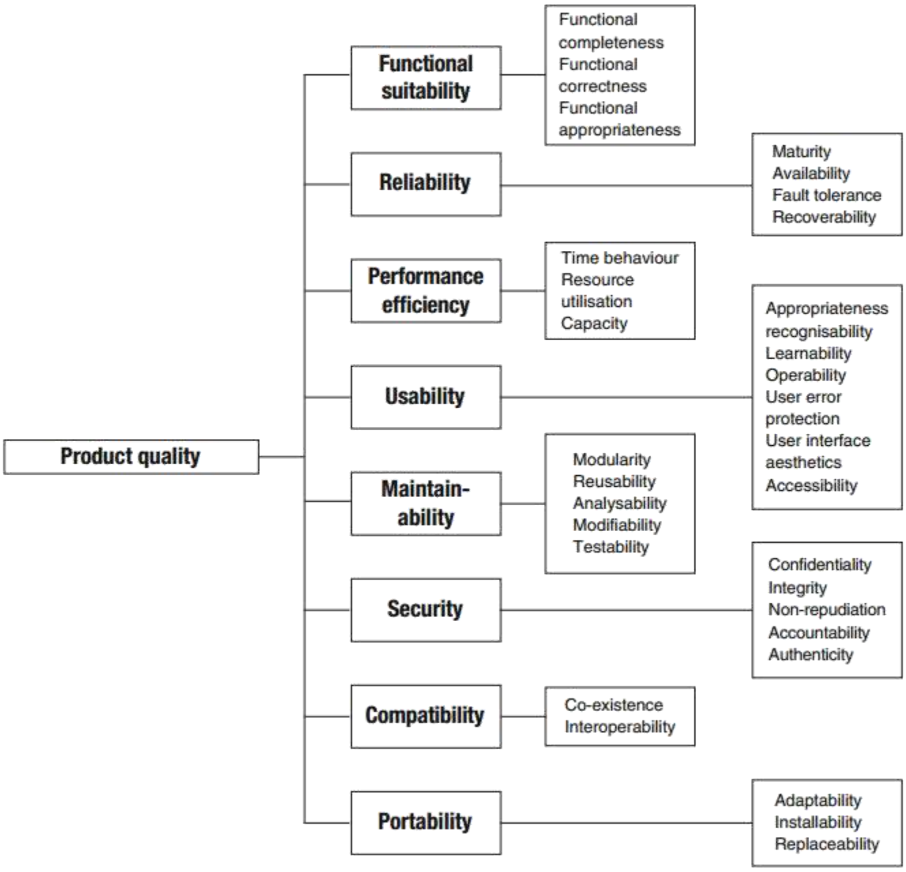


Figure 7. Quality Characteristics of ISO 25010 [11].

As another example, the Service Measurement Index (SMI) [12], which makes easier the comparison between cloud-based services by defining multiple parameters grouped in seven categories: accountability, agility, assurance, financial, performance, security and privacy, and usability. Moreover, and taking into account that factory automation is now a key objective for beyond LTE and 5G cellular networks (3GPP Release 13 onwards), the European 5G PPP (5G Infrastructure Public Private Partnership) has indicated [13] new network characteristics to be achieved at an operational level, such as: 1000 times higher mobile data volume per geographical area, 10 to 100 times more connected devices, 10 times to 100 times higher typical user data rate, 10 times lower energy consumption, end-to-end latency of < 1ms.

Regarding new ways to identify and prioritize business value opportunities (along the digital thread in data-centric ecosystems), the McKinsey diagnostic framework [7] proposes a tool called "Digital Compass" which uses the eight value drivers that have significant impact on the performance of a typical manufacturing company:

- Resource/process
- Asset utilization
- Labour
- Inventories
- Quality
- Supply/demand match
- Time to market
- Service/aftersales

According to the compass framework, Industry 4.0 solutions should lead to substantial enhancements for each of these value dimensions.

Moreover, from a more general perspective, the Factories of the Future (FoF) initiative [14] is based on three key pillars: economic, social and environmental sustainability, so these areas should be also targeted in the definition of KPIs in AUTOWARE. With a similar goal, the authors of [15] proposed a Total Performance Index (TPI) encompassing productivity, environment, and social considerations for manufacturing processes. According to the authors, this approach allows wider evaluation of the impact of other factors, such as environment and sustainability, which are increasingly emphasized in business.

3.3 Description of the proposed method

The AUTOWARE use cases expect tangible and quantifiable benefits, which alleviates the identified limitations. Thus, a uniform process for impact assessment has been established:

1. **Definition of the use case objectives**: the first phase is to describe the manufacturing processes in which the performance indicators are defined. The goals of these processes should be specified, as done in D1.1.
2. **Definition and sorting out of KPIs** that are related to use case objectives. The key goals identified in D1.1 serve as a preliminary identification of KPIs and the examination of gaps between AS IS and TO BE situations allows the definition of BPIs.

3. **Analysis** of KPIs (technical and business) carried out by a multi-partner collaboration. All AUTOWARE partners were engaged in the questionnaire construction and in online interviews to clarify the performance indicators.
4. **Organization** of KPIs. Besides prioritization, this includes documentation of the criteria for evaluation of the commonly agreed KPIs outlining exactly what needs to be measured to ensure tangible benefits. However, it is necessary to take into account that, as stated in [16], "KPIs are not always suggesting quantitative objectives, but looking for identification of the evolution of certain parameters which could show the evolution of the market and the ICT ecosystem".
5. **Impact assessment and monitoring** of KPIs according to each criterion, thereby identifying improvements in performance. Moreover, collected KPIs shall be conditioned to detect new circumstances and deviations from the original planning and make necessary improvements.
6. **Review** performance indicators. This methodology assumes that a relatively small set of KPIs can be elaborated in this first stage. Thus, if needed, KPIs can be modified or even created according to the advancements of the project.

Therefore, this top-down approach (Figure 8) starts with the business strategy and gives directions for operational areas to focus on.

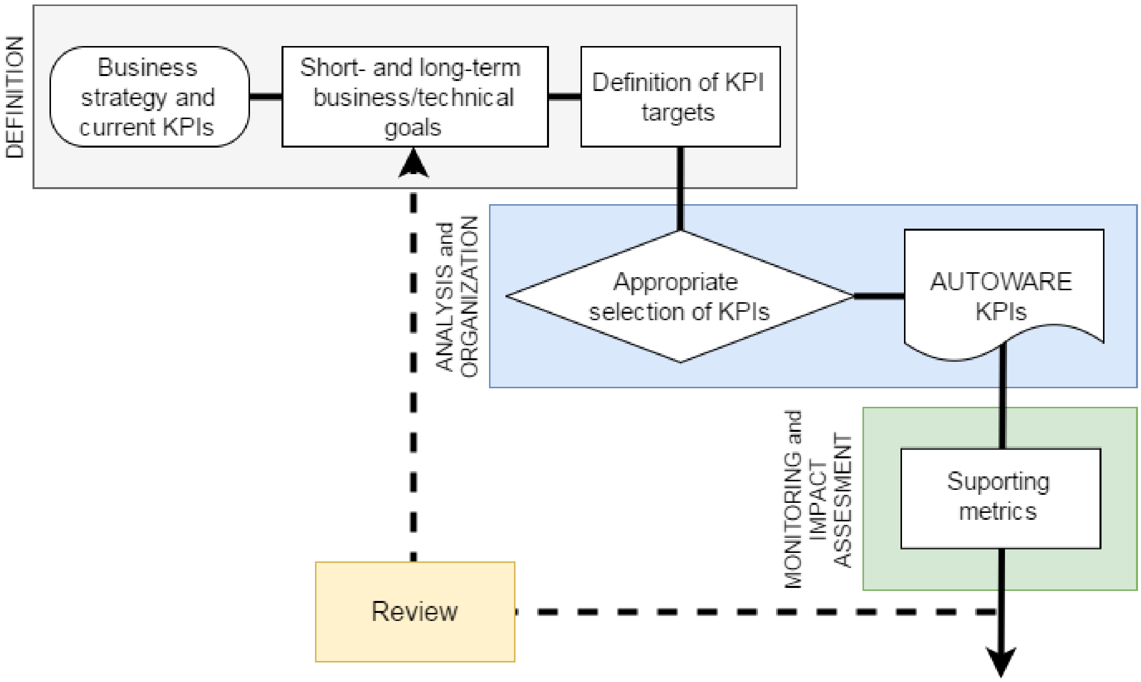


Figure 8. Proposed process for KPI specification.

According to the ISO 22400 standard, a KPI is defined by its content ("a quantifiable element with a specific unit of measure, including the formula that should be used to derive the value of the KPI"), and context ("a verifiable list of conditions that are met"). In

AUTOWARE, since the relevance and context of these KPIs may vary and in order to avoid ambiguity, this information be described homogeneously using the following format:

KPI name	Metric defined to evaluate the success of the solutions developed by AUTOWARE for a given scenario.
Type	Please choose between the following categories: Business: - Costs - Efficiency - Flexibility - Sustainability - Quality - Innovation Technical: - Orchestration & Digital Twin - Cloud and Simulation - Information Processing - Data Distribution and Fog Computing - Industrial Communications and Control - Security and Certification
Relevance	"High", "Medium" and "Low"
Target and description	Please specify why this metric is relevant
Data necessary to calculate the KPI	To contextualise these KPIs, please describe the main evaluation criteria and possible calculation methods/formula

Figure 9. Template for KPI specification.

Furthermore, it is worthy to note that KPIs and requirements must be well-aligned, so that the requirements will be clustered based on the related business goals and will be mapped to the most relevant KPIs. In any case, various KPIs can be assigned to different requirements. In order to automatically map requirements against the performance metrics to monitor them, the relation between them will be provided as shown in Figure 10, where KPIs and requirements are classified according their types.

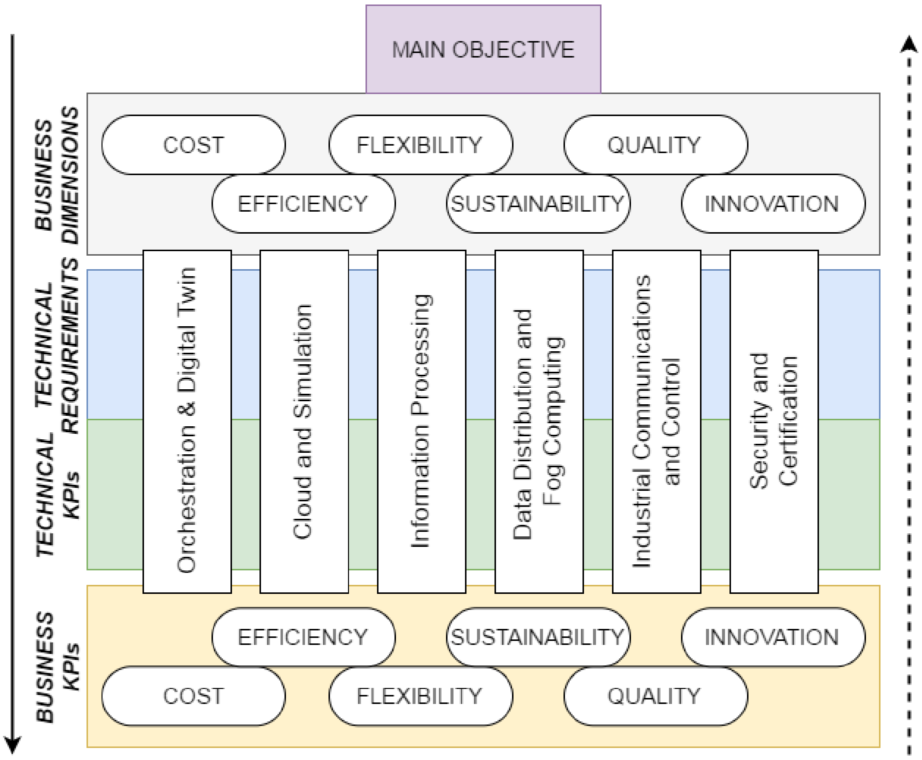


Figure 10. Relationships between goals, requirements and KPIs.

3.3.1 Generalisation

Proposed KPIs are subject to specific conditions related to each use case. However, it is possible to select those KPIs that best describe strategic manufacturing objectives for wider purposes. With that aim, through an inductive approach, general KPIs are derived from examination of more specific indicators. Thus, it is necessary to compare the business and technical KPIs between use cases and limit them in the group which best meets manufacturing SMEs' expectations.

As mentioned before, in order to ensure correlation, generalised KPIs will be also associated, as far as possible, with general requirements of interest.

The following sections present research and innovation requirements from the use cases. First, the KPIs and requirements of the three neutral experimentation scenarios are defined.

4. KPIs and Requirements of Use Case 1 – Neutral Experimentation Facility Extension

4.1 Neutral cognitive digital automation process experimentation infrastructure

4.1.1 Business goals and performance indicators

SmartFactoryKL experimentation infrastructure aims to short reconfiguration time to adapt the rapid market change and to realize mass customization. To achieve this, first requirement is the reduction of engineering time to modify the production line. Second aspect is the fast stabilization of the product quality produced by new facility. Main key performance indicators are 1) Learning time of human operator to run new process, 2) Learning time to find root cause of quality failure and 3) Line change time to introduce new order. The requirements to achieve these KPIs are shown in Figure 11 and are described in following sections.

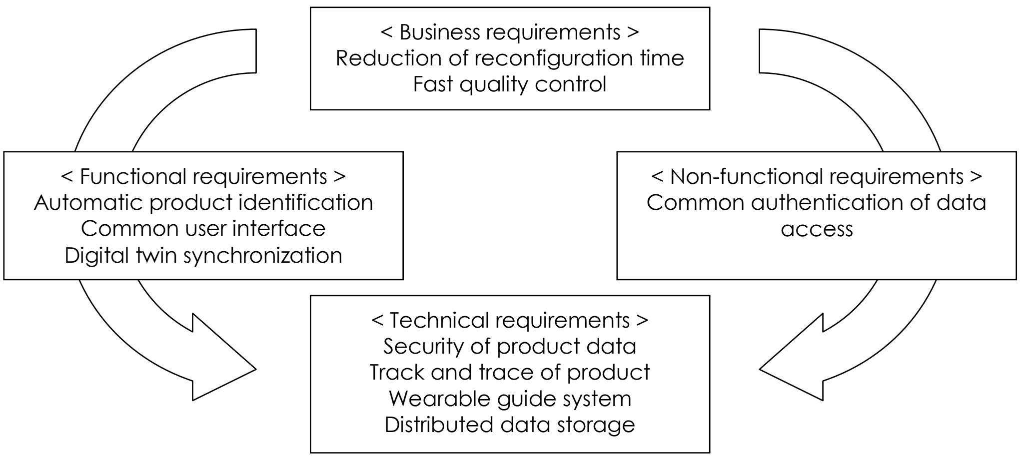


Figure 11. Requirements of Neutral cognitive digital automation process experimentation infrastructure.

KPI name	**BPI03 Reduction of re-configuration time**
Type	Business / Flexibility
Relevance	"High"
Target and description	Rapid module change, Agile manufacturing, Mass customization Configuration time effects the waiting time for preparing new production system for new products.

	Modular factory (SmartFactoryKL) is the representative facility for this purpose.
Data necessary to calculate the KPI	resource data OPC-UA orde data optimized schedule part detection camera image

KPI name	BPI04 Fast quality control
Type	Business / Quality
Relevance	"High"
Target and description	Rapid module change, High product quality, Mass customization Even if production line is changed, quality control needs the more time because of the needs of stabilized production system. This is also one of main factors of rapid reconfigurable system
Data necessary to calculate the KPI	"product data resource data OPC-UA part detection camera image order data"

KPI name	TPI03 Security of product data
Type	Technical / Innovation
Relevance	"Medium"
Target and description	Safe collaboration with global factory: Product data is secure form the users outside own factory
Data necessary to calculate the KPI	Network traffic Response time Product data

KPI name	**TPI04 Track and trace of product**
Type	Technical / Flexibility
Relevance	"High"
Target and description	"Fast detection of root cause of quality problem Real-time response: ADOMe provides the real-time data into the database. And the product data is traceable"
Data necessary to calculate the KPI	Energy consumption Connectivity speed between module and product Response time

KPI name	**TPI05 Wearable guide system**
Type	Technical / Efficiency
Relevance	"Medium"
Target and description	"Reduce the product life cycle and cope with market trend rapidly Realize mass customization: Guide video runs on wearable device New production system helps the workers through the video of manual working"
Data necessary to calculate the KPI	Processing speed Connectivity speed Transmitted frames I/O Lag

KPI name	**TPI06 Distributed data storage**
Type	Technical / Flexibility
Relevance	" High"
Target and description	Fast reconfiguration of production system: Reconfigured production line can be realized by distributed data of each edge or node

Data necessary to calculate the KPI	Reconfiguration time

4.1.2 Business requirements

The business requirements of SmartFactory are the reduction of re-configuration time and fast quality control. To cope with fast market change, the production line re-organizes the sequence of working station while replacing old machines into new machines. This configuration time is the loss of cost. By orchestration and digital twin, the time can be optimized with real-time information. And all information of production systems is collected and analysed through the factory network distributing data and handling them in fog computing.

Requirement name	**BR02 Reduction of reconfiguration time**
Type	Business, Functional
Priority	High
Purpose and description	Configuration time effects the waiting time for preparing new production system for new products. Modular factory (SmartFactoryKL) is the representative facility for this purpose
Application area (Business / Technological)	Flexibility / Orchestration + Digital Twin
Constraints or dependencies. If technical: - Data needed - Communication needed - Software components needed	The modules nor their code can be altered - - Communication between modules and infrastructure boxes - OPC-UA, MQTT

Requirement name	**BR03 Fast quality control**
Type	Business, Functional
Priority	High
Purpose and description	Even if production line is changed, quality control needs the more time because of the needs of stabilized

	production system. This is also one of main factors of rapid reconfigurable system
Application area (Business / Technological)	Quality / Data Distribution + Fog computing
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	The module is equipped with cameras and cannot be changed. - Finalized product - Communication between workcell vision computers and cameras - OpenCV, OPC-UA

4.1.3 Functional requirements

There are 3 functional requirements: automatic product identification, common user interface and digital twin synchronization. *Automatic product identification* is for each machine to recognize the individual item of specific product entering the workstation and to operate itself with specific program for each product. *Digital twin synchronization* is the supporting function to automatic product identification. Factory system keep the virtual data of each machine and each product same as real one by updating it with real-time data collection. And to reduce the learning time of human operator, *common interface* with wearable delve should be provided to advanced user device such as augmented reality.

4.1.4 Non-functional requirements

Distributed database and modular machine controllers are complex system in terms of data security. Factory system requires fast data sharing while the company knowledge should be secured from other comparatives. *Common authentication of data access* is required for all human operators as well as machine controller. The data access should be granted by single manager of the factory. For this common authentication is key requirement of modular factory system.

4.1.5 Technical requirements

The technical requirements of SmartFactory are the security of product data, track-trace of product, wearable guided system, and distributed data storage. Between factories departments, the accessibility of each product data should be controlled in distributed databases because the process knowledge and design information are shared in the specific contracts with each company. In terms of data handling, the appropriate decision finished in given time can be realized by the real-time information of product and machines. Track and trace architecture for product enables factory database to achieve real-time data update. And the machine maintenance operators and manual assembly operators suffers studying a lot of manuals and instructions of customized machines and products. Wearable devices reduce the effort of human operators to learn how to handle new machine and products. At last the data should be distributed in order to enable production machine to be re-configurable physically.

Requirement name	**TR07 Security of product data**
Type	Technical, Non Functional
Priority	Medium
Purpose and description	The product data must be secure during and after production to keep the confidential data of the factory safe.
Application area	Security + Certification
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	Distribution of product data. All modules in the modular factory use the same specifications to understand the product data. - Product data (status, order ID etc.) - Communication between the module and the product - Network traffic monitor

Requirement name	**TR08 Track and trace of product**
Type	Technical, Functional
Priority	High
Purpose and description	To make sure the product is being produced according to the order, to locate the product and get the status.
Application area	Orchestration + Digital Twin
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	Real-timeness of data update. The product memory should have a common data format to be readable in all modules. - Sensory data (product memory) - Communication between the product and the modules. Additionally, the monitoring software and the modules for product status - Digital Object Memory, Battery, Wifi AP

Requirement name	TR09 Wearable guided system
Type	Technical, Functional
Priority	Medium
Purpose and description	To aid the worker during production, maintenance, identification, a wearable device can be used.
Application area	Industrial Communications + Control
Constraints or dependencies. If technical: - Data needed - Communication needed - Software components needed	Wireless video streaming. Depends on technical specification of product, the device and the requirements - Camera images, Training data - (Real-time) Communication between product and the wearable device. Communication between wearable device and edge server. - OpenCV, AR SDK, Tensorflow

Requirement name	TR10 Distributed data storage
Type	Technical, Functional
Priority	High
Purpose and description	To share the various data generated by different sources of distributed controller in production line while synchronizing common data which should be shared and controlled real-timely for the seamless production optimization.
Application area	Data Distribution + Fog computing
Constraints or dependencies. If technical: - Data needed - Communication needed - Software components needed	Data traceability - The message for update, insert and deletion of data - Real-time communication between software components and databases - OWL interface library, protégé

Requirement name	TR29 Standardized information protocol
Type	Technical, Functional
Priority	High
Purpose and description	To assure that the workcells are able to communicate between each other to ensure compatibility, even between different manufacturers
Application area	Industrial Communications + Control
Constraints or dependencies. If technical: - Data needed - Communication needed - Software components needed	The PLC's of the workcells are able to run a unified information protocol - OPC-UA message format (SFKL standard) - OPC-UA message format (SFKL standard) - OPC-UA client, OPC-UA server

Requirement name	TR30 Physical interface of Production modules
Type	Technical, Functional
Priority	High
Purpose and description	To benefit from a modular production structure, it is necessary for the workcells to be compatible to each other
Application area	Industrial Communications + Control
Constraints or dependencies. If technical: - Data needed - Communication needed - Software components needed	Product type and product size - Sensor data of module connector - OPC-UA communication, RFID sensor connection - Topology manager

4.1.6 Relationship with AUTOWARE Framework

In this section the relationship with the AUTOWARE architecture is investigated. It consists of the relation of the reference architecture, standardization, and ecosystem.

Reference architecture

The table in the Bellow show the relationship by Mapping between the framework and there requirements. Each requirement distributed to into each layers.

	Business goal	Business requirement	Technical requirement
Enterprise			Security of product data
Factory	Setup time needed to integrate with mfg. service, Time to find root cause of quality problem	Fast quality control	Wearable guided system, Track and trace of product
Workcell		Reduction of reconfiguration time	Standardized information protocol, Physical interface of Production modules,
Field devices			Distributed data storage

Standards

1. OPC-UA (IEC 62541): OPC Unified Architecture (OPC UA) is a machine to machine communication protocol for industrial automation developed by the OPC Foundation. Distinguishing characteristics are: 1) Focus on communicating with industrial equipment and systems for data collection and control, 2) Open - freely available and implementable under GPL 2.0 license, 3) Cross-platform - not tied to one operating system or programming language, 4) Service-oriented architecture (SOA), 5) Inherent complexity - the specification consists of 1250 pages in 14 documents, 6) Robust security, 7) Integral information model[1].
2. Standards for the modular connector (IEC 61984 / EN 60664-1): IEC 61984:2008 applies to connectors with rated voltages above 50 V and up to 1000 V a.c. and d.c. and rated currents up to 125 A per contact, for which either no detail specification exists or the detail specification calls up this standard for safety aspects. Changes with respect to the previous edition include: addition of new definitions, of new clauses, tables and annexes for clarification, improvement

[1] https://en.wikipedia.org/wiki/OPC_Unified_Architecture

and better readability. The contents of the corrigendum of October 2011 have been included in this copy[2].

Ecosystem

1. SmartFactory Consortium: SmartFactoryKL is a network of more than 51 member organizations from industry and research. These partners perform research and development projects related to Industrie 4.0 and the factory of the future. The work ranges from developing their vision and preparing descriptions all the way to industrial implementation.
   We create the perfect framework for our partners to communicate and carry out joint research, development, testing, and implementation. The cooperation of our members on equal terms is a major guarantee of success at SmartFactoryKL. Because we are an independent organization, we can provide a neutral platform for exchange among leading companies and institutes regarding Industrie 4.0. Our work is based on the values of mutual respect, openness, and trust.
   SmartFactoryKL have built the partnership with EU H2020 consortium, DFKI, Technology university of Kaiserslautern and Digital innovation hub by providing the test-bed of control communication, automation architecture and wireless communication. In the same way, SmartFactoryKL will connect with AUTOWARE consortium, too. SmartFactoryKL provides this neutral facility and standards to AUTOWARE ecosystem by easing the digital modelling of CPPS systems, by providing a business development platform, and by providing the access to neutral industrial experimentation sites. Main customers will be IT providers, automation companies and research entities. These customers will receive the service of the membership of SmartFactoryKL consortium, independent projects, AUTOWARE web platform, the participants of EU Digital innovation hub or Reginal network.
2. German SME competence centre (Mittelstand 4.0-Kompetenzzentrum): The Mittelstand 4.0 – Kompetenzzentrum Kaiserslautern is a State-funded organization that helps Small – and Medium sized enterprises with digitalization and industry 4.0 applications. A total of 23 SME 4.0 competence centres throughout Germany support the companies. With much current know-how as well as illustrative and testing possibilities this country widely surface covering support network for the middle class offers the enterprises digitization to the touch. In addition, medium-sized agencies are working on cross-cutting digitisation topics such as cloud

[2] https://webstore.iec.ch/publication/6223

computing, communication, trade and processes and are using multipliers to spread these across the board.

The competence centre informs companies about new technologies and introductory examples of information material and information events. Implementation and consulting projects are also offered.

This already established network and connections can use the solutions of the Autoware project to implement them in small and medium sized companies.

4.2 Neutral reconfigurable workcell experimentation infrastructure

JSI has been designing and implementing a new kind of an autonomous, ROS-based robot workcell (see Figure 12), which is attractive not only for large production lines but also for few-of-a-kind production, which often takes place in SMEs. The proposed workcell is based on novel ICT technologies for programming, monitoring and executing assembly operations in an autonomous way. It can be nearly automatically reconfigured to execute new assembly tasks efficiently, precisely, and economically with a minimum amount of human intervention.

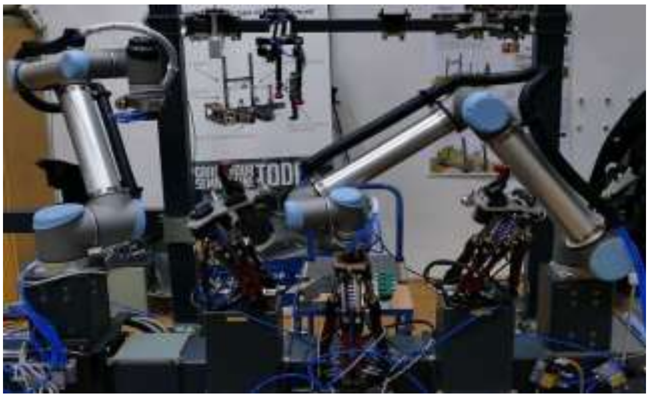


Figure 12: A reconfigurable robot workcell

The described reconfigurable robot workcell can be used to integrate, customize, test, validate and demonstrate AUTOWARE service architecture. Experiments can be performed in the area of human-robot collaboration, especially programming by demonstration – kinesthetic teaching, since the proposed workcell includes robots that are safe for collaboration with humans. The aim is to show that programming of robot tasks can be accelerated and that robots can be used to augment the capabilities of human workers, freeing them to do what humans are good at; dexterity and flexibility rather than repeatability and high precision. The connection of the workcell to services such as cloud computing, machine learning (including visual learning), data analytics, and 3-D printing will be tested.

4.2.1 Business goals and performance indicators

Costs and limited number of use cases that can be addressed by current robotic systems are often the main barrier that prevents the increased take up of robot technologies in industrial production, especially in SMEs. By achieving the technical requirements specified below, we will both **decrease the costs** and **increase the number of use cases** that can be addressed by the proposed workcell. This will make the workcell **attractive to SME-like manufacturing**, which is often characterized by the production of small lot sizes and consequently frequent changes of the manufacturing setup. This is our main business goal.

KPI name	BPI01 Cost of manufacturing per product
Type	Business / Costs
Relevance	"High"
Target and description	Manufacturing companies cannot keep production in Europe unless the cost of production is sufficiently low.
Data necessary to calculate the KPI	The overall costs depend on initial set up time of the workcell, cycle time of automated robot assembly compared to human workers, costs of equipment and its depreciation time. Data necessary: Frequency of changeover; Facts : Cost reduction not estimated yet in practice

KPI name	BPI02 Number of available assembly operations
Type	Business / Efficiency
Relevance	"High"
Target and description	The aim is to enable the application of robotics for customized production. Production of smaller lot sizes can be automated.
Data necessary to calculate the KPI	Access to all available assembly operations. Data necessary: Return of Investment for specific case; Facts: Not estimated yet for ReconCell use cases

KPI name	TPI01 Cycle time of assembly processes
Type	Technical / Costs
Relevance	"High"

Target and description	Ideally the robot workcell should be at least as fast human workers for assembly. Increased productivity: Less workers needed to assemble a product.
Data necessary to calculate the KPI	Measure time needed to assemble a complete workpiece. Data necessary: Measured cycle time; Facts: 3 Use cases: Elves Automotive headlight 1min 20sec, 2: Logic Data Linear Drives, 2 min; 3 Precizika Metal, Robot part assembly, 2min 20 sec

KPI name	TPI02 Time needed to prepare a new assembly process
Type	Technical / Efficiency, Flexibility
Relevance	"High"
Target and description	The aim is to reduce the reconfiguration time to minimize the period when the workcell cannot be used. Increased production: Time when the workcell cannot manufacture new products is reduced
Data necessary to calculate the KPI	Measure time needed to setup a new assembly process. Data necessary: Measured average time needed to setup cell for new product assembly. Facts: 1: Elvez - setup for different automotive lights: 2 min; 2: Logic data, Setup for different assembly components - 30 sec; 3: Precizika Metal; Setup for different components applied in the robot joint assembly: 3 min 10 sec

4.2.2 Business requirements

The main requirement when robots are introduced into industrial production is that the overall **manufacturing costs should be reduced** compared to manual work. This is important to make industrial production viable in higher income countries, such as for example European Union member states. Another requirement is that the system should be easily **reconfigurable to new use cases** to enable the application of robot technologies for customized production and small lot sizes.

Requirement name	BR01 Enable the application of robotics for customized production

Type	Business, functional
Priority	High
Purpose and description	Costs and limited number of use cases that can be addressed by a robotic system are often the main barrier that prevent the increased take up of robot technologies in industrial production, especially in SMEs. By achieving the specified technical requirements, we will both decrease the costs and increase the number of use cases that can be addressed by the ReconCell system.
Application area	Flexibility
Constraints or dependencies	Requires efficient implementation of user interfaces for setting up the workcell, effective robot control software, robot simulation system, etc.

4.2.3 Functional requirements

A reconfigurable workcell only makes sense if **a sufficient number of assembly operations** is implemented to support different application scenarios. The number of supported operations can be increased by exploiting sensory data available in the workcell (forces and torques, vision), advanced simulation technologies (digital twin), and by introducing human-robot collaboration. Besides effective robot operation, the workcell should also support additional functionalities such as **visual quality control**, **QR code readers,** integration with standard software tools (e.g. SCADA, MES, ERP), and also the ability to send data to the **cloud**, where time-consuming **machine learning algorithms** can be applied (high performance computing). This way the robotic workcell can be integrated into a larger infrastructure of a smart factory.

4.2.4 Non-functional requirements

The overall software architecture in the proposed workcell is based on ROS and enables effective communication between different software components. Standard ROS tools can be used to communicate between different parts of the system that do not require real-time communication. Robot control, including sensor-based robot control, requires real-time operation, therefore a real-time system is used for low-level control instead of ROS.

Cycle times are highly dependent on the actual product to be assembled. A good general benchmark is to compare the performance of the workcell to the performance of a human worker or workers. Automation is only profitable if the workcell is able to assemble the product at a lower cost than a human worker(s) can. There are several factors influencing this calculation, including the number of hours per month the workcell is in operation (t_1) / the worker does assembly (t_0), average cycle time of the workcell (c_1) / worker (c_0), average salary of the worker in assembly per month (s), cost of the workcell, installation, service, and maintenance per month in life-time of the workcell (r), and the fraction of the human worker time spends on programming new assemblies (f). Automation is profitable if **to-be productivity** $p_1 = {(t_1/c_1)}/{(s * f + r)}$ is greater than **as-is productivity** $p_0 = {(t_0/c_0)}/{s}$. Note that the fraction of time the human worker spends on programming new assemblies depends on the effectiveness of the integrated software tools and reconfiguration technologies.

4.2.5 Technical requirements

To ensure that the company selling a reconfigurable robotic workcell can support a variety of use cases, it is necessary to support many different assembly scenarios. This way the workcell will become interesting to an increased number of SMEs and larger companies. Thus, we have a functional requirement that the reconfigurable robot workcell should have **a large number of essential assembly operations** implemented. An important KPI in this context is the **cycle time of automated robot assembly** and its comparison with human workers.

Requirement name	**TR01 Sufficient number of assembly operations implemented**
Type	Technical, Functional
Priority	High
Purpose and description	To ensure that the market for a reconfigurable robot workcell is big enough, the workcell should support as many different assembly scenarios as possible. This way it will become interesting to both SMEs and larger companies.
Application area	Industrial Communications + Control
Constraints or dependencies. If technical: - Data needed - Communication needed - Software components needed	Depends on technical specification of robots, sensors, and peripheral equipment - Sensory data (proprioception, force-torque sensors, vision) - Real-time communication between hardware components

	- ROS (Robot Operating System), robot control software

Short setup times of new assembly processes are important for companies with frequent product changes. Increased automation of the setup process, supported by effective user interfaces and modern simulation technologies, is essential to achieve this goal. To this end JSI has been working toward integration of **user friendly robot programming technologies**, **simulation**, and **robot learning techniques**. This way the time when the workcell cannot manufacture new products can be reduced. Further software components that would be nice to have but have a lower priority at the moment include ability to **transfer large quantities of data to the cloud**, e.g. to implement learning through **high performance cloud computing**.

Requirement name	**TR02 Visual quality control**
Type	Technical, Functional
Priority	Medium
Purpose and description	The application of advanced vision software is essential to fully automate quality control in robotic workcells.
Application area	Information Processing (Analytics)
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	Workcell needs to be equipped with cameras / 3-D sensors - Digital images - Communication between workcell vision computers and cameras - ROS (Robot Operating System), OpenCV

Requirement name	**TR03 Fast setup times for a new assembly process**
Type	Technical, Non-Functional
Priority	Medium
Purpose and description	Short setup times for each new assembly process are important for companies with frequent product changes. Increased automation of the setup process, supported by modern simulation &

	reconfiguration technologies, is essential to achieve this goal.
Application area	Orchestration & Digital Twin
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	Requires integration of user friendly robot programming technologies, simulation, reconfiguration, and robot learning. - Information about location of all workcell elements - Real-time communication between hardware components - ROS (Robot Operating System), robot simulation software, robot learning software

Requirement name	**TR05 Ability to transfer large quantities of training data to IT systems outside of the workcell**
Type	Technical, Non Functional
Priority	Low
Purpose and description	The application of learning technologies for visual processing and robot control often requires a large quantity of data and significant computational resources, which are not available locally.
Application area	Cloud and Simulation
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	Communication between the ReconCell system and the cloud. It is necessary to store the data about the workcell during its operation. - Information about the workcell state during its operation stored in ROS bags. - Communication between workcell computers and sensors - ROS (Robot Operating System), integration with cloud

Requirement name	**TR06 Automated assembly cycle time comparable to the manual production**
Type	Technical, Functional
Priority	High

Purpose and description	To introduce robot assembly into industrial production, robot performance should be as close as possible to human performance. While it is often not possible to achieve this level of performance, human performance is a good benchmark.
Application area	Industrial Communications + Control
Constraints or dependencies	Improve the performance of robot control programs.

4.2.6 Summary

In this section, a list of technical and business requirements and key performance indicators has been provided, which can be used to quantifiably measure the success of neutral reconfigurable workcell. They are summarized in Figure 13. Technical requirements & KPIs are classified according to the AUTOWARE business dimensions that are most relevant for the neutral reconfigurable workcell: cost, efficiency, flexibility, and quality. Note that some of them require certain trade-offs to be made: increased flexibility can also increase the costs compared to less flexible solutions. Where applicable each technical requirement was matched with a technical KPI. However, some of the requirements, like for example visual quality control, are to application specific to define a general KPI for a neutral environment.

Objective	Neutral reconfigurable robotic workcell					
Business dimensions	Cost	Efficiency		Flexibility		Quality
Technical requirements	Time to assemble a new product	Time to setup a new assembly process	Transfer of large quantities of data to IT systems outside the cell	Sufficient number of assembly operations	QR codes for product identification and tracking	Visual quality control
Technical KPI	Cycle time	Setup time	Speed of data transfer	Number of assembly operations		
Business KPI	Manufacturing costs per product			Number of different assembly applications		

Figure 13. List of requirements and key performance indicators.

4.3 Neutral experimentation infrastructure for intelligent automation applications for robotic industrial scenarios

4.3.1 Business goals and performance indicators

Tekniker experimentation infrastructure aims to meet some goals in most of the business areas analysed in Autoware project. First of them is the cost goal through the reduction of manual process by the integration of autonomous mobile platforms for manufacturing and the reduction of accidents (associated costs) due to an increase in safety in the collaborative area by the use of additional information coming from other systems. Tekniker aims also to reduce the stops due to lack of material thanks to a better coordination between different elements in the robotic cell (bi-manipulation and mobile robot) to improve the efficiency. To meet flexibility and quality goals, Tekniker plans to provide automatic adaptation to changing conditions or anticipation to changing operating conditions and flexible task planning based on sensor information and AUTOWARE enablers, and provide the integration of automated processes can guarantee process quality and repeatability. Last, regarding the innovation goal, Tekniker is working on robustness increase of the system by using cognitive competences: intelligent automation services based on open architecture for task planning and an increased number of customers, due to a better understating of the advantages of the implemented technologies. The requirements to achieve these KPIs are described in following sections.

KPI name	BPI08 Efficient transport
Type	Business / Costs
Relevance	"High"
Target and description	Reduction of manual process for material transport using mobile platforms
Data necessary to calculate the KPI	Proportional to cost of operation, installation and material

KPI name	BPI09 Coordination among productive systems
Type	Business /Efficiency
Relevance	"Medium"

Target and description	Better coordination between different elements in the robotic cell (bi-manipulation and mobile robot). Reduction of stops due to lack of material
Data necessary to calculate the KPI	Wireless communication efficiency

KPI name	BPI10 Flexible task planning
Type	Business / Flexibility
Relevance	"High"
Target and description	Automatic task planning of robots considering changes in robot task execution/sensor inputs, or anticipation to changing operating conditions.
Data necessary to calculate the KPI	Adaptation to changes using sensory input

KPI name	TPI17 Reduce Cost of manufacturing per product
Type	Technical / Innovation
Relevance	"High"
Target and description	Reduction of manual process integrating higher level of automation and using humans for added value operations
Data necessary to calculate the KPI	Costs improvement

KPI name	TPI18 Efficient navigation
Type	Technical / Efficiency
Relevance	"High"
Target and description	Reduction of stops due to lack of material thanks to a better material feeding
Data necessary to calculate the KPI	Success ratio of material feeding (reaching goal), time stopped due to lack of material, time to navigate among destinations

KPI name	TPI19 Accuracy of system localization

Type	Technical / Quality
Relevance	"High"
Target and description	To position the platform in the required location to perform the manufacturing operations
Data necessary to calculate the KPI	Error in positioning

KPI name	**TPI20 Safety ratio**
Type	Technical / Efficiency
Relevance	"High"
Target and description	Guarantee safety assurance according to norms and safety criteria
Data necessary to calculate the KPI	Risk detection ratio with sensors

4.3.2 Business requirements

As explained in D1.1 Tekniker business goals and KPIs are focused on the reduction of stops due to lack of material, the automatic adaptation or anticipation to changing conditions, the reduction of accidents and the increased number of customers. To achieve these Business goals the following Business requirements are defined:

Requirement name	**BR15 Higher efficiency in assembly cell**
Type	Business, Functional
Priority	Medium
Purpose and description	Higher efficiency of manufacturing factories using combined robotic solutions
Application area (Business / Technological)	Costs / Industrial Communications + Control
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	Requires integration standard communication capabilities like OPC-UA, Coordination of different production resources (bi-manipulator and mobile robot) and providing Interoperability among the elements of the cell - Data of process - Real-time communication in some hardware components

	- ROS (Robot Operating System), robot simulation software, robot learning software

Requirement name	**BR16 Technological support**
Type	Business, Non-Functional
Priority	High
Purpose and description	Provide companies technological support in developing collaborative, intelligent, safe robotic manufacturing solutions
Application area (Business / Technological)	Innovation
Constraints or dependencies	Hardware and Software demonstrators' availability is important to show to the customers the potentiality of the solution.

Requirement name	**BR17 Flexible and collaborative robotics in manufacturing**
Type	Business, Functional
Priority	High
Purpose and description	To provide solutions for flexible and collaborative robotics in manufacturing, specially integrating adaptive robotic, human robot collaboration and safety related technologies
Application area (Business / Technological)	Flexibility / Information Processing (Analytics)
Constraints or dependencies. If technical: **- Data needed** **- Communication needed** **- Software components needed**	- - Communication between workcell elements - ROS (Robot Operating System)

4.3.3 Functional requirements

Tekniker has defined 5 functional requirements, aiming to provide i) *more efficient communication between the work cell elements (bi-manipulator, safety elements, mobile platform, etc.), ii) flexibility of the solution enabling robot-robot collaboration* *(mobile robot and bi-manipulator), iii) coordination of different production resources (bi-manipulator and mobile robot) and providing interoperability among the elements of the cell, iv) intelligent sensor fusion for human tracking, ability to distinguish persons and other kind of elements in the working area and v) contextual adaptation: systems sharing information and adapt based on the contextual information.*

4.3.4 Non-functional requirements

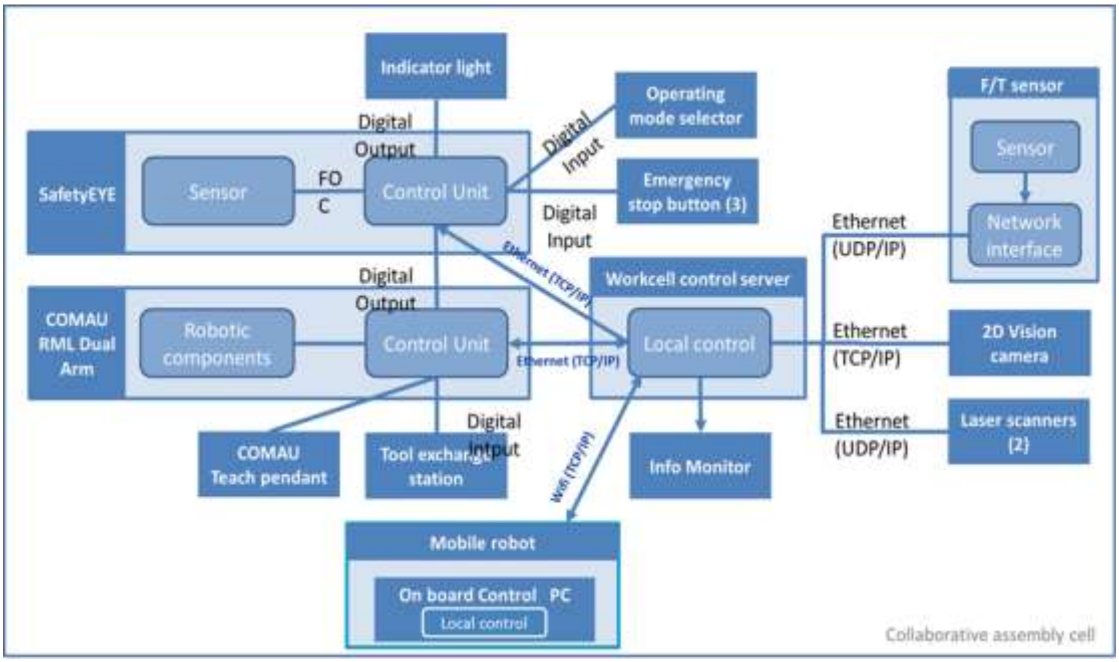
Tekniker proposed multipurpose assembly cell is aim to work as a CPS thanks to the integration of enabling communication mechanisms between the cell elements and the re-configurability and human-robot collaboration. Therefore, Tekniker's workcell requires flexibility in mounting, accuracy and reliability beyond the capabilities of workers, often demanding collaboration between worker and robot, and the non-functional requirements identified so far are:

1. *Extension of the multipurpose assembly cell to serve as demonstrator for the next robotics generation, characterized by complex products with short production cycles.*
2. *The work cell as a CPS, with a high integration with all the elements inside the work cell*
3. *Implementation of standard communication and reference architecture in the workcell*

4.3.5 Technical requirements

1. Efficiency in the computing processes orchestration and communication

In IK4-TEKNIKER lab scenario there is not only one machine controller, but several local controllers. The following figure shows the high-level overview of the hardware infrastructure and network communications in the scenario.



One of the requirements is to improve the **efficiency** of the communication and the **parallelization** among the different local controllers and processes summarized in the table below.

Local controller	Description
Safety Eye Control Unit < -- > Workcell control server	It consists of Analysis Unit (AU) and the Programmable Safety System (PSS). The PSS executes a preinstalled user program for SafetyEYE and it is the interface to the COMAU dual arm control system. It provides the inputs/outputs (e.g. output switching elements OSSDs, control of the indicator light unit, the reset button input). The PSS user program consists of several preinstalled, approved standard function blocks. It ensures an appropriate reaction, when a warning or detection zone is violated. The PSS input and output assignment is defined by using the SafetyEYE configurator.
Laser scanners < -- > Workcell control server	Sick LMS laser scanners get information of the distance of an obstacle (e.g. distance of the obstacle to the robot to allow a progressive variation of the speed of the robot). The laser scanners are connected to the work cell control server though Ethernet with a scanning frequency of 50Hz.
Force/Torque sensor < -- > Workcell control server	The ATI force/torque sensor – Gamma is a multi-axis force and torque sensor with a frequency up to 7000Hz. ATI Net F/T interface is the network interface for the force and torque sensor that allows

	to capture the force/torque information provided by the sensing device.
2D vision camera < -- > Workcell control server	The UI-5250CP camera is a 2D camera with a resolution of 1600 x 1200 pixels, a frame rate of 35 frames per second and gigabit Ethernet connectivity.
Mobile robot < -- > Workcell control server	The mobile robot is connected to the work cell control server through Wi-Fi to receive motion commands and send status information. There is not specific response time of communication.

Requirement name	**TR26 Multipurpose assembly cell combining material transport and assembly operations**
Type	Technical, Non Functional
Priority	Medium
Purpose and description	Extension with a mobile platform of the multipurpose assembly cell to serve as demonstrator for the next robotics generation, characterized by complex products with short production cycles
Application area	Orchestration + Digital Twin
Constraints or dependencies	Software components needed

Requirement name	**TR27 Standard communication mechanisms in the workcell components**
Type	Technical, Functional
Priority	High
Purpose and description	The work cell elements have to communicate with other components following the reference architecture using communication standards (OPC-UA)
Application area	Industrial Communications + Control
Constraints or dependencies	Software components needed

Requirement name	TR28 Mobile platform as a CPS
Type	Technical, Functional
Priority	Low
Purpose and description	The mobile platform as a cyberphysical system provides services and coordinates with other industrial components or systems
Application area	Industrial Communications + Control
Constraints or dependencies	Communication needed

Requirement name	TR31 Wireless robust and reliable communication
Type	Technical, Functional
Priority	High
Purpose and description	Communication with the mobile platform and the other elements in the workcell should be guaranteed
Application area	Industrial Communications + Control
Constraints or dependencies	Communication needed

2. Information processing for autonomous navigation and localization

Cloud computing capabilities can be of interest for:

- Coordination of several mobile platforms for part transportation, to increase efficiency.
- Running computationally expensive tasks (e.g. path planning) in the cloud to reduce local computing requirements. The robust and precise localization of the robot in the shop floor. Currently, the localization of the robot can be determined using several approaches (histogram filters, Kalman filters, particle filters). They all rely on sensory input from onboard sensors and a map of the environment. One can also put artificial landmarks in the environment and use sensors to estimate the pose relative to those marks. It would be of great interest if the localization of the robot could be provided from outside as additional information.

- High level management of intelligent behaviours for the workcell. (e.g. interaction with the mobile platform, coordination of the robotic cell)

Requirement name	TR23 Autonomous navigation
Type	Technical, Functional
Priority	High
Purpose and description	The mobile platform must be able to navigate autonomously in the layout using sensor information Running computationally expensive tasks (e.g. path planning) in the cloud to reduce local computing requirements
Application area	Information Processing (Analytics)
Constraints or dependencies	Software components needed

Requirement name	TR24 System localization
Type	Technical, Functional
Priority	High
Purpose and description	The localization system of the mobile platform has to provide accurate enough positioning for material transport and tending operations.
Application area	Information Processing (Analytics)
Constraints or dependencies	Data needed

3. <u>Real-time information communication and processing</u>

The following figure shows the schematic process management information workflow:

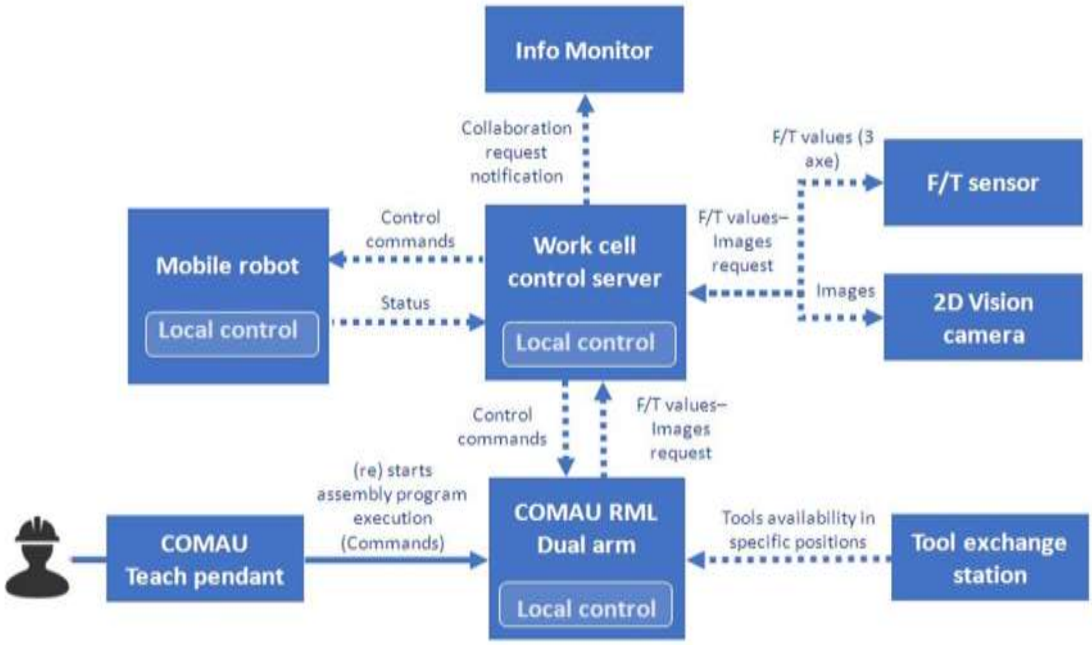


Figure 14. Management information workflow.

Along with the main assembly process there is a background process that oversees managing safety related issues. The schematic safety management information workflow can be seen in the following figure:

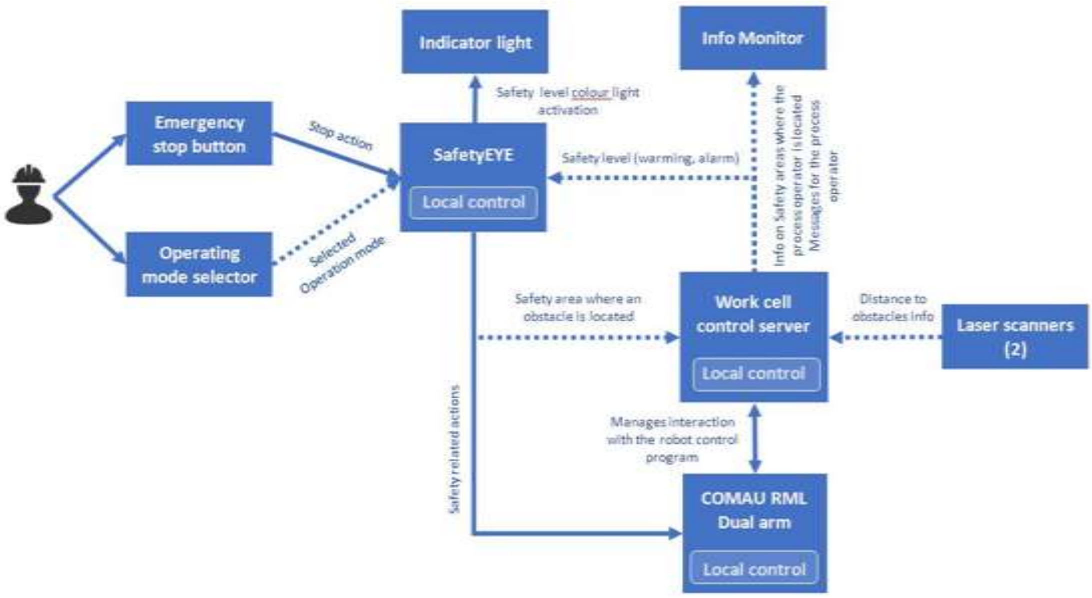


Figure 15. Safety management information workflow.

Safety modules (safetyEYE and work-cell laser scanners) are mission-critical and require real-time response. The modules that rely on real-time capability are safetyEYE and LaserScanners. On the other hand, image processing modules are network-intensive, as they exchange high resolution images for processing parts information.

Requirement name	**TR25 Real-time information communication and processing, Functional**
Type	Technical
Priority	Medium
Purpose and description	Safety modules (safetyEYE and work-cell laser scanners) are mission-critical and require real-time response.
Application area	Security + Certification
Constraints or dependencies	Communication needed

5. Description and scope of Use Case 2 – Industrial Cognitive Automation Validation

5.1 Business goals and performance indicators

The recycling market is changing rapidly due to global changes where the quality requirements of the incoming and outgoing material are increased. As a result, systems that are in place to separate waste material from the target material need to be improved continuously to cope with this change. More specific, in paper recycling, a major challenge is the separation of cardboard and waste materials from paper. Not only does the system need to be improved to decrease the percentage of rest material, in addition the system needs to evolve from a static system to a dynamic system which can rapidly reconfigure to handle different input batches of quality.

It is indeed so that the quality of the supply stream varies significantly between suppliers and this is becoming a major challenge in recent years. This is mainly because of the increasing number of carton types and a number of innovations in carton materials themselves as it is becoming increasingly harder to distinguish carton from paper. Paper/carton come from random sources and have extremely irregular colors, shapes, folds, sizes and densities. Each variable in the input requires additional layers of sorting systems and affects the quality of the output. In contrast to traditional waste separation techniques used in PET or metal recycling such as gravity, magnetic and eddy current separation, paper and carton from uncontrolled sources are difficult to sort. Paper, residue cardboards, greasy or food cartons and plastics need to be removed as they affect the recycling quality. In the current system, mixed paper and carton sources are moved on a conveyor towards an air separator. The air separator separates the paper and carton into two conveyors. One belt recycles the high concentration carton and the other, the high concentration paper. However, on each belt residual paper or carton still exists and this has to be further separated. Residual carton mixed in paper results in poor quality (black spots) while paper mixed in carton creates a lower grade residual stream. In this stream the % of carton is a quality KPI.

KPI name	**BPI12 Paper/cardboard separation efficiency**
Type	Business / Quality
Relevance	"High"

Target and description	The future of industrial automation lies with the development of cognitive technology running on a virtual self-optimizing control system for paper/cardboard separation, which is simple to configure, able to learn, optimize and connected by a wireless edge-based cloud
Data necessary to calculate the KPI	Percentage of waste material still found after separation process

KPI name	**TPI21 Time needed to adapt to a batch of different quality to be sorted**
Type	Technical / Efficiency
Relevance	"High"
Target and description	The aim is to apply deep learning model so the cognitive technology in the line is able to learn and optimize changeover times. Adaptive and auto learning calibration connected by a wireless edge-based cloud should minimise adaptation time.
Data necessary to calculate the KPI	Measure time needed for a successful system reconfiguration

5.2 Business requirements

The objective is to demonstrate an industrial cognitive automation system in a full-scale packaging line using both software and hardware innovation: in particular, by using a combination of movement technology and deep learning techniques on 3D volumetric data in an inline production situation (fast cycle times). Furthermore, the aim is to automatically detect relevant features in batches of different composition by means of efficient convolutional neural architectures (to be designed), compatible with 3D point clouds coming from 3D acquisition devices. The engineering machine building customers can then shorten conveyer belts and generate higher production rates, while ensuring product modification flexibility for end-customers and avoiding lengthy manual feature engineering by vision-engineers.

Requirement name	**BR18 Enable the application of computer-based vision analysis and fog-cloud deep learning solutions for "conveyor belt" automation scenarios**

Type	Business, Non-functional
Priority	High
Purpose and description	The aim is to automatically detect relevant features in batches of different composition by means of efficient convolutional neural architectures (to be designed), compatible with 3D point clouds coming from 3D acquisition devices
Application area	Flexibility, Efficiency
Constraints or dependencies	Requires using a combination of movement technology and deep learning techniques on 3D volumetric data in an inline production situation (fast cycle times)

5.3 Functional requirements

For Stora Enso, mechanical sorting whether automated or manual is slow and expensive and manual work has to be limited to be cost effective. Traditional machine vision systems which sort based purely on rules (colour or visual patterns) applied to images turn out to be insufficient needs to speed up their sorting process to keep up with growing production demands for their various product line, while retaining or even reducing their volume, energy and manpower requirements. AI-driven enabled machine vision combined with suction-tool robot sorting systems is a potential game-changer for paper recyclers in general and Stora Enso in particular, as it can reduce sorting layers, volume and energy.

5.4 Non-functional requirements

The Stora Enso pilot is focused on automated paper/cardboard separation in the recycling industry. The pilot integrates novel camera based vision systems and specialized grippers to ensure separation at a very high conveyor belt speed, and will develop the following technologies to confront the challenges of a changing and heterogeneous environment:

- Vision control system that includes:
    - AI learning framework component that reduces the learning times for vision-controlled robots
    - Cloud-based AI delivery architecture that orchestrates the execution of real-time AI algorithms on a series of GPU dedicated machines to achieve real-time video sensor processing of multiple cameras targeting latencies less than 100ms.

5.5 Technical requirements

In the following sections first analysis in in critical domains are shown before presenting a first technical requirements definition:

Cloud and Simulation layer

In the context of Industrial Cognitive Automation, Deep learning information processing must be done on specialized hardware. There is a difference in the processing need between the learning phase (entry and submission of a new product), and the inference stage (normal runtime). It would be very costly to have supercomputing capacities on premise (pro machine) just for the learning phase. There is a clear incentive to build up critical mass in GPU datacentres that can be more optimally used because of different customers using it. As conclusion, we proposed to solve Deep learning product teaching application with Cloud Computing.

Our Use Case implementation would be accompanied with the generation of 3D data point clouds, which need to be processed. At the moment, our data management systems are located on the fog (local cloud, in slow sync with the cloud), while all Deep learning modules to be implemented can be parallelized, Teaching in new products modules require low frequency interaction with end-user, and Link 3D scanner, network and inference device modules can be considered as mission-critical and network-intensive.

Information processing (analytics) layer

In the scenario of the Industrial Cognitive Automation Use Case MEL 3D scanner, LMI scanner, IDS camera sensors like will be available, obtaining 3D point clouds (Proprietary Robovision 3D point cloud format) and normal 2D images. In the other hand, the pilot will have access to log files and list of interventions stored historically over time.

Some deep learning software components are prior knowledge of Robovision and are available under R&D license to other partners.

Summary for technical requirements

Although many questions were focussed on communication topics, our short-term development effort is not aimed at changing the communication structure. One area of future development is in Cloud based data aggregation, but our main focus is on the next topics:

Requirement name	**TR32 Manage and reduce change over time (downtime)**
Type	Technical, Functional
Priority	High
Purpose and description	Reducing both the time and skills needed to process different batches will improve efficiency and reduce payback time of our machines
Application area	Information Processing (Analytics)
Constraints or dependencies	Data needed

Requirement name	**TR33 Increase Task Completion time (speed of the process)**
Type	Technical, Functional
Priority	High
Purpose and description	The deep learning modules need to be parallelized to improve the speed of the process. There is a difference in the processing need between the learning phase (entry and submission of a new product), and the inference stage (normal runtime).
Application area	Information Processing (Analytics)
Constraints or dependencies	Depends on Vision control system and deep learning framework

6. Description and scope of Use Case 3 – Industrial Cooperative Assembly of Pneumatic Cylinders

6.1 Business goals and performance indicators

The main business objective is the support and improvement of the manual assembly process of cylinders by using collaborative robotics. Humans should be relieved from assembly tasks that can be better handled by cognitive robots, to increase effectiveness and productivity. This is achieved by letting humans do what they can do best and let robots do complementary tasks, reducing human intervention by implementing a Human-Robot-Cooperation approach, increasing flexibility by rapidly switching from one product variant to the other, and maintaining constant scalability with respect to the assembly of individualized products.

Concerning the cost section SMC sees a range of possibilities where AUTOWARE technologies can improve their current expenses because of the high expenditure of time needed for the manual assembling process. By implementing the AUTOWARE technology, some of the manual assembling steps should be automated. A cost effect will be achieved by reducing the assembly time and therefore reducing the assembly personnel working costs. This results in a decrease of the overall manufacturing costs. With this reduction, SMC expects an increase of the competitiveness of the German production facility to other European and global production sites.

KPI name	BPI06 Manufacturing cost/ assembly personnel working cost
Type	Business / Costs
Relevance	"High"
Target and description	Cost reduction: A cost effect will be achieved by the reduction of the assembly time and therefore reduction of the assembly personnel working costs.
Data necessary to calculate the KPI	Assembling time per product with and without the use of the robot.

Another effect of the reduced assembly time is the increase of productivity by raising the number of produced pieces per employee. Additionally, an increased efficiency of the employee is achieved by transferring non-value-added activities and monotonous repetitive tasks to the robot. This will avoid errors due to concentration problems and will help to ensure the consistently high-quality level of SMC products. This can be measured by the rejected rate of manufactured parts.

KPI name	BPI05 Productivity
Type	Business / Costs
Relevance	"High"
Target and description	Increase of productivity: Increase of productivity by raising the number of produced pieces per employee (output per head or output per unit of time).
Data necessary to calculate the KPI	Number of produced products per time unit with and without the use of the robot.

Concerning the quality SMC expects 100% reliable quality measuring and documentation of material length and dimensions of the final product. Inspection of critical parts of the cylinder (e.g. check if the cylinder is burr-free, check of the crimping depth of the piston rod). This documentation of the quality measuring process will serve for verifiability of potential quality complaints by customers.

KPI name	BPI07 Production quality
Type	Business / Quality
Relevance	"Medium"
Target and description	Reliable quality: 100% reliable optical quality inspection and measuring, of critical product features.
Data necessary to calculate the KPI	Number of produced products with failures with and without the use of the robot.

Also the safety of the collaborative workplace is very important and needs to consider the industrial safety standards. Only if a safe working environment for humans collaborating with the robot is ensured, the workplace can be implemented in the production environment. Therefore multiple safety standards as DIN EN ISO 10218, ISO/TS 15066, DIN EN ISO 13857 or the German "BG/BGIA-recommendation for the design of workplaces with collaborative robots" for example have to be considered. Additionally the employees have to be trained in handling the robot.

KPI name	BPI14 Safety of the human-robot collaboration
Type	Business / Sustainability
Relevance	"High"
Target and description	Ensure a safe working environment for humans collaborating with the robot.
Data necessary to calculate the KPI	Number of accidents and near accidents at work.

KPI name	BPI13 Training of employees
Type	Business / Sustainability
Relevance	"Medium"
Target and description	Training of the robot programmers and employees of the assembling area regarding the interaction with the robot (5 training days for each employee)
Data necessary to calculate the KPI	Number of trainings done.

And lastly in the field of innovation SMC foresees to gain experience in dealing with collaborative robots (Industry 4.0). Use AUTOWARE as a demonstration project for the external presentation of SMC's innovation and know-how as an innovation aspect. The demonstrator will be shown to external customers.

According to our investigations use case 3 "Industrial Cooperative Assembly of Pneumatic Cylinders" will not have a significant impact on environmental sustainability. However, a complete traceability of the assembled products makes the processes more sustainable. By the documentation of the results of the quality measuring process, the traceability of the assembled products will increase resulting in an increase of sustainability in the after-sales domain since valuation and handling of potential complaints can be better processed.

Concerning flexibility humans will unquestionably remain the most flexible being in assembling different components. However, the AUTOWARE approach will help to increase the flexibility in preparing individualized assembly processes for customized products by sharing the work steps between human and robot.

Table below present the technical KPIs that complement previous business KPIs.

KPI name	Type	Relevance	Target and description	Data necessary to calculate the KPI
TPI07 Process data retrieval time	Efficiency	High	Faster user feedback containing all important information for the assembly process (tools, components,…)	Various measurements of the execution time using the target HW/SW platform. Elaboration of possible weak points wrt the performance.
TPI08 Robustness of object detection	Efficiency		Augmented Virtuality: Direct visual alignment of physical world and digital scenery.	The robustness of the object recognition/detection will be evaluated through the acquisition of the false positive and false negative rates for different scenarios including different types of cylinders.
TPI09 Response time for object detection	Efficiency	High	Augmented Virtuality: Direct visual alignment of physical world and digital scenery.	Various measurements of the execution time using the target HW/SW platform. Elaboration of possible weak points wrt the performance
TPI10 Robustness of determining the assembly state	Efficiency	High	Knowledge about the current state can be used to guide the worker through the current step and visualize the upcoming assembly step.	The robustness of the determining the assembly state will be evaluated through the acquisition of the false positive and false negative rates for different scenarios.
TPI11 Response time for determining the assembly state	Efficiency	High	Knowledge about the current state can be used to guide the worker through the current step and visualize the upcoming assembly step.	Various measurements of the execution time using the target HW/SW platform. Elaboration of possible weak points wrt the performance
TPI12 Execution time of quality assessment	Efficiency	High	Relieving the human worker from cognitive demanding tasks.	Various measurements of the execution time using the target HW/SW platform. Elaboration of possible weak points wrt the performance
TPI13 Accuracy of quality assessment	Quality	High	Relieving the human worker from cognitive demanding tasks.	Actual/target comparison of measurements.
TPI14 Scanning data storage time	Efficiency	High	Quality assessment reports (scans and images) are stored for documentation and future analysis.	Various measurements of the execution time using the target HW/SW platform. Elaboration on how different geometries affect the scanning performance.
TPI15 time to change production line	Flexibility	High	Enables flexible changes of production lines.	Performing measurements in order to determine the needed time when it comes to change the line from one product to another.
TPI16 Easiness to change production line	Flexibility	High	Enables flexible changes of production lines.	Usability-evaluation at SMC

6.2 Business requirements

Requirement name	BR04 Automation of manual assembling steps
Type	Business, Functional
Priority	High
Purpose and description	Support and improvement of the manual assembly process of pneumatic cylinders by the use of collaborative robotics.
Application area (Business / Technological)	Costs / Industrial Communications & Control
Constraints or dependencies	Complex assembling steps cannot be transferred to the robot.

Requirement name	BR05 Reduction of the assembly personnel working costs and the manufacturing costs
Type	Business, Functional
Priority	High
Purpose and description	By implementing the AUTOWARE technology, some of the manual assembling steps should be automated. A cost effect will be achieved by the reduction of the assembly time and therefore reduction of the assembly personnel working costs. By reducing the assembly personnel working costs, the manufacturing costs will also decrease.
Application area (Business / Technological)	Costs/Information Processing (Analytics)
Constraints or dependencies	The assembly personnel working costs depend on the needed assembly time. Only if the assembly time can be reduced, the assembly personnel working costs can be reduced as well. The performance of the robot in terms of gripping and moving speed can affect the assembly time, if it is below the human working speed.

Requirement name	BR06 Increase of productivity
Type	Business, Functional
Priority	High
Purpose and description	Increase of productivity by raising the number of produced pieces per employee by the reduction of the assembly time (by transferring non-value-added activities to the robot). The employees will be relieved from non-value adding and monotonous repetitive tasks.
Application area (Business / Technological)	Efficiency/ Information Processing (Analytics)
Constraints or dependencies	The productivity depends on the needed assembly time. Only if the assembly time can be reduced, the productivity can be increased. The performance of the robot in terms of gripping and moving speed can affect the assembly time, if it is below the human working speed.

Requirement name	BR07 Economic efficiency regarding the acquisition costs
Type	Business, Non-Functional
Priority	High
Purpose and description	Increase of economic efficiency, appropriate integration costs per workstation.
Application area (Business / Technological)	Efficiency/ Information Processing (Analytics)
Constraints or dependencies	Only if there are sufficient savings regarding the assembling personnel working costs, the high acquisition costs will pay off.

Requirement name	BR08 Ensuring consistent high quality level and documentation of the measuring results
Type	Business, Functional

Priority	High
Purpose and description	100% reliable quality measuring and documentation of material length and dimensions of the final product. Inspection of critical parts of the cylinder (e.g. check if the cylinder is burr-free, check of the crimping depth of the piston rod).
Application area (Business / Technological)	Quality/ Information Processing (Analytics)
Constraints or dependencies	Realization of inspection of all quality specifications. Assembling steps only can be transferred to the robot, if 100% good quality is guaranteed.

Requirement name	**BR19 Safety concept**
Type	Business, Non-Functional
Priority	High
Purpose and description	Safety concept of the workplace according to safety standards DIN EN ISO 10218, ISO/TS 15066, DIN EN ISO 13857, German "BG/BGIA-recommendation for the design of workplaces with collaborative robots" is needed to implement the collaborative workplace in the production environment.
Application area (Business / Technological)	Sustainability/Security & Certification
Constraints or dependencies	If the AUTOWARE concept does not fulfil the listed safety standards, the system must not be used in the production environment.

Requirement name	**BR13 Traceability of the assembled products and verifiability of quality complaints**
Type	Business, Functional
Priority	Medium

Purpose and description	By the documentation of the results of the quality measuring process, the traceability of the assembled products will increase.
Application area (Business / Technological)	Quality/Orchestration & Digital Twin
Constraints or dependencies	PLM interface needed for data transfer and storage

Requirement name	**BR14 Production flexibility**
Type	Business, Functional
Priority	Medium
Purpose and description	The AUTOWARE approach will help to increase the flexibility in preparing individualized assembly processes for customized products.
Application area (Business / Technological)	Flexibility/Orchestration & Digital Twin
Constraints or dependencies	Setup time for product changes has to be appropriate.

Requirement name	**BR11 Increase of the competitiveness of the German production facility**
Type	Business, Non-Functional
Priority	Medium
Purpose and description	By reducing the manufacturing costs, SMC expects an increase of the competitiveness of the German production facility to other European and global production sites.
Application area (Business / Technological)	Costs/Industrial Communications & Control
Constraints or dependencies	The competitiveness of the German production facility depends on the manufacturing costs and the productivity. Only if the assembly personnel working costs can be reduced or the productivity can be raised, the competitiveness will increase.

Requirement name	BR12 Gain of know-how
Type	Business, Non-Functional
Priority	Medium
Purpose and description	Training of the robot programmers and employees of the assembling area regarding the interaction with the robot.
Application area (Business / Technological)	Innovation/Cloud and Simulation
Constraints or dependencies	The gain of know-how depends on the good cooperation between the AUTOWARE partners and the transfer of data and information.

Requirement name	BR10 Marketing tool
Type	Business, Non-Functional
Priority	Low
Purpose and description	Use AUTOWARE as a demonstration project for the external presentation of SMC's innovation and know-how.
Application area (Business / Technological)	Innovation/Information Processing (Analytics)
Constraints or dependencies	Use of SMC technique for the industrial demonstrator.

6.3 Functional requirements

As a functional requirement, the system should extract all production (i.e. product and process) information from the PLM system, such as the construction plan, CAD models and workflow, with respect to the currently executed manufacturing order. Based on this information the system should detect the current assembly state by utilizing object recognition services.

Therefor it is necessary to develop a digital object memory to detect and identify the different products by the use of sensors. The dynamic configuration of the robot system should be realized by combining visual computing, semantic technologies and the robot control unit. By matching them to their digital counterpart, a link between real and digital world on an advanced semantic level is created allowing for significant increase of efficiency of internal order processing as well as the certainty of decision-making. After determining the state, the system should communicate it to the user and visualize all tools and assembly components needed for the specific assembly state.

Apart from the process monitoring requirements there is also a high focus on the quality assessment part to promote SMCs high expectations on production quality. The documentation of the quality measuring process will serve for verifiability of quality complaints by customers.

Therefor the system should scan parts and check quality features in an automated way (optical sensors and view planning) with respect to the workflow. For that the system's optical sensing technology must be able to robustly capture the materials of the industrial assembly parts used and the sensors must provide sufficient data and accuracy to enable proper quality assessment and further reasoning. Since the objective is to support the assembly of pneumatic cylinders with varying piston diameters (between 32 – 63 mm) and stroke (5 – 100 mm) the robot should have a high range of application so that it can be used for the assembly of different cylinder types and relevant quality aspects. In addition, the system's scanning and guidance technology must automatically adapt to different sized objects and workflows without explicit user configuration to increase the production flexibility. For that evaluation and optimization of hardware and software is needed. All quality assessment results should then be stored as historic data in a database for further analysis.

6.4 Non-functional requirements

Keeping in mind the production costs the system should not overly prolong the operating time of the assembly process. However, it should be considered that the AUTOWARE system will extend the current assembly process with additional processing steps, which are right now not incorporated in the working process. However, they are needed to solve SMCs pain points and enhance the current manual assembly process. Examples are among others an autonomous high accuracy scanning system and a historic data storage system. Nonetheless, we anticipate compensating the process time for these demanding tasks by performing work steps in parallel by the human worker and the robot.

Concerning the quality aspect, the scanning system should provide consistent 2D and 3D scanning quality throughout the operation time to assure long-term comparable results. For that, robust hardware and calibration routines are needed.

During the phase of development, the safety aspects of the human-machine interaction have to be considered also. Since the use case requires tight human-robot-collaboration and the human health has the highest priority, security standard for the robot operation in the workspace populated by humans have to be met in order to eliminate unwanted contact between humans and robots. We might require using high-frequency laser barriers to trigger an emergency stop and shut down the assembly process. In addition, the cognitive abilities and reliability of the robot must be ensured to enable human-machine interaction. In order that they will be able to act, react and identify opportunities for actions through observation.

To ensure usability the system should provide an intuitive user interface since it is also used as guidance system to provide novice workers their first steps into the manual assembly process. By visualizing the current working step, needed tools and furthermore the robot's intentions to prepare upcoming tasks the human is interactively trained to assemble the pneumatic cylinder in collaboration with the robot.

6.5 Technical requirements

For the technical realization of the requirements stated above, we foresee to have a collaborative robot work-cell that will be installed with all necessary hardware components. The following images show a preliminary set up of the working-cell and the foreseen communication links between different the components.

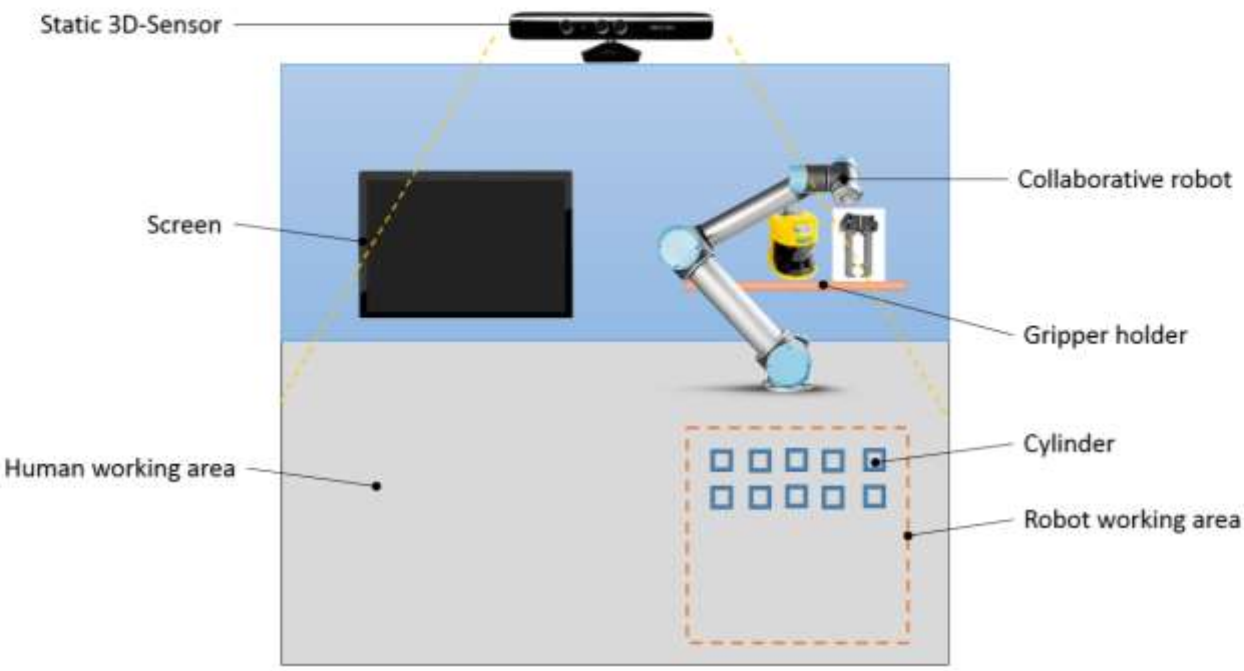


Figure 16: A conceptual setup for the collaborative work cell.

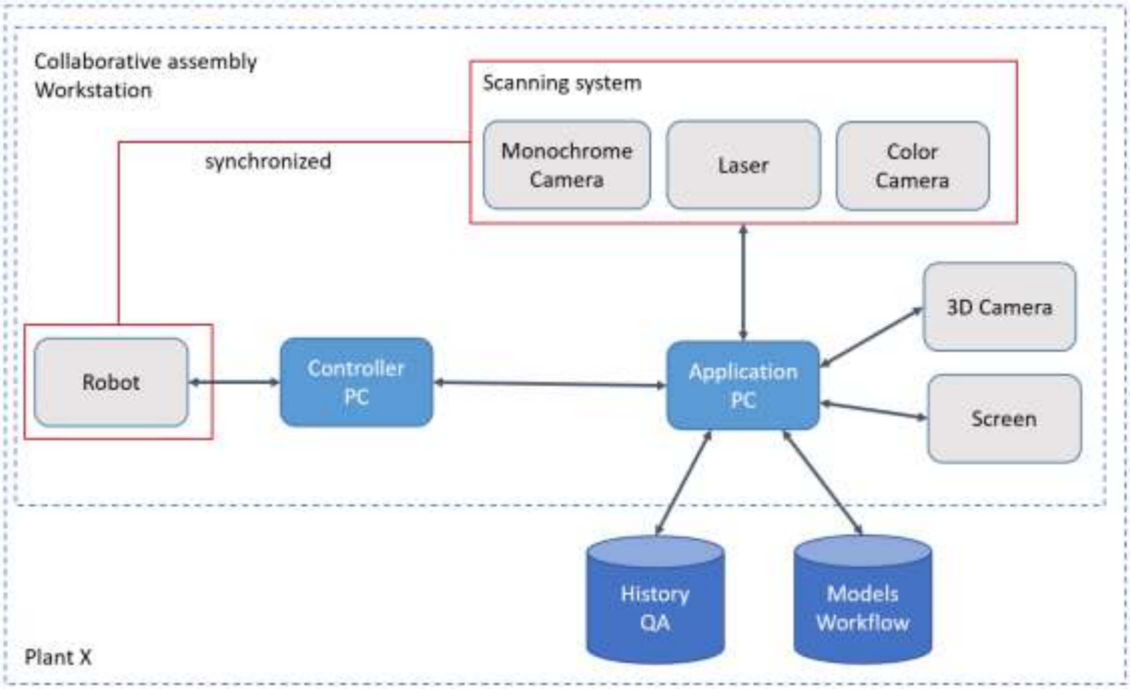


Figure 17: Communication architecture of hardware modules.

At least one lightweight collaborative robot will be integrated into the work-cell. 2D and 3D optical sensors will allow a 3D reconstruction of the working environment. A scanning system will be attached to the robot's end effector consisting of a monochrome camera paired with a laser line projector for 3D geometry acquisition and a 2D colour camera for quality documentation and texturing. The robot will use the 3D reconstructed environment for inspection and identification of the current assembly state. The images acquired with the 2D sensors will be used for object detection and product identification. Once the robot interprets and understands what he "sees" (cognitive abilities) he will be able to act, react and identify opportunities for actions through observation. The controller computer will be used to control the robot. The application PC is used to process the sensor data (e.g., for object detection) and to send and store scanned images. The monitor will be used for intention visualization to visualize in 3D how the robot will collaborate with the human. All connections indicated with arrows should be realized with deterministic Ethernet. Between control pc and application pc we will have a TCP/IP based socket connection.

After an observation of the current offer on collaborative robots we decided on the Universal Robot UR-5[3]. UR-5 robots are capable of lifting weights up to five kilograms and have been certified by TÜV (Technischer Überwachungs-Verein - a German organization that work to validate the safety of products) and tested in accordance with EN ISO

[3] https://www.universal-robots.com/products/ur5-robot/

13849:2008 PL d and EN ISO 10218-1:2011, Clause 5.4. This safety system makes him usable for human-robot collaboration and appropriate for this use case.

The semantic model for assembly processes is an essential component because it enables the robots to learn and gain cognitive abilities. By means of the semantic model the robot attaches meaning and context to the objects he sees in the work-cell. That is why we need to model the domain knowledge for manual assembly processes as a semantic model. To realize this, we foresee to use Protégé[4] a free, open-source ontology editor and framework for building intelligent systems. The modelled database will store all production information and CAD models and will be used for automatic extraction of processes and mapping onto the semantic model. An additional database is deployed to store images, 3D scans and quality assessment results to serve as documentation of the quality measuring process. To provide access to the information an interface is needed for data transfer and storage to SMCs utilized Oracle E6 – PLM System.

Requirement name	Type	Priority	Purpose and description	Application Area	Constraints or dependencies
TR11 Extraction of production information from the PLM system	Functional	High	The system should extract all production information from the PLM system based on the manufacturing order	Orchestration + Digital Twin	Data needed
TR12 Detection of current assembly state	Functional	High	The system should detect the current assembly state and communicate it to the user.	Information Processing (Analytics)	Reference data needed from the PLM system
TR13 Tool and component visualization	Functional	High	The system should visualize all needed tools and assembly components for every assembly state.	Orchestration + Digital Twin	Reference CAD models needed from the PLM system
TR14 Tools and components detection	Functional	Medium	The system should detect tools and components in the working area and match them to their digital counterpart.	Orchestration + Digital Twin	Reference CAD models needed from the PLM system

[4] https://protege.stanford.edu/

TR15 Automatic part scan and quality features check	Functional	High	The system should scan parts and check quality features in an automated way (optical sensors and view planning) with respect to the workflow	Information Processing (Analytics)	Software components for quality check needed
TR16 Storage of quality assessment results	Functional	Medium	The system should store the quality assessment results as historic data in the database for further analysis.	Data Distribution + Fog Computing	Software components needed
TR20 Robust material capturing of assembly parts	Functional	High	The system's optical sensing technology must be able to robustly capture the materials of the industrial assembly parts used	Information Processing (Analytics)	Evaluation and optimization of hardware and software needed
TR21 System's sensors provide sufficient data and accuracy	Functional	High	The system's sensors must provide sufficient data and accuracy to enable proper quality assessment and further reasoning	Information Processing (Analytics)	Evaluation and optimization of hardware and software needed
TR22 Automatic adapt to different sized objects and workflows	Functional	Medium	The system's scanning and guidance technology must automatically adapt to different sized objects and workflows without explicit user configuration	Information Processing (Analytics)	Software components needed
TR18 Reduction of assembly time.	Non-Functional	Low	Reduction of the assembly time.	Orchestration + Digital Twin	None
TR19 Ensure consistent quality and comparable results	Non-Functional	Medium	The system should provide consistent quality and comparable results (in long term?)	Security + Certification	Robust hardware and calibration routines
TR17 Safe Human-Robot-Collaboration	Functional	High	The system should operate next to humans in a safe way. Contact forces between robot and human are limited to a	Security + Certification	Additional sensors hardware

			non-dangerous level.		
TR34 Gripping and handling of components	Functional	Low	Gripping and handling of cylinder components and final products	Information Processing (Analytics)	Gripper capable of gripping and handling parts
TR35 Support of repetitive and monotonous assembly steps	Non-Functional	Low	Support of repetitive and monotonous assembly steps	Information Processing (Analytics)	Notion which steps are repetitive and monotonous

7. Integrated requirement mapping

Next pages present some of the mappings obtained by analysing the relationships among the different requirements and KPIs and project objectives, business goals and technological dimensions of AUTOWARE.

7.1 Requirements alignment to overall Project Objectives

Req#	Use Case	Project Objectives Business Requirement	PO1. Ubiquitous connectivity of CPPS	PO2. To avoid "data deluge" to decision makers	PO3. Business development framework as a service for automation	PO4. To fit the multi-disciplinary needs of SME industry	PO5. To link to CPS and TAPP concept	PO6. Access to several European digitalization initiatives and platforms	PO7. Joint Proof of Concept of AUTOWARE	PO8. To disseminate and create awareness around the AUTOWARE framework	PO9. To influence pre-normative and standardization activities
BR01	JSI	Enable the application of robotics for customized production			X	X	X	X		X	
BR02	SFKL	Reduction of re-configuration time		X	X				X		
BR03	SFKL	Fast quality control		X		X					X
BR04	SMC	Automation of manual assembling steps			X				X		
BR05	SMC	Reduction of the assembly personnel working costs and the manufacturing costs							X		
BR06	SMC	Increase of productivity							X		
BR07	SMC	Economic efficiency regarding the acquisition costs				X					
BR08	SMC	Ensuring consistent high quality level and documentation of the measuring results				X			X		
BR10	SMC	Marketing tool								X	
BR11	SMC	Increase of the competitiveness of the German production facility							X		X
BR12	SMC	Gain of know-how				X					
BR13	SMC	Traceability of the assembled products and verifiability of quality complaints				X					
BR14	SMC	Production flexibility			X	X			X		
BR15	Tekn	Higher efficiency				X			X		
BR16	Tekn	Technological support	X					X	X		
BR17	Tekn	Flexible and collaborative robotics in manufacturing	X						X		
BR18	Stora	Enable the application of computer-based vision analysis and fog-cloud deep learning solutions for "conveyor belt" automation scenarios				X					
BR19	SMC	Safety concept				X					

Req#	Use Case	Project Objectives / Technical Requirement	PO1. Ubiquitous connectivity of CPPS	PO2. To avoid "data deluge" to decision makers	PO3. Business development framework as a service for automation	PO4. To fit the multi-disciplinary needs of SME industry	PO5. To link to CPS and TAPP concept	PO6. Access to several European digitalization initiatives and platforms	PO7. Joint Proof of Concept of AUTOWARE	PO8. To disseminate and create awareness around the AUTOWARE framework	PO9. To influence pre-normative and standardization activities
TR01	JSI	Sufficient number of assembly operations implemented					■		■		
TR02	JSI	Visual quality control				■					
TR03	JSI	Fast setup times for a new assembly process		■							
TR05	JSI	Ability to transfer large quantities of training data to IT systems outside of the workcell	■						■		
TR06	JSI	Automated assembly cycle time comparable to the manual production							■		
TR07	SFKL	Security of product data	■			■		■			
TR08	SFKL	Track and trace of product					■				
TR09	SFKL	Wearable guide system				■					
TR10	SFKL	Distributed data storage	■			■					
TR11	SMC	Extraction of production information from the PLM system		■							
TR12	SMC	Detection of current assembly state		■							
TR13	SMC	Tool and component visualization		■							
TR14	SMC	Tools and components detection		■							
TR15	SMC	Automatic part scan and quality features check		■							
TR16	SMC	Storage of quality assessment results				■					
TR17	SMC	Safe Human-Robot-Collaboration				■					■
TR18	SMC	Reduction of assembly time.								■	
TR19	SMC	Ensure consistent quality and comparable results				■					
TR20	SMC	Robust material capturing of assembly parts				■					
TR21	SMC	System's sensors provide sufficient data and accuracy				■					
TR22	SMC	Automatic adapt to different sized objects and workflows			■	■					
TR23	Tekn	Autonomous navigation							■		
TR24	Tekn	System localization							■		
TR25	Tekn	Real-time information communication and processing	■								
TR26	Tekn	Multipurpose assembly cell combining material transport and assembly operations							■		

Req#	Use Case	Project Objectives Technical Requirement	PO1. Ubiquitous connectivity of CPPS	PO2. To avoid "data deluge" to decision makers	PO3. Business development framework as a service for automation	PO4. To fit the multi-disciplinary needs of SME industry	PO5. To link to CPS and TAPP concept	PO6. Access to several European digitalization initiatives and platforms	PO7. Joint Proof of Concept of AUTOWARE	PO8. To disseminate and create awareness around the AUTOWARE framework	PO9. To influence pre-normative and standardization activities
TR27	Tekn	Standard communication mechanisms in the workcell components	■								
TR28	Tekn	Mobile platform as a CPS					■				
TR29	SFKL	Standardized information protocol		■		■					■
TR30	SFKL	Physical interface of Production modules				■					
TR31	Tekn	Wireless robust and reliable communication	■								
TR32	Stora	Manage and reduce changeover time				■					
TR33	Stora	Increase Task Completion time (speed of process)				■					
TR34	SMC	Gripping and handling of cylinder components and final products			■						
TR35	SMC	Support of repetitive and monotonous assembly steps			■						

7.2 KPIs alignment to overall Industry 4.0 Areas

KPI#	Use Case	Industry 4.0 Areas KPI	Costs	Efficiency	Flexibility	Sustainability	Quality	Innovation
BPI01	JSI	Cost of manufacturing per product	X					
BPI02	JSI	Number of available assembly operations		X				
BPI03	SFKL	Reduction of re-configuration time			X			
BPI04	SFKL	Fast quality control					X	
BPI05	SMC	Productivity [pcs / head or pcs / h]	X					
BPI06	SMC	Manufacturing cost/ assembly personnel working cost [€ / pcs]	X					
BPI07	SMC	Production quality [Not good pcs / produced pcs]					X	
BPI08	Tekniker	Efficient transport	X					
BPI09	Tekniker	Coordination among productive systems		X				
BPI10	Tekniker	Flexible task planning			X			
BPI12	Stora	Paper/cardboard separation efficiency					X	
BPI13	SMC	Training of employees [No. of trainings implemented]				X		
BPI14	SMC	Safety of the human-robot collaboration [Near accidents at work / year]				X		
TPI01	JSI	Cycle time of assembly processes	X					
TPI02	JSI	Time needed to set up a new assembly process		X	X			
TPI03	SFKL	Security of product data						X
TPI04	SFKL	Track and trace of product			X			
TPI05	SFKL	Wearable guide system		X				
TPI06	SFKL	Distributed data storage			X			
TPI07	SMC	Process data retrieval time		X				
TPI08	SMC	Robustness of object detection		X				
TPI09	SMC	Response time for object detection		X				
TPI10	SMC	Robustness of determining the assembly state		X				
TPI11	SMC	Response time for determining the assembly state		X				
TPI12	SMC	Execution time of quality assessment		X				
TPI13	SMC	Accuracy of quality assessment					X	
TPI14	SMC	Scanning data storage time		X				
TPI15	SMC	time to change production line			X			
TPI16	SMC	Easiness to change production line			X			
TPI17	Tekniker	Reduce Cost of manufacturing per product	X			X		X
TPI18	Tekniker	Efficient navigation		X				
TPI19	Tekniker	Accuracy of system localization					X	
TPI20	Tekniker	Safety ratio		X				
TPI21	Stora	Time needed to adapt to a batch of different quality to be sorted		X				

7.3 KPIs mapping to Requirements Set

		Business Requirements	application of robotics	re-configuration time	Fast quality control	Automation of steps	assembly costs	Increase of productivity	Economic efficiency	Ensuring measuring	Marketing tool	competitiveness	Gain of know-how	Traceability of products	Production flexibility	Higher efficiency	Technological support	collaborative robotics	deep learning	Safety concept
		Use Case	JSI	SFKL	SFKL	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	Tekn	Tekn	Tekn	Stora	SMC
KPI#	**Use Case**	**Business KPI**	BR01	BR02	BR03	BR04	BR05	BR06	BR07	BR08	BR10	BR11	BR12	BR13	BR14	BR15	BR16	BR17	BR18	BR19
BPI01	JSI	Cost of manufacturing per product		■			■	■	■						■					
BPI02	JSI	Number of available assembly operations						■	■						■			■		
BPI03	SFKL	Reduction of re-configuration time		■																
BPI04	SFKL	Fast quality control																		
BPI05	SMC	Productivity [pcs / head or pcs / h]				■		■	■			■								
BPI06	SMC	Manufacturing cost/ assembly personnel working cost [€ / pcs]					■													
BPI07	SMC	Production quality [Not good pcs / produced pcs]								■										
BPI08	Tekn	Efficient transport														■				
BPI09	Tekn	Coordination among productive systems														■		■		
BPI10	Tekn	Flexible task planning														■		■		
BPI12	Stora	Paper/cardboard separation efficiency																	■	
BPI13	SMC	Training of employees [No. of trainings implemented]											■							
BPI14	SMC	Safety of the human-robot collaboration [Near accidents at work / year]																		■

KPI#	Use Case	Technical KPI	BR01 JSI application of robotics	BR02 SFKL re-configuration time	BR03 SFKL Fast quality control	BR04 SMC Automation of steps	BR05 SMC assembly costs	BR06 SMC Increase of productivity	BR07 SMC Economic efficiency	BR08 SMC Ensuring measuring	BR10 SMC Marketing tool	BR11 SMC competitiveness	BR12 SMC Gain of know-how	BR13 SMC Traceability of products	BR14 SMC Production flexibility	BR15 Tekn Higher efficiency	BR16 Tekn Technological support	BR17 Tekn collaborative robotics	BR18 Stora deep learning	BR19 SMC Safety concept
TPI01	JSI	Cycle time of assembly processes						■								■				
TPI02	JSI	Time needed to set up a new assembly process					■	■	■						■					
TPI03	SFKL	Security of product data																		
TPI04	SFKL	Track and trace of product																		
TPI05	SFKL	Wearable guide system																		
TPI06	SFKL	Distributed data storage																		
TPI07	SMC	Process data retrieval time																		
TPI08	SMC	Robustness of object detection																		
TPI09	SMC	Response time for object detection																		
TPI10	SMC	Robustness of determining the assembly state																		
TPI11	SMC	Response time for determining the assembly state																		
TPI12	SMC	Execution time of quality assessment																		
TPI13	SMC	Accuracy of quality assessment												■	■					
TPI14	SMC	Scanning data storage time				■		■						■						
TPI15	SMC	time to change production line													■					■
TPI16	SMC	Easiness to change production line													■					■
TPI17	Tekn	Reduce Cost of manufacturing per product															■			
TPI18	Tekn	Efficient navigation																■		
TPI19	Tekn	Accuracy of system localization																		
TPI20	Tekn	Safety ratio																		
TPI21	Stora	Time needed to adapt to a batch of different quality to be sorted																	■	

		Technical Requirements	number of operations	Visual quality control	Fast setup times	transfer large data	Automated assembly cycle	Security of product data	Track & trace of product	Wearable guide system	Distributed data storage	Extraction of PLM info	Detection of assembly state	Tool & comp visualization	Tools & comp detection	Automatic quality check	Storage of quality assessm	Safe H-R-Collaboration	Reduction of assembly time	Ensure consistent quality	Robust material capturing	sensors data accuracy	Automatic adapt	Autonomous navigation	System localization	Real-time information	Multipurpose assembly cell	Standard communication	Mobile platform as a CPS	Standardized info protocol	Physical interf of modules	WL robust reliable comm	changeover time	Increase Task Completion time	Gripping and handling	Support of repetitive steps
		Use Case	JSI	JSI	JSI	JSI	JSI	SFKL	SFKL	SFKL	SFKL	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	Tekn	Tekn	Tekn	Tekn	Tekn	Tekn	SFKL	SFKL	Tekn	Stora	Stora	SMC	SMC
KPI#	**Use Case**	**Business KPI**	TR01	TR02	TR03	TR05	TR06	TR07	TR08	TR09	TR10	TR11	TR12	TR13	TR14	TR15	TR16	TR17	TR18	TR19	TR20	TR21	TR22	TR23	TR24	TR25	TR26	TR27	TR28	TR29	TR30	TR31	TR32	TR33	TR34	TR35
BPI01	JSI	Cost of manufacturing per product			■		■												■										■							
BPI02	JSI	Number of available assembly operations		■	■				■																				■							
BPI03	SFKL	Reduction of re-configuration time							■																											
BPI04	SFKL	Fast quality control								■	■																									
BPI05	SMC	Productivity																																		
BPI06	SMC	Manufacturing cost/ assembly personnel working cost																																		
BPI07	SMC	Production quality																																		
BPI08	Tekn	Efficient transport																									■									
BPI09	Tekn	Coordination among productive systems																									■	■	■			■				
BPI10	Tekn	Flexible task planning																								■	■									

KPI#	Use Case	Business KPI	TR01	TR02	TR03	TR05	TR06	TR07	TR08	TR09	TR10	TR11	TR12	TR13	TR14	TR15	TR16	TR17	TR18	TR19	TR20	TR21	TR22	TR23	TR24	TR25	TR26	TR27	TR28	TR29	TR30	TR31	TR32	TR33	TR34	TR35
BPI12	Stora	Paper/cardboard separation efficiency																																		
BPI13	SMC	Training of employees																																		
BPI14	SMC	Safety of the human-robot collaboration																																		

		Technical Requirements	number of operations	Visual quality control	Fast setup times	transfer large data	Automated assembly cycle	Security of product data	Track & trace of product	Wearable guide system	Distributed data storage	Extraction of PLM info	Detection of assembly state	Tool & comp visualization	Tools & comp detection	Automatic quality check	Storage of quality assessm	Safe H-R-Collaboration	Reduction of assembly time	Ensure consistent quality	Robust material capturing	sensors data accuracy	Automatic adapt	Autonomous navigation	System localization	Real-time information	Multipurpose assembly cell	Standard communication	Mobile platform as a CPS	Standardized info protocol	Physical interf of modules	WL robust reliable comm	changeover time	Increase Task Completion time	Gripping and handling	Support of repetitive steps
		Use Case	JSI	JSI	JSI	JSI	JSI	SFKL	SFKL	SFKL	SFKL	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	SMC	Tekn	Tekn	Tekn	Tekn	Tekn	Tekn	SFKL	SFKL	Tekn	Stora	Stora	SMC	SMC
KPI#	Use Case	Technical KPI	TR01	TR02	TR03	TR05	TR06	TR07	TR08	TR09	TR10	TR11	TR12	TR13	TR14	TR15	TR16	TR17	TR18	TR19	TR20	TR21	TR22	TR23	TR24	TR25	TR26	TR27	TR28	TR29	TR30	TR31	TR32	TR33	TR34	TR35
TPI01	JSI	Cycle time of assembly processes					■						■	■					■							■	■									
TPI02	JSI	Time needed to set up a new assembly process	■		■		■																				■		■							
TPI03	SFKL	Security of product data						■																												
TPI04	SFKL	Track and trace of product							■																											
TPI05	SFKL	Wearable guide system								■																										
TPI06	SFKL	Distributed data storage									■																									
TPI07	SMC	Process data retrieval time																	■																	
TPI08	SMC	Robustness of object detection											■			■				■																
TPI09	SMC	Response time for object detection																	■																	
TPI10	SMC	Robustness of determining the assembly state											■			■				■																

KPI#	Use Case	Technical KPI	TR01	TR02	TR03	TR05	TR06	TR07	TR08	TR09	TR10	TR11	TR12	TR13	TR14	TR15	TR16	TR17	TR18	TR19	TR20	TR21	TR22	TR23	TR24	TR25	TR26	TR27	TR28	TR29	TR30	TR31	TR32	TR33	TR34	TR35
TPI11	SMC	Response time for determining the assembly state																	■																	
TPI12	SMC	Execution time of quality assessment																	■																	
TPI13	SMC	Accuracy of quality assessment																																		
TPI14	SMC	Scanning data storage time																																		
TPI15	SMC	time to change production line																																		
TPI16	SMC	Easiness to change production line																																		
TPI17	Tekn	Reduce Cost of manufacturing per product																																		
TPI18	Tekn	Efficient navigation																						■	■											
TPI19	Tekn	Accuracy of system localization																						■	■											
TPI20	Tekn	Safety ratio																								■										
TPI21	Stora	Time needed to adapt to a batch of different quality to be sorted																															■	■		

7.4 Business Requirements alignment to Industry 4.0 Areas

Req#	Use Case	Requirement	Costs	Efficiency	Flexibility	Sustainability	Quality	Innovation
BR01	JSI	Enable the application of robotics for customized production			■			
BR02	SFKL	Reduction of re-configuration time			■			
BR03	SFKL	Fast quality control					■	
BR04	SMC	Automation of manual assembling steps	■					
BR05	SMC	Reduction of the assembly personnel working costs and the manufacturing costs	■					
BR06	SMC	Increase of productivity		■				
BR07	SMC	Economic efficiency regarding the acquisition costs		■				
BR08	SMC	Ensuring consistent high quality level and documentation of the measuring results					■	
BR10	SMC	Marketing tool						■
BR11	SMC	Increase of the competitiveness of the German production facility	■					
BR12	SMC	Gain of know-how						■
BR13	SMC	Traceability of the assembled products and verifiability of quality complaints				■		
BR14	SMC	Production flexibility			■			
BR15	Tekniker	Higher efficiency in assembly cell	■					
BR16	Tekniker	Technological support						■
BR17	Tekniker	Flexible and collaborative robotics in manufacturing			■			
BR18	Stora	Enable the application of computer-based vision analysis and fog-cloud deep learning solutions for “conveyor belt” automation scenarios			■			
BR19	SMC	Safety concept				■		

7.5 Requirements-Set alignment to Autoware Framework

Req#	Use Case	Technology layers / Technical Requirement	Orchestration & Digital Twin	Cloud & Simulation	Information Processing (Analytics)	Data Distribution & Fog Computing	Industrial Communications & Control	Security & Certification
TR01	JSI	The system should have a number of assembly operations implemented					X	
TR02	JSI	Visual quality control			X			
TR03	JSI	Fast setup times for a new assembly process	X					
TR05	JSI	Ability to transfer large quantities of training data to IT systems outside of the workcell		X				
TR06	JSI	Automated assembly cycle time comparable to the manual production					X	
TR07	SFKL	Security of product data						X
TR08	SFKL	Track and trace of product	X					
TR09	SFKL	Wearable guide system					X	
TR10	SFKL	Distributed data storage				X		
TR11	SMC	Extraction of production information from the PLM system	X					
TR12	SMC	Detection of current assembly state			X			
TR13	SMC	Tool and component visualization	X					
TR14	SMC	Tools and components detection	X					
TR15	SMC	Automatic part scan and quality features check			X			
TR16	SMC	Storage of quality assessment results				X		
TR17	SMC	Safe Human-Robot-Collaboration						X
TR18	SMC	Reduction of assembly time.	X					
TR19	SMC	Ensure consistent quality and comparable results						X
TR20	SMC	Robust material capturing of assembly parts			X			
TR21	SMC	System's sensors provide sufficient data and accuracy			X			
TR22	SMC	Automatic adapt to different sized objects and workflows			X			
TR23	Tekniker	Autonomous navigation			X			
TR24	Tekniker	System localization			X			
TR25	Tekniker	Real-time information communication and processing						X
TR26	Tekniker	Multipurpose assembly cell combining material transport and assembly operations	X					
TR27	Tekniker	Standard communication mechanisms in the workcell components					X	
TR28	Tekniker	Mobile platform as a CPS					X	
TR29	SFKL	Standardized information protocol					X	
TR30	SFKL	Physical interface of Production modules					X	
TR31	Tekniker	Wireless robust and reliable communication					X	
TR32	Stora	Manage and reduce changeover time			X			
TR33	Stora	Increase Task Completion time (speed of process)			X			
TR34	SMC	Gripping and handling of cylinder components and final products			X			
TR35	SMC	Support of repetitive and monotonous assembly steps			X			

Req#	Use Case	Technological enablers / Technical Requirement	Industrial Connectivity	Data Distribution	OpenFog – HW platform	FIWARE for Industry	Augmented Virtuality	Cognitive/Deep Learning Vision	Flexible Robotic Cell – ROS-NGSI	TSN Configurator	Manual Robotic Task Programming	Engineering & Simulation as a Service - CloudFlow
TR01	JSI	Sufficient number of assembly operations implemented							■			
TR02	JSI	Visual quality control						■				
TR03	JSI	Fast setup times for a new assembly process					■		■		■	
TR05	JSI	Ability to transfer large quantities of training data to IT systems outside of the workcell			■							■
TR06	JSI	Automated assembly cycle time comparable to the manual production							■		■	
TR07	SFKL	Security of product data		■		■						
TR08	SFKL	Track and trace of product	■							■		■
TR09	SFKL	Wearable guide system					■					
TR10	SFKL	Distributed data storage	■		■							■
TR11	SMC	Extraction of production information from the PLM system		■								
TR12	SMC	Detection of current assembly state						■				
TR13	SMC	Tool and component visualization					■					
TR14	SMC	Tools and components detection						■				
TR15	SMC	Automatic part scan and quality features check						■				
TR16	SMC	Storage of quality assessment results		■								
TR17	SMC	Safe Human-Robot-Collaboration							■			
TR18	SMC	Reduction of assembly time.							■			
TR19	SMC	Ensure consistent quality and comparable results						■				
TR20	SMC	Robust material capturing of assembly parts					■					
TR21	SMC	System's sensors provide sufficient data and accuracy					■					
TR22	SMC	Automatic adapt to different sized objects and workflows							■			
TR23	Tekniker	Autonomous navigation							■			
TR24	Tekniker	System localization							■			
TR25	Tekniker	Real-time information communication and processing	■									
TR26	Tekniker	Multipurpose assembly cell combining material transport and assembly operations							■			
TR27	Tekniker	Standard communication mechanisms in the workcell components	■									
TR28	Tekniker	Mobile platform as a CPS							■			
TR29	SFKL	Standardized information protocol	■									
TR30	SFKL	Physical interface of Production modules	■									
TR31	Tekniker	Wireless robust and reliable communication	■									
TR32	Stora	Manage and reduce changeover time		■				■				
TR33	Stora	Increase Task Completion time (speed of process)						■				
TR34	SMC	Gripping and handling of cylinder components and final products									■	
TR35	SMC	Support of repetitive and monotonous assembly steps									■	

8. Generalised Indicators and Requirements for AUTOWARE Use Cases

This section includes a generalization of previously reported application-specific KPIs for use beyond the scope of the particular AUTOWARE use cases. Thus, the aim of the work reported here is to analyse the results obtained and provide a set of strategic KPIs and relevant requirements to assist manufactures to enhance their businesses performance.

8.1 Business KPIs

Regarding business-related KPIs, there is a clear need for increasing effectiveness and productivity by reducing time and manufacturing costs associated with the automatic configuration of production lines, reducing manual assembling processes and human intervention, as far as possible.

Thus, the main BPIs remain the increasing of manufacturing productivity through adaptable factory automation systems that shorten reconfiguration times with zero- error production of services. These objectives would meet new and complex market needs (e.g., customized end-products).

The main manufacturing-specific indicators gathered in this iteration are:

- Number of customers.
- Number of available assembly operations.
- Cost of manufacturing per product.
- Maintenance management indicators and reduction of engineering time:
    - Cycle time of automated assembly.
    - Number of produced pieces.
    - Number of operation stops.

8.2 Technical KPIs

To give general indicators that are valid for every factory automation system,

- Speed of data transfer
- Quality of Experience and user interface usability

8.3 Key business requirements

Business requirements of five use-case scenarios are related to achieve the integration of highly flexible and autonomous workcells that reduce manual processes within manufacturing companies. This involves the following requirements:

- Flexibility of the solution and contextual adaptation through automatic adaptation to changing operational conditions.

- High level management/orchestration and digital twin synchronization.
- To increase system robustness and maintain or improve high quality production based on autonomous quality assessments.
- Implement intuitive user interfaces for process visualization and guidance, via augmented reality, human-robot collaboration, etc.

8.4 Key technical requirements

Previously-described use cases aim at updating manufacturing systems by introducing and combining multiple technical capabilities. From a general point of view, they can be grouped as follows:

- Implementation of interoperable and plug-and-play components.
- Automatic product information retrieval and tracking.
- Real-time data collection.
- Distributed data storage and processing them in fog and cloud computing environments.
    - Data security.
- Reliable and real-time response for those safety modules that are mission-critical.

8.5 KPIs linked to AUTOWARE Use Cases performance

Next table presents an updated vision of the KPIs linked to the different use cases performance in accordance to the M21 status of each Use Case and the measures obtained from first demos.

Use Case	KPI	Target	M21	Rationale
Neutral Experimentation Facility Extension SmartFactory	Unplanned downtime: (Personnel)	-15%	0% (est. -10%)	Reduced stress through worker support with augmented reality
	Learning curve of new employees	-15%.	0% (est. -15%)	Faster training through augmented reality support

	Assembly time:	-15%	-10%	Optimized production process planning and product scheduling via planning optimization
	More effective exploitation of existing process knowledge (MES, PLM)	+15%	+10%	Visualization of documents and process data through dataglasses, recognition of current process step of a product
	Number of experiments	+10%	+25%	Experiments with data glasses, edge processing, network analysis, product memory
	Number of cloudified experiments	+35%	+20%	Use of cloud service platform for visualization purposes
	Number of cognitive collaborative equipment used by industry	+30%	0% (est. +10%)	Testing of devices for AR with industry partners

Neutral Experimentation Facility Extension JSI	Unplanned downtime: (Personnel)	-15%	Not relevant	JSI is a research institute, not a production plant
	Learning curve of new employees	-15%	Being evaluated currently	
	Assembly time:	-15%	-20%	Assembly time of automotive light experiment is significantly shorter
	More effective exploitation of existing process knowledge (MES, PLM)	+15%	Not relevant	JSI is a research institute, not a production plant
	Number of experiments	+10%	+20%	New experiments regarding visual inspection of assembly tasks are planned
	Number of cloudified experiments	+35%	Not yet available	Currently under development
	Number of cognitive collaborative equipment used by industry	+30%	+25%	PbD have been successfully exploited in several

				industrial experiments
Neutral Experimentation Facility Extension TEKNIKER	Efficient transport	-10%	*	Automating material transport
	Coordination among productive systems	+95%.	*	Information exchange for task coordination
	Flexible task planning	+95%	*	Adapting to events may happen in the work environment
	Reduce Cost of manufacturing per product	+10%	*	Automating more processes
	Efficient navigation	+10%	*	Improving the performance of navigation systems
	Accuracy of system localization	+15%	*	Better positioning of platform
	Safety ratio	+10%	*	Obstacle avoidance introduction
Industrial Cognitive Automation STORA ENSO	Switch-over cost with respect to the setup cost of a new product variant	-30%	/	Still in set-up
	Switch-over time with respect to the setup cost of a new product variant	-30%	/	Still in set-up
	Reprogramming cost for mass customization	-50%	/	Still in set-up

	(Re)training time for mass customization	From days to hours	/	Still in set-up
	Realtime latency for co-simulation / situation awareness	<100 ms	/	Still in set-up
	Modularity	+20%	/	Still in set-up
Industrial Cooperative Assembly of Pneumatic Cylinders SMC	Productivity	+17%	/	**
	Manufacturing cost/ assembly personnel working cost	+3,1%	/	**
	Production quality	100%	/	**
	Training of employees	2 Trainings	/	**
	Safety of the human-robot collaboration	No accidents	/	**

* [TEKNIKER] The first experimentations performed only allow to evaluate partial metrics related to some of the KPIs, since not all the scenario has been setup and many of them need the coordination of the different robotic systems . The KPIs related to efficient navigation and accurate localization have been evaluated performing some experimentation explained in D1.4a.

** [SMC] For using the collaborative demonstrator in the real production environment it needs to consider the industrial safety standards. Therefore multiple rules and standards as DIN EN ISO 10218, ISO/TS 15066, DIN EN ISO 13857 or the German "BG/BGIA-recommendation" have to be considered. For the necessary local CE certification a system integrator has to lead through the CE certification process. Costs for an external system integrator will exceed the budget and the planned investment costs.
Because of that, it is planned to review the use case in cooperation with Fraunhofer, which will be located in their research environment, where are less restrictions regarding the safety requirements. The allocation of the costs for hardware and software as well as the SMC usage right of the demonstrator still has to be negotiated.
Related to the missing CE certification process there is currently only a theoretical chance for the return of investment. So it is not possible to do first tests and measurements of KPIs. The demonstrator will be setup earliest in M27 or latest in M30.

8.6 Organisational KPIs for AUTOWARE

Regarding the following KPIs focused on organisational aspects and linked to the Use Cases, target and measurement will be adjust for each of the AUTOWARE use cases.

KPI	M21 Values
Number of business processes involved	• SmartFactory: 0 • JSI: 3 • Tekniker* • Stora Enso: 2 • SMC: 0
Number of experiments performed	• SmartFactory: 12 • JSI: 2 • Tekniker* • Stora Enso: 0 • SMC: 0
Number of enablers used	• SmartFactory: 5 • JSI: 2 (PbD & deep learning) • Tekniker* • Stora Enso: 1 • SMC: ?
Number of services implemented	• SmartFactory: 4 • JSI: 1 (under development: deep learning of visual classifiers) • Tekniker* • Stora Enso: 0 • SMC: 0
Number of employees involved	• SmartFactory: 4 • JSI: not relevant, JSI is a research organization • Tekniker* • Stora Enso: 5 • SMC: 5
Number of employees trained	• SmartFactory: 0 • JSI: not relevant, JSI is a research organization • Tekniker*

	• Stora Enso: / • SMC: 0
Average cycle-time improvement	• SmartFactory: 10% • JSI: depends on use case, but up to 20% • Tekniker* • Stora Enso: / • SMC: 0
Integration costs	• SmartFactory: - • JSI: not yet available • Tekniker* • Stora Enso: / • SMC: 0
Process cost reduction	• SmartFactory: - • JSI: not yet available • Tekniker* • Stora Enso: / • SMC: 0
Process quality improvement	• SmartFactory: 0 • JSI: not yet available • Tekniker* • Stora Enso: / • SMC: 0
Process efficiency improvement	• SmartFactory: 0 • JSI: depends on use case, but up to 20% • Tekniker* • Stora Enso: / • SMC: 0

* [TEKNIKER] The first experimentations performed only allow to evaluate partial metrics related to some of the KPIs, since not all the scenario has been setup and many of them need the coordination of the different robotic systems . The KPIs related to efficient navigation and accurate localization have been evaluated performing some experimentation explained in D1.4a.

8.7 Digitalization & certification survey report alignment with AUTOWARE

As mentioned within deliverable D6.1b Innovation, dissemination and Communication Action Plan, a survey on Digitalization and Certification Levels has been designed with the aim of enhancing the SME engagement strategy and activities. After the initial launch with occasion of SQS's QATEST International Conference on Software QA and Testing on Embedded Systems among its network of professionals interested on digital transformation within different sectors from CPPS providers, SW Quality testers to IT and industrial solution integrators, a first analysis has been performed on the data collected.

One of the main goals aimed is to gather and analyse critical information over current digitalisation level, infrastructure and technological status and certification needs on this potential SME market. For this aim a formulary with a set of questions has been designed based on a two steps methodology for the target identification and clustering, and for the collection of specific information and knowledge refinement through more customised surveys and interviews. Next table identifies main sections in the formulary, with the set of questions focused on digitalization and certification:

Sections	Questions
Target identification	Country where the headquarter of your organisation is located
	Your organisation is….
	Activity of your organisation…
	End market is your company…
Digitalization	Which areas is your company carrying out a digitalization strategy in?
	Is your company implementing any of the following selected project types?
Technologies & solutions	What extent are the following technologies implemented in your organisation?
	What extent are the following technological systems/solutions implemented in your organisation?
Impact & challenges	What extent Digital Transformation has an impact on the following indicators?
	Which of the following constraints is your company facing when adopting digital transformation?

	What extent are the following items key success factors for digital transformation?
	Do you think that the following measures should be introduced to foster the adoption of digitalization?
Standards & Certifications	What technological standards are key or do you foresee will be key in the future for your products and/or developments?
	What certifications are relevant in your sector of activity?

In this first initial launch most of the respondents have answered that the headquarters of their organisations are in Spain (55%) or in Portugal (25%). In addition, 45% of organisations have more than 250 employees and turnover more than 50M €. A 30% of the organisations activity are Consulting companies and a 10% dedicate to Research & Development (10%). And the end market of the surveyed companies are oriented to Rail market (17,5%).

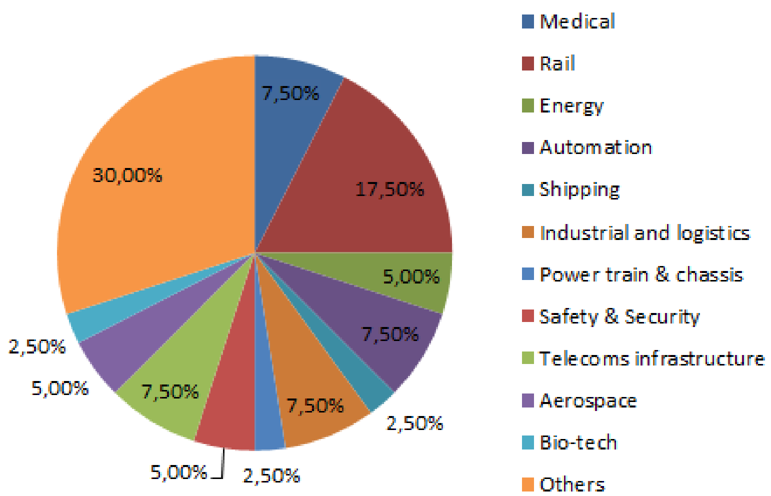


Figure 18: End Market classification

To the question of "in which areas is your company carrying out the digitalization strategy" the most of them answered that management is the main area. Moreover, they are implementing "Product life cycle management" (42,5%) and "Process optimization and automation" (47,5%)) in project types.

Figure 19: Digitalization areas (left) and Project types (right)

Regarding the level of implementation of the different technologies, as can be seen in Figure 20, Fog Computing, AI, BigData and Cloud computing are the main technologies where the focus of next implementations is set. While in Figure 21 we can see the main constraints faced by companies when adopting digital transformation, i.e. cost and RoI, time and qualified personnel.

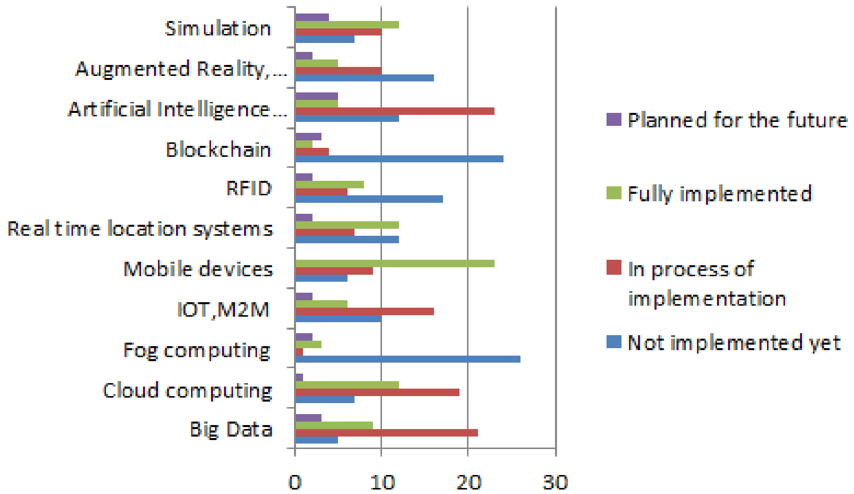


Figure 20: Technologies implementation extents

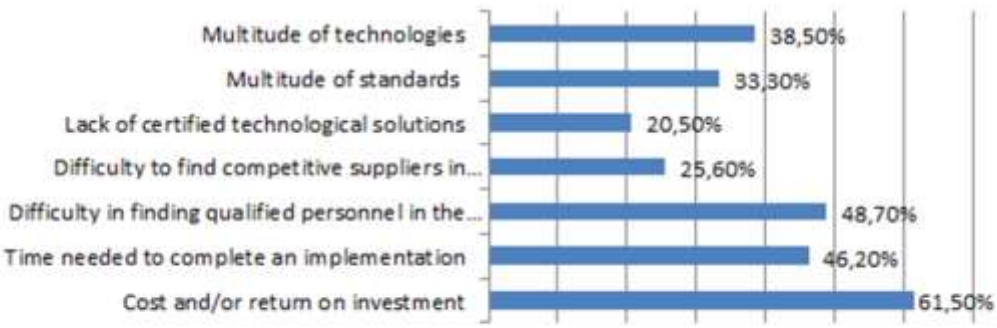


Figure 21: Constraints when facing digital transformation

Finally the companies answering the survey have identified the key factors and needed measures to enhance the digital transformation as can be seen in the next figures.

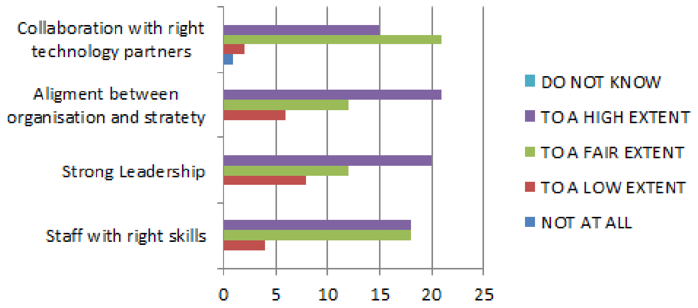


Figure 22: Key factors for success

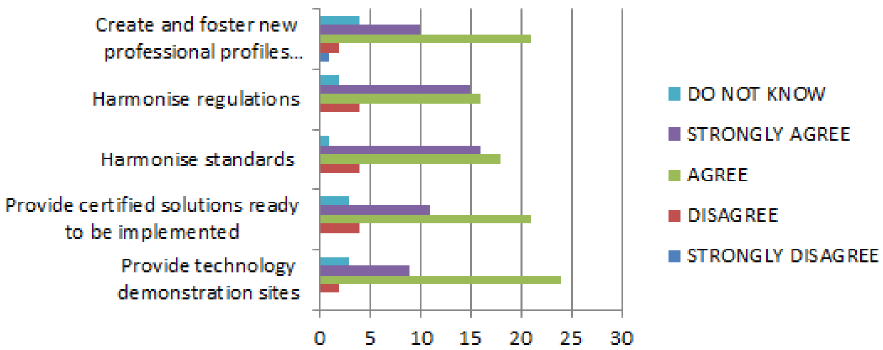


Figure 23: Measures to foster technologies adoption

9. Conclusion

Along with an overview of related work, this report has presented the approach to the KPI selection adopted for the overall assessment of measurable objectives. With respect to the process, as planned, it was supplemented with interviews with the technology providers, in which some of the ambiguities in the questions and responses to the questionnaires were explored in more detail.

Initially, taking into account the number of requirements collected, we agreed to have two different phases: from a more conservative to a more ambitious and challenging scenario. As a result of this second iteration, this last version of deliverable D1.2b includes a review of current indicators and requirements refined and updated, as appropriate, based on the experiences with the first trials deployment phase and the development of technical WPs. Together with this set of requirements and KPIs, a generalised indicators and requirements set is presented, and the alignment of the initial report obtained from the first launched survey on digitalisation and certification levels with AUTOWARE framework vision.

The current status of the collected business and technical requirements and associated KPIs has allowed us to identify synergies that ensures a correct alignment of the use cases with project objectives, with Industry 4.0 goal areas and with AUTOWARE framework's technological layers and enablers, establishing an optimal foundation for new business and manufacturing models in terms of growth, productivity, and profitability.

In conclusion, use cases can benefit from the AUTOWARE project through data-driven Industry 4.0 potentials along the integrated digital thread facilitated by smart services that build the AUTOWARE architecture for next generation manufacturing systems. Conversely, use cases will serve to measure the project success.

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