AUTOWARE

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

D1.4a AUTOWARE Guidelines

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Project partners

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TTTech Computertechnik AG	TTT
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Executive Summary

This public deliverable (D1.4a) presents the initial guidelines and recommendations for the Autoware ecosystem stakeholders to support further use cases building, concluding with the assessment of the Key Performance Indicators (KPIs) obtained through reference implementation and piloting activities by WP5. It has been constructed from the AUTOWARE Task T1.5 "AUTOWARE Lessons Learned" first phase's four months in the project. This task address the analysis of the data collected and the piloting activities through an assessment of the experimentation KPIs and the impact measurement.

In the introductory part of D1.4a, the objectives and scope of work with a clarification of the inter work-package (WP) relations are mentioned. Then, the second part of this document deals with the methodology established for the AUTOWARE requirements and KPIs definition, which has been validated with the use cases implemented by AUTOWARE partners. This methodology supports the definition of the scenarios for the automation digitalization in an iterative way in order to elicit and refine the business and technical requirements and specify the Key Performance Indicators, while aligning them with the AUTOWARE Reference Architecture. The choice of the method was also based on the previous successful applications in other European projects

In the last part of the document, sections 3, 4 and 5, the focus will be on the implementation and measurement of the PIs in each of the neutral and industrial use cases and on their interpretation to obtain some Lessons Learned that help improve the final implementation of the use cases.

Keywords

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

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Acronyms

BPI	Business Performance Indicator
DoA	Description of Action
FoF	Factories of the Future
KPI	Key Performance Indicator
SME	Small and Medium-sized Enterprise
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 present the guidelines and main recommendations for a successful use case scenario definition and identification of requirements and Key Performance Indicators (KPIs) involved in reaching flexible and reconfigurable manufacturing systems relying on AUTOWARE reference model.

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 3.1).
    - Reconfigurable workcells (**JSI**, Section 3.2).
    - Collaborative robotics environments (**Tekniker**, Section 3.3).
- **Industrial production lines**, where paper recycling and machinery sectors are respectively involved:
    - Industrial cognitive automation for the recycling industry (**STORA**, see Section 4), where automation is applied in visual inspection, selection and separation of paper recycling.
    - Manufacturer of pneumatic automation products (**SMC**, Section 5), 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" and AUTOWARE use cases reports in D1.2 "Data-driven digital manufacturing requirements & KPIs", a scenario-driven requirements engineering and KPI identifying methodology is presented to analyse the necessities of proposed use cases.

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.

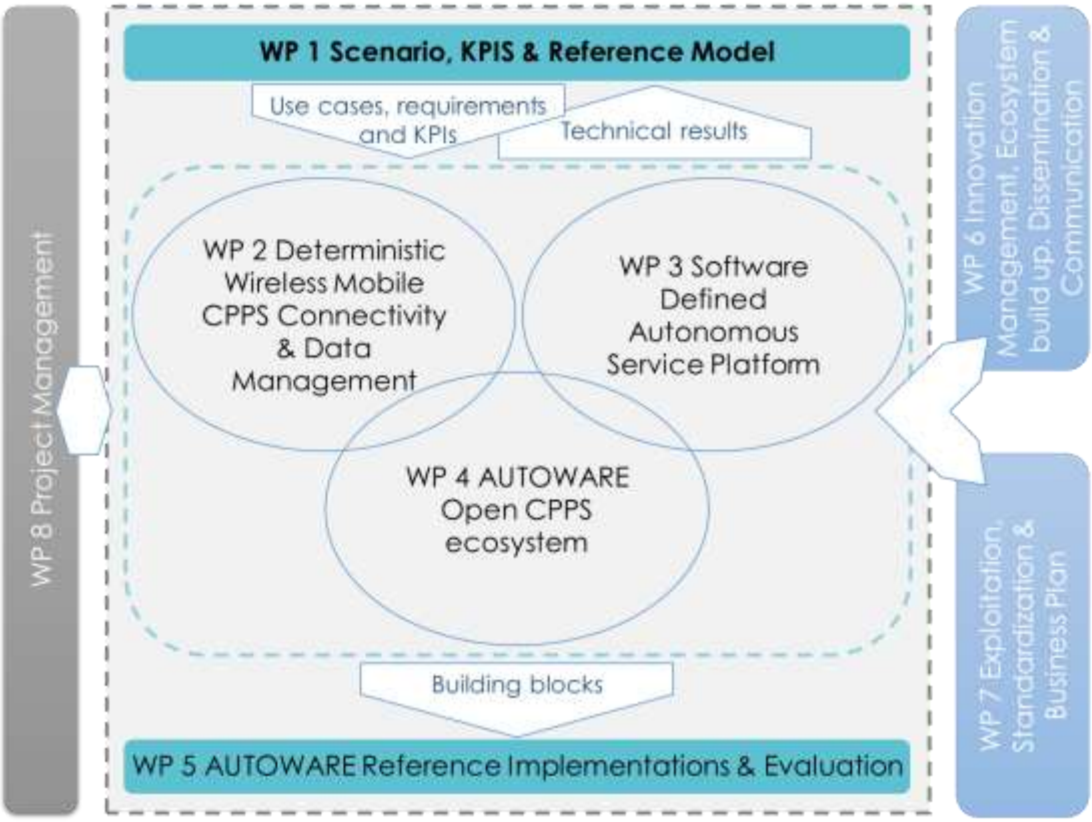


Figure 1. Work plan for AUTOWARE.

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 deliverables D1.2a and D1.2b performed in T1.3. In this point, the present document focuses on the activities of the T1.5 "AUTOWARE Lessons Learned", which according to the Description of the Action (DoA), have the following objective: to derive guidelines and lessons learned from the KPI analysis of reference implementations and pilots for data-intensive business digitalization in AUTOWARE multi-sided ecosystem.

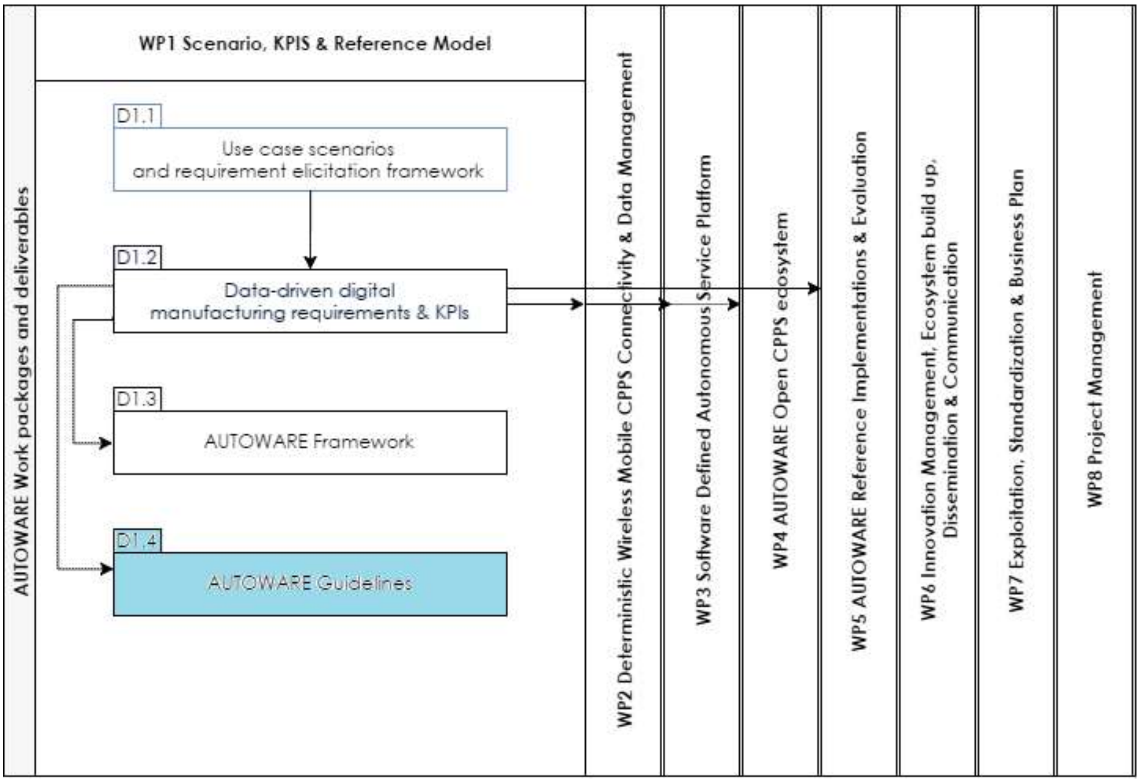


Figure 2. Contributions to other WPs and deliverables.

The remainder of this deliverable is organized as follows:

1. Chapter 2 is concerned with the guidelines and definition of the methodology for determining requirements and performance indicators in AUTOWARE.
2. Chapters 3 to 5 present each use case assessment, based on KPIs measurement, conclusions and lessons learned during the first half of the project.
3. Finally, conclusions are outlined in Chapter 6.

1.3 Target audience

This deliverable is intended to be a guideline, not only for AUTOWARE project partners, but for manufacturing SMEs since it aims at gathering changing needs of manufacturing businesses.

2. Guidelines for Use Case building

2.1 Methodology for requirements collection

This section aims at describing the selected methodology for requirements collection, which relies on different activities involving AUTOWARE use case partners. Requirements illustrate the user's needs and will be used to identify relevant research topics in the AUTOWARE domain.

It is presented in an iterative approach for requirements identification, which is based on the methodology initially developed in the FITMAN project [2], and also successfully used in BEinCPPS. Both projects adapt the methodology of Wellington [4], which follows a 4-step method: 1.) Brainstorming, 2.) Classifying and categorising, 3.) Creation of the guide, and 4.) Interview schedule. This approach is also similar to other methodologies, such as, for example, "Documentation of requirements approached to users" (DoRCU) [1], which is focused on obtaining software requirements and sets an iterative process where the final user is in a key position. The methodologies selected are methodologies of requirements engineering. These are: (i) Documentation of requirements approached to users (DoRCU), which is a methodology oriented to obtain software requirements

In AUTOWARE, the methodological approach includes four main steps, which can be considered basic steps of Requirements Engineering, repeated in two different phases:

- **Elicitation**: The main task of the first step is to examine, update and detail the situation information and limitations obtained in the use case definition (D1.1). Once the business context is understood, an initial data gathering and definition of a first version of the requirements should be generated in this stage.
- **Analysis**: being aware of the current situation (AS-IS) allow the identification of weaknesses and opportunities for improvement (TO-BE situation) of the existing solutions.
- **Specification**: this step processes, translates and documents the identified set of needs into a consistent and unambiguous requirements specification. Therefore, the content will be classified and categorised to achieve a harmonized format and quality.
- **Validation**: selected requirements will be refined further taking into account the project context and objectives. This last stage takes place in the second iteration in order to confirm the obtained requirements, along with the Industrial Partners' expectations.

As shown in Figure 3, these activities end with the definition of a document containing the requirements (D1.2).

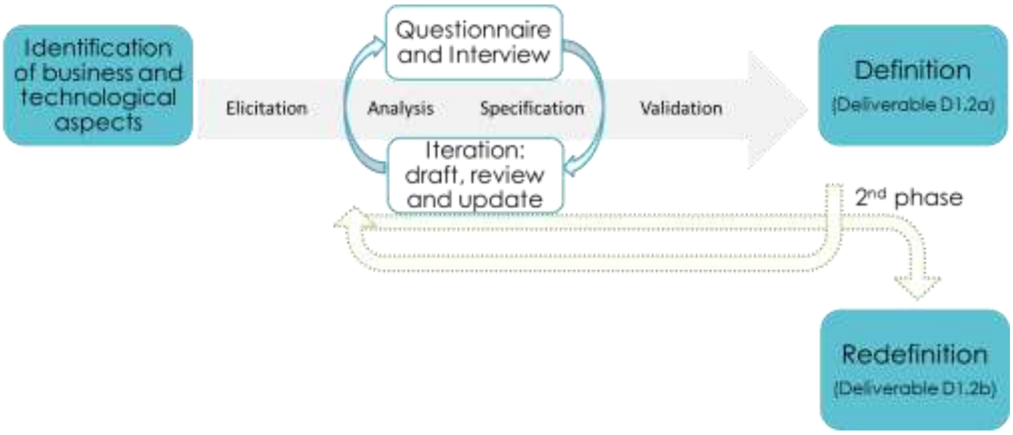


Figure 3. AUTOWARE methodology approach for gathering requirements.

The requirements determination process is going to run in two main phases: one cycle of requirements, development and evaluation for the first half year of the project, and a second iteration for improving initial work. In this way, the D1.2b addresses a review and a refinement of identified requirements (and indicators) based on experience gained in the first half of the project, and taking into account related feedback from the technical work packages.

2.1.1 Description of the proposed methodology

Regarding the methods used to collect the data, several questionnaires and interviews served to survey the use case partners. Hence, in order to structure the data, future use cases shall be able to specify business and technical requirements based on provided questionnaires (included as annex). The elaboration of questionnaires is substantiated with the technological trends and challenges detected by technical partners. In any case, the following information should be obtained:

- Definition of requirement: What intended functionality of the manufacturing system should be implemented?
- Priority: setting priority values facilitates to maintain the coherence of the information:
  - High ("must have")
  - Medium ("could have")
  - Low ("should have")

Moreover, requirements are differentiated according to their level of abstraction [3], as shown in Figure 4 and Figure 5. The former figure includes:

- **Business requirements** relate to business objectives, vision and goals. They are typically defined at a very high level (conceptual) and provide business needs or problems that need to be addressed through a specific activity.

- **Functional requirements** specify a behaviour or function (i.e., something the system should do). For example, external interfaces, authentication, reporting requirements, etc.
- **Non-functional requirements** describe how the system will work or should behave. Some typical non-functional information technology (IT) requirements are:
  - Performance (e.g., response time, throughput, utilization, Ideal Cycle Time / (Operating Time / Total Pieces), etc.)
  - Scalability
  - Capacity
  - Reliability, Recoverability and Availability (i.e., Operating Time / Planned Production Time)
  - Quality (e.g., Good Pieces / Total Pieces)
  - Maintainability
  - Serviceability
  - Security and Data Integrity
  - Regulatory
  - Usability and Manageability
  - Environmental
  - Interoperability
- **Technical requirements** to evaluate the IT infrastructure (hardware and software components, protocols, standards, etc.). In other words, whereas a business requirement states the 'why' for a project, a technical requirement outlines the 'what'.

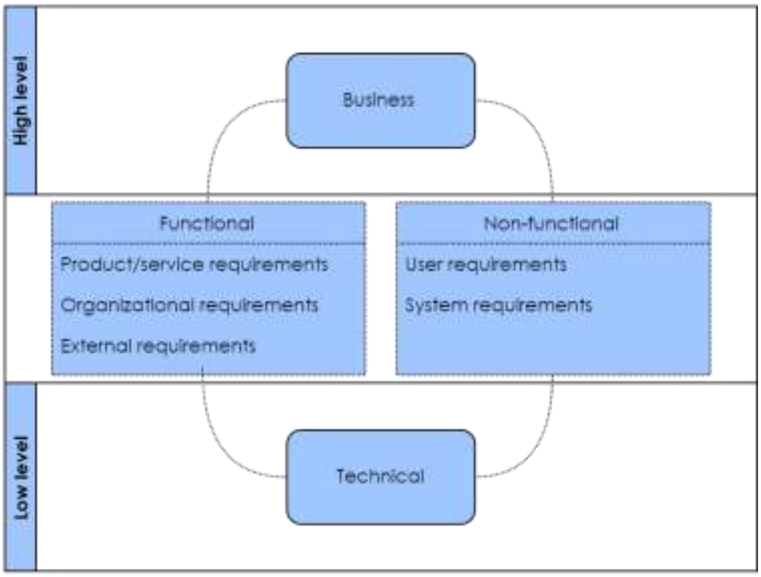


Figure 4. Requirement types.

The aim of the Figure 5 is to suggest that requirements must cover the whole system in a holistic view: from the business requirements to the Architectural design aspects.

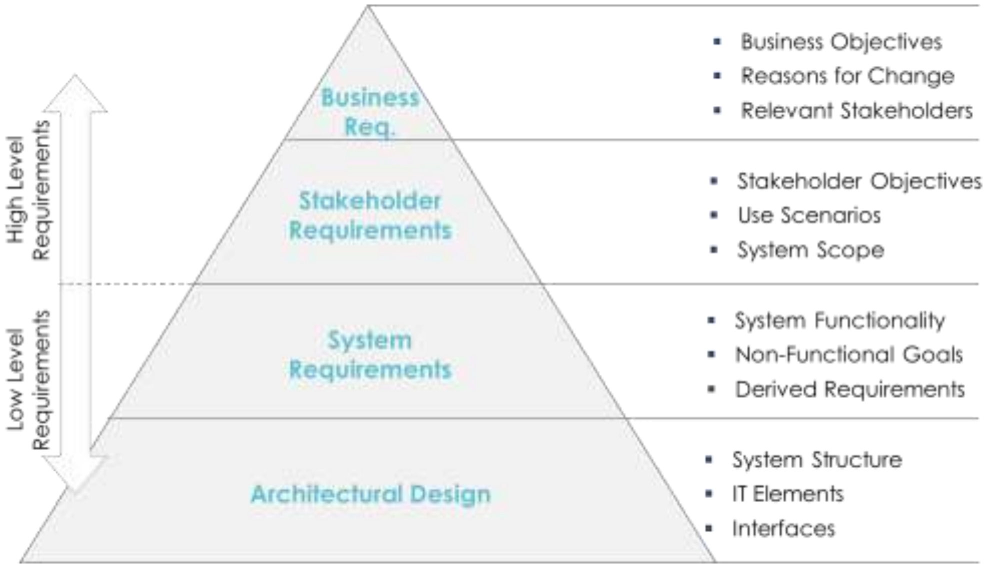


Figure 5. Requirements pyramid.

Taking into account that the implementation of the use cases will be carried out by pilot owner and its technology partners, this information should be gathered from those involved in the processes included in the use cases. Thus, they will contribute to transcribe the collected scenario requirements into technical specifications, as well as to facilitate the understanding of state-of-the-art technologies. In this way, they act as consulting facilitators for assessing and comparing available technologies.

Once studied filled questionnaires, iterative interactions with use case partners and stakeholders will be conducted to assure understanding and clarify possible difficulties encountered during the completion of the questionnaire. This phase will verify and improve the findings by updating, and negotiating previously-included requirements. Apart from the interviews, face-to-face meetings in the actual manufacturing environments will consolidate the collected data into the reporting forms and pull together all potential partners.

Finally, requirements must be clear and concrete in order to properly design and implement the AUTOWARE architecture. Hence, in order to produce a final specification, the requirement definition will be based on the following compact template:

Requirement name	
Type	Business/Technical, Functional/Non-Functional
Priority	"High", "Medium" and "Low"

Purpose and description	Please specify why this requirement is relevant
Constraints or dependencies. If technical: - Data needed - Communication needed - Software components needed	To contextualise these requirements, please describe which actors, conditions and even limitations are expected to be relevant in the requirement.

Figure 6. Structure of requirement

2.2 Method to define Performance Indicators in AUTOWARE

The effectiveness of AUTOWARE innovations need to be assessed by clear KPIs. There are numerous definitions of the KPI concept; for example, according to [5], 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.

2.2.1 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" [6]. According to [7], 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 [8], 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 [9] 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.

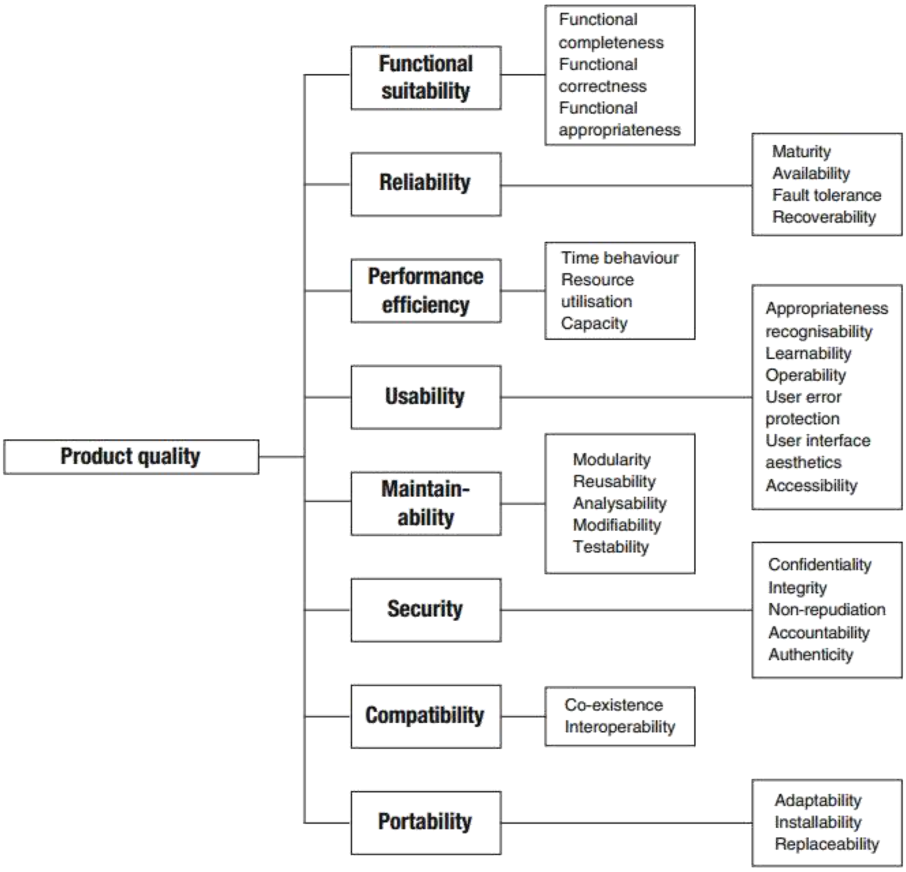


Figure 7. Quality Characteristics of ISO 25010 [10].

As another example, the Service Measurement Index (SMI) [11], 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 [12] 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 [6] 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 [13] 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 [14] 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.

2.2.2 Description of the proposed method

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 [15], "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.

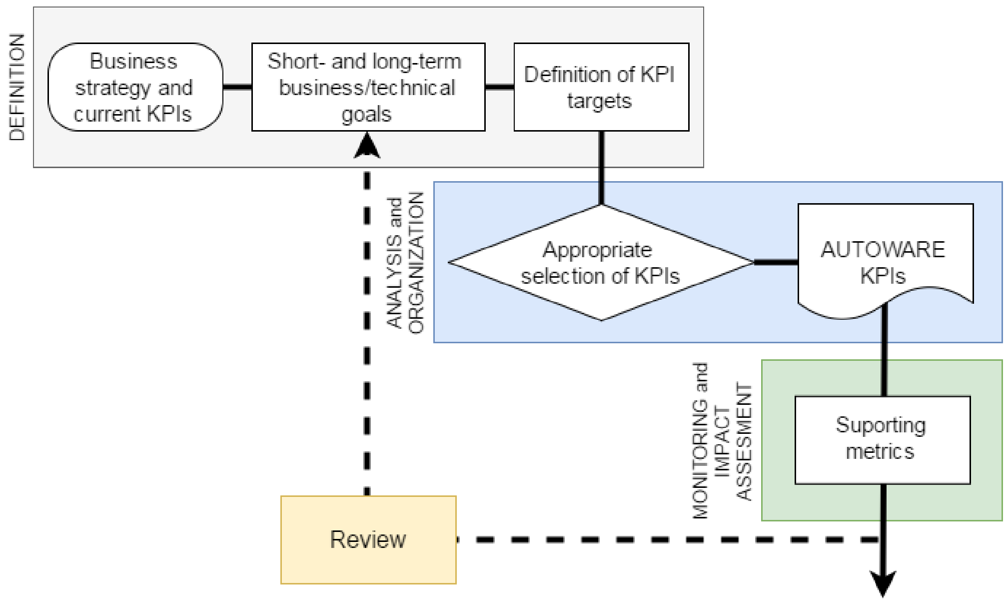


Figure 8. Proposed process for KPI specification.

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.

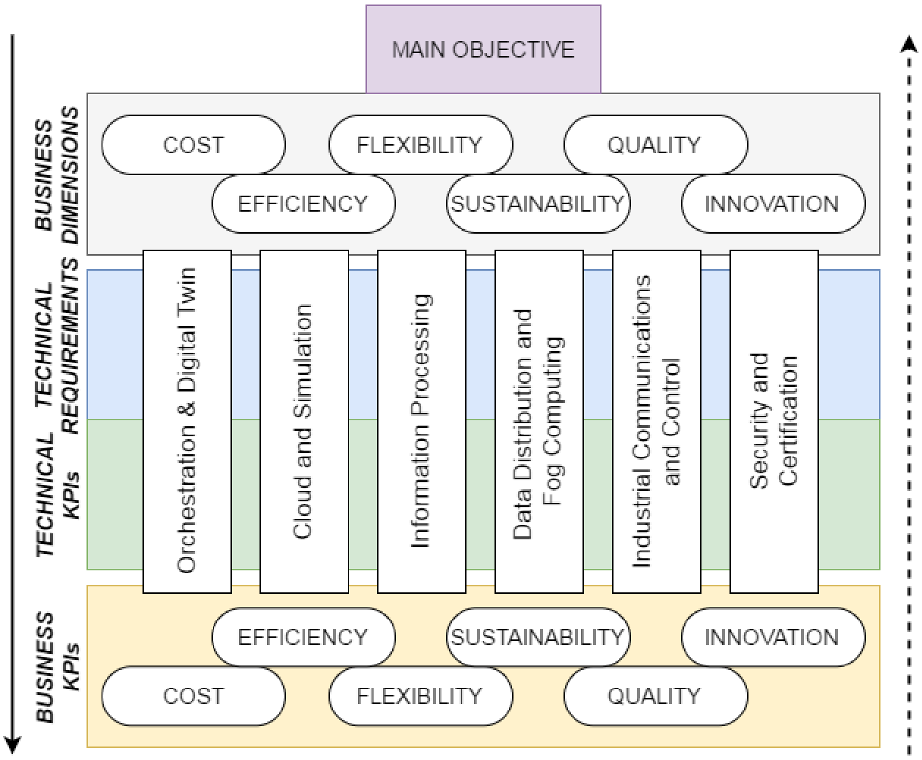


Figure 10. Relationships between goals, requirements and KPIs.

2.3 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 11) 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 [16], 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.

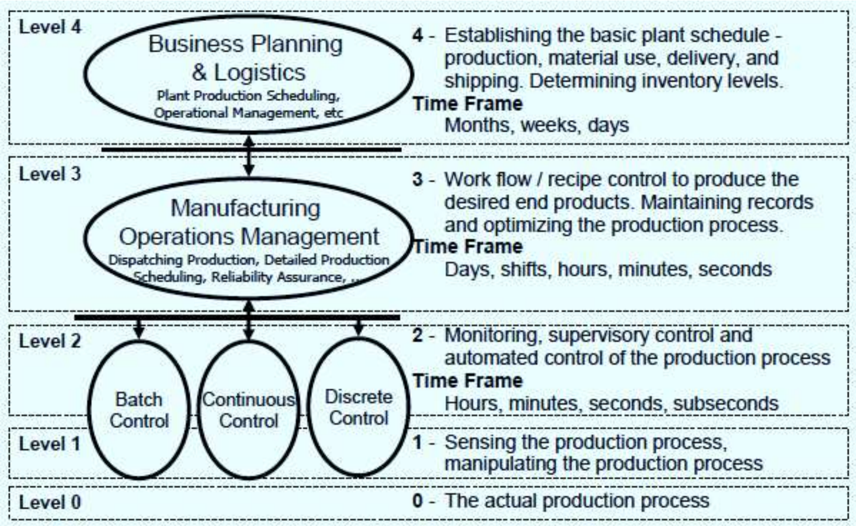


Figure 11. The IEC 62264 control hierarchy [17].

2.3.1 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 [18].
- **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 [19], namely, data management and analytics, real-time command and control, connectivity and security.

Questionnaires are based on the combined expertise of AUTOWARE technological partners. Figure 12 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, making the data more easily understandable and comparable.

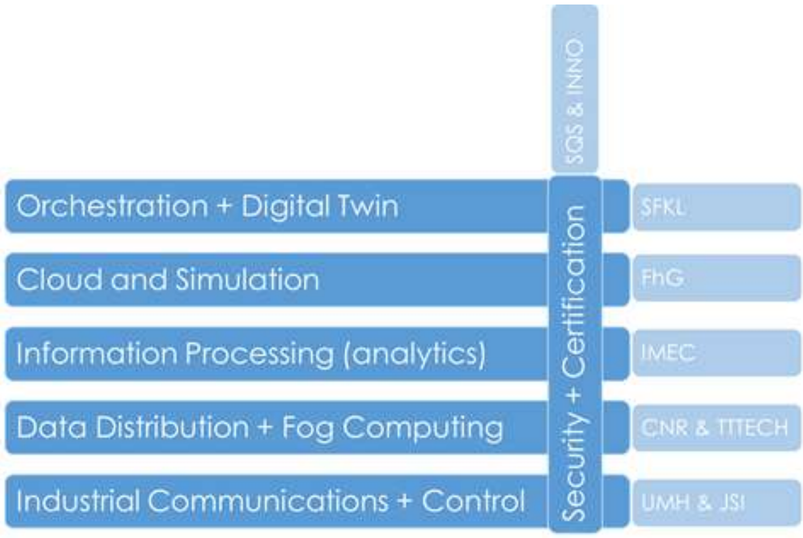


Figure 12. Layered structure for requirements collection.

This classification has been added to the template proposed for specifying the requirements.

2.3.2 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 [2]:

- **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. Use Case 1 assessment – Neutral Experimentation Facility Extension

3.1 Neutral cognitive digital automation process experimentation infrastructure

3.1.1 KPIs measurement

1. Reduction of re-configuration time

The reconfiguration time is the time span required to change the functions and/or sequence of the production line. On the one hand, entire production modules, but also only individual production steps can be changed. This reconfiguration time has several dimensions. On the one hand, the time required to physically change the production line can be measured, e.g. by connecting a new module. However, if other parameters change, the new configuration of the plant must still be able to recognize and communicate with its neighbors via OPC-UA. The new processing step must also be recognized in production planning and existing production plans must be adapted. All in all, these times can be used to measure how long the production plant or the individual components must be taken out of operation, i.e. how long the down-time is in the event of a change.

However, changes do not only occur when changing the system, but also when changing process steps for a specific product. In such a case, the time it takes to inform a product of the change in processing steps and the time it takes to adapt the production program to these new plans must be measured. Accordingly, "dead times" in which the product is not yet updated must be measured.

In sum, these times represent the KPI dimensions flexibility and costs.

2. Fast quality control

An important component of a flexible, modular production system is fast quality control. This quality control must be flexible enough to adapt to different production sequences and production steps. Therefore, optical control with the help of camera systems is used. The image can be evaluated by specially mounted cameras to identify the current production status and possible defects.

The evaluation of the image material plays a special role here. The evaluation of the camera images must be flexible enough to cope with different environments. Therefore, AI algorithms are used for evaluation. For this image evaluation, the speed of analysis and the accuracy of the result play a decisive role. The speed includes the process of feeding in the raw image from the camera, identifying relevant image contents up to the calculated result and is measured in [ms]. The accuracy describes the correctly identified objects and production conditions including the correctly identified quality characteristics in relation to the actually existing production conditions and quality characteristics.

A fast quality control maps the KPI dimension quality.

3. *Security of product data*

Cyber security is an ever-increasing challenge for manufacturing companies and must be considered especially in the case of highly modular and networked systems. The introduction of active product memories and networked, interconnected production modules makes the introduction of security components essential to protect against attacks.

But it is not only the communication and the components within a system that need to be protected. The global connection of production facilities must also ensure communication between different production sites.

To ensure the security of product data, especially when using an active product memory, the traffic volume in the network must be monitored. If a pattern to be assigned to an attack is to be detected during the monitoring of traffic between the network participants, countermeasures can be initiated in good time. The traffic volume is measured in packets sent and received per second.

It must also be ensured that the response time of the network participants is within a fixed profile. A deviation in the response time may indicate an unregistered or incorrect participant.

4. *Track and trace of product*

Tracking a product plays an important role in flexible production plants. Because product information is stored on the product itself in the form of a product memory, a secure connection must be established to access this information at all times. The link between the product data in the database and the product must be in real time.

To ensure a high availability of the system, the energy consumption on the active product memory must be measured. This is used to determine the possible total runtime. The system can only be actively used in production if sufficient runtime can be guaranteed.

Stable and fast connectivity must also be guaranteed. This can be measured on the one hand by the speed, i.e. the number of transmitted packets within a second, but also by the response time of the system.

5. Wearable guide system

To counter the increasing complexity of products in the production process, new technologies can be used to support the workers. Wearables such as data glasses represent such a support system. These can be used to provide the worker with additional information and multimedia content.

Important for measuring the KPI is the production time of a worker for a product. This includes the determination of the production step in which the product is located and the subsequent execution of the next production step. This must be measured with and without the support system.

The computing power and duration of the system must also be measured. The recognition of the current production step is measured via camera information. The computing time from input to identification and the result must be measured.

The transfer rate between the calculating edge server and the data glasses must also be recorded. This can be measured by the number of sent and received data packets per second.

6. Distributed data storage

To ensure a fast reconfiguration of the production system, the files must be available in distributed form.

The distributed data is mainly used to optimize the production process and the machine sequence for orders. Distributed storage of the data can also be used to obtain the relevant data for the respective storage location (e.g. a production module) directly from it.

Data that must be collected for this KPI represents the capacity and computing power of the distributed storage systems, their response times and the overall time of the reconfiguration before and after use of the distributed data storage.

3.1.2 Lessons learned

ADOMe

During the test runs with the active product memory, it must dial into the W-Lan network belonging to a production module at any time during the production process. However, this change from one WLAN network to the next is problematic. This means that there is no connection for a few seconds when changing. During this time it is not possible to communicate with the ADOMe.

Object detection and Quality Control

The precise and fast recognition of the product and the manufacturing condition plays an important role in this use case. An AI algorithm is used for detection. Since this network is intended to enable particularly fast evaluations, it is intended for use in the edge layer. Therefore, the architecture must be adapted in such a way that it also works on weak hardware with acceptable runtimes. Such an adjustment must be carried out after the training, e.g. by pruning. Quality characteristics for the collection of training data must also be defined in order to minimize the time needed to find a suitable network.

Wearable guide system

During the implementation of the communication between the data glasses and the edge devices, it was found that the time delay between streaming and evaluation takes too long. Streamed images from the data glasses are only evaluated after a few seconds. This makes it difficult to restore the results, as the results may refer to visual material that is no longer in the user's field of vision. Therefore new possibilities must be found, like the adaptation of the hardware by a dedicated camera for streaming.

However, new benefits have also emerged. The streamed image can also be used for other use cases and other UI interfaces by decoupling it from the data glasses. It can thus be used to enable remote maintenance.

3.2 Neutral reconfigurable workcell experimentation infrastructure

3.2.1 KPIs measurement

In this phase of the project, the main improvements relate to the introduction of advanced programming by demonstration technologies – in our workcell synonymous with kinesthetic teaching – and 3-D printing for the production of customized fingers. The first KPI (cycle time) was evaluated on the use case related to the assembly of automotive lights. The newly proposed learning by demonstration approach supplemented by incremental learning enabled us to nonuniformly change the speed of execution, resulting in faster performance of assembly tasks (up to 20% speed ups). Further improvements were provided by the newly designed system for finger exchange, which enabled us to exchange 3-D printed fingers instead of whole grippers. This way we can reduce the overall cost of assembly process and the reliability of grasping operations, ultimately resulting in faster performance of assembly tasks. We have not yet formally evaluated the reduction of costs achieved by the new finger exchange system and 3-D finger printing.

Currently we are working on the integration of new visual quality control procedures based on deep learning technologies. As deep learning is a computationally expensive process, it will be performed remotely using edge/cloud computing. This way we expect to improve the reliability of the quality control process.

3.2.2 Lessons learned

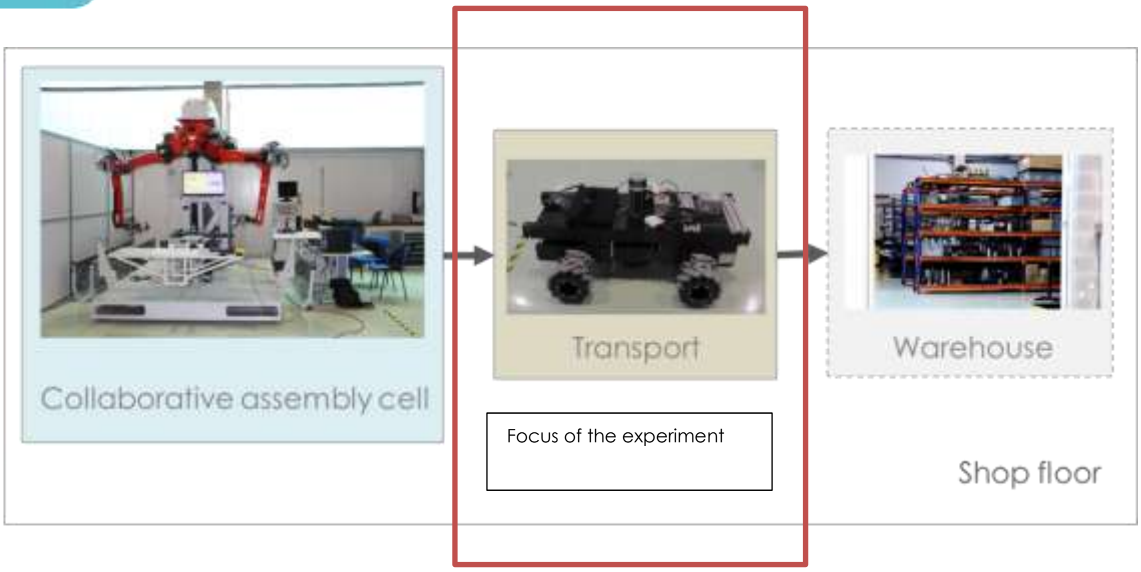
Our current experiments showed that programming by demonstration is a useful technique for the implementation of industrial assembly tasks. We were able to solve complex industrial assembly problems using PbD without using expensive simulation systems. However, it has proven to be difficult to demonstrate assembly tasks at optimal speeds. Our work has shown that additional machine learning technologies are needed to achieve faster cycle times.

In the past, a lot of robotics research focused on the development of dextrous grippers. However, is has proven difficult to use them in industrial applications. The main reason is that it has not yet been possible to achieve high reliability typically required by industrial application. Maintenance is also a serious problem. The developed finger exchange system + 3-D printing have proven to be a viable solution for our industrial use cases. For example, we would not be able to implement the assembly of automotive light housings with dextrous hands or a simple two-finger gripper with fixed fingers.

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

The first experimentations performed only allows to evaluate 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 metrics evaluated are related to the following KPIs:

KPI	Description
BPI08	Efficient transport
TPI18	Efficient navigation
TPI19	Accuracy of system localization



The objective is to design efficient and safe autonomous navigation strategies. To this end, the first step is to stablish the best performance algorithms that allow building a map of the environment where the robot has to move. A comparison of SLAM (Simultaneous Localization and Mapping) systems for Industry 4.0 mobile manipulation applications has been performed.

The objective of this first experimentation is:

- To compare the maps obtained with different algorithms
- To evaluate the quality of the planning
- To measure and compare the pose estimation among the different algorithms
- To improve the accuracy of the positioning in the destination point

The approach is to select three state of the art SLAM algorithms, specifically: Gmapping[1], Hector_mapping[2] and Cartographer (Google)[3].

3.3.1 KPIs measurement

The experiment has been performed ant Tekniker facilities using a mobile platform and a laser tracker to set the Ground Truth of the defined metrics.

[1] Giorgio Grisetti, Cyrill Stachniss, Wolfram Burgard) https://openslam-org.github.io/gmapping.html
[2] Technische Universität Darmstadt http://www.sim.informatik.tu-darmstadt.de/publ/download/2011_SSRR_KohlbrecherMeyerStrykKlingauf_Flexible_SLAM_System.pdf
[3] https://static.googleusercontent.com/media/research.google.com/es//pubs/archive/45466.pdf

Figure 13: Experiment setup

As a result of the experimentation some quantitative comparisons have been performed in order to evaluate the quality of the localization estimation using the navigation algorithms. Figure 14 shows the different trajectories performed and the estimation obtained. It can be noticed that the Hector algorithm obtains less performance than the others, although all of them are quite similar.

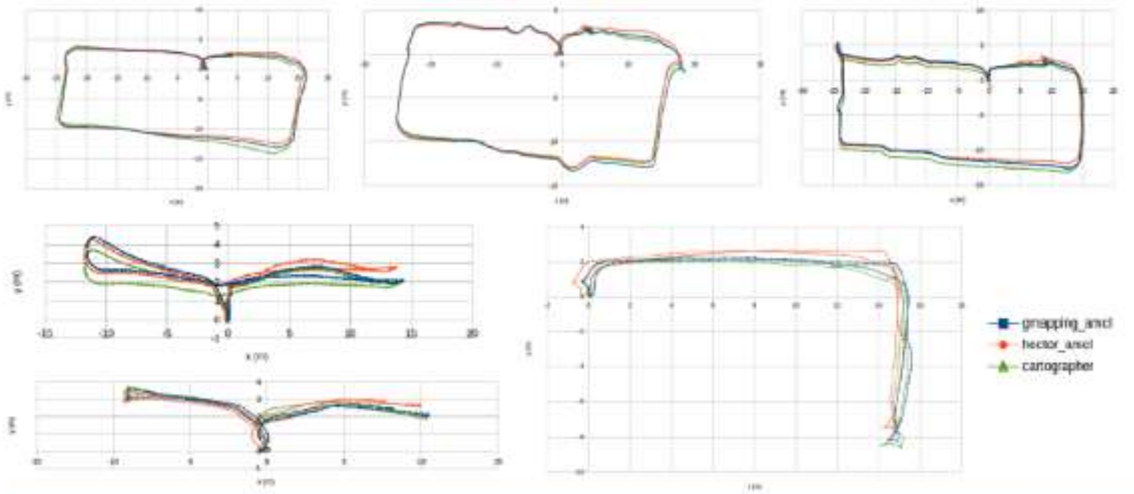


Figure 14: Comparison of different trajectories with the selected SLAM algorithms

Considering accuracy in positioning, in translation and in rotation, the results also show that the best performing algorithm is Gmapping although Cartographer is quite similar as it can be seen in Figure 15.

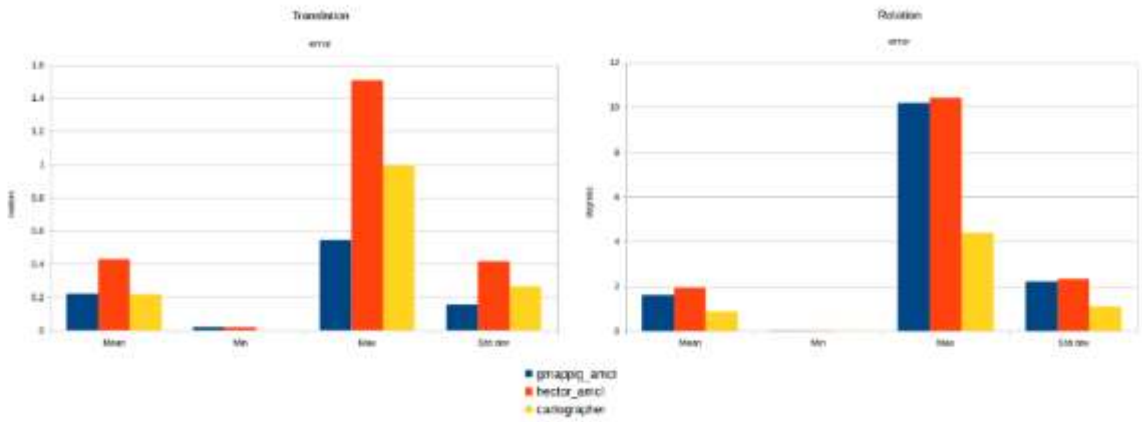


Figure 15: Overall results in positioning

3.3.2 Lessons learned

From the experimentation performed little differences in the mapping and hence in the pose estimation, can be concluded with the different strategies.

Sudden movements reduce the navigation system performance, so this aspect should be considered during the definition of the material transport routes for instance. The approach based on probabilistic estimations also help in dealing with information errors.

4. Use Case 2 assessment – Industrial Cognitive Automation Validation

4.1 KPIs measurement

The two relevant KPI's are the:

- 'Time needed to adapt a batch of different quality to be sorted'
- 'Paper/cardboard separation efficiency'

These KPI's need to be measured both on the on-site facility as on the off-site development replica. According to the current planning as proposed at the Bilbao-meeting in July, the off-side replica would allow for a first measurement at the earliest at the start of October when the replica set-up would be complete but net yet optimized. Also according to the planning, in October feedback at the Stora Enso facility is scheduled, where the on-site KPI measurements can take place.

4.2 Lessons learned

At this moment, the schedule of the off-site replica is still on track. Lessons learned so far include the heterogeneity of the paper/cardboard waste stream as observed at Stora

Enso. This requires careful sampling to assure that the offline-development data gathered is representative across batches.

5. Use Case 3 assessment – Industrial Cooperative Assembly of Pneumatic Cylinders

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.

5.1 KPIs measurement

N/A

5.2 Lessons learned

During the phase of development, the safety aspects of the human-machine interaction have to be considered. 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. 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.

Current planning is to review the use case in cooperation with Fraunhofer. 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.

6. Conclusion and next steps

This document has presented the first outcome of the task T1.5 AUTOWARE Lessons Learned in its first cycle with the assessment of the Key Performance Indicators (KPIs) obtained through reference implementation and piloting activities by WP5. With the objective of supporting Autoware ecosystem stakeholders' further use cases building, an initial guideline has been also proposed with the methodology to define automation digitalization use cases while specifying the technical and business requirements and KPIs, which ease the alignment of these future use cases with AUTOWARE Framework and Reference Architecture.

Future flexible and cognitive manufacturing scenarios will be focused on connecting resources and exploiting the data available to improve the existing value chain. In practice, the choice and development of cognitive capabilities are determined by the actual needs of industrial environments. Furthermore, in this document the corresponding use case definition questionnaire and proposed requirement and KPI specification templates have been detailed.

Finally, KPI assessment has been presented by each use case together with a reflection on the lessons learned obtained through the initial implementation of the use cases scenarios. Despite this analysis indicated positive trends, some of the KPIs were not measured or were measured in a qualitative way due to the status of some of the use cases, i.e. Stora delayed entry into the project. However, plans have been defined to improve future results in this task and ensure a total assessment in the next version of the deliverable.

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Annex: Use Case definition Questionnaire Template

Use case definition - Questionnaire

Document Owner	INNO		
Date	24/11/2016	Version	0.1

Identification	
Contact information	

Version History

Nr.	Date	Author (Organization)	Description
1	24/11/2016	E. Molina (INNO)	First version of the questionnaire

Table of Contents

Proof of Concept of AUTOWARE enabled capabilities (Industrial Pilot)

This document is concerned with the definition of use case scenarios for testing, demonstration, and evaluation of the AUTOWARE solutions. It consists of high level descriptions of the use cases, with descriptions of the main processes that the use cases involve, and detailed scenarios describing both the current "as-is" situations as well as possible "to-be"-situations where it is shown how cognitive autonomous production techniques can be used to improve the processes.

Business impact

Business Process Dimension

Give a description of the business objectives, benefits and main beneficiaries. *Describe basic process and TRL of technology involved?*

AUTOWARE Platform Dimension

Describe the related business modifications introduced by the implementation of the platform. *Relevance and use of deterministic communications, control cloudification & app- ization, data distribution, reconfigurable robot workcells, autonomous robotics, etc.?*

Business Objectives

Define a set of business objectives that the company expects to achieve with their industrial pilot.

AS-IS Scenario

Please give a concise summary of the AS-IS scenario you wish to improve with AUTOWARE by describing the company's current way to perform the activities the Industrial Pilot is focused into.

AS-IS PROCESS

Please describe the underlying process(es) for your AS-IS scenario in simple steps:

1)
2)
3)
4)

STAKEHOLDERS INVOLVED

Please try to identify all the stakeholders involved in the above scenario and process(es):

-
-
-

IDENTIFIED PROBLEMS

What are the pain points you wish to address and improve?(design-manufacturing, product-service, knowledge-sentiment, real-digital, business-innovation):

- *Problem A*
- *Problem B*

TECHNICAL ELEMENTS

1) *Legacy systems related questions*

Which legacy systems are used in your company for the manufacturing process and their lifecycle management?

- *Product Name*
- *Description*
- *Availability for the project* (full access/copy/APIs/no access/…)

- *Product Name*
- *Description*
- *Availability for the project* (full access/copy/APIs/no access/…)

2) *Legacy systems data formats*

For each of the listed legacy systems, do you have information about the data formats for importing/exporting data the legacy system supports (e.g., CSV), or does it support a Program Interface?

3) *Legacy systems interfaces*

TO-BE Scenario

Please give a concise summary of the TO-BE scenario, derived from the AS-IS situation by giving a description of the future of the company with the incorporation of the AUTOWARE technology.

TO-BE PROCESS

Please describe the underlying process(es) for your TO-BE scenario in simple steps:

Benefits

Describe the benefits that the implementation of the AUTOWARE technology proposed is expected to provide at a general level. This description should detail expected benefits in competiveness, reduction of costs, effectiveness of processes, enhancement of product quality, benefit in production, improvement in company image, all.

Expected Results

What are the specific results that the company expects as a result of the experimentation (indicators of business level improvements)?

Weaknesses & Bottlenecks

Regarding the implementation of the technology, describe the weakness and bottlenecks that can appear and the contingency plans that have been defined.

Potential KPI Impacts

Define tangible business and technical indicators that can help to measure the achievement of the business objectives. (E.g.: reduction of time in manufacturing,

quality enhancement, reduction of accidents/business interruptions, increase in benefits, reduction of costs, etc.).	
KPI	***IMPACT AREA*** *(technical, process, business, sector…)*

Technical feasibility

General Description

Give a general description of the experimentation that is going to be implemented. Technology to be implemented, location of the installation of the technology in the company, number of devices, characteristics, all.

Storyline

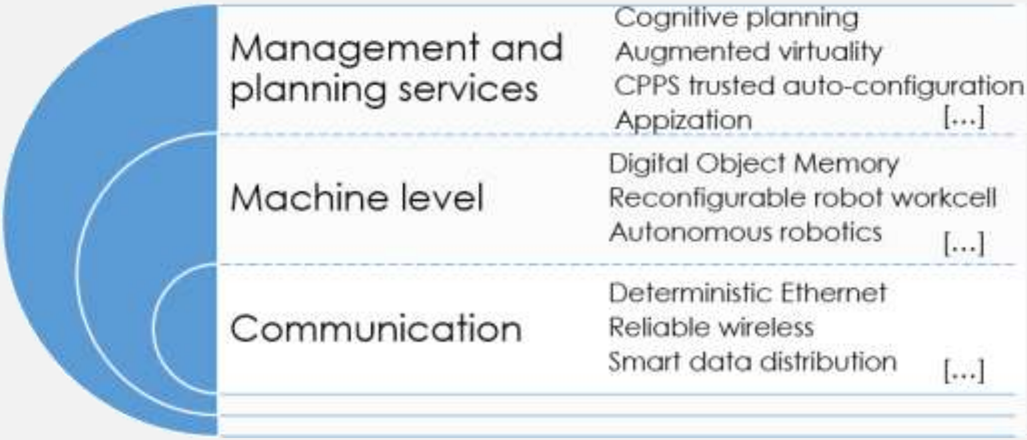
Give a description of the way the AUTOWARE platform will be used after the installation. Name the benefits and procedures involved. Enrich the understanding with a storyline.

Industrial Pilot Sequence

Describe the different step required for the implementation of the Industrial Pilot. Include a schedule, a description of the activities, expose their importance and how they will merge into the consecution of the objectives.
Infrastructures to be used (Machines & telecommunication networks/connections?)
Applications & tools to be used
Digital services to be used

AUTOWARE Platform / Technology Layers

For each framework level, identify and describe the AUTOWARE components and involved, including short description of the As-Is process.



Management and planning services

- *3 top functionalities*
    -
    -
    -
- *Actors (main responsibility, 3 top tasks, tools, applications, etc.)*
    -
    -
    -
- *Current As-Is process description*
    -

Machine level

- *3 top functionalities*
    -
    -
    -
- *Actors (main responsibility, 3 top tasks, tools, applications, etc.)*
    -
    -
    -
- *Current As-Is process description*
    -

Communication level

- *3 top functionalities*
    -
    -
    -
- *Actors (main responsibility, 3 top tasks, tools, applications, etc.)*
    -
    -
    -
- *Current As-Is process description*
    -

Industrial Pilot Diagram

Half page diagram showing process data flow/architecture overview/…