Project number: 826276

CPS4EU

Cyber Physical Systems for Europe

D8.9 – USE CASE REQUIREMENTS v3

Reviewer: B.Bauer (UnA), F.Greff (Thales)

Dissemination level: Public

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V0.2 20.10.15	15/10/2020	E.Londero - ETH	Update of all sections
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1 INTRODUCTION

1.1 *Purpose*

Deliverable D8.9 provides an update about the state of the art of cyber physical systems and related technologies that are adopted in the industrial automation field and in WP8 Industry Automation Use Cases.

The analysis of the use cases carried out during the first year of the project and the related requirements have been reviewed in light of the preliminary physical and functional architecture described in deliverable D8.3. For the methodology used to define the requirements, please refer to Section 3 in deliverable D8.1.

The links between this document and other work packages and tasks are listed in Table 14, Appendix A. A glossary, with the description of acronyms and abbreviations, is available in Table 15, Appendix B.

For each Industry Automation use case in WP8, the document provides (see §3):

- the consolidated description of the use case, focusing on the main goals, on the environment where it will be deployed and on the related processes;
- the consolidated list of functional and non-functional requirements, together with their means of validation and the links to their functional components.

The field "means of validation" provides an indication about how the requirement will be validated and can be filled with one of the following options: by deliverable, by design and by demonstrator.

In the case the validation will be performed with a demonstrator, we considered three options addressing different levels of maturity:

I. technology demonstrator: demonstrator of a specific technology adopted in a use case;
II. preliminary demonstrator: demonstrator of a part of a use case or preliminary demonstrator of an entire use case;
III. demonstrator: complete demonstrator of a use case.

1.2 *Scope*

The following WP8 Industry Automation Use Cases will be addressed:

- UC4 - Automatic Vacuum System (LEONARDO)
- UC5 - Trimming Quality Improvement (LEONARDO)
- UC6 - Thermoplastic Production Line Monitoring (LEONARDO)
- UC7 - Aircrafts Health Management System (LEONARDO)
- UC8 - Material Flow Analytics and Simulation (TRUMPF)
- UC9 - Mobile CPSs (WIKA).

2 CPS For Industrial automation: STATE OF THE ART UPDATE

This chapter provides an update about the state-of-the-art of Cyber-Physical Systems applied to Industrial Automation. It describes the outcomes of a Systematic Literature Review performed by collecting research works addressing Cyber-Physical Systems, and Industrial Automation indexed on Scopus.

The description points out areas of interest, emerging technologies, and methodologies, opening with the introduction to the fourth industrial revolution. The main objective of this chapter is the positioning of CPS4EU research activities concerning the state of the art of CPS in Industrial Automation. Starting from the systematic Literature Review (SLR) in this area, and the description of project Use Cases (UCs), one of the main results of this study is the mapping of solutions at state of the art with respect to UCs of WP8 (Figure 1). The amount of available research works reveals the research community's interest in these areas. It also emerges the criticality of some aspects that need additional investigations in line with project objectives.

The final goal of this type of research project activity is to extract a mapping that could be useful for driving future decisions to deal with Industrial Automation UCs' requirements. Project teams basing on existing researches, and coherently with other project activities and their skills, will consider the best solutions for each of the UCs' requirements.

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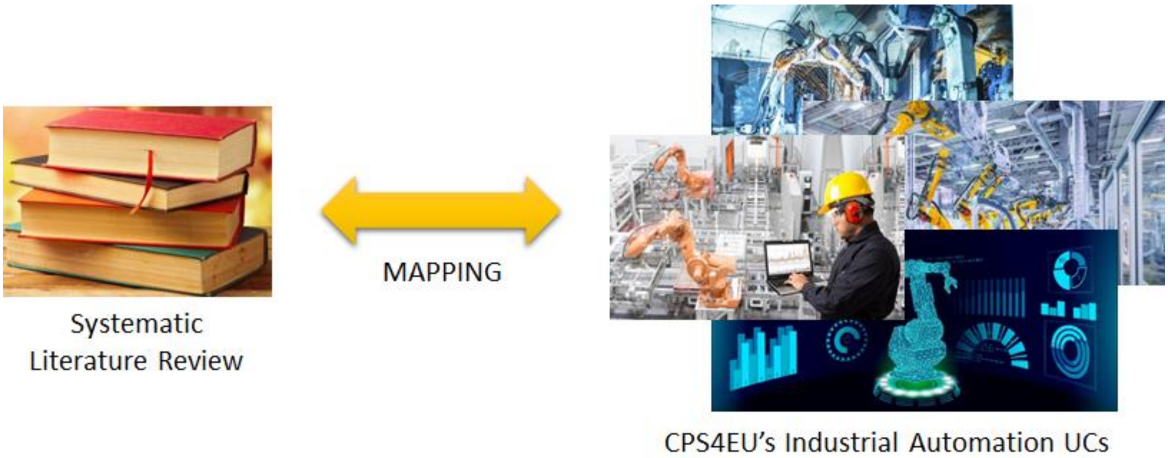

Figure 1 - SoTA objective: Mapping between SLR emerging solutions and CPS4EU's UCs requirements.

The analysis is organized as follows: section 2.1 introduces the phenomenon known as the "fourth industrial revolution" enabled by innovative technologies for the digitalization of the manufacturing sector (see section 2.2), while section 2.3 focuses on CPS specific for the Industrial Automation field. Finally, the literature review, in Section 2.4, illustrates the results of the state-of-the-art analysis and Section 2.5 provides some insights by mapping possible solutions and/or methodologies to WP8 Use Cases.

The last version of this document has been updated with further studies of the literature corresponding to the emerging challenges revealed by analyzing more in-depth the use cases in WP8. Accordingly, Section 2.4 and Section 2.5 have been updated for including the revealed findings about Indoor Localization and Time Synchronization.

2.1 *Industrial Automation*

In the last decade, manufacturing systems has gone through a significant metamorphosis in its paradigms. This transformation was mainly due to changes in market conditions and technology availability. The term "Industry 4.0" (also known as the "fourth industrial revolution") was coined in German in 2011 [1] and refers to the industrialization process leveraging innovative technologies for the digitalization of the manufacturing sector. The Internet of Things (IoT), seen as a system that interrelates computing devices, mechanical and digital machines, objects, or people, plays a crucial role in that sense. The evolutionary process that led to today's industrial structure represented by Industry 4.0 paradigm has stratified over the centuries and was created through the previous industrial revolutions. New technology developments, a lot of intelligent, interconnected assets and products, traceability of processes, led to a collective, shared, and collaborative information management at the supply chain level, and to a new service logic thanks to cloud technology.
The Industry 4.0 paradigm is realized through nine leading technologies:

1) Big Data and Analytics. Data derived from different sources (i.e., machinery, production systems, customer services, and so on) must be collected and analyzed in real-time for decision-support systems.
2) Advanced Manufacturing Solutions. They deal with the adoption of robots able to cope with complex tasks and that can also collaborate with workers.
3) Simulation. 3D simulations of products, materials, and production processes support the product design phase at the moment. However, in the future, they could also enable the test and optimization phases in the virtual world, reducing needed times and increasing product quality.
4) Horizontal and Vertical System Integration. It is a new organizational model vision that goes beyond the pyramidal one. It follows a totally integrated system at each production phase and each factory.
5) The Industrial Internet of Things (IIoT). All equipment into the factory have integrated computational skills and are inter-connected. In this way, all devices can communicate with each other and with centralized controllers, speeding up analysis and decision-making.
6) Cybersecurity. With the augmented connectivity, a cybersecurity need has increased in turn. Reliable communications and advanced machine access management are fundamental.
7) Cloud. Cloud technology allows the management of large amounts of data on open systems. It enables error reduction, resources savings, cost reduction, and velocity.

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8) Additive Manufacturing. It principally regards the adoption of 3D printing for example in prototyping or additive production. That represents a return on the investment in terms of cost reduction and production flexibility.
9) Augmented Reality. Innovative systems can adopt virtual and augmented reality to enhance communication and interaction with workers. For example, they are used to give instructions during a process or a more comprehensive vision during the production process.

Relatively to the present project, the objective of this Chapter is describing the state of the art of Cyber-Physical Systems (CPS) applied to the Industrial Automation paradigm. In this sense, the following sections introduce the CPS, and then the state of the art for CPS for Industrial Automation will be discussed through a literature review process.

2.2 *CPS for Industrial Automation*

Industrial automation aims at increasing factory throughput, product quality, and cost efficiency. In the last decades, industrial automation has mostly focused on automated, individual machines. Assembly lines are used to chain various processing steps and allow for fully automated production of goods, to increase the efficiency of the production process and the overall competitiveness of the industry.

The state of the art of the European industry is different. Real-time information access for procedures, although vital, is not available at the shop floor level. In case of a change in processes or actions, workers or machines must wait until instructions are manually transferred or data is loaded in the production system. The factories of the future demand a close integration between ERP and shop-floor and require real-time access of data at production level for real-time execution. Data collected from machines and business processes needs to be filtered, analyzed, and then delivered in the required format to provide insights, which in return will help to give better process control, optimize, and reduce overhead costs.

Nevertheless, practical realizations of multi-scalable dynamic signal processing based on CPS are missing, and production systems able to self-configure when the boundary conditions change are at an early stage of development. The European roadmap for CPS in manufacturing identifies the main challenges and opportunities[1]. There is a need for migrating signal processing, modelling, learning, and fundamental decision-making techniques to a cloud-based/agent-based architecture. These aim at managing alarms and events locally by auto-configuring machine parameters based on the knowledge stored and processed by reinforcement learning systems housed in the cloud to form a CPS system.

In summary, to improve the company's performance in terms of costs and time, it is essential to evolve towards a smart factory. It can rely on systems able to analyze production data in real-time, provide data at "enterprise-level", self-react consequently (where possible), and support the decision-making process (where needed). In short, a smart, connected, secure, collaborative, and self-reacting production process. Practical examples regard simpler user interfaces; more dynamic adaptivity during the addition or removal of new machines, and changes in the factory setup; supporting cooperative aspects between heavily connected systems.

Therefore, the relevant aspects of smart manufacturing are (see Figure 2):

1. Horizontal integration through value networks;
2. Vertical integration, e.g., within a factory/or production shop;
3. Life cycle management, end-to-end engineering;
4. Human beings orchestrating the value stream.

[1] https://cordis.europa.eu/project/rcn/193437/factsheet/en

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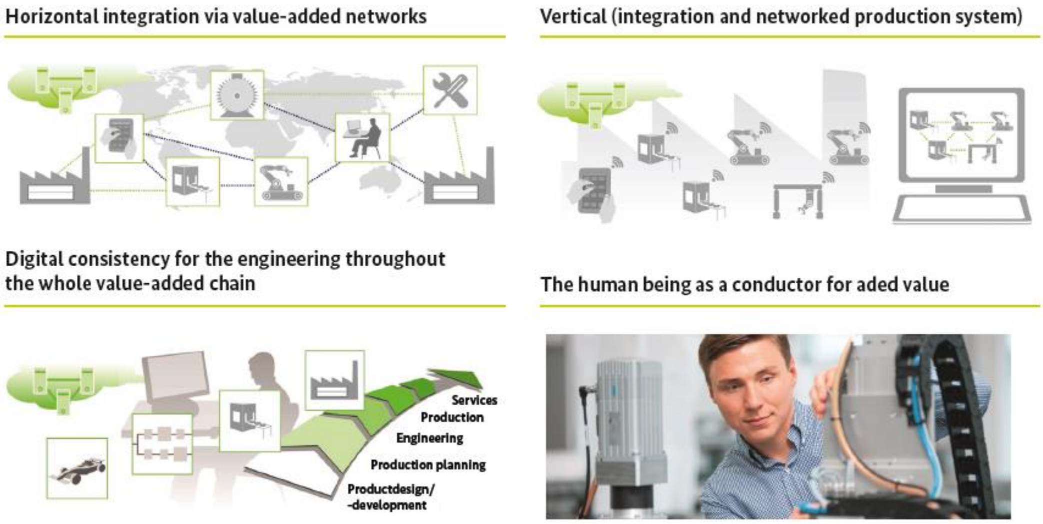

Figure 2 - Relevant aspects of Smart Manufacturing [2].

Considering the equipment hierarchy of an enterprise shown in Figure 3, interoperability is needed at any level. In particular, the interoperability should be guaranteed at any level in which a production asset (i.e., a plant, a machine, a station, an assembly inside a machine, switchgear, a motor, a tube, etc.) is positioned. Interoperability is the capability of two or more components or systems to perform a specific function cooperatively by using the information that they exchange. That involves the complete enterprise, which consists of the shop floor level for production and the office floor level for the organization of the company.

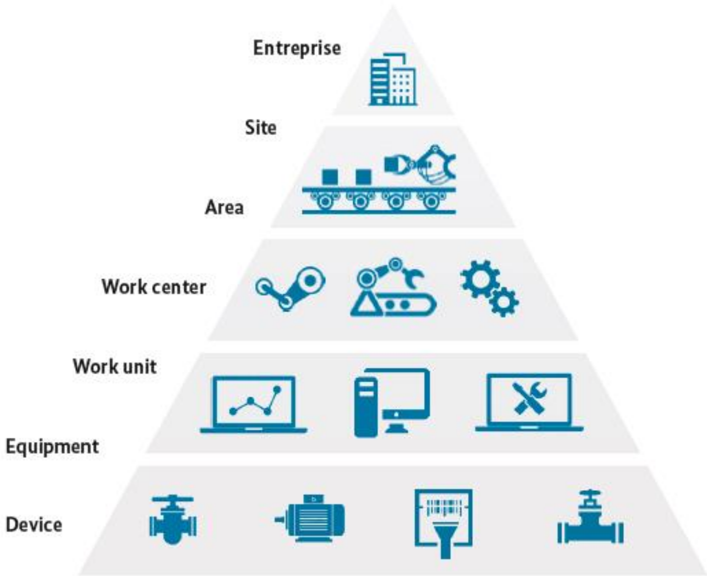

Figure 3 – Equipment hierarchy of an enterprise.

Like interoperability, security is crucial. Systems must guarantee confidentiality, integrity, and availability of saved and transferred information. A study conducted between April 2012 and January 2014, titled Project SHINE (SHodan INtelligence Extraction[2]) pointed out that there are more than 500.000 devices deployed in control systems environments connected to the Internet (either intentionally or unintentionally) [2]. According to a press release by Gartner, the rapid growth of that number will lead to exceeding 20.4 billion devices in 2020 [4]. So, the development and implementation of proper cyber-security measures are of critical importance in order to make manufacturing platforms digitally safe and secure from cyber-attacks.

[2] https://www.shodan.io/

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2.3 *CPS4EU Use Cases for Industrial Automation*

CPS4EU deals with the following use cases:

1) Material Flow Planning and Optimization: all parts of the production, machine states, workers are part of a complete digital model (digital twin) of the shop floor. Through novel CPS technology interaction, this model is used for organizing, real-time controlling, forecasting as well as for the local and global scheduling of the production processes (TRUMPF)
2) Mobile CPS: this use case will tackle "cooperative lifting" challenges, where a huge object will be lifted and moved by at least two mobile cranes. Furthermore, the use-case will support the integration of predictive maintenance processes, distributed decision making, and collaborative algorithms (WIKA)
3) Automatic Vacuum System: this use case will deal with a specific assembly process on large composite structures and aims to automate drilling activities on such structures that currently are human driven (LEONARDO)
4) Trimming Quality Improvement: the objective of this use case is to create a system able to collect data coming from sensors and numerical control machines and to analyze it with quality statistic algorithms to understand the main root causes of defects. To complete the cycle, the CPS, by reacting to different conditions, will be able to modify machine parameters so to avoid the damage or defect itself (LEONARDO)
5) Thermoplastic Production Line Monitoring: The objective of this use case is to monitor and control process parameters to achieve the best possible quality of the final thermoplastic product, meeting customer specifications (LEONARDO)
6) Health Management System for Aircrafts: For this use case, the CPS is a system whose SW is able to receive data from an aircraft and perform the following high-level functions:
    - Troubleshooting: support and improve failure detection and fixing
    - Trend Monitoring: management of aircraft's data to monitor aircraft's system behavior and performances
    - Preventive and Predictive Maintenance: definition of maintenance tasks, according to the aircraft's system monitoring, in order to anticipate failures
    - Fleet Spare Management: spare parts prediction and optimization of the maintenance planning process, in order to maximize the operational availability of the aircraft (LEONARDO)

2.4 *Literature Review*

A literature review aims to find the current knowledge about a topic by collecting and analyzing available theoretical and methodological contributions. It allows proposing new theories by examining consolidated ones or simply creating a knowledge base useful to the scientific community in further investigations.

Among possible ways to conduct a literature review, we choose the Systematic Literature Review (SLR). It allows sketching different approaches and solutions in order to highlight the pros and cons of a specific *field of study [5]*. An SLR is useful when:

1. We want to understand whether and how much a *research topic* has been treated;
2. We want to contextualize our research work into the reference *field*;
3. We want to define and highlight relevant aspects.

This literature review objective is to classify the contributions to Cyber-physical systems in the area of Industrial Automation published during the years into international journals or presented at international conferences. Such classification intends to create an accurate summary of the state of the art of ICPS of recent years.

The literature review activity made employing the Scopus site started from the query "cyber-physical AND system AND industry AND automation" which returned 382 documents[3] published in the period 2011 – 2019 and distributed as exposed in Figure 4. As can be evinced from the figure, in the last four years, the attention to ICPS has grown enormously. However, we focus on the period 2016-2019 in which there are a total of 335 documents.

[3] Research is done on November 26, 2019

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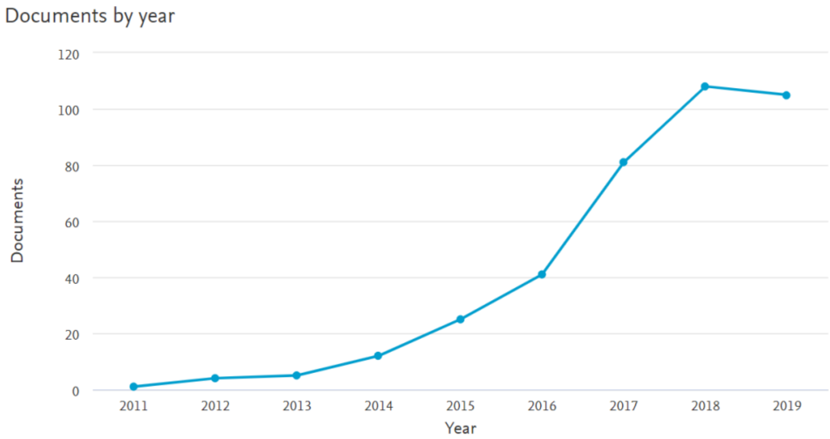

Figure 4 – Timeline about works publishing.

Considered documents mainly concern "Engineering" and "Computer Science" subject areas (Figure 5). So, we focus on those (307 documents), that are distributed as follows:

- 182 Conference Papers;
- 93 Journal Articles;
- 11 Conference Reviews;
- 9 Book Chapters;
- 1 Book.

The most active research institutes are located in Germany and Spain, while the most involved authors are: Garcia Marcelo and Marcos Marga, both from Universidad del Pais Vasco, Spain.

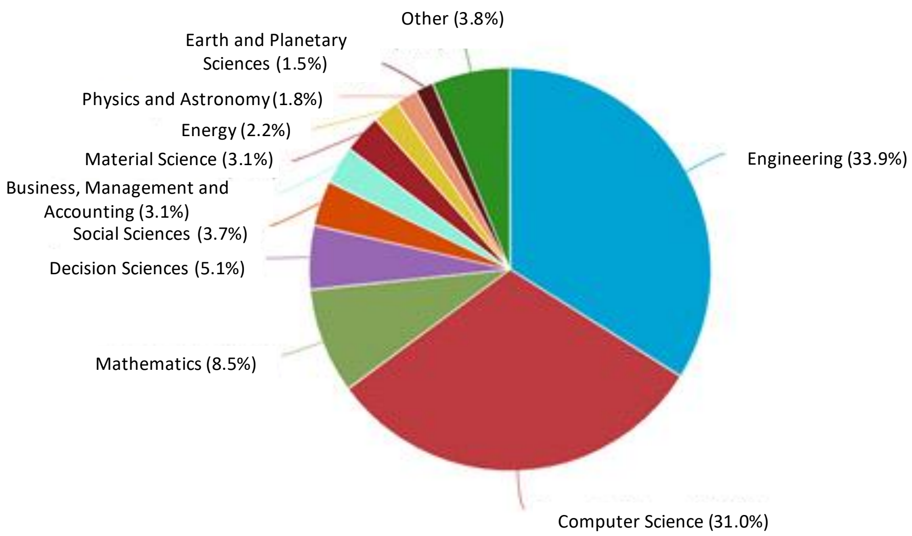

Figure 5 - Literature works by subject area.

The document analysis consists of two steps: (1) reading of title and abstract to decide if it is coherent with the topic; (2) reading the overall text to extract information.

The objective of this literature review is to understand and update the state of the art of CPS applied to industrial automation. In particular, the study will emphasize research results preferring the most recent ones in area of interest. The discussion focuses on specific areas of interest considered mostly related to the Industrial Automation use cases in CPS4EU (WP8) (e.g., Digital Twin, Predictive Maintenance, and so on). Additionally, essential aspects of ICPS like interoperability, security, and Human-Machine collaboration, are included in the description.

The following sections will propose, for each introduced area of interest, state-of-the-art existing (or emerging) solving approaches.

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The update of the literature review attains with Indoor Localization and Time Synchronization problems that affect some of the use cases in WP8. The literature review includes ad-hoc research activity of novel and suitable approaches for addressing these challenges. New considered documents mainly concern “Engineering” and “Computer Science” subject areas. So, we focus on those (23 documents), that are distributed as follows:

- 17 Conference Papers;
- 5 Journal Articles;
- 1 Technical Report.

2.4.1 Digital Twin

A digital twin, as a replica of a physical entity, enables its simulation and, jointly, its continuous monitoring, maintenance, management, optimization, and safety [7], [8], [9].

It can map all kinds of physical data of the product to a virtual space. The virtual product can reflect the whole lifecycle process of the corresponding physical product. Based on the digital twin, the product design process can be divided into conceptual design, detailed design, and virtual verification (see Figure 6).

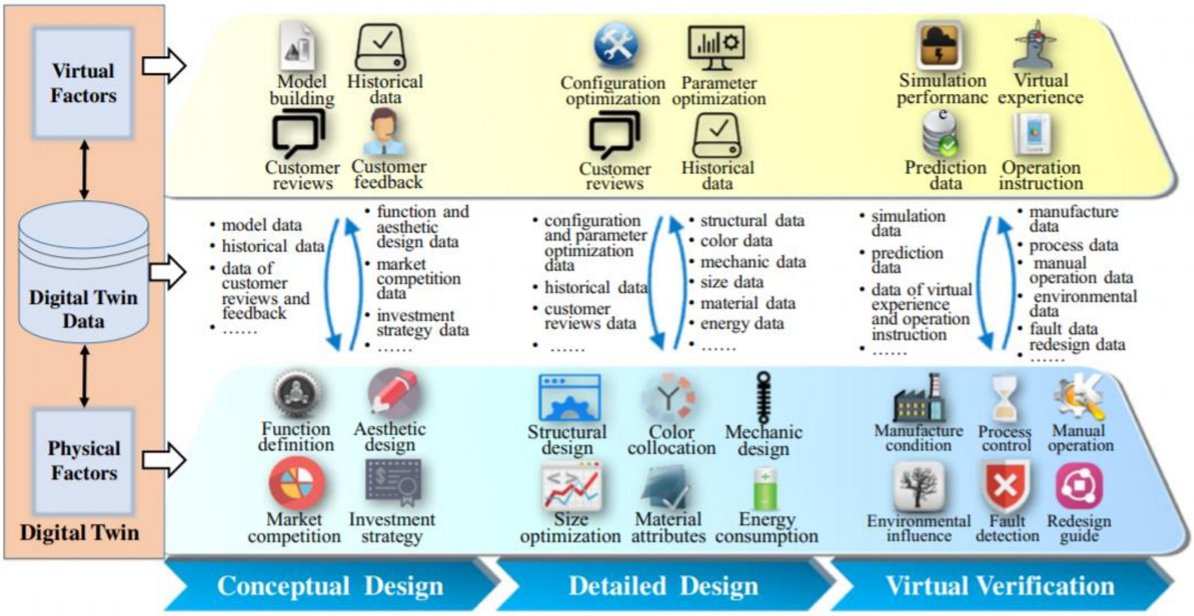

Figure 6 - Digital twin-based product design [6].

A Digital Twin simulation may be of two types [9]: (1) synchronized with the physical part of the CPS, but also limited to the boundaries of the CPS itself (e.g., a single workstation); (2) hosted outside the CPS system itself, and able to simulate workstations and the whole production system behaviors [10], [11]. However, as expressed by Kritzinger et al. [11], a proper digital twin enables data exchange in both directions (from the physical to digital entity and vice versa). In this way, the digital entity acts as a controller for the physical one.

Digital twins are usually designed for specific analysis about a considered system and can provide different services. In particular, we identify five categories of services described as follows: scheduling, real-time controlling, forecasting, data-driven decision making, failure management, and fixing.

2.4.1.1 Scheduling

The scheduling refers to the management of production processes. It is usually managed by excel files and Enterprise Resource Planning (ERP) systems. However, by implementing an Advanced Planning and Scheduling (APS) system as a component of the ERP, it is possible to adopt mathematical optimization techniques and heuristics to predict the future production schedule. In this sense, in [12], a cloud-based approach is proposed, while a method promoting the use of traditional relational database systems is described in [13]. Alternatively, by automatic monitoring (through IIoT), the Job Shop Scheduler (JSS) can track the tasks, understand the completion time of a job and, eventually make a rescheduling [14].

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2.4.1.2 *Real-time controlling*

Classic industrial control applications (Networked Control Systems) mainly consist of the plant and the controller that exchange sensor or control signals [15]. The Model Based Control systems use a simulation of the plant to calculate the control values [16]. It is possible to integrate the administration shell into an asset or somewhere else in the Industry 4.0 system (e.g., at a dedicated server or in a cloud) [17]. In this sense, a real-time distributed cognitive control system is presented in [18]. An example of real-time monitoring regards communication between an Automation Studio software solution and a Programmable Logic Computer (PLC), which controls a specific robot [19]. An analogous system regards the monitoring of a Kuka youBot[4] by means of a Raspberry Pi 3B[5] board [20]. Another type of monitoring approach regards the adoption of Multi-Agent Systems (MAS) [21]. Often, cloud/fog/edge computing are considered key technologies in the area of real-time controlling [22].

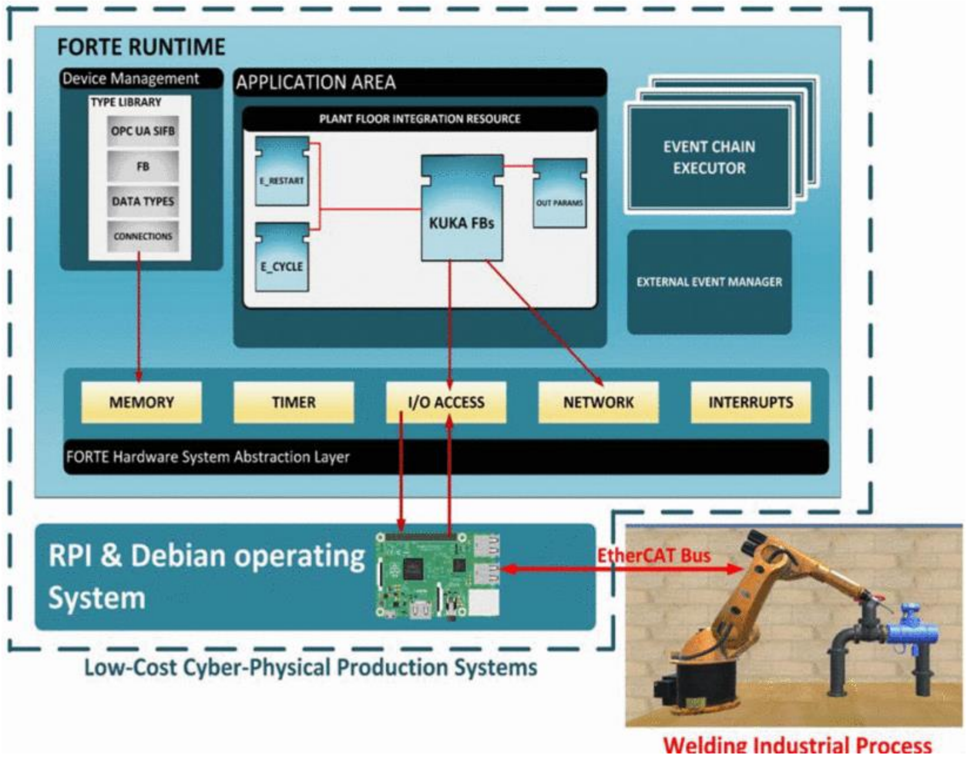

Figure 7 - Control robot architecture [20].

2.4.1.3 *Forecasting*

Forecasting (or prediction) activities analyze raw data to understand the system behavior and predict future events. It is part of the advanced analytics strictly correlated to decision-making activities [23]. A neural network [24] or other machine learning algorithms such as Multiple Linear Regression, Support Vector Regression, Decision Tree Regression, and Random Forest Regression [25] can generate predictions particularly useful in developing managerial decisions.

Finally, examples of applications based on Deep Learning are presented in [24], and [26].

2.4.1.4 *Data-driven decision-making*

In the industrial automation context, decision-making can refer to multiple goals:

- Maximizing the uptime, productivity, and efficiency;
- Avoiding costly failures and unplanned downtime.

Prescriptive analytics automates the decision-making process about planning, scheduling, control, operation, and so on, leveraging any combination of optimization, heuristics, and machine learning techniques [23].

[4] https://www.kuka.com/en-de/products/robot-systems/kuka-education

[5] https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/

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Regarding the methodologies behind the decision-making process, the most popular are the ones based on the Group Decision Making (GDM) process. For example the Multiple Criteria Decision Making (MCDM), which is composed by the following steps : (1) identify the problems, (2) construct the preferences, (3) evaluate the alternatives, and (4) determine the best ones [27]. Alternatively, the Analytical Hierarchy Process (AHP) is a holistic approach that allows measuring the coherence between the evaluation metrics and the suggested alternatives given by the team who is taking the decision [28]. However, such an approach could result in inaccurate judgments of the decision-makers. So, recently, a fuzzy extension has been proposed (AHP-Fuzzy (FAHP)) [29].

Furthermore, Ansari et al. [30] introduced a methodology aiming to quantify the level of autonomy of workers or ICPS in decision-making, and human productivity employing Digital Assistance Systems.

2.4.1.5 Failure management and fixing

After a system fault, the human technician should be able to react rapidly by making a suitable corrective action (i.e., corrective maintenance). In a distributed networked environment, understanding the fault source could be very hard, and human errors could increase. In this sense, Botaschanjan et al. [31] recommended a function-oriented development instead of a model-based one. They assert that the functional engineering encapsulates the detailed engineering model, with their function reducing the complexity. Inspired to that, in [32], an approach using skills as an interface to a component model is proposed. In particular, the authors model, by the Modelica[6] language, the system and the related GUI used for showing faults to humans (Figure 8).

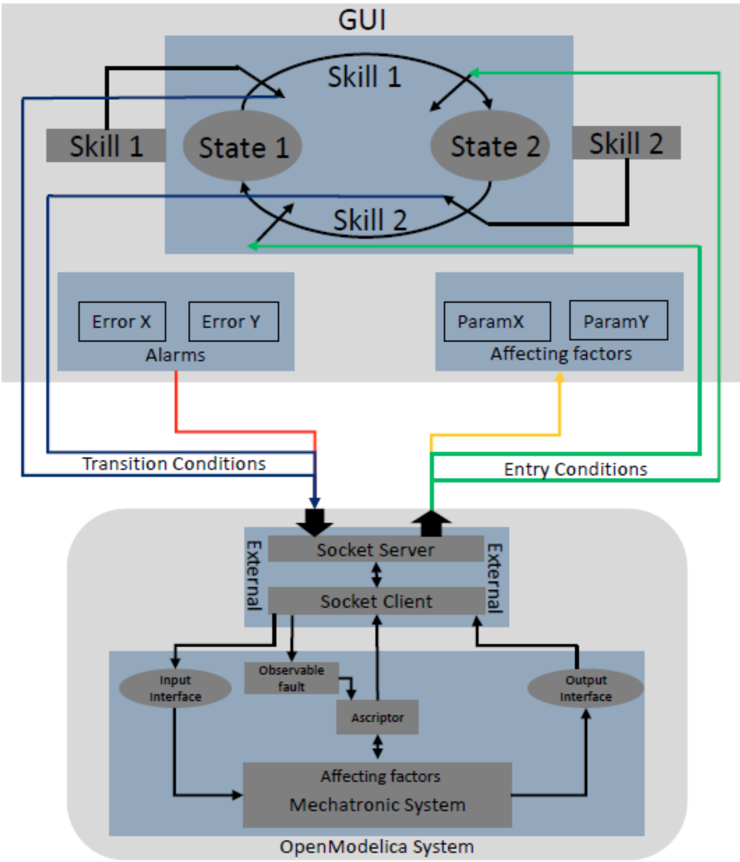

Figure 8 - Interactive fault ascription with a digital twin [32].

Mohrle et al. [33] defined a taxonomy of failure types for each flow type. A flow type is a classification of possible interactions between components. This type of annotation acts as a machine-readable vocabulary and a template for potential failure behavior for the human.

[6] https://www.modelica.org/tools

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The majority of the recent works introduce the Predictive Maintenance as a solution that predicts the condition of the system and schedules corrective maintenance accordingly (see Section 2.4.5).

2.4.2 Simulation

A simulation acts as a digital twin of the real component. It is useful to understand the physical system and check its performance.

The open-source tool Maestro, developed as part of the INTO-CPS project[7], enables co-simulation using the Functional Mock-up Interface (FMI) standard [34].

Zenisek et al. propose a simulation of condition monitoring of industrial production plants by a stream-wise generation and publication of sensor data [35].

A DBMS-centric infrastructure [13], shown in Figure 9, allows the prototyping and simulation of a production plant. The database is considered the fundamental and invariant ground enabling the architectural link between the physical and the virtual industrial plant. The idea is to separate the data infrastructure from the business logic. Once the data inputs and outputs are available through the DBMS relations (tables), it is possible to abstract and simulate the business logic that constitutes the algorithms that produce outputs from the inputs, by developing them with the preferred language, and by testing, calibrating and compiling them back into the DBMS-centric implementation through the plug-ins approach.

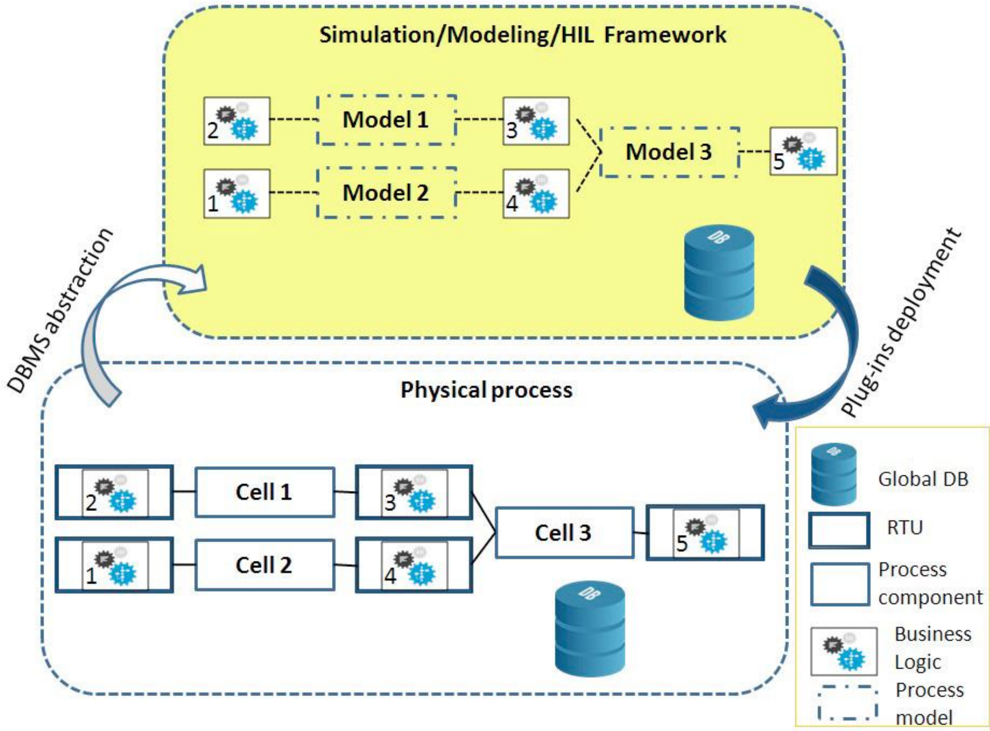

Figure 9 - DBMS abstraction and development framework.

On the other hand, Simulink[8], a MATLAB-based modelling language for dynamic systems, can be used to simulate them after their modelling as block diagrams [36].

2.4.3 Fault Identification/anomaly detection

From a system design point of view, adopting well-defined models (e.g., FTA, FEMA, BPMN) for requirements derivation, business processing modelling and so on, creates a common knowledge-model for stakeholders also in terms of operation-time measures regarding anomaly detection and fault treatment [37].

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[7] https://into-cps.org/

[8] https://www.mathworks.com/products/simulink.html

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Machine Learning techniques, such as a convolutional neural network (CNN), are often adopted in automatic anomaly detection [38]. For example, data deriving from real-time monitoring should be joined with the past one for a machine learning-based anomaly detection [25]. In this sense, Nkonyana et al. also introduce experimentation using Ensemble Learning [39].

Another type of solution involves the integration of an autonomous robot (agent) into the wireless sensor network able to localize and monitor the alarm system [40].

2.4.4 Collaborative Algorithms

Due to their structure, CPS consist of collaborating individual systems that need proper coordination between different parts. In terms of facility coordination, genetic algorithms can support optimization goals [41]. Nogueira et al. propose a vision-based collaborative framework [42]. The framework combines gesture control, collision avoidance, and collaborative behavior.

In [43], a cyber-physical synchronization scheme for distributed CPS controllers is presented. The idea is to have a distributed motion control where each single-axis robot is controlled by its networked microcontroller (MCU)-based platform (i.e., the low-level controller (LLC)).

A digital twin based on Multi-Agent System architecture can exploit a similarity metric between assets during operating conditions to identify "friends" and sharing operational data within these clusters of friends [44].

At this level, we can also consider networks of CPS (i.e., two or more collaborative CPS connected to each other). In this sense, in [45], a dynamicity constraint model is defined and applied to a real transport robot fleet scenario.

From the technology point of view, cloud/fog/edge computing are considered powerful when low-latency data are required [22].

2.4.5 Predictive Maintenance

The Predictive Maintenance predicts the condition of the system and schedules corrective maintenance accordingly. Prognostics and health management (PHM) is a key process for Predictive Maintenance (PM) which consists of seven modules shown in Figure 10 (i.e., data acquisition and processing, condition assessment and diagnostic, fault prognostics and decision support, human-machine interface (HMI)) [46].

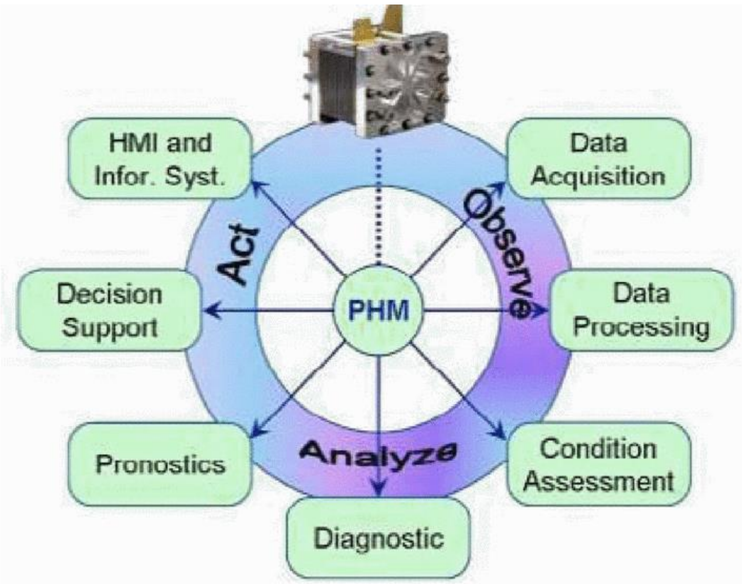

Figure 10 - PHM Architecture [46].

A solution, presented in [46], exploits IoT and cloud computing. It enables the connection of the industrial environment, and by offering a Dashboard allows to monitor, supervise, and control an important number of machines geographically separated.

Kshitij et al. [44] propose Collaborative Learning to predict the Remaining Useful Life (RUL) of a fleet of turbofan engines. Three layers compose the architecture and interact with the assets (see Figure 11):

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1. Virtual Assets: standardize data from different assets and push it into the Digital Twin.
2. Digital Twins: generate the asset-specific model using other assets in the fleet and the asset itself.
3. Social Platform: makes an enterprise-level analysis (e.g., clustering similar assets or analyzing machine data to generate fleet analytics).

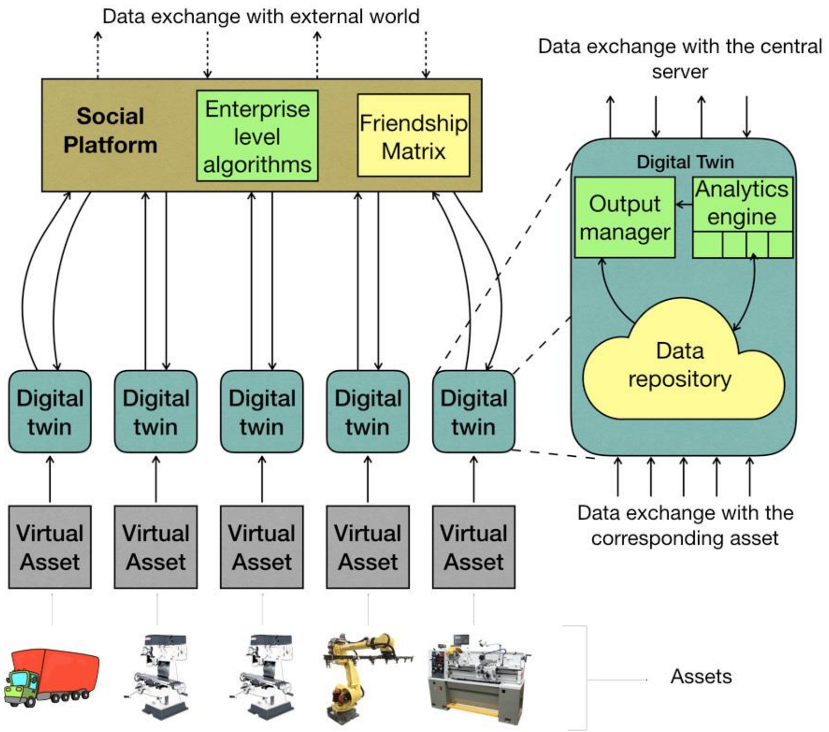

Figure 11 - A Multi-Agent System architecture for Collaborative Learning [44].

In terms of Condition-based maintenance, Fumagalli et al. propose a framework based on Process Hazard Analysis (PHA). It builds a knowledge discovery that incorporates both prior knowledge and proper interpretation of data analytics results to discover hidden patterns that anticipate risky scenarios [47].

The Advanced Process 913 (AP-913)[9] methodology is adopted in [48] to make a drift analysis. AP-913, defined by the World Association of Nuclear Operators (WANO), aims to assist operators in nuclear power plants to increase Equipment Reliability and enhance the System Performance in a standardized process.

Finally, the emerging blockchain concept is applied for the realization of a three-layered architecture supporting predictive maintenance [49].

2.4.6 Interoperability

The nature of ICPS as systems that intertwine multiple subsystems (both physical and software) make the interoperability a crucial aspect. By the emergence of the integrated network of smart automation devices, cloud services, cloud platforms, and enterprises, new problems of interoperability arise. In this sense, Figure 12 highlights the difference between this type of integration and a hierarchical model. Matters related to interoperability encompass inconsistencies among data formats or standards, compatibility issues between different versions of software, misinterpretation of the terminology used, or misunderstandings of the terminology used for data exchange, and so on.

The interaction among different layers of CPS must support real-time communication, even their heterogeneity. So, standards capable of meeting the requirements of various stakeholders are needed. Reference architectures supporting vertical and horizontal interoperability phases (e.g., Reference Architecture Model for Industry 4.0 (RAMI 4.0) [66], Industrial Internet Reference Architecture (IIRA) [68]) are still at a conceptual level, and their implementation has not been fully accomplished at the operational level due to the relative absence of

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[9] https://www.epri.com/#/pages/product/1003479/?lang=en-US

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standardization [69]. Moreover, the knowledge about what domains cover these standards, and eventual overlaps among them are not yet formalized.

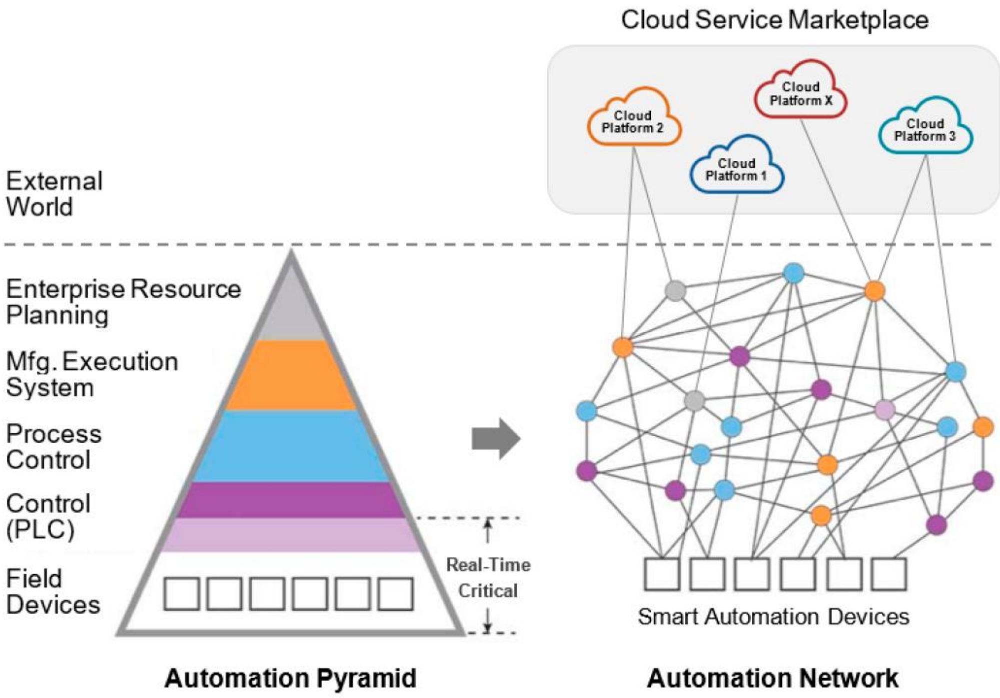

Figure 12 - Evolution of the hierarchical model of enterprise control system integration toward an integrated network of smart automation devices, cloud services, cloud platforms, and enterprises [69].

Interoperability is often achieved by the introduction of a semantic layer [51], [52]. Semantic technologies can add meaning to machine-to-machine communication by establishing ontologies of interlinked terms, concepts, relationships, and entities. Particularly, an Open Semantic Framework (OSF) containing an extensible set of core ontologies that capture concepts that cut across domains, enables specific applications to access their required information. Core ontologies, together with domain-specific knowledge packs (KPs), allow vertical and horizontal interoperability: between agents within a domain and across domains, respectively. Furthermore, the access to stored knowledge is achieved by a REST API querying interface based on prefabricated SPARQL query templates. Finally, the OSF enables the knowledge visualization: for instance, given a specific semantic node, queries deliver that node's properties, information about its type, and links to adjacent nodes. The information should be displayed through interfaces that support 3D interaction [53].

Other types of solution regard a microservice-based software architecture aiming to support the heterogeneous device integration problem [54], or an ad hoc modelling language (e.g., CyPhyML [55]) as the composition of several sublanguages.

Furthermore, authors in [56] propose a mapping of the production processes modelled in Business Process Modelling and Notation (BPMN) language into Petri Nets (PN) semantics.

2.4.7 Security

What emerges from interoperability and cooperation issues is a real need for cybersecurity and privacy. Particularly, security is the intersection of three important attributes: confidentiality, integrity, and availability. Consequently, possible attacks threat one or more of these security attributes. Attacks on data integrity are known as deception attacks and represent the largest class of attacks on cyber-physical systems. The attacks on confidentiality alone are named disclosure attacks. An example of attack on availability is the denial of service (DoS) attack that renders inaccessible some or all the components of a control system by preventing transmissions of sensor or/and control data over the network [57].

Defense strategies consist of [57]:

- Prevention: approaches that measure (in an offline way) the state of security/vulnerability of systems and eventually identify critical components.
- Detection: the system is continuously monitored for anomalies caused by adversary actions.

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- Mitigation: actions that aim to disrupt and neutralize the attack and reducing its impact.

Most of the available studies focus on detection strategies. Approaches devoting to intrusion detection adopt machine learning [58], or Hidden Markov Models [59]. From the prevention point of view, an integrated Host-based solution is proposed in [60]. However, the spreading of the Blockchain technique to ensure security is also emerging in this area of research [61], [49].

2.4.8 Human-Machine Collaboration

Innovative ICPS should steadily consider the role of workers inside the factory. Often human capabilities can help computerized actions (if not yet able to do) that, in turn, can even improve human capabilities. So, we need deeply integrated hybridized systems. In [62], the authors introduce a new trend towards Cyber-Physical Social Systems (CPSS).

Most innovative solutions propose the integration of Augmented Reality in the system enabling collaboration between workers and machines [63], [64]. Industrial wearable systems are recommended to establish a human-cyber-physical symbiosis to support real-time, trusting, and dynamic interaction among operators, machines, and production systems (see Figure 13) [65].

The human-machine interaction (HMI) requires adaptive UI that are capable of learning from their experience and predicting possible developments of a given situation [66].

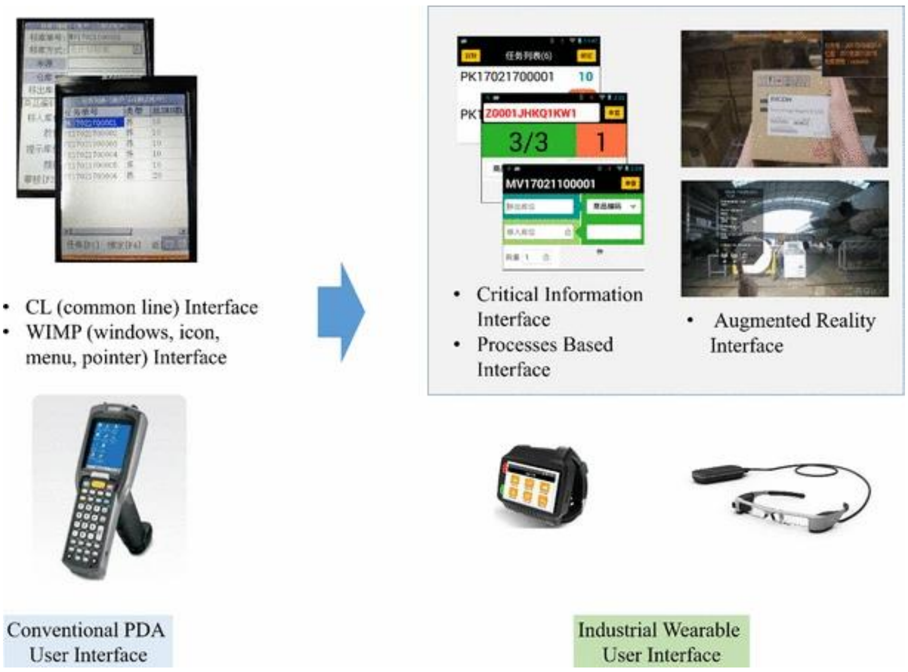

Figure 13 - Industrial wearable user interface for industrial mobility

2.4.9 Data analytics

Data analytics regards the need for methodologies for the handling, retrieving, and storing of vast amounts of data in terms of hardware and software solutions [70]. It opens multiple correlated challenges: gathering data coming from heterogeneous sources even in real-time, pre-processing it (as needed), aggregating, and supplying it to specific algorithms. The final data processing is different for each objective; however, some examples regarding:

- ML algorithms for data prediction;
- Statistic algorithms to understand dependencies among variables/sources of information (e.g., sensors).
- Decision-making algorithms to decide on the basis of the real situations.

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2.4.10 Scalability

As the number of connected components becomes high, scalability becomes a significant challenge. The scalability regards three aspects: (1) Data scalability which is inherent to the large amount of sensing data; (2) Scalable collaboration, which requires that heterogeneous devices and systems communicate and collaborate with each other; (3) Scalable management: horizontal and vertical integration places non-trivial management and maintenance challenge to the system administrators [70].

2.4.11 Indoor Localization

Indoor localization refers to the identification of a device or user location in an indoor environment. Available approaches and applied technologies are numerous. A first broad differentiation regards:

- **Device Based Localization**. The user device calculates its relative location based on some *Reference Nodes* (RN) or anchor nodes. This type of localization is useful in case the node needs assistance in navigating around any space.
- **Monitor Based Localization**. Reference or anchor nodes passively collect positions of connected entities. It is mainly adopted for tracking nodes and accordingly providing different services.
- **Proximity Detection**. The idea consists of estimating the distance between a node and a Point of Interest (PoI). It is useful, for example, in recognizing a reliable and cost-effective solution for context-aware services.

In all categories, approaches are mainly characterized by the adopted techniques: Received Signal Strength Indicator (RSSI), Channel State Information (CSI), Angle of Arrival (AoA), Time of Flight (ToF), Time Difference of Arrival (TDoA), Return Time of Flight (RToF), and Phase-of-Arrival (PoA). For example, in combination with RSSI, there are fingerprinting/scene analysis and probabilistic methods (i.e., Neural Networks (NN), k-Nearest Neighbors (kNN), and Support Vector Machine (SVM)). Indoor localization approaches can be also discriminated based on the adopted wireless technology (i.e., WiFi, Bluetooth, ZigBee, RFID, UWB, Visible Light, Acoustic Signals, and ultrasound). Finally, emerging IoT technologies such as Sigfox, LoRA, IEEE 802.11ah, and weightless can be potentially used for indoor localization [71].

Examples of literature applications are reported in the following.

2.4.11.1 Device Based Localization (DBL)

A solution combining WiFi to UWB radios is presented in [72]. Leveraging a WiFi mesh backbone and a UWB allows deployment in areas without existing (wired) backbones. One of the most recently adopted technology regards the Beacon, a Bluetooth Low Energy (BLE) based protocol considered, indeed, as energy-efficient [73]. It is demonstrated that, in combination with WiFi, Beacon improves the localization accuracy by 23%. Besides, authors in [74] demonstrate the improved accuracy by fingerprinting and filtering modifications while an evaluation of Beacon parameters impact is presented in [75]. Hu et al. [76] proposed a system leveraging the received light intensity (RLI), that can vary based on different indoor locations.

2.4.11.2 Monitor Based Localization (MBL)

Wang et al. experimented with a CSI fingerprinting system based on deep learning: after a training phase, the model is adopted to identify the user's location [77]. In the Pallas system [78], the user's location is estimated by RSSI values. In particular, the system starts from the indoor floor plan and locations of deployed WiFi monitors. WiFi monitors continuously collect the received signal strength (RSS) of WiFi transmissions coming from nearing smartphones. Then, collected traces are transferred to a central server (for constructing a database) that guides the real-time localization.

Regarding the adoption of RSSI, there are research works studying RSSI measurements' intrinsic variability and the effects of external interferences on the RSSI values [79]. Besides, numerous studies in this area demonstrate a Bluetooth-based network's feasibility in terms of accuracy. An example is detailed in [80]: the system utilizes RSSI values from the user devices to compute the distance between the device and the fixed distributed Bluetooth receivers.

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2.4.11.3 Proximity Detection

LocaLight system [81] that leverages the light intensity that can decrease due to the user's shadow through the adoption of RFID sensors placed on the floor is particularly suitable for detecting if any individual is within close vicinity of the light. WalkieLokie [82] calculates entities' positions through the measurement of the acoustic signals. It is suitable for proximity and relative position-based services. LiTell [83] and its extension LiTell2 [84] adopt fluorescent lights. The fundamental principle relies on the fact that any used RN has a different characteristic frequency detected by the camera on the user device. Then, different users can be localized based on their proximity to a certain RN. LiTell2 differs for the possibility to work with LEDs. Willis and Helal [85] experimented with a system for which the user shoe is integrated with an RFID reader that can communicate with the user device using Bluetooth. Then, the ground is equipped with an RFID tag grid so that the reader in user shoes can read the position-related information and convey it to the blind users.

2.4.12 Time synchronization

In wireless sensor networks, each node senses some measures (e.g., humidity, temperature) that need to be timestamped in order to be further analyzed, thus time synchronization is a challenging problem for wireless sensor networks. Synchronization of clocks is essential for mapping events in real time, scheduling the sleep cycle of nodes and for collision free transmission.

Approaches for time synchronization in wireless sensor networks can be distinguished in:

- **Centralized**: central (or reference) nodes act as a synchronizer for all nodes in the network. Usually, a root node starts the process by propagating a time message; then, receiving nodes adapt local time according to the received one. A typical centralized algorithm is the Timing Synchronization Protocol for Sensor Networks (TPSN).
- **Distributed**: to overcome problems related to scalability, synchronization overhead, and error accumulation, algorithms based on the distributed time synchronization mechanism, in which there are no reference nodes, are introduced. Examples are the Distributed Consistent Time Synchronization (DCTS) and the Global Time Synchronization algorithm. As foreseeable, these algorithms present problems related to the convergence rate and energy consumption [86].

The following sections report examples of literature applications for the two categories.

2.4.12.1 Centralized Algorithms

Regarding this category of algorithms, a series of experiments by applying the TPSN to real cheap wireless sensor nodes are in [87], [88]. Results demonstrated that performance could change based on different features, such as the node architecture and the radio system's limited bandwidth when common commercial wireless communication channels such as WiFi, BlueTooth, ZigBee are adopted. Presented studies provide an on-line optimization method in terms of performance and energy consumption. In [89], authors measure the capacity of remote virtual machines offered by cloud service providers (i.e., Amazon AWS, Google Cloud, Microsoft Azure) to retrieve the time reference from a time server. Experiments were based on the Network Time Protocol (NTP) and revealed a consistency among providers together with different tests.

2.4.12.2 Distributed Algorithms

An example of applying a distributed algorithm in the area of CPS is presented in [90]. It consists of a virtual single-hop network in which every node can directly communicate with every other node. The approach inherits concepts from Glossy that provides sub-microsecond time synchronization accuracy [91]. Regarding the measurement noise, Stanković et al. [92], propose convergent algorithms for both clock skew and clock offset. A consensus-based protocol is introduced in [93]. The main idea is to adopt consensus algorithms to average local information and to achieve a global agreement on a specific quantity of interest.

2.5 *State of the art for CPS4EU Industrial Use cases*

This chapter provides an update of the state of the art about Cyber-Physical Systems in the CPS4EU Industrial use cases.

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2.5.1 UC4 - AUTOMATIC VACUUM SYSTEM

The objective is automating drilling activities by synchronizing two CPSs (i.e., DRILL and VACUUM). In this sense, research and development is moving toward synchronization solutions based on collaborative algorithms. A mutual tracking of DRILL and VACUUM should guarantee the detection of their positions and consensus to operate [42]. In particular, the adoption of an indoor localization methodology could improve the collaboration between parts. In this sense, by considering the literature review, the most suitable solutions involve the category of Device Based Localization and Proximity Detection. The literature analysis reveals a plethora of applicable techniques and technologies in both categories. However, since UC4 requirements focus on low latency and localization accuracy, one of the fitting solutions could be the adoption of Beacon. It is especially suitable for proximity detection when distances are particularly limited. Furthermore, since in many research works, authors demonstrated a meaningful accuracy of the RSSI technique, it could be merged with Beacon.

A predictive maintenance task must understand the tip remaining useful life. In this area, several research works address predictive maintenance by proposing all-inclusive solutions or by experimenting with some ML algorithms. The tip remaining useful life could be predicted based on collected sensor data by means of ML algorithms or Deep Learning algorithms [24], [26]. Information about the tip's remaining lifetime should be shown to a human operator in a brief time. In this sense, preferably one should not adopt cloud computing approaches exclusively.

2.5.2 UC5 - TRIMMING QUALITY IMPROVEMENT

The use case focuses on the analysis of multiple sensor data to understand the causes of defects (i.e., delamination during trimming/milling). It could be represented as a problem of real-time monitoring of multiple sensor data that should be combined conveniently. The objective is principally to understand the main root causes of defects that, according to the state of the art, could be achieved through AI/ML modelling on historical data, such as a drift analysis [48]. The solution, in order to manage historical data, could adopt Big Data oriented solutions and, for example, cloud storage/computing [22].

This use case also introduces the time synchronization requirement: sensor monitoring and their result combination need sharing a timestamp. The literature review shows an implicit impossibility in perfect synchronization and that every new synchronization policy may introduce new issues. A global time reference might be redundant in some cases, and a relative time could be preferred. At the same time, a distributed synchronization could result in a more complicated scenario, with a relevant computation overhead.

2.5.3 UC6 - THERMOPLASTIC PRODUCTION LINE MONITORING

This use case aims to realize a CPS able to obtain a transformation process in the field of thermoplastic production in an accurate way. The required steps involve heating, pressing, and cooling.

The thermoplastic quality depends on multiple parameters that, in turn, influence a lot of processes. According to the state of the art, the solution could involve real-time controlling algorithms (from a dedicated server or cloud) [17]. Sensor data supports the forecasting of other parameters through ML algorithms [24]. Otherwise, by means of a simulation of the components [16], the system could understand how to set-up the process. In this sense, adopting cloud storage could improve the efficiency in data management.

2.5.4 UC7 - AIRCRAFT HEALTH MANAGEMENT SYSTEM

This use case will address the following main features: Troubleshooting, Trend Monitoring, Predictive Maintenance, and Spare Management.

At the state of the art, systems supporting troubleshooting, implement failure management and solution fixing, sometimes they also use representation and recognition of failure through semantic technologies, for instance, in [33].

ML algorithms [24], or technologies for drift analysis [48] have been used for collecting data and performing anomaly detection on critical parameters; such results may be interesting for addressing Trend Monitoring.

Analogously, machine learning and deep learning algorithms are used at state of the art for predictive maintenance. From the literature point of view, there is a clear trend of enriching tools with smart equipment exploiting (I)IoT and cloud computing for addressing Predictive Maintenance. In this sense, it is not only a

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problem regarding the creation of predictive models but also the design of a dashboard to allow monitoring and controlling operation for a huge number of machines, also geographically separated [46].

Spare Management could be seen as an optimization supply problem. In this sense, inspired by the state of the art, it could be achieved by adopting optimization, heuristics, or machine learning techniques, or a combination of them [23].

2.5.5 UC8 - MATERIAL FLOW ANALYTICS AND SIMULATION

The main objective of UC8 is summarized as a flexible production management of complex processes on the shop-floor. One of the main features of UC8 regards the realization of a digital twin of the shop floor. It is composed by the scheduling of production processes that can be integrated into a traditional ERP [12], in particular, a real-time re-scheduling that adapts itself to simulation results.

According to state of the art, there is a need for an integrated solution allowing vertical and horizontal interoperability, for instance, by integrating MES (Manufacturing Execution Systems), PLM (Product Lifecycle Management), and ERP. This integration should be carried out by adopting semantic data annotation and preferring the use of standards and architectures that are service oriented. The production hall should be represented through semantic annotation, and data processing should consider semantic working on static and dynamic data [51].

At state of the art, dedicated solutions are aimed at monitoring the production tasks, at understanding the completion time, and eventually, at rescheduling the activities [14]. The tracking of material flow is supported by a dedicated server or hosted in a cloud solution [17], [12].

ML or Deep Learning algorithms are ever more proposed or adopted to address prediction; in particular, simulation exploits ML models for predicting the production. This leads to the possibility of data-driven decision making for planning, scheduling, and controlling operations [24], [26].

2.5.6 UC9 – MOBILE CPS.

This use case regards a collaborative lifting of huge objects by multiple cranes. In this sense, it is possible to adopt a solution based on remote monitoring of the lifting process inspired by the work in [17]. Furthermore, coherently with state of the art, collaborative algorithms should manage the concurrence of the lifting process. An example solution could be a networked microcontroller that controls each crane [43], which should also guide the decision-making of the human operator by, for example, combining optimization, heuristics, and machine learning techniques [23]. It follows that specific GUIs are needed. In this sense, most trending solutions at state of the art adopt Augmented Reality [63].

2.6 *Conclusions*

This chapter presents a Systematic Literature Review regarding the main issues linked to CPS in Industrial Automation. Some relevant and recent solutions are described for each topic; then, a mapping between research trends and use cases is included in CPS4EU's for industrial Automation (Section **Erreur ! Source du renvoi introuvable.**). The main outcome is the awareness of the positioning of CPS4EU research for Cyber-Physical Systems applied to Industrial Automation.

Figure 14 outlines the resulting mapping. In particular, it presents the involved subset of problems faced by CPS4EU, giving an idea of CPS4EU's positioning in the area of CPS for Industrial Automation. Even if the areas of interest are not limited to the following ones, we can conclude in this chapter that the CPS4EU project will mainly impact in terms of research on:

- Interoperability, which should be guaranteed when multiple components interact with each other and for enabling the integration and reuse of the CPS.
- Predictive Maintenance should help operators in preempting problems or failures during tasks.
- Scalability. Industry Automation processing needs vary from cloud to edge computation; this requires defining hybrid architectures enabling edge, fog, and cloud computing to reduce the latency of real-time answers and enable huge processing activities in the cloud.

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- Data Analytics should produce a comprehensive knowledge of the domain able to guide subsequent choices.
- Time Synchronization, correlated to the Interoperability aspect, should guarantee a shared clock synchronization in order to manage real-time events when multiple components interact.

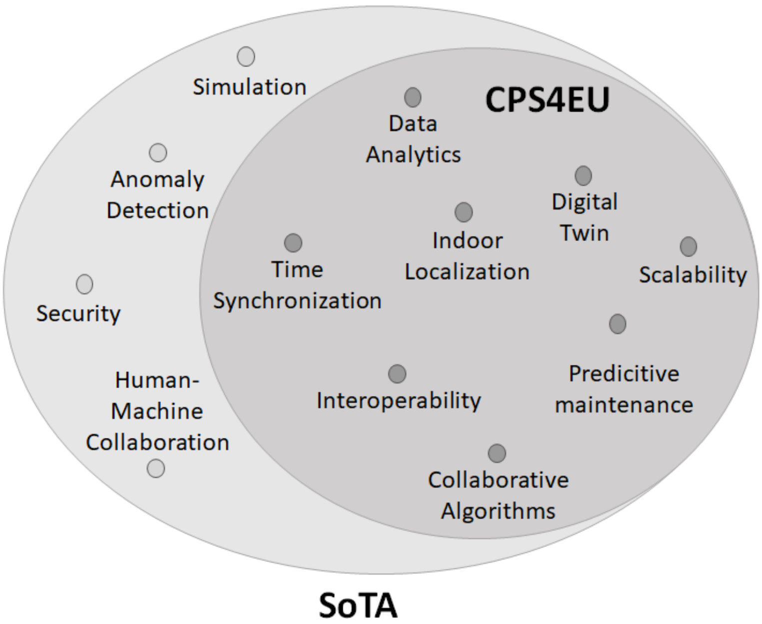

Figure 14 – The research positioning of Industrial Automation in CPS4EU w.r.t. SoTA.

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3 USE CASE ANALYSIS

This chapter provides a description of industrial use cases and, for each use case, reports the consolidated results of the requirements elicitation obtained following the methodology described in D8.1, Section 3.

3.1 *UC4 - Automatic Vacuum System*

3.1.1 Overall Description

3.1.1.1 High level Use Case Description

Leonardo's aerostructure division manufactures composite and metal parts and structures for military and civil aircraft for major world players in airframe market such as Boeing, Airbus, Bombardier, ATR, Lockheed Martin.

The use case will deal with a specific assembly process on large composite structures and aims to automate drilling activities on such structures that currently are human driven.

During drilling activities, the human intervention is doubled: one person drills while the other – positioned on the opposite side of the large structure – has to vacuum the carbon fiber dust that is produced. The use case will automate the movements of the vacuum system to "follow" the drill position.

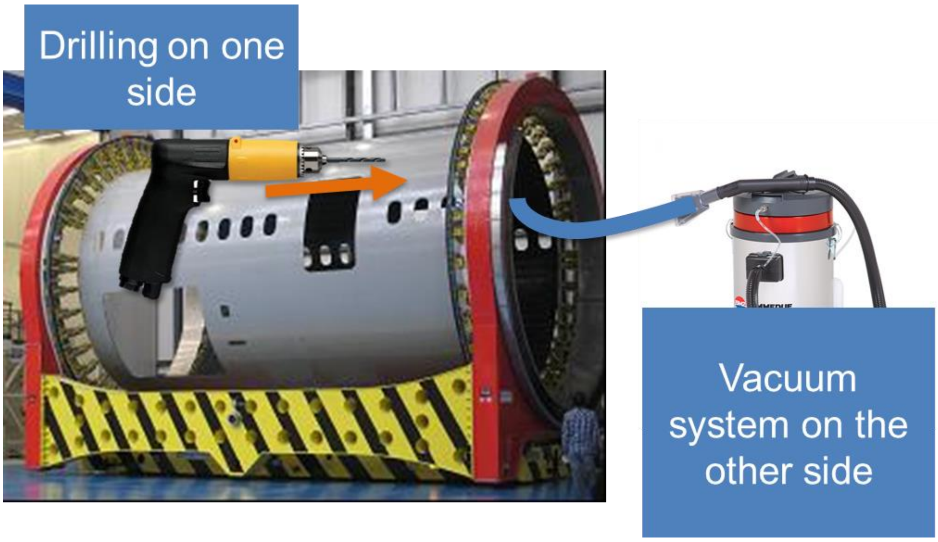

Figure 15 - UC4 overview.

The objective of this use case is to have CPS (DRILL and VACUUM) exchanging information and cooperating so that the vacuum system moves automatically to "follow" the drill.

3.1.1.2 Main Features

The first CPS (**DRILL**) will be implemented on the drill tool while the second CPS (**VACUUM**) will be placed in a working area on the opposite side of the part to be worked. The aim is to make the vacuum move on a support framework (as depicted in the picture below), following *precisely* the position of the **DRILL** in order to vacuum the carbon fiber dust produced.

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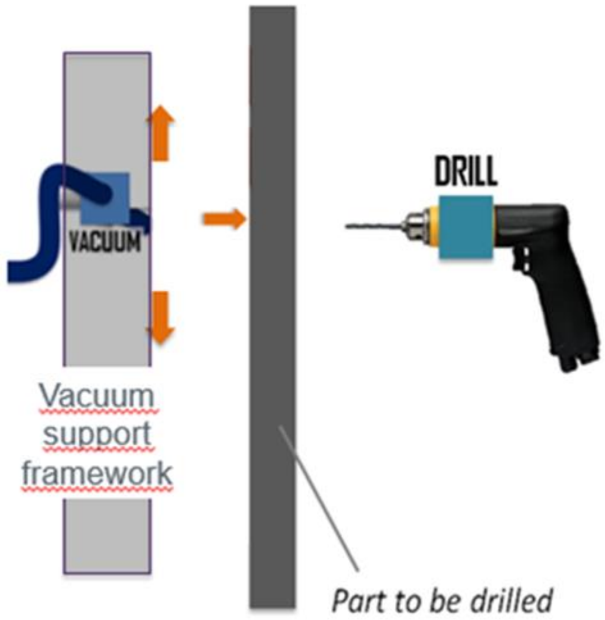

Figure 16 - UC4 components.

Furthermore, there is a need to evaluate the drilling tool wear, currently left to the operators.

The drills used in Grottaglie for manual drilling – and therefore in this use case – are not provided with position identification and there is no plan to replace them, as they represent a legacy system that is compliant with current certifications. Moreover, the economic investment needed for the tools upgrade does not justify the associated ROI. Here hence the need for the drill to be equipped with an adequate device (see requirements).

Demonstration will be run in Leonardo's Grottaglie production plant, on a Boeing 787 production panel (or on a representative one).

Process

A **reference system** has to be used to acknowledge and compare DRILL and VACUUM positions.

DRILL operation should be disabled until the VACUUM reaches its corresponding position on the opposite side of the part.

The following steps are to be put in place:

- DRILL calculates its position and sends it to the VACUUM
- VACUUM receives DRILL position
- VACUUM calculates its corresponding target position with respect to the DRILL, using the reference system
- VACUUM actuators move the vacuum hose to the target position on the opposite side of the DRILL
- VACUUM informs the DRILL it has reached the target position
- DRILL receives consent to proceed: DRILL operation is enabled to allow perforation.

Tool Predictive Maintenance

Currently, drilling tool tip wear is evaluated by operators. As a consequence, the regrind and regeneration process is greatly affected by the number of tools to be manually checked and managed: in fact, many tools are not returned for regrinding/regenerated when it is actually needed. This generates:

- defects - such as ovalized holes or delaminated, burned, scratched areas - due to worn out tools
- shorter tool lifetime when the tool is returned too early
- tool management responsibility demanded to the single operator

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- no objective evaluation criteria to be used, as no historical data can be analyzed to produce objective standards.

The Use Case envisages a system that is able to identify the mounted drill bit, understand its usage and wear in order to evaluate when it's time to replace it, possibly inhibiting the drill usage when specific criteria are not met.

3.1.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
UC4-FNC-01	Functional Requirement	Vacuum physical framework	The VACUUM shall be mounted on a physical support framework , on the inner side of the fuselage barrel that enables the VACUUM to reach different positions of the fuselage. The vacuum support system will have to follow the fuselage curve so that the vacuum hose can get close to the fuselage position where the holes are made.	High	fuselage barrel, vacuum tool	By technology demonstrator
UC4-FNC-02	Functional Requirement	Vacuum positioning	The VACUUM support framework shall be equipped with a positioning module able to move the vacuum hose that is mounted on the framework, to a requested target position	High	vacuum support system, vacuum positioning module	By technology demonstrator
UC4-FNC-03	Functional Requirement	Detection of positioning	DRILL and VACUUM shall be able to understand their position with respect to a coordinate reference system	High	Indoor positioning system, vacuum positioning module	By technology demonstrator
UC4-FNC-04	Functional Requirement	Interactions between DRILL and VACUUM	DRILL and VACUUM shall communicate to exchange information on their positions and to give/receive acknowledgement messages	High	Field interconnection module	By technology demonstrator
UC4-FNC-05	Functional Requirement	Operator Consensus for drilling	VACUUM shall be directed to a target position only after the DRILL operator has confirmed it is ready to drill at that position.	High	Consensus button/switch on drill, drill control	By preliminary demonstrator
UC4-FNC-06	Functional Requirement	Vacuum consensus for drilling	DRILL perforation must be allowed only when the VACUUM is in place	High	Green led on drill, drill control	By preliminary demonstrator
UC4-FNC-07	Functional Requirement	Tool predictive maintenance	The drill tip wear should be estimated to predict the tip remaining useful life	Medium	Edge detection and pattern recognition algorithms	By technology demonstrator
UC4-FNC-08	Functional Requirement	Obstacle perception	While the VACUUM is moving to reach the target position, obstacles are to be detected so that it can stop in time to avoid collision. Obstacles can be static objects or dynamic objects (possibly humans).	Medium	Vacuum positioning module, Vacuum support framework	By preliminary demonstrator
UC4-SEC-01	Security Requirement	Communication Security	Field communication shall support the reliability, integrity and confidentiality of the messages exchanged	High	Data sensing modules and data collection modules with IoT Framework	By design
UC4-OPR-01	Operational Requirement	Communication on edge	DRILL and VACUUM shall communicate with each other at the edge to minimize latency	High	Field interconnection module	By design
UC4-PRF-01	Performance Requirement	Real-time communication and execution	DRILL and VACUUM must cooperate in near real time	Medium	Drill control, vacuum control, field interconnection module	By demonstrator

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UC4-PRF-02	Performance Requirement	Communication Reliability	Communication should ensure delivery and quality of data transmission against interferences (e.g. noise, disturbances and/or frequency constraints on plant)	Medium	Field communication protocol	By design

Table 1 - UC4 requirements.

3.2 *UC5 - Trimming Quality Improvement*

3.2.1 Overall Description

3.2.1.1 High level Use Case Description

During trimming/milling activities delamination can be experienced on parts, caused by different phenomena that are difficult to be managed because of the high complexity and high numbers of variables (vibration, detachment of the part being cut, tool wear, speed, humidity, temperature, air pressure, etc.).

The objective of this use case is to create CPS(s) able to collect data coming from sensors and numerical control machines (CNC[10]), analyze them with a quality statistic algorithm and understand the main root causes of defects and then provide real time information in order to change the setting of machine parameters to reduce the risk of damage or defect.

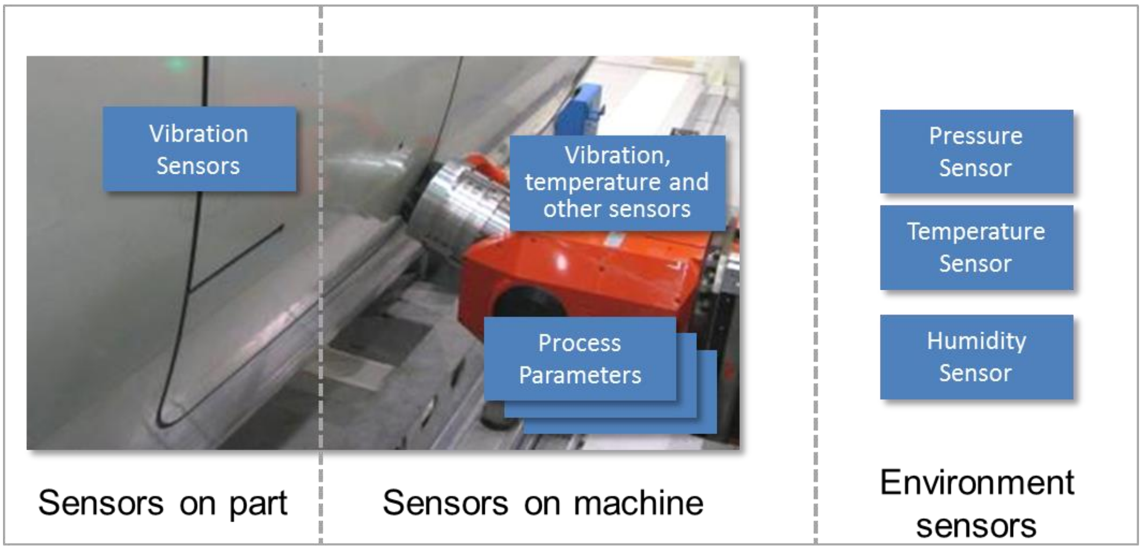

Figure 17 - UC5 overview.

3.2.1.2 Main Features

Among delamination causes there are parameters – such as tool rotation speed and moving speed – that at the moment are fixed for the whole process, unknown factors – such as vibrations on tool and surface – and adhesion between part and supporting tool (the part being cut tends to detach itself from the main part).

[10] In CNC machines programs are fed in the computer to control machine operations

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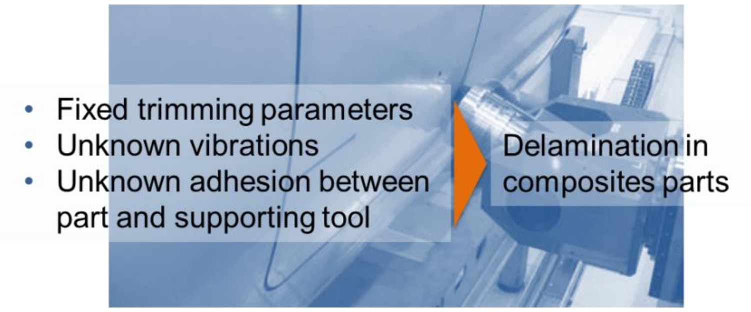

Figure 18 - UC5 delamination in composite parts possible causes.

The use case is composed by two phases:

The **first phase** focuses on the production of the quality prediction model, starting from the acquisition of sensor data on trimming sessions, along with the corresponding ex-post evaluation of the output quality, in order to build a significant history to feed into the AI/ML box with the aim to identify the correlation between parameters that can produce defects.

The **second phase** is devoted to the real time application of the quality prediction model in order to suggest the setting of tool parameters, with the aim to reach the best final quality. The ability to automate the parameter setting by interfacing with the PLC machine at this stage is not envisaged; the Use Case will provide parameters to the PLC operator for the real time manual setting.

At the end of the cycle, the quality of the trimming is valuated (by the NDI inspection), attributed to the new dataset and fed into the system, with the aim to further improve the AI/ML prediction model. The continuous feeding of datasets may result in a refinement of the quality prediction model. When it happens, the new model will be tested and eventually replace the previous model.

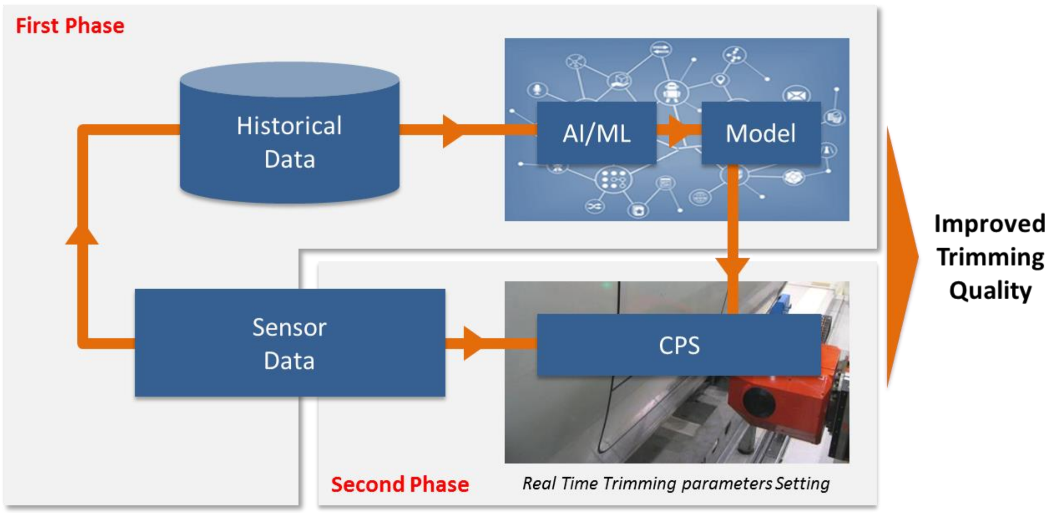

Figure 19 - UC5 first and second phases.

3.2.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
UC5-FNC-01	Functional Requirement	Environment parameters acquisition	Information regarding environment temperature, pressure and humidity shall be measured	High	Environmental sensing module	By design,

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						By technology demonstrator
UC5-FNC-02	Functional Requirement	Vibration parameters acquisition	Vibrations shall be measured on the part being worked, on the trimming tool tip, on the Trimming machine.	High	Sensing modules with vibration sensors; Sensorized trimmer mandrel	By design, by technology demonstrator
UC5-FNC-03	Functional Requirement	Air flow parameters acquisition	The flux and temperature of the air flow that is hoovered from the fuselage part being worked shall be measured	High	Sensing module equipped with temperature and flux sensors	By design, by technology demonstrator
UC5-FNC-04	Functional Requirement	TRIMMER parameters acquisition	The TRIMMER tip rotation, trimmer moving speed, position, shall be measured during the trimming process	High	Trimming machine, trimming acquisition module	By design, by technology demonstrator
UC5-FNC-05	Functional Requirement	Part identification	The part being worked shall be identified in order to label the data obtained during the trimming process	High	Trimmer Part program; trimming acquisition module	By design, by technology demonstrator
UC5-FNC-06	Functional Requirement	Correlation model	The system shall support discovering of correlations between the collected process variables and the reported defects using machine learning techniques	High	Data collection module, data analysis module	By design, by demonstrator
UC5-FNC-07	Functional Requirement	Process Monitoring	The system should provide the operator with alerts on process variables according to the correlation model output	Mediu m	HMI, prediction module	By preliminary demonstrator
UC5-SEC-01	Security Requirement	Communication Security	Field communication shall support the reliability, integrity and confidentiality of the messages exchanged	High	Data sensing modules and data collection modules with IoT Framework	By design
UC5-PRF-01	Performance Requirement	Real-time communication and execution	The system should provide the operator with information in near real-time to enable the operator to adjust the settings of production machine	Mediu m	Data, collection module, prediction module on the edge, HMI	By demonstrator
UC5-OPR-01	Operational Requirement	Interoperability	The system should be able to support various protocols and interfaces for communication at the edge and to data center	High	Data collection module with, IoT framework	By design, by technology demonstrator
UC5-FNC-08	Functional Requirement	Remote Management	The system should support remote management and software updates of firmware and business logic	Mediu m	IoT framework management	By design, by technology demonstrator
UC5-FNC-09	Functional Requirement	Update of the correlation model	The correlation model should be updated and improved through collection of new processing data, including results from the quality inspection	Mediu m	Prediction Module; Data Science module	By technology demonstrator
UC5-PRF-02	Performance Requirement	Communication Reliability	Communication should ensure delivery and quality of data transmission against interferences (e.g. disturbances and/or radio frequency constraints of the production floor)	Mediu m	Field communicatio n protocol	By design

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Table 2 - UC5 requirements.

3.3 UC6 - THERMOPLASTIC PRODUCTION LINE MONITORING

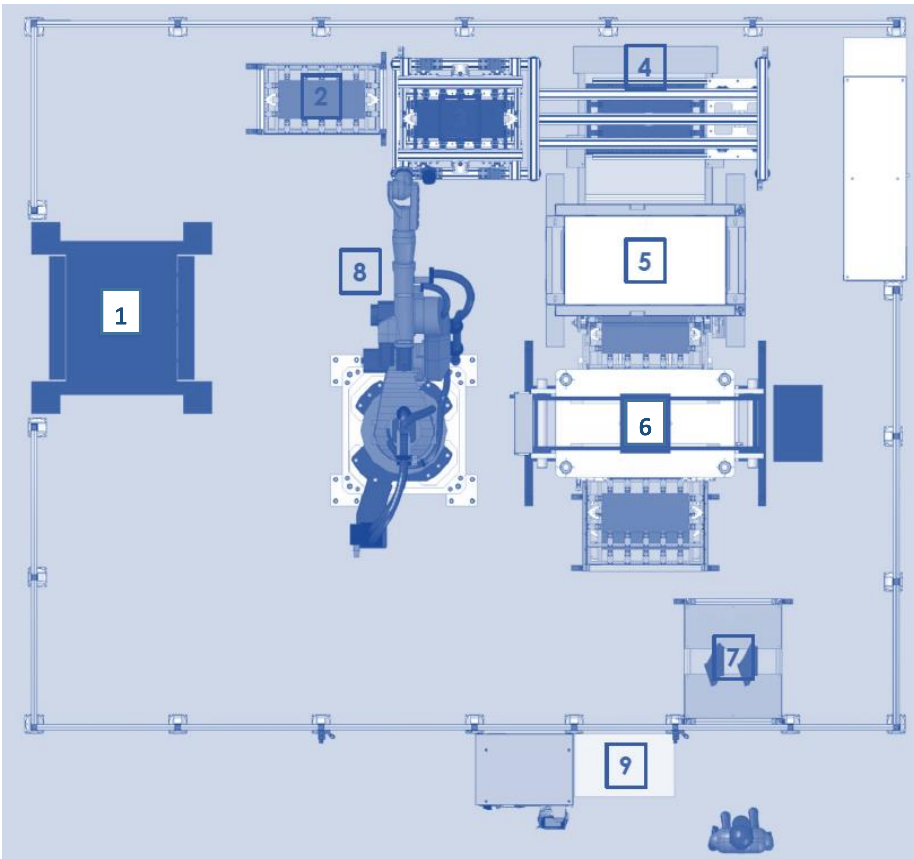
3.3.1 Overall Description

3.3.1.1 High level Use Case Description

A new Thermoplastic Production Line is in the process of being installed in the Grottaglie production plant to manufacture thermoplastic matrix composites parts[11]. The production line will be fully automated.

The objective of this use case is to achieve the best possible quality of the final thermoplastic product, meeting customer specifications. The quality of the final product sheet is evaluated through:

- dimensional checks (e.g. sheet thickness, especially where it bends)
- surface quality checks.



① drying oven
② frame storage station
③ frame clamping
④ frame transfer conveyor belt
⑤ heating device (IR oven)
⑥ moulding press
⑦ moulded parts storage station
⑧ grasping station
⑨ management console

Figure 20 - UC6 production line overview

[11] *Thermoplastic composites are used for aerospace structures due to their high specific strength and stiffness, enhanced toughness and high temperature resistance. A thermoplastic resin differs from a thermoset resin (epoxy for example) in that is can be re-formed multiple times to the desired shape. Thermoset composites (i.e. epoxies) on the other hand permanently lock into place after cure and, once they are cured, they cannot be re-formed or re-shaped. A thermoplastic composite, however, can be re-heated and once it is above its softening temperature it can be re-formed.*
This characteristic also provides the ability to use fast cycle times to heat the thermoplastic composite, form it, and shape it in seconds or minutes versus hours that it would take a thermoset to cure.

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3.3.1.2 *Main Features*

The formatting of these complex parts requires an accurate setting of the transformation process, heating, pressing and cooling which has to comply with strict standards and requirements.

To be implemented, the thermoplastic resin is heated to high temperature and undergoes a controlled rate cooling to obtain the appropriate structure and determining the mechanical properties of the composite material part. The manufacturing processes envisages thermoplastic stamp forming (shaped in a hot press).

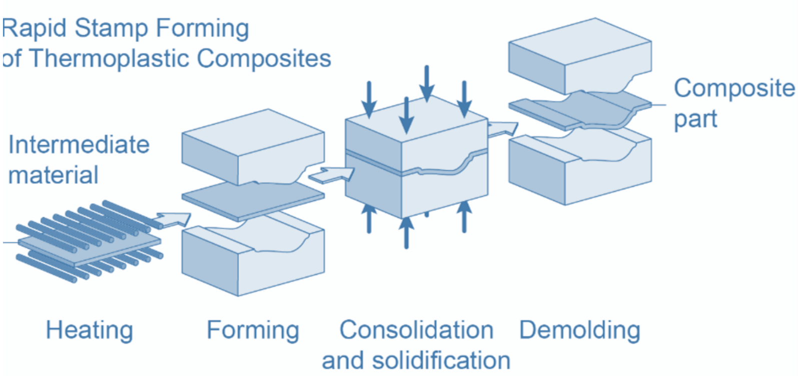
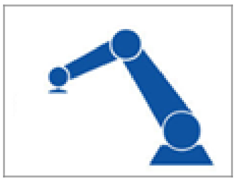
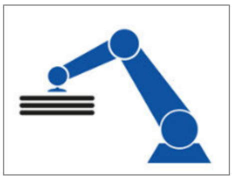
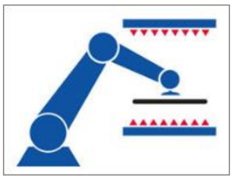
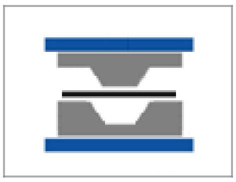


Figure 21 - UC6 stamp forming of thermoplastic composites.

Pressure, times, temperatures depend on thickness, dimension, geometry of the part and are to be monitored in order to correctly stamp form the part. These are the parameters to be collected by CPSs for later analysis.

The following are the main steps of the process as will be implemented in the production line:

The thermoplastic sheets are placed in racks inside the drying oven ① where they are kept for a certain amount of time at a given temperature.	
Through the robot arm the grasping station ⑧ is able to grasp and hold the sheet so that can be moved to station ③.	
Here thermoplastic sheet is picked up and clamped into a frame. A critical step is the correct positioning of the sheet.	
The sheet is placed into the heating device ⑤ which was previously heated to the required temperature. Here it is heated and begins to sag. During the passage from ① to the IR oven ⑤ the sheet temperature decreases, depending also on the ambient temperature. Such reduction affects the subsequent heating phase in the IR oven which is programmed by PLC to reach a certain temperature. The distribution of heat on the sheet coming out of the IR oven - relevant for the final quality of the product - is not currently monitored and it is not monitored before the sheet enters the IR oven.	
The robot arm inserts the sheet into the moulding press ⑥ a then it is left for a certain amount of time at a lower temperature for consolidation.	

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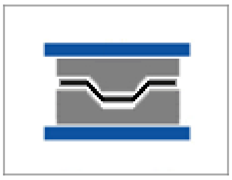
When the mould closes, the part is moulded by an hydraulic press in a process called “casting under pressure”.



When the process is completed, the part can be removed from the mould and piled up in the stocking station.

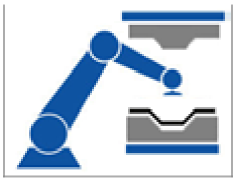


Figure 22 - UC6 production line steps.

The main objective of the Use Case is to identify the factors that contribute to the final quality of the product.

The system will support the production process through the collection of data to enable the discovery of the correlation between environment parameters (temperature, pressure, humidity) / process parameters (e.g. oven temperature, casting pressure, etc.) and the quality of the final part.

Then, depending on the parameters set, it will be possible to estimate a priori the quality of the final part or adjust the real time parameters to achieve the best quality.

Means of validation of the requirements is not filled (i.e. not applicable (N/A)) as the scope in CPS4EU of this use case is limited to requirements definition.

3.3.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
UC6-FNC-01	Functional Requirement	Thermoplastic sheet dimensional checks	The system should provide dimensional checks of the thermoplastic sheet thickness to evaluate the quality of the final product	Medium	Sensing module with Image analysis, 3D reconstruction	N/A
UC6-FNC-02	Functional Requirement	Surface quality checks	The system should provide information regarding the uniformity of the sheet surface to evaluate the quality of the final product	Medium	Sensing Module with edge detection and pattern recognition algorithms	N/A
UC6-FNC-03	Functional Requirement	Thermoplastic sheet temperature after heating	The system shall check that temperature uniformity on the thermoplastic sheet and that medium temperature is in the consented range, when the sheet exits the oven	High	Sensing module with Temperature recognition	N/A
UC6-FNC-04	Functional Requirement	Thermoplastic sheet temperature before moulding	The system shall check that medium temperature is in the consented range, before the sheet is moulded	Medium	Sensing module with Temperature recognition	N/A
UC6-FNC-05	Functional Requirement	Environment parameters acquisition	Information regarding environment (temperature, pressure and humidity) shall be measured	High	Sensing module with environmental sensors;	N/A
UC6-FNC-06	Functional Requirement	Correlation model	The system shall support the discovery of correlations between process variables and the final quality of the sheet	High	Data collection module, data analysis module	N/A
UC6-FNC-07	Functional Requirement	Process Monitoring	The system should provide the operator with the optimal	Medium	prediction module, HMI	N/A

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Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
			parameter setting according to the correlation model			
UC6-SEC-01	Security Requirement	Communication Security	Field communication shall support the reliability, integrity and confidentiality of the messages exchanged	Medium	Data sensing modules and data collection modules with IoT Framework	designN/A
UC6-OPR-01	Operational Requirement	Interoperability	The system should be able to support various protocols and interfaces for communication at the edge and to data center	High	Data collection module with IoT framework	N/A
UC6-FNC-08	Functional Requirement	Remote Management	The system should support remote management and software updates of firmware and business logic	High	IoT framework management	N/A
UC6-PRF-01	Performance Requirement	Communication Reliability	Communication should ensure delivery and quality of data transmission against interferences (e.g. disturbances and/or radio frequency constraints of the production floor)	Medium	Field communication protocol	N/A

Table 3 - UC6 requirements.

3.4 *UC7 - Aircraft Health Management System*

3.4.1 Overall Description

3.4.1.1 High level Use Case Description

The Aircraft Health Management System (AHMS) is devoted to gathering, collecting and analyzing data concerning aircraft fleet maintenance.

The overall system (depicted in the figure below) consists of different modules, located both on-board and on-ground, providing data and HW / SW framework, whose objective is to collect and correlate all data in order to support AHMS users.

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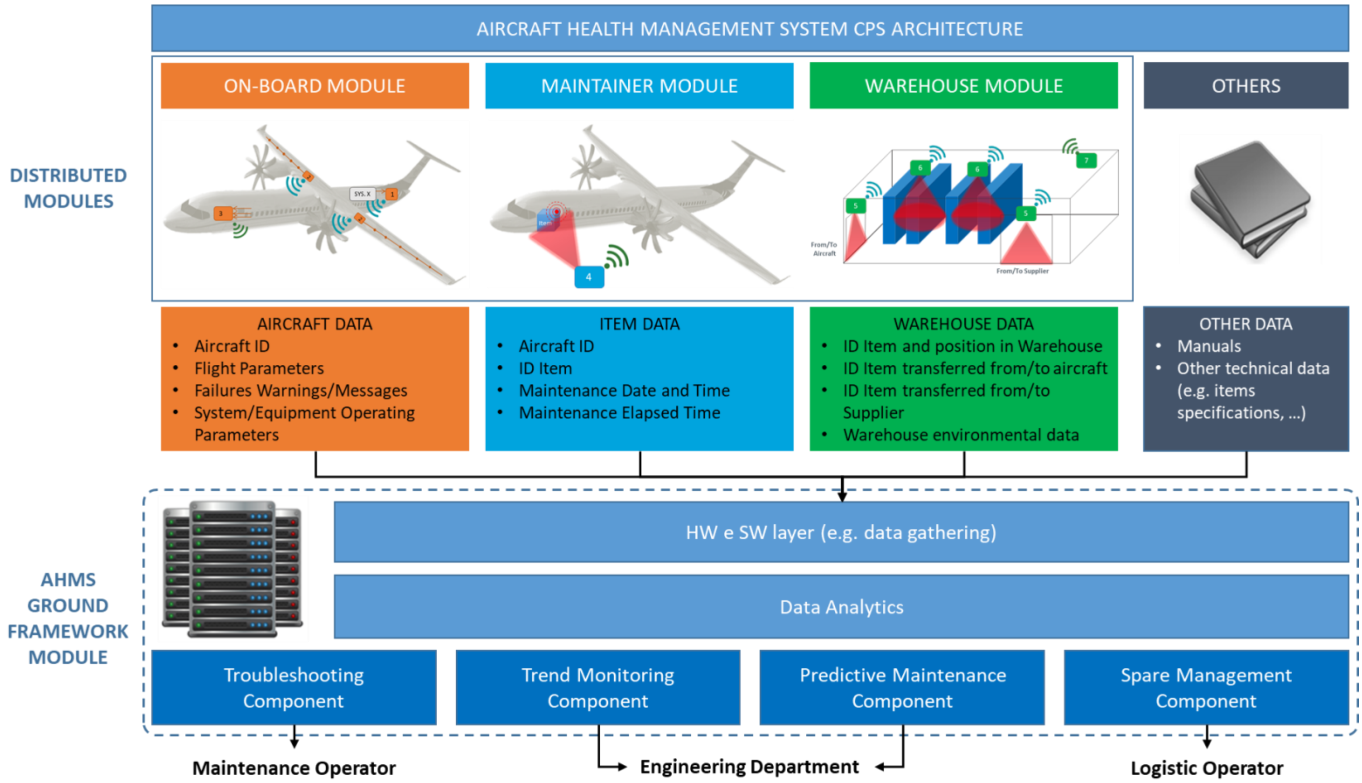

Figure 23 - AHMS CPS – overall picture

Data coming from aircraft belong to two main categories: failures (i.e. events having a possible impact on aircraft availability) and performances (to be used to monitor aircraft systems health status). The first have to be fixed as soon as possible, the latter have to be used to anticipate future possible failures whenever possible.

Regarding warehouse data, they are related to equipment/components removed from aircraft to be repaired (at Customer or Supplier premises) and equipment/components available as spare in the warehouse.

Other data (e.g. maintenance, manuals) could be handled by such a framework. In this Use Case the focus will be limited only to Technical Manuals used in the Troubleshooting feature.

3.4.1.2 Main Features

The global picture of this use case is very complex. Within the CPS4EU project, the focus will be on the Ground Framework module and particularly on the following components:

- Troubleshooting: this component provides support to the Maintenance Operator in order to limit aircraft downtime.
- Trend Monitoring: this component allows the Operator to monitor aircraft systems performances.
- Predictive Maintenance: this component is intended to anticipate possible failures analysing performance data.
- Spare Management: this component aims to optimize warehouse and supply chain management, reducing the risk of aircraft downtime due to missing parts.

3.4.1.3 Limitations

The following limitations and constraints should be considered for development:

- For items to be installed on aircraft, the aeronautical regulations (e.g. qualification) shall be applied.
- The system shall be designed taking into account that data generated (both on board and on ground), for IPR reason, are to be disclosed according to legal agreements between involved parts.

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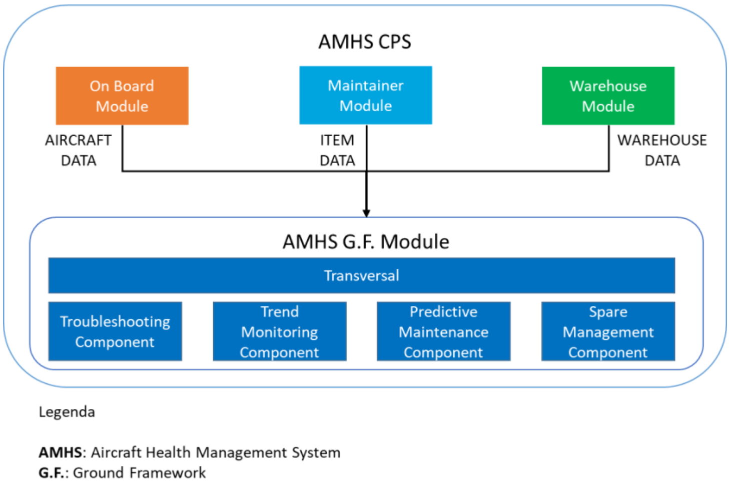
3.4.2 REQUIREMENTS

The AHMS consists of different modules. In this section requirements are provided for:

- **On-Board module**, installed on the Aircraft
- **Maintainer module**, used by Maintenance Operator
- **Warehouse module**, installed inside warehouse
- **AHMS Ground Framework (GF)**, module on ground where data are collected and analysed.



High level requirements for all the CPS modules are described in the following paragraphs in order to provide a complete picture of the overall CPS Scenario.

More detailed requirements are provided for the Troubleshooting, Trend Monitoring, Predictive Maintenance and Spare Management components of the AHMS Ground framework module.

Means of validation of the requirements is not filled (i.e. not applicable (N/A)) for the Trend Monitoring, and Predictive Maintenance components as the scope in CPS4EU of this use case is limited to the implementation of the Troubleshooting and Spare Management components of the AHMS Ground framework module.

3.4.2.1 On-Board Module

The main objectives of On-Board module are:

- collect information from sensors or aircraft System (e.g. Flight Control System)
- elaboration of streams of data / extraction of features /recording
- sharing of data on board or towards ground

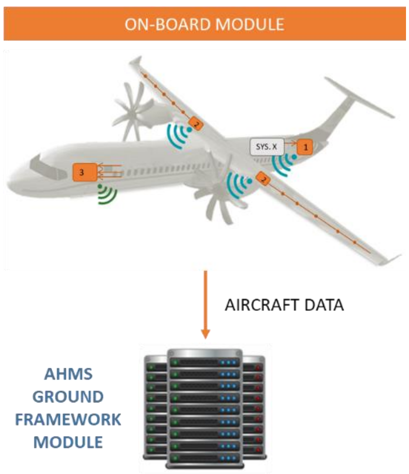


Figure 24 - AHMS CPS – On-Board module

In following table requirements related to the On-Board module are detailed.

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Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
UC7-INT-01	Interface Requirement	Connection within aircraft	The On-board CPS shall be able to receive data from the aircraft system.	High	Onboard Module	N/A
UC7-FNC-01	Functional Requirement	Recording data on NVM	The On-board CPS shall be able to record received data on a non-volatile memory.	High	Onboard Module	N/A
UC7-FNC-02	Functional Requirement	Computation	The On-board CPS shall be able to perform computation based on data received from the aircraft system.	High	Onboard Module	N/A
UC7-FNC-03	Functional Requirement	Modifiable algorithm	The On-board CPS shall be able to perform computation using user-modifiable algorithms without impacting aircraft certification.	Medium	Onboard Module	N/A
UC7-FNC-04	Functional Requirement	Algorithm upload	The Operator shall be able to upload The On-board CPS user-modifiable algorithms.	Medium	Onboard Module	N/A
UC7-FNC-05	Functional Requirement	Aircraft system data	The On-board CPS shall be able to receive the following aircraft system data: identification data, configuration data, maintenance data, performance data and usage data.	High	Onboard Module	N/A
UC7-INT-02	Interface Requirement	Connection to AHMS Ground Framework	The On-board CPS shall be able to transmit the aircraft system data to AHMS Ground Framework through a wireless connection when the aircraft is on-ground.	High	Onboard Module	N/A
UC7-SEC-01	Security Requirement	Secure connection	The On-board CPS shall provide a secure wireless connection.	High	Onboard Module	N/A
UC7-DSG-01	Design Constraints	Power supply	The On-board CPS power supply shall be compliant with the aircraft system power supply.	High	Onboard Module	N/A
UC7-DSG-02	Design Constraints	Power consumption	The On-board CPS power consumption shall be limited to TBD% of the aircraft system power consumption.	Medium	Onboard Module	N/A
UC7-DSG-03	Design Constraints	Weight	The On-board CPS weight shall be limited to TBD% of the aircraft system weight.	Medium	Onboard Module	N/A
UC7-DSG-04	Design Constraints	Volume	The On-board CPS volume shall be limited to TBD% of the aircraft system volume.	Medium	Onboard Module	N/A
UC7-OPR-01	Operational Requirement	EMC regulation	The On-board CPS hardware shall be compliant with applicable EMC regulations (AC 20-190).	High	Onboard Module	N/A
UC7-OPR-02	Operational Requirement	Environmental regulation	The On-board CPS hardware shall be compliant with applicable environmental regulations (DO 160 G).	High	Onboard Module	N/A

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Table 4 – UC7 requirements - On-Board module

3.4.2.2 Maintainer and Warehouse modules

Purposes of the Maintainer and Warehouse modules are:

- to identify items removed/installed on aircraft for maintenance activities
- to identify items inside the warehouse or moved towards the aircraft/Supplier
- to elaborate data in order to have an up-to-date status of the warehouse
- to share collected information with AHMS GF and other devices

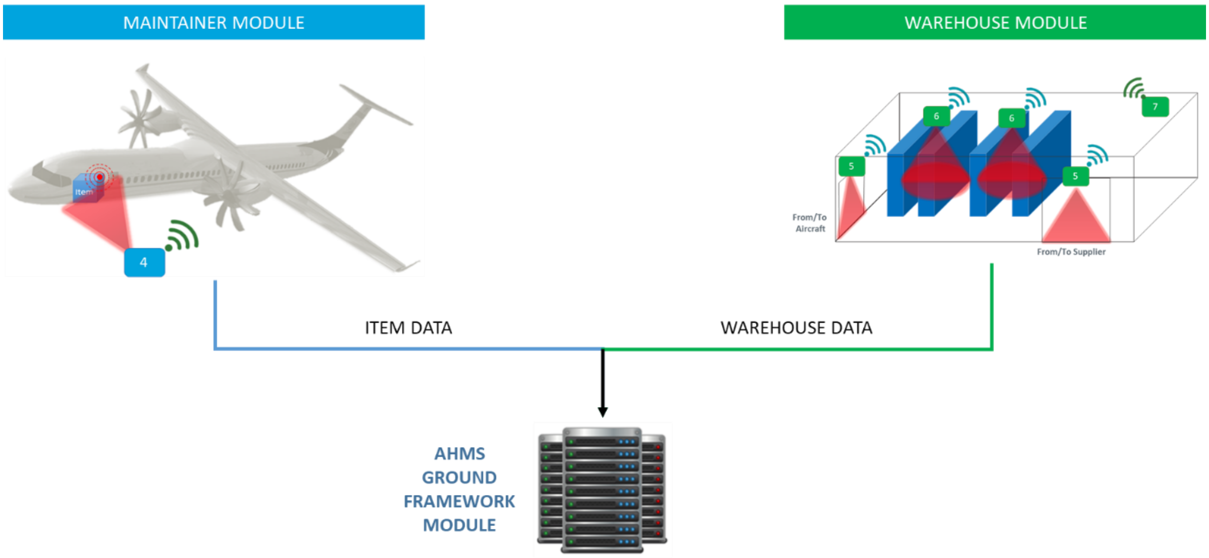

Figure 25 - AHMS CPS – Maintainer and Warehouse modules

In the following table, the requirements related to the Maintainer module are detailed.

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**	**Link to functional components**	**Means of validation**
UC7-FNC-06	Functional Requirement	Communication with CPS Ground Framework	The Maintainer CPS shall be able to exchange data with the AHMS Ground Framework	High	Maintainer Module	N/A
UC7-FNC-07	Functional Requirement	Communication within Maintenance CPS	The Maintainer CPS shall be able to exchange data with other Maintainer CPSs	High	Maintainer Module	N/A
UC7-FNC-08	Functional Requirement	Aircraft Replaceable Item Identification	The Maintainer CPS shall be able to identify in an automated way the items on aircraft that are subject to maintenance activity. To each item is applied a component (e.g. RFID plate) that stores item identification information.	High	Maintainer Module	N/A

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UC7-FNC-09	Functional Requirement	Replaceable Item Removal/Installation	The Maintainer CPS shall be able to discriminate between items Removed from aircraft and items Installed on aircraft using the component (e.g. RFID plate) that stores item identification information.	High	Maintainer Module	N/A
UC7-FNC-10	Functional Requirement	Maintenance Elapsed Time	The Maintainer CPS shall be able to record the Maintenance Elapsed Time (i.e. interval of the maintenance activity excluding logistic delays).	Medium	Maintainer Module	N/A
UC7-FNC-11	Functional Requirement	Data collection and processing	The Maintainer CPS shall be able to collect and process identified item data	High	Maintainer Module	N/A
UC7-FNC-12	Functional Requirement	Interaction with other devices (e.g. Wearable, Portable Computational Devices…)	The Maintainer CPS shall be able to interact with other devices and/or AHMS Ground Framework, to allow the automated identification of the information required to perform maintenance activities (troubleshooting, removal/installation procedures…)	Medium	Maintainer Module	N/A
UC7-INT-03	Interface Requirement	Communication	The Maintainer CPS shall exchange data through wireless connection	High	Maintainer Module	N/A
UC7-PRF-01	Performance Requirement	Item Identification Data Transfer Speed	The Maintainer CPS data transfer time for Item Identification shall not last longer than 3 seconds	High	Maintainer Module	N/A
UC7-DSG-05	Design Constraints	Maintenance CPS Portability	The Maintainer CPS shall be portable or wearable by the maintainer personnel during maintenance activities	Medium	Maintainer Module	N/A
UC7-FNC-13	Functional Requirement	Maintenance Date and Time	The Maintainer CPS shall be able to record the Maintenance Date and Time	High	Maintainer Module	N/A
UC7-FNC-14	Functional Requirement	Operator User ID	The Maintainer CPS shall be able to store and manage the Maintenance Operator User ID.	High	Maintainer Module	N/A

Table 5 – UC7 requirements - Maintainer module

In the following table the requirements related to the Warehouse module are detailed.

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**	**Link to functional components**	**Means of validation**
UC7-FNC-15	Functional Requirement	Communication with CPS Ground Framework	The Warehouse CPS shall be able to exchange data with the AHMS Ground Framework	High	Warehouse Module	N/A
UC7-FNC-16	Functional Requirement	Communication within Warehouse CPS	The Warehouse CPS shall be able to exchange data with others Warehouse CPS	High	Warehouse Module	N/A

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UC7-FNC-17	Functional Requirement	Item Identification	The Warehouse CPS shall be able to identify in an automated way the items: - Inside the Warehouse - Moved from/to aircraft to/from the Warehouse - Moved from/to Supplier to/from the Warehouse To each item is applied a component (e.g. RFID plate) that stores item identification information	High	Warehouse Module	N/A
UC7-FNC-18	Functional Requirement	Inventory Data Collection and Processing	The Warehouse CPS shall be able to collect and pre-process inventory data before sending them to the AHMS Ground Framework	High	Warehouse Module	N/A
UC7-PRF-02	Performance Requirement	Inventory Data update	The Warehouse CPS shall be able to send updated items inventory information (e.g. stock, position..) to the AHMS Ground Framework each 5 minutes	High	Warehouse Module	N/A
UC7-SEC-02	Security Requirement	Secure Connection	The Warehouse CPS wireless communications shall be encrypted during data transfers	High	Warehouse Module	N/A
UC7-FNC-19	Functional Requirement	Environmental Conditions	The Warehouse CPS shall be able to acquire data on the environmental conditions (e.g. temperature, humidity).	Medium	Warehouse Module	N/A
UC7-FNC-20	Functional Requirement	Modifiable Algorithms	The Warehouse CPS shall be able to perform computation using user-modifiable algorithms	High	Warehouse Module	N/A
UC7-FNC-21	Functional Requirement	Environmental restrictions DB	The Warehouse CPS shall be able to retrieve item stocking environmental conditions restrictions from dedicated DB.	Medium	Warehouse Module	N/A
UC7-FNC-22	Functional Requirement	Environmental conditions warning	The Warehouse CPS shall be able to generate a warning if the environmental conditions are out of limits for stocked items.	Medium	Warehouse Module	N/A

Table 6 – UC7 requirements - Warehouse module

3.4.2.3 AHMS Ground Framework (GF) module

The AHMS GF is a complex environment whose scope is to support Customer maintenance operations.

It manages a large amount of data, e.g.:

- data collected during in-flight operations;
- data coming from maintenance and warehouse;
- all information related to aircraft (e.g. manuals).

The AHMS framework is the ground node enabling the data exchange between all actors involved in Maintenance. In addition to Operators belonging to Customers, a link to Airframer (i.e. the aircraft manufacturer and support services provider) is foreseen as well. The main reason of this link is to simplify the Airframer support. For sure this sharing of data between Customer and Airframer has to be done in accordance to a framework of rules (e.g. commercial agreements, need-to-know/IPR rules and security requirements).

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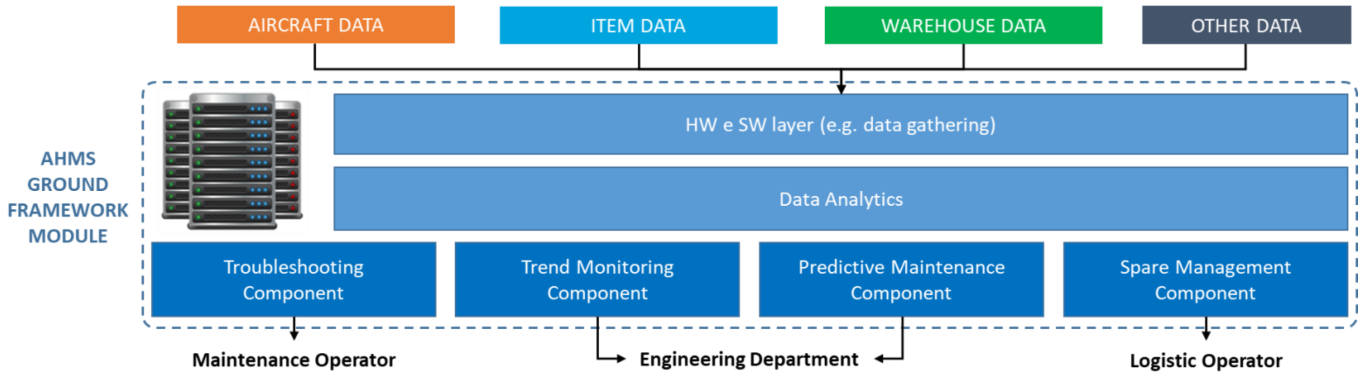

Figure 26 - AHMS CPS – Ground Framework

AHMS, through dedicated interfaces in the GF, is intended to support the users belonging both to Customer and Airframer entities, in particular:

- Customer users:
  - **Maintenance Operator**, in charge of performing the maintenance tasks according to planning;
  - **Engineers**, in charge of analysing data and, if needed, scheduling maintenance tasks;
  - **Logistic Operator**, in charge of managing parts transportation, optimizing spares according to the needs.
- Airframer users:
  - **Airframer Operator**, not specific tasks defined. In order to limit the perimeter of CPS4EU no specific requirements are associated to Airframer User. In this document the Airframer User has access to all data and components available to the Customer users, and mainly has a monitoring/managing generic purpose.

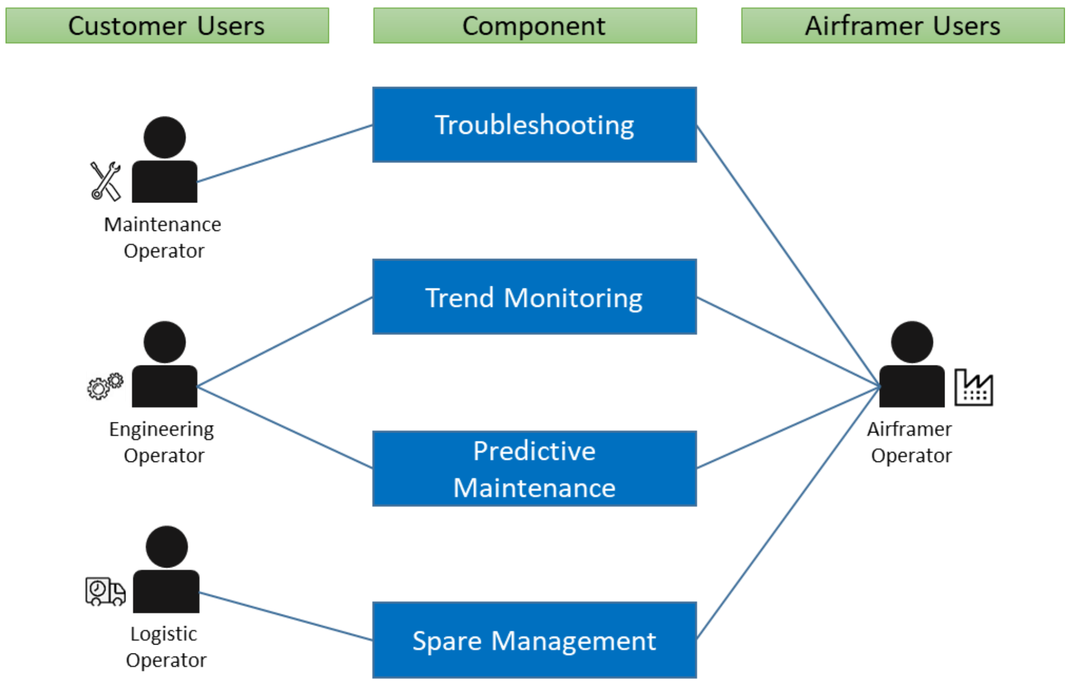

Figure 27 - AHMS Ground Framework users

In particular, data coming from On-Board, Maintainer and Warehouse modules, are used to:

- provide **Maintenance Operator** with information supporting Troubleshooting. Each failure occurred during flight is associated to specific procedures in order to help failure isolation. Moreover, based on historical data, the System supports the Operator suggesting solutions with higher success probability.

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- provide **Engineering Operator** with the capability of:
    - (Trend Monitoring) monitoring aircraft systems performance w.r.t. predefined and customizable thresholds
    - (Predictive Maintenance) setting maintenance actions anticipating possible future failures calculated following two possible approaches: comparison w.r.t. historical database or w.r.t. predictive models able to calculate Remaining Useful Life (RUL).
- provide **Logistic Operator** with information (Spare Management) supporting his/her decisions by monitoring the actual spare demand, considering equipment / components removals, logistics, inventory (e.g. spare parts) and maintenance task planning.

In next sections AHMS GF requirements are provided as follows:

- Transversal req.: applicable to the framework module itself in order to guarantee all components;
- Troubleshooting req.
- Predictive req.
- Trend Monitoring req.
- Spare Management req.

3.4.2.3.1 Transversal requirements

Requirements listed in this section are not specific, but common across all AHMS Ground framework components. They cover transversal areas, such as security.

Means of validation of those requirements is not filled (i.e. not applicable (N/A)) as they are concerned with the design and implementation of infrastructural and security elements of this use case that are relevant for a final protoype/industrial product but are beyond the scope of the preliminary protoype that is implemented in the project.

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**	**Link to functional components**	**Means of validation**
UC7-P&C-01	Policies &Compliance Requirement	Security requirement for military applications	The AHMS GF shall be compatible with military regulations (e.g. U.S. Security Authority for the North Atlantic Treaty Organization Affairs - USSAN, ...).	High	AHMS GF - Transversal component	N/A
UC7-P&C-02	Policies &Compliance Requirement	Security requirement for civil applications	The AHMS GF shall be compatible with EUROCAE ED203A airworthiness security methods and considerations.	High	AHMS GF - Transversal component	N/A
UC7-P&C-02	Policies&Compliance Requirement	IPR	The AHMS GF shall be able to guarantee IPR, segregating data belonging to different Customers	High	AHMS GF - Transversal component	N/A
UC7-SEC-03	Security Requirement	User identification	The AHMS GF shall allow different users profile to access according to need-to-know criteria	High	AHMS GF - Transversal component	N/A
UC7-SEC-04	Security Requirement	Login	The AHMS GF shall provide protected logins with configurable permissions.	High	AHMS GF - Transversal component	N/A
UC7-SEC-05	Security Requirement	Antivirus	The AHMS GF shall provide an antivirus scanning capability for its components.	High	AHMS GF - Transversal component	N/A

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UC7-SEC-06	Security Requirement	AHMS security barrier	The AHMS GF shall provide a security barrier with other on-board and off-board systems.	High	AHMS GF - Transversal component	N/A
UC7-INT-04	Interface Requirement	Communication to CPS for Aircraft	The AHMS GF shall be able to receive data coming from the aircraft through both wired and wireless connections when the aircraft is on-ground.	High	AHMS GF - Transversal component	N/A
UC7-INT-05	Interface Requirement	Communication to CPS for Warehouse	The AHMS GF shall be able to receive data coming from the Warehouse CPS through Wireless connection	High	AHMS GF - Transversal component	N/A
UC7-INT-06	Interface Requirement	Communication to CPS for Maintenance	The AHMS GF shall be able to receive data coming from Maintainer CPS through a wireless connection.	High	AHMS GF - Transversal component	N/A
UC7-DSG-06	Design Constraints	Server and cloud solution	The AHMS GF shall be compatible both for a cloud and server based solution. Note: in case of server (located at Customer premises) based solution, data/information will be exchanged with Airframer by means of a physical support (external HDD, others,…)	High	AHMS GF - Transversal component	N/A
UC7-FNC-23	Functional Requirement	Back-up	The AHMS GF shall provide a back-up capability for all operator's data.	High	AHMS GF - Transversal component	N/A
UC7-SEC-07	Security Requirement	Data integrity	The AHMS GF functions shall be able to guarantee adequate data integrity	High	AHMS GF - Transversal component	N/A
UC7-FNC-23	Functional Requirement	AHMS services	The AHMS GF shall be able to support the following services: - Troubleshooting - Preventive/predictive maintenance - Trend Monitoring - Spare Management Note: requirements specific to each service can be found in the section dedicated to that sheet	High	AHMS GF - Transversal component	N/A
UC7-FNC-25	Functional Requirement	AHMS users	The AHSM shall be manageable by the following users: Maintenance Operator (belonging to Customer): interacting with Troubleshooting service; Engineering Operator (belonging to Customer): interacting with Preventive/Predictive Maintenance service; Logistic Operator (belonging to Customer): interacting with Spare Management service; - Airframer Operator (belonging to Airframer): monitoring and managing all services. - Administrator (belonging to Customer and Airframer): managing the tool setting new user profile	High	AHMS GF - Transversal component	N/A
UC7-FNC-26	Functional Requirement	Analytics / Algorithm integration	The AHMS GF shall be able to host third party's SW and/or algorithms (introduced to add a service).	High	AHMS GF - Transversal component	N/A

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UC7-FNC-27	Functional Requirement	Analytics / Algorithm upload	The AHMS GF shall allow the user to upgrade third party's SW and/or algorithms.	High	AHMS GF - Transversal component	N/A
UC7-FNC-28	Functional Requirement	Customer and Airframer	The AHMS GF shall be used by Customers and Airframer, according to bilateral commercial/legal agreement	High	AHMS GF - Transversal component	N/A
UC7-DSG-07	Design Constraints	AHMS Hardware - commercial PC	A subset of AHMS GF functions (e.g. operator HMI, simple computations) shall be compatible with commercial PCs.	High	AHMS GF - Transversal component	N/A
UC7-DSG-08	Design Constraints	AHMS Hardware - tablet	The AHMS GF shall be able to be hosted on tablet to be used by Maintenance Operator during tasks near the aircraft.	High	AHMS GF - Transversal component	N/A
UC7-DSG-09	Design Constraints	Growth capability	The AHMS GF shall be designed in order to offer a 50% growth capability in terms of computational power and storage with respect to the entry-into-service.	High	AHMS GF - Transversal component	N/A
UC7-DSG-10	Design Constraints	Open world SW	The AHMS GF shall be compatible as much as possible with open-world standards.	Medium	AHMS GF - Transversal component	N/A
UC7-DSG-11	Design Constraints	User modifiable SW	The AHMS GF functions shall be configured as much as possible using configuration files.	High	AHMS GF - Transversal component	N/A
UC7-OPR-03	Operational Requirement	GUI - user	The AHMS GF shall be able to manage different GUI, according to AHMS user task.	High	AHMS GF - Transversal component	N/A
UC7-OPR-04	Operational Requirement	GUI - profile	The AHMS GF shall display GUI according to pre-set user identification profile	High	AHMS GF - Transversal component	N/A
UC7-OPR-05	Operational Requirement	GUI	The AHMS GF GUI shall be easy to understand and use with minimal training for the operators.	High	AHMS GF - Transversal component	N/A
UC7-OPR-06	Operational Requirement	GUI	The AHMS GF GUI shall use language-independent symbols wherever possible.	High	AHMS GF - Transversal component	N/A
UC7-USB-01	Usability Requirement	GUI	The AHMS GF shall also provide a Web-Based GUI solution.	High	AHMS GF - Transversal component	N/A
UC7-OPR-07	Operational Requirement	GUI	The AHMS GF shall provide standard colour coding for alerts severity levels.	High	AHMS GF - Transversal component	N/A
UC7-FNC-29	Functional Requirement	Multiple User Logins	The AHMS GF shall be able to manage multiple different User logins from separate devices at the same time.	High	AHMS GF - Transversal component	N/A
UC7-FNC-30	Functional Requirement	Multiple User Data View	The AHMS GF shall allow different Users to view the same set of data at the same time from separate devices.	High	AHMS GF - Transversal component	N/A
UC7-FNC-31	Functional Requirement	Multiple User Analysis	The AHMS GF shall allow different Users to perform analyses on the same set of data at the same time from separate devices.	High	AHMS GF - Transversal component	N/A

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UC7-FNC-32	Functional Requirement	Data modification/ update alert	The AHMS GF shall warn Users when Data relevant to their Tasks has been modified/updated.	Medium	AHMS GF - Transversal component	N/A
UC7-DSG-12	Design Constraints	AHSM independent services	The AHMS GF shall be able to support The AHMS GF services (Troubleshooting, Predictive/Preventive Maintenance, Trend Monitoring and Spare Management) independently. Note: according to the needs of the Customer, the four services can be offered all together or only as a selected subset.	Medium	AHMS GF - Transversal component	N/A
UC7-FNC-33	Functional Requirement	Data tables	The AHMS GF shall allow Users to view the Data used for analyses in Tables.	High	AHMS GF - Transversal component	N/A
UC7-FNC-34	Functional Requirement	Data Export	The AHMS GF shall allow to export data and analyses results.	High	AHMS GF - Transversal component	N/A
UC7-FNC-35	Functional Requirement	Reporting	The AHMS GF shall allow to produce a pre-defined set of Reports Note: further requirements on the Reports will be detailed in the service-specific excel sheets.	High	AHMS GF - Transversal component	N/A
UC7-FNC-36	Functional Requirement	Third party's SW Import	The AHMS GF shall be able to exchange data with third parties SW (SAP, RCM SW,…).	High	AHMS GF - Transversal component	N/A
UC7-FNC-37	Functional Requirement	User Manual	The AHMS GF shall be able to host a Rapid User Manual.	Medium	AHMS GF - Transversal component	N/A
UC7-DSG-13	Design Constraints	GUI - Touch Screen	The AHMS GF GUI shall be compatible with Touch Screen devices.	Medium	AHMS GF - Transversal component	N/A
UC7-INT-07	Interface Requirement	Data and Data Flow standardization	All the Data and Data Flow shall be standardized.	High	AHMS GF - Transversal component	N/A
UC7-SEC-08	Security Requirement	User authorization	The AHMS GF shall be usable only by skilled authorized personnel.	High	AHMS GF - Transversal component	N/A
UC7-FNC-38	Functional Requirement	Query	The AHMS GF shall allow the user to generate grouping query on data tables.	High	AHMS GF - Transversal component	N/A
UC7-FNC-39	Functional Requirement	User ID	The AHMS GF shall be able to store and manage a unique User ID for each user that logs in.	High	AHMS GF - Transversal component	N/A
UC7-SEC-09	Security Requirement	Actions recording	The AHMS GF shall be able to associate the User ID to every action performed by the users, in accordance with privacy policies.	High	AHMS GF - Transversal component	N/A

Table 7 – UC7 AHMS Ground Framework: - transversal requirements

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3.4.2.3.2 Troubleshooting requirements

The objective of Troubleshooting component is to support the Maintenance Operator fixing failures occurred during a flight and possibly affecting the aircraft availability.

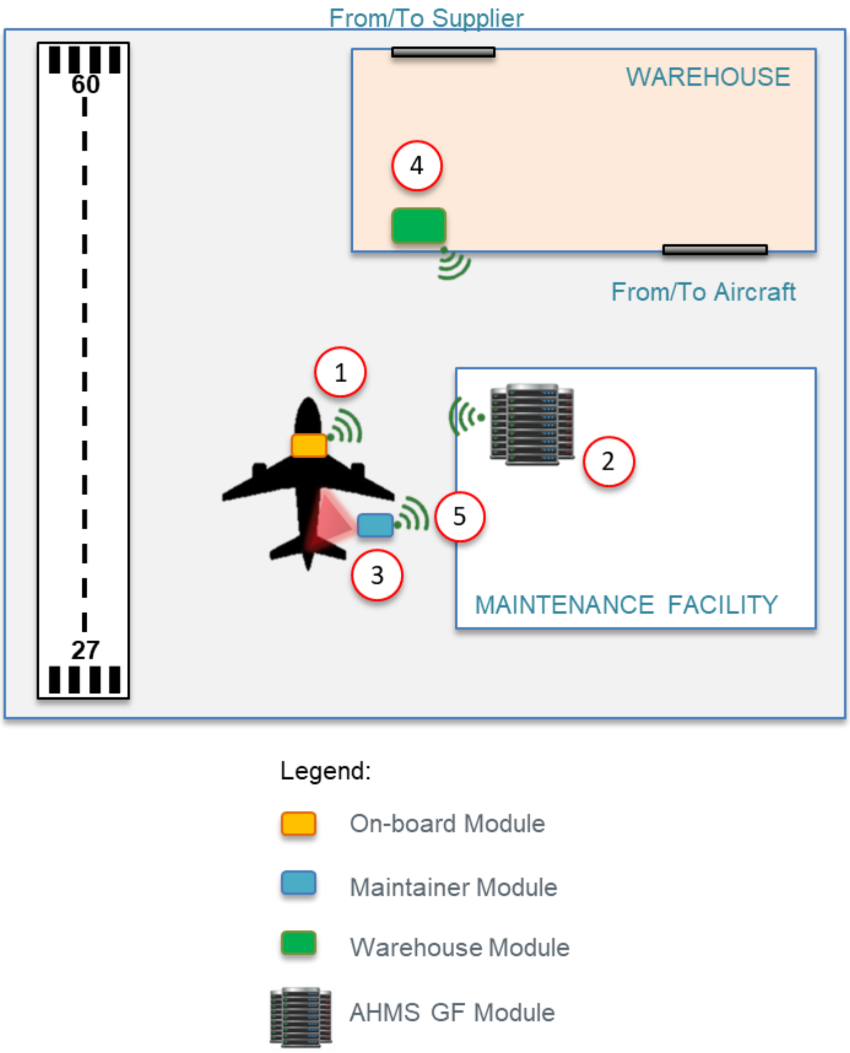
In general, during the Troubleshooting process, the Maintenance Operator relies on aircraft manuals where procedures to fix failures are described. Procedures often include several possible approaches to solve a failure, including the removals of different items or minor corrective actions on aircraft. Moreover, it is not always easy to keep a historical track of the identified solutions.

To improve this process, the idea for CPS4EU is to provide the Maintenance Operator with an additional tool: the AHMS GF provides a dedicated statistics functionality that shows the most convenient Troubleshooting approach, based on historical data analysis on recorded failures, removed items and, if necessary, flight parameters. Additionally, it can automatically link the failure to the identified solution.

To achieve this result, the Troubleshooting component shall be able to:

- analyse the data collected by the On-Board module;
- show only the failures that may require a maintenance action by the Operator along with charts that display the evolution of the flight parameters over the mission time;
- show the relevant Fault Isolation procedure manuals, using the failure *Fault Code,* an alphanumeric string that identify the procedure to be followed;
- support the Operator by calculating and showing a historical index rate of the most successful Troubleshooting approaches and possible items to be removed.

A typical usage scenario, which involves the Maintenance Operator and the Troubleshooting component, can be depicted as follows:



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The main operations sequence of the above scenario has been schematized in the Flow Chart of the next page. The numbers in red circles indicate the operations in which the modules of the AHMS (On-Board, Maintainer, Warehouse and AHMS G.F. modules) are directly involved.

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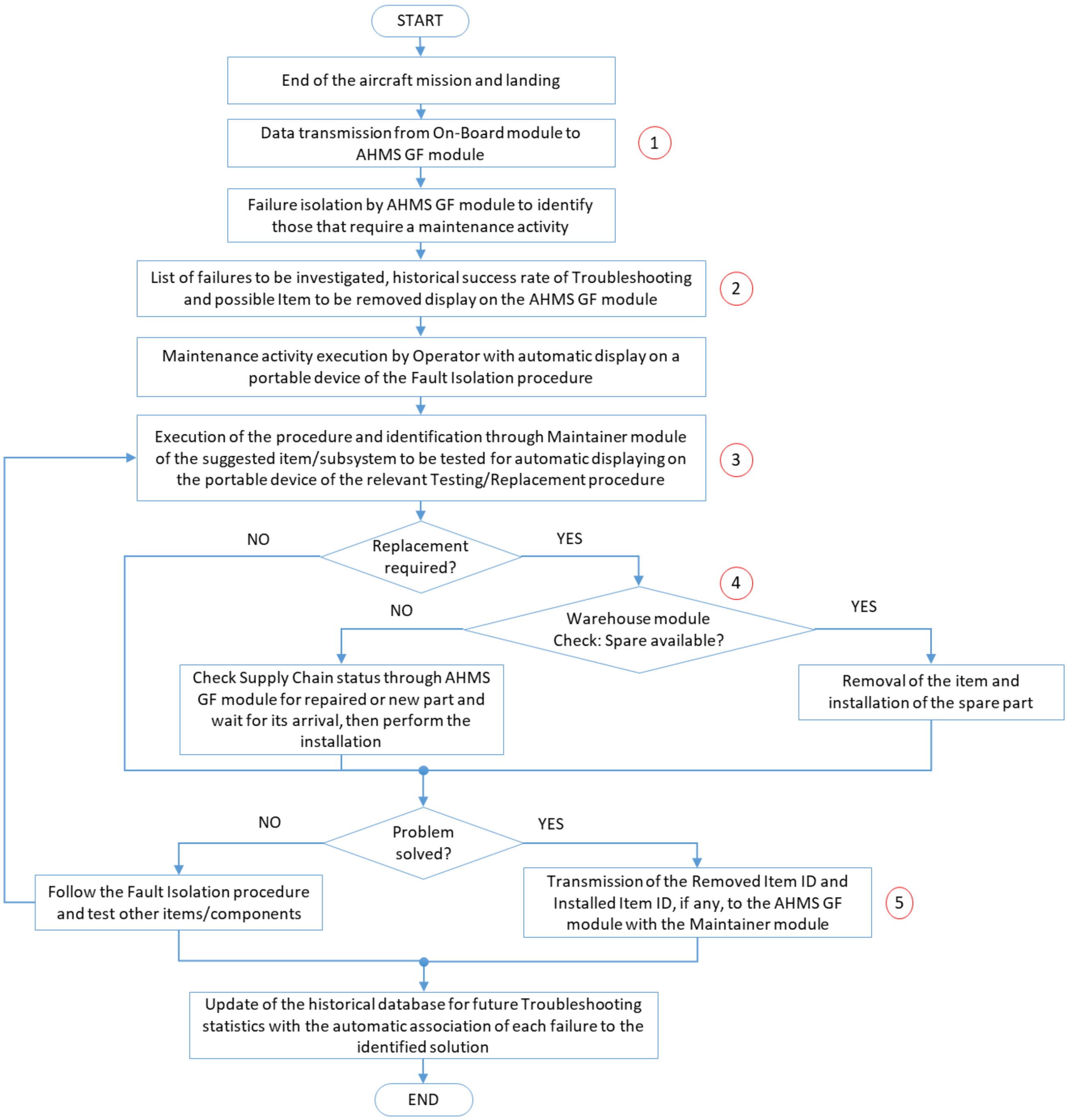

Figure 28 - Troubleshooting component main operations sequence

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**	**Link to functional components**	**Means of validation**
UC7-OPR-11	Operational Requirement	Maintenance Operator	The AHMS GF shall allow the Maintenance Operator to access Troubleshooting service	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-OPR-12	Operational Requirement	Airframer Operator	The AHMS GF shall allow the Airframer Operator to access Troubleshooting service	High	AHMS GF - Troubleshooting component	By preliminary demonstrator

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UC7-FNC-71	Functional Requirement	Messages between Customer and Airframer	The AHMS GF shall allow Maintenance Operator and Airframer Operator to exchange text messages during maintenance activities.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-72	Functional Requirement	Data between Customer and Airframer	The AHMS GF shall allow Maintenance Operator and Airframer Operator to exchange data and images during maintenance activities.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-73	Functional Requirement	On-Board CPS data management	The AHMS GF shall be able to store and manage the following data collected by the On-Board CPS of each aircraft of the Fleet: - alerts and warnings; - failures; - maintenance messages; - event date and time; - flight parameters.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-74	Functional Requirement	Maintainer CPS data management	The AHMS GF shall be able to store and manage the following data collected by the Maintainer CPS during Troubleshooting: - Aircraft ID (unique key for each aircraft in the AHMS GF); - Item ID (unique key for each item part number and serial number combination in the AHMS GF); - Maintenance Elapsed Time; - Maintenance Date and Time; - Activity typology: Item removed from aircraft or installed on aircraft; - Maintenance Operator User ID.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-75	Functional Requirement	Fault Code identification	The AHMS GF shall be able to analyse the failures collected from the last flight using Airframer defined Isolation Algorithms to identify only the failures and relevant Fault Code that require a maintenance activity.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-76	Functional Requirement	Fault Isolation procedure	The AHMS GF shall be able to link to each Fault Code the relevant Fault Isolation procedure contained in the Troubleshooting Manuals.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-77	Functional Requirement	Procedure success rate	The AHMS GF shall be able to calculate the success rate of each option included in a Fault Isolation procedure, as the percentage of the times in which an option solved the issue vs. the total times of the Fault Isolation procedure execution.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-78	Functional Requirement	Procedure probable faulty items	The AHMS GF shall be able to determine the most probable faulty items to be removed for each Fault Isolation procedure using the success rate and relationship with flight parameters patterns, if any	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-79	Functional Requirement	Average Maintenance Elapsed Time	The AHMS GF shall be able to calculate the actual average Maintenance Elapsed Time of each removal and installation recorded by the Maintainer CPS.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-80	Functional Requirement	Fault Code display	The AHMS GF shall be able to show to the Maintenance Operator the Fault	High	AHMS GF - Troubleshooting component	By preliminary

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			Codes that require a maintenance activity.			demonstrator
UC7-FNC-81	Functional Requirement	Fault Code selection	The AHMS GF shall allow the Maintenance Operator to select a single, a subset or all the Fault Codes on which he will directly perform the activities.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-82	Functional Requirement	Fault Code details	The AHMS GF shall be able to automatically show the Fault Isolation procedure, success rate and possible items to be removed for each Fault Code selected by the Operator.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-83	Functional Requirement	Flight Parameters	The AHMS GF shall be able to show the flight parameters in a parameter vs time chart.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-84	Functional Requirement	Flight Parameters interaction	The AHMS GF shall allow the Maintenance Operator to change the scale and the formatting of the chart and filter the flight parameters to be shown.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-DSG-14	Design Constraints	AHMS GUI - tablet	The AHMS GF GUI shall be able to show the Fault Code details (ref. req. UC7-FNC-14) on commercial portable devices with diagonals between 10" to 15"	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-85	Functional Requirement	Item to be tested	The AHMS GF shall be able to automatically show the Operator the Testing/Replacement procedure of the Item/Subsystem to be tested identified by the Maintainer CPS	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-86	Functional Requirement	Warehouse check	The AHMS GF shall be able to access to the Warehouse CPS stock data and external Supply Chain management software (e.g. SAP) to show the Operator if a spare part is available for replacement.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-87	Functional Requirement	Maintenance Time	The AHMS GF shall be able to show the Maintenance Operator the designed Maintenance Time reported in the manuals and the average actual Maintenance Elapsed Time.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-88	Functional Requirement	Removal and Installation records	The AHMS GF shall be able to insert a new record in a dedicated DB for each Item ID tracked by the Maintainer CPS for removal and installation events. To each record shall be associated the Maintainer CPS data registered.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-89	Functional Requirement	Removal and Installation records details	The AHMS GF shall be able to associate to each removal and installation record the item additional information retrieved from a dedicated DB through the Item ID (e.g. item part number and serial number, description, Supplier, ...)	High	AHMS GF - Troubleshooting component	By preliminary demonstrator

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UC7-FNC-90	Functional Requirement	Maintenance Operator Notes	The AHMS GF shall allow the Maintenance Operator to insert notes relevant to the Maintenance performed for each Fault Code: - Troubleshooting option that solved the issue; - Troubleshooting solutions different from Item removal (e.g. on-aircraft tests, minor components replacement, ...); - Textual description of the activity performed; - Summary of the Item removal reason, if any.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-91	Functional Requirement	Failure Catalogues	The AHMS GF shall be able to show Maintenance Operator for each Fault Code the possible System/Item components causing the failures, retrieved from the Failure Catalogues.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-92	Functional Requirement	Airframer Notes	The AHMS GF shall allow the Airframer Operator to add for each removed Item the results of dedicated post-removal failure investigations. The results include: - classification of the defect; - root cause type; - root cause detailed description.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-93	Functional Requirement	Fault Code - Item link	The AHMS GF shall be able to link to each Fault Code the removed Item ID, if any, along with the Maintenance and Airframer Operators note.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-94	Functional Requirement	Failures-Flight parameters relationship	The AHMS GF shall be able to analyse the flight parameters and the registered failures to identify possible parameters patterns that may cause a failure.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-95	Functional Requirement	Failure messages description	The AHMS GF shall be able to link the failures, alerts and warnings messages to their relevant description retrieved from a dedicated DB.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-96	Functional Requirement	Failure causes statistics	The AHMS GF shall be able to calculate failure causes statistics based on the Airframer Operator investigations notes.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-97	Functional Requirement	Failures searching and statistics	The AHMS GF shall allow the user to perform a search of failures, alerts and warnings showing relevant failure causes statistics.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-98	Functional Requirement	Fault Codes queries	The AHMS GF shall allow the user to generate grouping queries on Fault Codes based on aircraft, date, removed item, Failure causes statistics.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-DSG-15	Design Constraints	Rates graphical representation	The AHMS GF shall be able to represent all the statistics using both charts and tables.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-99	Functional Requirement	Update of Isolation algorithms	The AHMS GF shall allow the updating of the Isolation Algorithms using xml or txt files.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator

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UC7-FNC-100	Functional Requirement	Algorithms version	The AHMS GF shall be able to save the algorithm version used to isolate the Fault Codes in the stored failures DB.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-DSG-16	Design Constraints	Procedure Format	The AHMS GF shall be able to support and manage Maintenance Procedures Manuals in xml or PDF.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-101	Functional Requirement	Troubleshooting Improvement suggestions	The AHMS GF shall allow the Maintenance Operator to suggest possible improvements or modification on the Troubleshooting procedures through a dedicated messaging functionality with the Airframer.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-102	Functional Requirement	Statistics for Fault Isolation improvements	The AHMS GF shall allow the Airframer Operator to look at the options success rate and the removed items in order to improve the Fault Isolation procedures.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-103	Functional Requirement	Statistics for Maintenance Times	The AHMS GF shall allow the Airframer Operator to look at actual Maintenance Elapsed Times, automatically highlighting deviations between designed and actual values.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-104	Functional Requirement	Automatic messages definition	The AHMS GF shall allow the user to define for each failure an automatic email or warning to a specific users list.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-105	Functional Requirement	Threshold for automatic messages	The AHMS GF shall allow the user to define specific threshold on the number of failure occurrences to send the automatic emails and warnings.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-PRF-03	Performance Requirement	Failure analysis duration	The AHMS GF shall be able to perform all the analysis and calculation relevant to the isolated Fault Code in no more than 10 minutes.	Medium	AHMS GF - Troubleshooting component	By design
UC7-FNC-106	Functional Requirement	Removals list filtering	The AHMS GF shall allow the user to manage the list of removed items by: - looking at the list; - filtering the list; - generating grouping queries; - generating charts.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-107	Functional Requirement	Flight Debrief Report	The AHMS GF shall allow the user to export reports containing for a selected flight: - summary of the mission (start, end, duration, landing, touch&go, …); - chart of flight parameters vs time; - list of alerts, warnings and isolated Fault Codes with relevant description.	Medium	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-108	Functional Requirement	Maintenance Activities Report	The AHMS GF shall allow the user to export reports containing for a selected flight or a time period the following: - list of Fault Codes analysed; - list of Troubleshooting solutions; - list of removed items with details.	High	AHMS GF - Troubleshooting component	By preliminary demonstrator
UC7-FNC-109	Functional Requirement	Unscheduled Removals	The AHMS GF shall be able to automatically categorize the removed items tracked by Maintainer CPS as	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator

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			Unscheduled Removals (removals due to corrective maintenance actions).			
UC7-FNC-110	Functional Requirement	Maintenance Operator User ID	The AHMS GF shall allow the user to temporarily assign and remove a Maintenance Operator User ID from each Maintainer CPS.	Low	AHMS GF - Troubleshooting component	By preliminary demonstrator

Table 8 – UC7 AHMS Ground Framework - troubleshooting requirements

3.4.2.3.3 Trend Monitoring requirements

The objective of Trend Monitoring component is to allow the Engineering Operator to monitor the performances of aircraft, analysing data coming from On-Board module.

Data gathered during the flight are collected at the end of the day on-ground and sent to AHMS GF module through a wireless connection.

Data are stored on-ground in order that last data are compared with historical data to trace Trend graphs.

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**	**Link to functional components**	**Means of validation**
UC7-OPR-09	Operational Requirement	Engineering Operator	The AHMS shall allow the Engineering Operator to access the Trend Monitoring service	High	AHMS GF - Trend Monitoring component	N/A
UC7-OPR-10	Operational Requirement	Airframer Operator	The AHMS shall allow the Airframer Operator to have access to Trend Monitoring service	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-55	Functional Requirement	Messages between Customer and Airframer	The AHMS shall allow Engineering Operator and Airframer Operator to exchange text messages during trend data analysis.	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-56	Functional Requirement	Data between Customer and Airframer	The AHMS shall allow Engineering Operator and Airframer Operator to exchange data and images during trend data analysis.	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-57	Functional Requirement	Analytics	The AHMS shall be able to analyse all trend data gathered during flights	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-58	Functional Requirement	Historical data	The AHMS shall be able to collect all trend data in a DBs to allow historical analysis	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-59	Functional Requirement	Thresholds	The AHMS shall be able to compare trend data with predefined thresholds (max, min)	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-60	Functional Requirement	Customizable thresholds	The AHMS shall allow the modification of predefined thresholds	High	AHMS GF - Trend Monitoring component	N/A

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UC7-FNC-61	Functional Requirement	Alarms	The AHMS shall allow the user to set alarms according to threshold supersede	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-62	Functional Requirement	Trend data	The AHMS shall be able to manage 1000 aircraft trend parameters	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-63	Functional Requirement	Trend data - frequency	The AHMS shall be able to manage different frequency trend data	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-64	Functional Requirement	Trend data - DB	The AHMS shall be able to record and manage 120TB trend data (5GB for each flight, for a fleet of 100 aircrafts, flying 8 times a day, for 30 years).	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-65	Functional Requirement	Trend data - each flight	The AHMS shall be able to record and manage 5 GB of trend data for each flight.	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-66	Functional Requirement	Trend data - subsystem	The AHMS shall organize trend data according to aircraft subsystem	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-67	Functional Requirement	GUI - Trend data - visualization	The AHMS shall allow the user to select trend data from a list	Medium	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-68	Functional Requirement	GUI - Trend data - zoom	The AHMS shall allow the user to select a time interval for trend data	Medium	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-69	Functional Requirement	Alarm pop up	The AHMS shall alert the user in case of a superseded threshold	High	AHMS GF - Trend Monitoring component	N/A
UC7-FNC-70	Functional Requirement	GUI - Trend data comparison	The AHMS shall allow the user to compare side by side trend data of different systems/items/parameters between them or with the aircraft mission profiles	High	AHMS GF - Trend Monitoring component	N/A
UC7-OTR-01	Other Requirements	Safety	The AHMS GF shall maintain or improve the level of safety of flight.	High	AHMS GF - Trend Monitoring component	N/A

Table 9 – UC7 AHMS Ground Framework: Trend Monitoring requirements

3.4.2.3.4 Predictive Maintenance requirements

The objective of Predictive component is to provide the Engineering Operator with a tool to monitor the performances of aircraft, analysing data coming from On-Board module, and possibly anticipate incoming failure. This capability can be considered a step forward w.r.t. Trend Monitoring component. Trend Monitoring allows comparing data w.r.t. historical data, while Predictive, taking advantage of predictive models or dedicated analytics, indicates Remaining Useful Life (RUL) of each monitored component.

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Predictive component is based on same Trend Monitoring data. Two possible approaches are foreseen:

- Model based approach: Trend Monitoring data are analysed by means of predictive model, integrated within AHMS GF, able to calculate RUL;
- Statistical approach: Trend Monitoring are analyses with statistical methodologies able to derive future evolution of a trend and provide a RUL estimation.

Based on RUL indication the Maintenance Operator is able to schedule intervention before the failure occurs.

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**	**Link to functional components**	**Means of validation**
UC7-OPR-08	Operational Requirement	Engineering Operator	The AHMS GF shall allow the Maintenance Operator to access Predictive service	High	AHMS GF - Predictive component	N/A
UC7-FNC-40	Functional Requirement	Airframer Operator	The AHMS GF shall allow the Airframer Operator to access to Predictive service	High	AHMS GF - Predictive component	N/A
UC7-FNC-41	Functional Requirement	Messages between Customer and Airframer	The AHMS shall allow Engineering Operator and Airframer Operator to exchange text messages during predictive data analysis.	High	AHMS GF - Predictive component	N/A
UC7-FNC-42	Functional Requirement	Data between Customer and Airframer	The AHMS shall allow Engineering Operator and Airframer Operator to exchange data and images during predictive data analysis.	High	AHMS GF - Predictive component	N/A
UC7-FNC-42	Functional Requirement	Approaches	The AHMS GF shall be able to manage two approaches for Trend data analysis: model based and statistical approach.	High	AHMS GF - Predictive component	N/A
UC7-FNC-43	Functional Requirement	Prediction models	The AHMS GF shall allow integration of third parties prediction models to calculate RUL from Trend data.	High	AHMS GF - Predictive component	N/A
UC7-FNC-43	Functional Requirement	Analytics	The AHMS GF shall be able to analyse Trend data by means of statistical approach to derive RUL.	High	AHMS GF - Predictive component	N/A
UC7-FNC-46	Functional Requirement	RUL (Remaining Useful Life)	The AHMS GF shall compute the RUL and related confidence level (when applicable) as soon as new Trend monitoring data are received from the aircraft.	High	AHMS GF - Predictive component	N/A
UC7-FNC-47	Functional Requirement	RUL colouring	The AHMS GF shall allow to set RUL colouring according to three predefined thresholds: Red, Yellow and Green.	High	AHMS GF - Predictive component	N/A
UC7-FNC-48	Functional Requirement	RUL threshold	The AHMS GF shall allow to customize RUL thresholds.	High	AHMS GF - Predictive component	N/A
UC7-FNC-48	Functional Requirement	Alarms	The AHMS GF shall allow the user to set alarms according to RUL thresholds.	High	AHMS GF - Predictive component	N/A
UC7-FNC-50	Functional Requirement	GUI - Trend Data and RUL - visualization	The AHMS shall allow the user to select trend data and related RUL from a list	High	AHMS GF - Predictive component	N/A

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UC7-FNC-50	Functional Requirement	Automatic messages definition	The AHMS GF shall allow the user to define, for each failure and associated RUL threshold, specific email message and the mailing list.	Medium	AHMS GF - Predictive component	N/A
UC7-FNC-51	Functional Requirement	Automatic messages transmission	The AHMS GF shall send the pre-defined messages to the related mailing list as soon as the computed RUL reaches the predefined threshold.	Medium	AHMS GF - Predictive component	N/A
UC7-FNC-52	Functional Requirement	RUL colouring	The AHMS GF shall display RUL with related colour code.	High	AHMS GF - Predictive component	N/A
UC7-FNC-53	Functional Requirement	RUL confidence level	The AHMS GF shall display RUL confidence level if provided by the prediction model.	High	AHMS GF - Predictive component	N/A

Table 10 – UC7 AHMS Ground Framework: Predictive Maintenance requirements

3.4.2.3.5 Spare Management requirements

The objective of Spare Management component is to support Logistic Operator decisions relevant to the management of spares available or to be acquired, highlighting possible shortage issues for both Scheduled and Unscheduled Maintenance activities.

The component shall be able to analyze the data collected by the Warehouse module relevant to stock availability, the Scheduled activities planning, the Unscheduled Removals trends and external parts Track & Trace software (i.e. SAP) in order to offer the Logistic Operator an overview of the parts availability and Customer demand rate. The component shall also consider the Customer flight activity performed and planned.

The main functionalities to be performed are:

- Display of the Scheduled Maintenance activities list foreseen by the Customer Maintenance manual. For each activity, the component calculates and shows an Estimated Expiration Date, function of calendar days or numbers of hours/cycles accumulated by the items and planned flight activity. Wherever a RUL is calculated by the Predictive component, the relevant removal can be shown as a foreseen Scheduled activity;
- Display of the Top Unreliable Items list identified by calculating the Unscheduled Removal Rate (URR) of each item and other reliability KPI, function of the Unscheduled Removals (UR) reported and the Customer flight activity. The reliability results are updated at time intervals that allow to achieve a pre-defined statistical level of confidence;
- Display, for both the lists above mentioned, of Availability Warnings that allow the Logistic Operator to take the best corrective/preventive decisions in time, avoiding aircraft on ground (AOG) due to missing of parts conditions.

A visual representation of the three functionalities above described can be depicted as follows:

Foreseen Scheduled activities	
Date	19/10/2020

Item	Activity Type	Task Identifier on Manual	Aircraft	Estimated expiration date	Availability Warning
Shock Absorber	Discard	13-6190-34	A005	21/10/2020 (2 days)	🟢
Air Cycle Machine	Overhaul	41-2133-5	A001	29/10/2020 (10 days)	🟡
Oxygen Masks	Overhaul	47-3511-7	A002	03/11/2020 (15 days)	🔴
Propeller Assy	Overhaul	33-6141-4	A012	18/11/2020 (30 days)	🟡
...	...	...	...	...	...

Top Unreliable Items	
Date	19/10/2020
Last Reliability Analysis Date	30/06/2020

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Item	Classification	#Unscheduled Removals	URR x 1000 Flight Hours	… Other Reliability KPI…	Availability Warning
VHF Radio	Repairable	115	3,59	…	
Brush Block	Not Repairable	166	2,58	…	
ECS Valve	Repairable	81	2,53	…	
Dimmer Unit	Repairable	58	1,81	…	
…	…	…	…	…	…

The Availability Warning is determined by using a Weighted Average Method that combines three performance indicators:

- **Failure Patterns Detector** that indicates a criticality due to recurring failure messages, which could lead to a possible removal. It is based on the analysis of historical and real time data acquired from On-Board module, consolidated with Maintenance data reported during Troubleshooting;

- **Removal Rate Alert** that highlights risky deviations from the average URR values, determined by comparing the most updated URR and relevant reliability KPI with pre-defined Alert Levels;

- **Risk of Shortage (ROS)** that indicates the probability of remaining without spare parts when requested, calculated using the Warehouse module collected data, the Supply Chain status information retrieved by external software, the foreseen Scheduled Removals and Customer flight activity. Wherever a RUL is calculated by the Predictive component, it can be used in the calculation as a foreseen Scheduled activity.

For each indicator is defined a range of low, medium and high severity thresholds. The severity is then turned into mathematical values that are multiplied by assigned weights.

The Logistic Operator can modify the weights, increasing or decreasing the impact of each indicator on the Warning. Moreover, based on the actual AOG reported for each item, the Spare Management component can determine and suggest weights modification to the Logistic Operator.

The calculated weighted values are then combined together in order to obtain an Availability Warning value that, depending on a pre-defined scale, is shown to the Operator with a symbol and colour scheme:

Availability Warnings

: Parts available, no warnings from performance indicators

: Possible parts unavailability foreseen, several warnings from performance indicators

: Parts unavailability foreseen, warnings from all performance indicators

Therefore, the possible benefits that derives from this new CPS4EU Spare Management component are:

- To avoid or reduce AOG events through warnings that allow to take corrective/preventive actions, considering the overall Fleet status;
- To optimize Stock during In-Service phase using actual Customer parts demand rate, reducing Safety Stock margins adopted during initial support, monitoring availability for parts with high demands and avoiding stock surplus.

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**	**Link to functional components**	**Means of validation**
UC7-OPR-13	Operational Requirement	Logistic Operator	The AHMS GF shall allow the Logistic Operator to access Spare Management service	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-OPR-14	Operational Requirement	Airframer Operator	The AHMS GF shall allow the Airframer Operator to access to Spare Management service	High	AHMS GF - Spare Management component	By preliminary demonstrator

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UC7-FNC-111	Functional Requirement	Messages between Customer and Airframer	The AHMS GF shall allow Logistic Operator and Airframer Operator to exchange text messages whenever necessary.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-112	Functional Requirement	Data between Customer and Airframer	The AHMS GF shall allow Logistic Operator and Airframer Operator to exchange data and images whenever necessary.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-113	Functional Requirement	Warehouse CPS data	The AHMS GF shall be able to store and manage the following data collected by the Warehouse CPS: - Item ID and relevant quantities available at stock; - Item position inside the warehouse; - Warehouse environmental conditions; - Environmental conditions warnings; - Item moved from/to Suppliers;	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-114	Functional Requirement	Scheduled Maintenance data	The AHMS GF shall be able store and manage the following data for Scheduled activities retrieved from a dedicated DB: - Item ID subject to Scheduled Maintenance (SM); - SM activity type (overhaul, discard, inspection, servicing, ...); - SM Task identifier; - Task interval; - Shelf life, if any; - Aircraft ID subject to SM.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-115	Functional Requirement	Flight activity data	The AHMS GF shall be able to manage the Customer flight activity, stored in a dedicated DB, particularly: - actual achieved Flight Hours (FH) per aircraft per day; - planned FH per aircraft per day.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-116	Functional Requirement	Track & Trace data	The AHMS GF shall be able to manage external parts Track & Trace software (e.g. SAP) data, like: - Items to be shipped to Supplier and relevant data; - Items shipped to Supplier and relevant data; - Items coming back from Supplier and relevant data; - New purchased spares.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-117	Functional Requirement	Materials for Scheduled Maintenance	The AHMS GF shall be able to manage data coming from Maintenance manuals, linked to the SM by the Task Identifier, indicating possible minor components, chemicals or other materials required.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-118	Functional Requirement	Current date	The AHMS GF shall be able to automatically store the current date and time when the user accesses the service.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-119	Functional Requirement	Item details	The AHMS GF shall be able to automatically retrieve from a dedicate DB for each item its unique Reference Number used to group different part numbers, the relevant Quantity installed on aircraft (QPA)	High	AHMS GF - Spare Management component	By preliminary demonstrator

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			and the number of Unscheduled Removals (UR).			
UC7-FNC-120	Functional Requirement	Estimated Expiration Date	The AHMS GF shall be able to calculate an Estimated Expiration Date for each Item subject to SM, using the current date, the SM Task interval and the planned flight activity. It shall be expressed as both Date and number of days between the current and estimated dates.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-121	Functional Requirement	Scheduled Maintenance Table	The AHMS GF shall allow the Logistic Operator to look at all the Items ID subject to SM in a table, ordered by increasing Estimated Expiration Date, that reports: - Item description; - SM Activity Type; - SM Task Identifier; - Aircraft ID; - Estimated Expiration Date; - Availability Warning.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-122	Functional Requirement	Reliability KPI	The AHMS GF shall be able to calculate Items Reliability Key Performance Indicators (KPI) relevant to a specific Observation Period: - Unscheduled Removals Rate (URR) [1/1000 FH]= #UR / (QPA x Sum(aircraft FH)) x 100 - Mean Time Between Unscheduled Removals (MTBUR) [FH] = 1 / URR x 1000 - Gradient = angular coefficient of the Linear Regression Trend line of URR - Standard Deviation (SD) = standard deviation of the URR	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-123	Functional Requirement	Observation period	The AHMS GF shall allow the user to change the observation period interval and typology (weeks, quarters, years).	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-124	Functional Requirement	Top Unreliable Items	The AHMS GF shall allow the Logistic Operator to look at a list of Top Unreliable Items, ordered by increasing URR, that reports: - Item description; - Item repairability type (Repairable/Not Repairable/Consumable); - Number of UR; - Reliability KPI; - Availability Warning. The Last Reliability Analysis Date shall be shown with the list.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-125	Functional Requirement	Top Unreliable Items number	The AHMS GF shall allow the user to change the number of Top Unreliable Items included in the list.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-126	Functional Requirement	Reliability KPI updating	The AHMS GF shall update the Reliability KPI at defined time intervals, based on the actual hours flown. The relevant Last Reliability Analysis Date shall be updated consequently.	High	AHMS GF - Spare Management component	By preliminary demonstrator

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UC7-FNC-127	Functional Requirement	Availability Warning	The AHMS GF shall be able to calculate an Availability Warning for each Item subject to Scheduled or Unscheduled removals using a Weighted Average Method that combines three Performance Indicators: - Failure Patterns Detector; - Removal Rate Alert; - Risk of Shortage (ROS). The Availability Warning numerical results shall be scaled to 100.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-128	Functional Requirement	Failure Patterns Detector	The AHMS GF shall be able to calculate a Failure Patterns Detector as a mathematical value between 0 and 100 that indicates a low, medium or high severity of the indicator, based on the failure's occurrences number of each item. For each item, the thresholds are: - LOW: x failures occurrences in the last flight - MEDIUM: x failures occurrences in the last n flight - HIGH: y failures occurrences in the last n flight where x, y and n are values customizable by the user and tailored to each item.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-129	Functional Requirement	Removal Rate Alert	The AHMS GF shall be able to calculate a Removal Rate Alert as a mathematical value between 0 and 100 that indicates a low, medium or high severity of the indicator, based on a comparison between the actual URR and three alert levels. For each item the thresholds are: - Low: Actual URR lower than the URRAvg - Medium: Actual URR between URRAvg and (URRAvg +2*Standard Deviation) -High: Actual URR higher than (URRAvg +2*Standard Deviation)	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-130	Functional Requirement	Risk of Shortage	The AHMS GF shall be able to calculate for each item a ROS as a mathematical value between 0 and 100 that indicates a low, medium or high severity of the indicator, based on a Poisson distribution that considers the Customer demand rate, the parts Supply Chain status, the foreseen Scheduled Removals and Customer flight activity. In details the ROS formula can be expressed as: ROS = 1 - SUM(λ^k/k!)*e^-λ where: - k goes from 0 to ST. SIZE-1 - λ = (T*Daily FH*QPA)/MTBUR is the Demand Rate - T = forecast days for the analysis or Turn Around Time (TAT)	High	AHMS GF - Spare Management component	By preliminary demonstrator

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			- ST.SIZE = number of items available at stock minus the number of items required for scheduled activities. For each item the customizable thresholds are initially set to: - Low: ROS lower or equal to 5% - Medium: ROS between 5% and 25% - High: ROS equal or higher than 25%			
UC7-FNC-131	Functional Requirement	Manual weights and thresholds modification	The AHMS GF shall allow the Logistic Operator to modify the weights and thresholds assigned to each Performance Indicator and the Availability Warning thresholds.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-132	Functional Requirement	AOG Condition	The AHMS GF shall allow the Logistic Operator to document if a removal has caused an Aircraft On Ground (AOG) condition due to missing parts.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-133	Functional Requirement	Recommended weights	The AHMS GF shall be able to suggest modification to the weights and thresholds assigned to each Performance Indicator, using the actual AOG recorded.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-134	Functional Requirement	Availability Warning colours	The AHMS GF shall be able to show the Logistic Operator the Availability Warning using a pre-defined set of colour scheme based on user customizable low, medium and high level thresholds: - Green: parts available, Availability Warning value lower or equal to 25; - Yellow: possible parts unavailability foreseen, Availability Warning value between 25 and 60; - Red: parts unavailability foreseen, Availability Warning value equal or higher than 60.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-135	Functional Requirement	Performance Indicators display	The AHMS GF shall allow the Logistic Operator to look at the calculated Performance Indicator for each SM or Top Unreliable Item selected from the lists.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-DSG-17	Design Constraints	Failure Patterns Detector display	The AHMS GF shall display the Failure Patterns Detector mathematical value using a gauge-like graphical representation.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-DSG-18	Design Constraints	Removal Rate Alert display	The AHMS GF shall display the Removal Rate Alert using a 2-D lines chart, that shows the URR over time and the alert lines, highlighting the values that overseed the defined thresholds.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-DSG-19	Design Constraints	Risk of Shortage display	The AHMS GF shall display the Removal Rate Alert using a 2-D pie chart, that shows the percentage of ROS, and using a table that reports the values used for its calculation.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator

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UC7-FNC-136	Functional Requirement	Recommended stock size	The AHMS GF shall be able to calculate and show in a table to the Logistic Operator a recommended stock size to satisfy the Fleet performances required by the Customer. The recommended stock size shall be calculated using the ROS formula of Req. UC7-FNC-22 and evaluating all the possible increasing ST. SIZE values until a user-defined ROS is achieved.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-137	Functional Requirement	Unused parts	The AHMS GF shall be able to warn the Logistic Operator in case of unused parts at stock in a user defined period of time.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-138	Functional Requirement	Parts availability report	The AHMS GF shall allow the user to export a report with: - parts available at stock; - parts in the Supply Chain; indicating for each part the relevant Availability Warning, if calculated.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-139	Functional Requirement	Scheduled activities report	The AHMS GF shall allow the user to export a report with the foreseen Scheduled Maintenances, including the Availability Warning, if calculated.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-140	Functional Requirement	Top Unreliable Items report	The AHMS GF shall allow the user to export a report with a selected number of Top Unreliable Items, including the Availability Warning, if calculated.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-141	Functional Requirement	Filter and queries	The AHMS GF shall allow the user to filter and generate queries on items subject to SM and Top Unreliable Items list.	High	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-142	Functional Requirement	AOG parts warnings	The AHMS GF shall be able to automatically warn the Logistic Operator in case of there are parts to be shipped or incoming from the Supplier for items causing AOG conditions, using Warehouse CPS data.	Medium	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-143	Functional Requirement	Track & Trace data updating	The AHMS GF shall be able to use the Warehouse CPS data to automatically update the parts status in external Track & Trace software.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-144	Functional Requirement	Shelf life	The AHMS GF shall be able to use the Warehouse CPS information (item availability and position) to recommend the use of spare parts with expiring shelf life first, if applicable.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-145	Functional Requirement	Warehouse Environmental status	The AHMS GF shall be able to show the Logistic Operator the Warehouse environmental conditions and Environmental conditions warnings with a relevant severity colour scheme, depending on overseeded thresholds.	Low	AHMS GF - Spare Management component	By preliminary demonstrator

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UC7-FNC-146	Functional Requirement	Environmental thresholds	The AHMS GF shall allow the user to set customizable environmental conditions thresholds.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-FNC-147	Functional Requirement	Environmental restrictions DB	The AHMS GF shall allow the user to look at stocked item environmental conditions restrictions reported in dedicated DB.	Low	AHMS GF - Spare Management component	By preliminary demonstrator
UC7-PRF-04	Performance Requirement	Calculation performance	The AHMS GF shall be able to perform the calculations relevant to the Availability Warnings in less than 5 minutes.	Medium	AHMS GF - Spare Management component	By design

Table 11 – UC7 AHMS Ground Framework: Spare Management requirements

3.5 *UC8 - Material Flow Analytics and Simulation*

3.5.1 Overall Description

3.5.1.1 High level Use Case Description

Flexible production management of complex processes on the shop-floor is important for the operation of combined smart production and logistics systems of the future. The development of CPS forms the technological foundation for the creation of a digital twin and hence for real-time optimization of production.

This use case combines CPS technologies such that it significantly improves the current state of sheet metal production in at least the following aspects: 1) comprehensive live state of the production (incl. material flow, 3D shop floor model enriched with semantics); 2) continuous optimization of production and 3) prediction and simulation of the production . Each of these aspects promises tremendous ROI for our customers and TRUMPFs own production facilities.

The use case further allows TRUMPF to assess which of these three dimensions are most valuable to pursue with own products and to explore which of the integrated CPS technologies (e.g. UWB, 3D scan, semantic image interpretation, simulation modelling) are customer-ready.

To enable the use-case it is at minimum required to have an acquisition of a digital shop floor model with automatic semantic annotation, the continuous tracking of all relevant shop floor objects such that it can be used to build and inform a shop floor simulation. In addition, it is important to consider and align these technologies to the regulatory requirements of the EU concerning data privacy laws.

The following diagram shows the components of this use-case:

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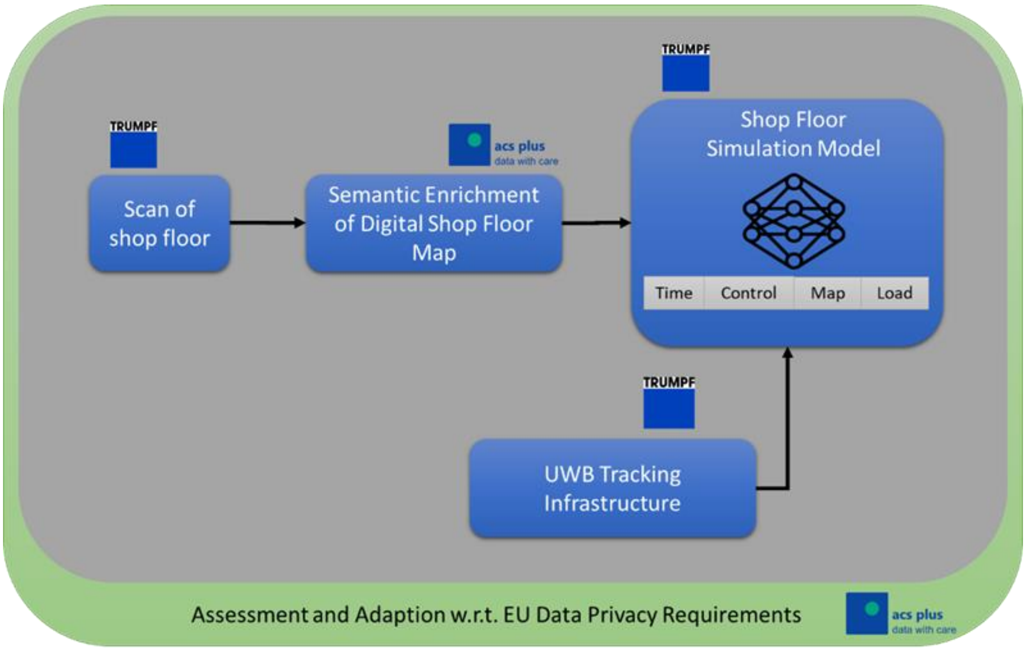
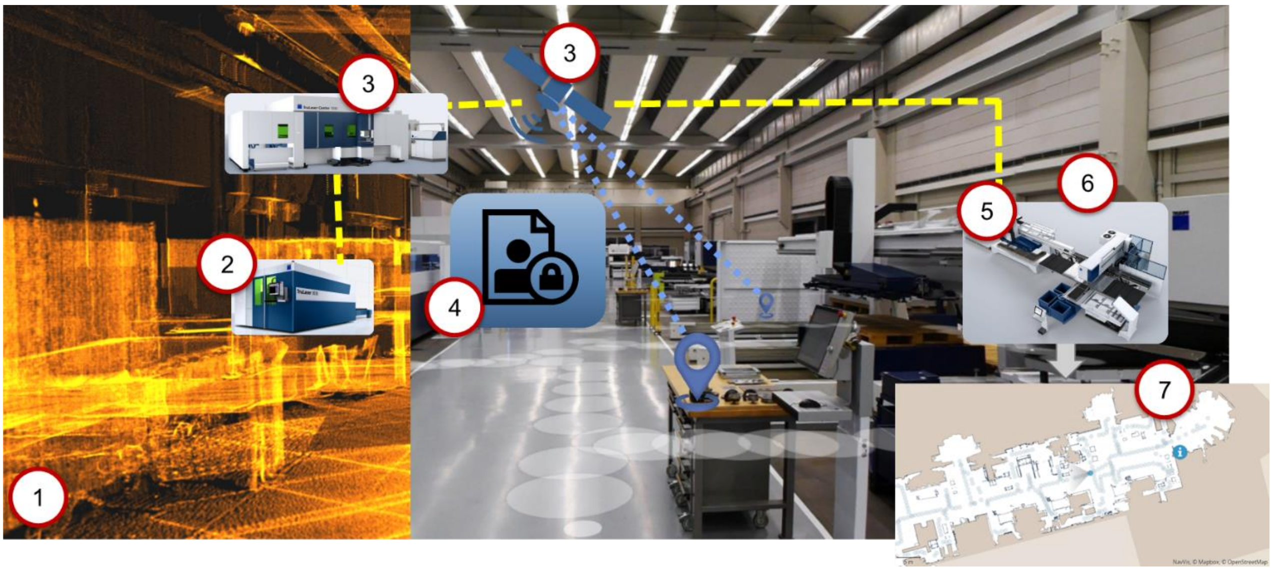


Figure 29 – UC8 overview.

3.5.1.2 Main Features

All parts of the production are part of a complete digital model (digital twin) of the shop floor. Through novel CPS technology interaction, this model is used for organization, real-time controlling, forecasting as well as local and global scheduling of production processes (TRUMPF).

The following figure shows the major functions which are also listed below:



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1. Map generation of shop floor
2. Enrichment of model with semantics
3. Provision of an accurate material flow tracking and communication infrastructure
4. Assessment and Adaption w.r.t. to EU Data Privacy Requirements
5. Initial creation of simulation model based on this data

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6. Adaption of shop floor model based on live stream of above data
7. Evaluate and interpret the simulation results for having a feedback for production planning

3.5.1.3 Limits

The following limitations apply for the use-case:

- Must use TRUMPF UWB localization system with default system settings
- Localization data provisioning using REST and Websockets
- Simulation framework is based on Anylogic Software
- Follow data privacy considerations derived by acs plus

3.5.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
UC8-FNC-01	Functional Requirement	Detecting the type and position of TRUMPF machines given a 3D production hall scan, respectively	The position, orientation and the type of the machine are to be recognized from 3D hall scan.	High	Semantic Enrichment Module	Demonstrator(I)
UC8-INT-01	Interface Requirement	Develop semantics of the production hall, which are compatible for manufacturing simulation. An interface to exchange information with simulation is required.	How should the recorded production hall plan (with semantics) be transferred to the simulation?	Medium	Semantic Enrichment Module, Simulation Module	Demonstrator(II)
UC8-FNC-02	Functional Requirement	Detection of third-party machine model types	Recognizing existence and position, given a database with pictures and dimensions.	Medium	Semantic Enrichment Module	Demonstrator(I)
UC8-ETH-01	Ethical Requirements	Provide analysis of use-case w.r.t. direct and indirect personal data	The data acquired in the use-cases is analyzed and assessed for data privacy aspects.	Medium	Complete Use-Case	Deliverable
UC8-ETH-02	Ethical Requirements	Development of data privacy recommendations and measures for the use-case	Based on the analysis, recommendations are provided, and measures are described which may affect various layers of data acquisition including data acquisition methods, transformation, protocols, etc.	Low	Complete Use-Case	Deliverable
UC8-OPR-01	Operational Requirement	Selection of a suitable device for the creation of 3D production hall scans	Devices are acquired and assessed for their applicability for UC8-FNC-01.	High	3D Scanner	Deliverable, Demonstrator (I)

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UC8-PRF-01	Performance Requirement	3D Production Hall Scan	Create a number of 3D scans of sheet metal shop floors	High	3D Scanner	Deliverable (I)
UC8-OPR-02	Operational Requirement	Set up UWB installation in production hall	UWB infrastructure is deployed in shop floor which allows to track material flow	High	UWB Localization System	Demonstrator (I)
UC8-ETH-03	Ethical Requirements	Cost vs effort-based decision on the implementation of data privacy measures	Based on the recommendations and available measures it should be decided which measures can be implemented to ensure conformance.	Medium	Complete Use-Case	Deliverable
UC8-FNC-03	Functional Requirement	Provide annotated machine positions as ground truth for automatic 2d or 3d shop floor annotation	For some of the scanned shop floors an annotated 2d floor plan is provided which should be used to validate the results of the automatic recognition of machine type and position in the 2d/3d maps	High	Semantic Enrichment Module, Simulation Module	Demonstrator (II)
UC8-FNC-04	Functional Requirement	Create initial shop floor simulation model	Create initial simulation model based on shop floor material flow and auxiliary data as well as machine positions.	High	Simulation Model, UWB localization system	Demonstrator (II)
UC8-PRF-02	Performance Requirement	Evaluate model performance	The simulation model should be evaluated regarding its accuracy and feedback quality for the production planning system	Medium	Simulation Model	Demonstrator (III)
UC8-INT-02	Interface Requirement	Provide positioning data and auxiliary shop floor data to simulation framework	Shop floor material flow and additional data should be provided in format which can be consumed by the simulation framework / the framework must cope with the provided data formats	High	Simulation Model, Cloud Interface	Demonstrator (II)

Table 12 - UC8 Requirements

3.6 *UC9 - Mobile CPS*

3.6.1 Overall Description

3.6.1.1 High level Use Case Description

Collaborative Lifting is a use case provided by WIKA Mobile Control GmbH for this project. It deals with the use of at least two mobile machines, i.e. cranes, to lift a huge object that cannot be lifted using a single mobile crane.

Nowadays, the planning of such a complex process is done either by classical methods for some cases (Pen & Paper) or using a planning and modelling software for others. Nevertheless, the execution of such a process still represents a challenge among the crane operators and fleet managers.

To accomplish a collaborative lifting process, it is mandatory that a lifting supervisor/ planer looks at the lifted object and at the machines and makes sure that the lifting is performed according to the plan. In many cases, the crane operators can have a restricted sight on the obstacles, humans and maybe other machines present on site, due to the size, volume and shape of the object lifted e.g., or due to complex movements that have to be performed. Thus, the lifting supervisor has to give instructions or hints to the crane operators via Walky-Talky or other means of communication to ensure a damage free lifting.

WIKA is proposing an innovative way to accomplish such complex task, relying on well-established technologies such as modelling, simulation, collaborative algorithms and new innovative technologies such as digital twins, AI-powered algorithms, real-time capable communication interfaces and cloud services. The integration and

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adaption of such technologies will make it possible to deliver the instructions for the collaborative lifting process on an HMI placed in the crane cabin and the lifting process will be supervised and monitored by a server (it can be a local server on site or a remote one such as a cloud).

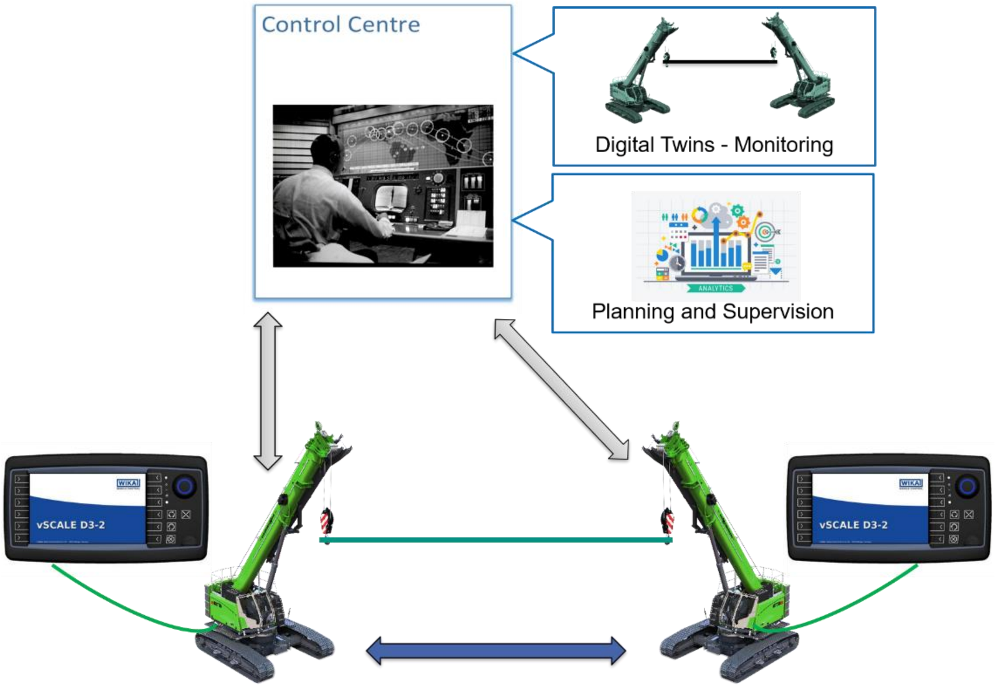

Figure 30 – UC9 overview.

3.6.1.2 Main Features

The collaborative lifting system will provide the following features:

- Lift planning:
  - Modelling and simulation of lifting process and of the used machines
  - Generating a lifting plan and missions/ trajectory for the cranes.
- Supervision and execution:
  - Machine management/ lift process management
  - Distribution of the missions for the machines
  - Possibility of autonomous execution of the lifting process.
- Monitoring based on digital twin:
  - Machine monitoring (health conditions, safety state)
  - Lifting process monitoring/ ensuring a correct execution of the planed lifting process
  - Monitoring the winch control system of the crane.
  - Using of redundant working and technological diverse sensor solutions for the controlling/observation/monitoring of processes, like winch control, space localization, dynamic observation via drones, etc.
  - Correlated consideration of redundant sources for sensor values

In the first phase, the lifting process (machines, objects, environment trajectories) will be modelled and simulated. From this simulation, lifting missions/contracts will be generated for every crane, describing the trajectories that each crane has to follow to accomplish the lifting process from point A to point B.

The cranes can operate automatically, so that they execute the received mission, or they could be driven by a crane operator by simply following the waypoints/trajectory calculated by the lifting planner, which will be displayed on an HMI found in each crane operator's cabin.

Additionally, the lifting process can be monitored and supervised by a control center, which gets real-time information from the cranes and ensures a correct execution of the lifting process.

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The machines will be able to communicate with the control center, in this case a remote system/application (cloud application) and they will be able to communicate with each other as well, to exchange relevant information to a safe execution of the collaborative lifting process.

3.6.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
UC9-FNC-01	Functional Requirement	Modelling and Simulation	Modelling and Simulation of lifting process and the used machines	Medium	construction areas, working platforms	By design Reviewed by OEM
UC9-FNC-02	Functional Requirement	Trajectory generation	Generating a lifting plan and missions/ trajectory for the cranes	Medium	management of construction areas, moving systems with consideration of obstacles	By design
UC9-FNC-03	Functional Requirement	Asset and process management	Machine management/ Lift process management	High	mobile machines, working platforms	By design
UC9-FNC-04	Functional Requirement	Contract assignment	Distribution of the missions for the machines	High	mobile machines (e.g. cranes)	By demonstrator
UC9-FNC-05	Functional Requirement	Autonomous lifting	Autonomous execution of the lifting process	Low	mobile machines, automation areas, non-safe areas (e.g. EX)	By design
UC9-FNC-06	Functional Requirement	Machine monitoring	Machine monitoring (health conditions, safety state)	High	automation areas	By demonstrator
UC9-FNC-07	Functional Requirement	Process monitoring	Lifting process monitoring/ ensuring a correct execution of the planed lift	High	automation areas, process control in general	By design
UC9-FNC-08	Functional Requirement	Winch system monitoring	Monitoring the winch control system of the crane	Medium	sensors for machines with changing /adapting dimensions	By design, by preliminary demonstrator
UC9-FNC-09	Functional Requirement	Display instruction on HMI	Display the generated instruction on HMI placed in the crane cabin	High	Automations areas	By demonstrator
UC9-PRF-01	Performance Requirement	Real-time operating system	Using real time operating system (Linux-RT)	High	industrial automation areas with deterministic behaviors	By design

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Requirement ID	Requirement Type	Short Description	Description	Priority	Link to functional components	Means of validation
UC9-OPR-01	Operational Requirement	Contracts management	Framework to manage the received contacts on the mobile machines	Low	sensor-PLC-actuator systems, w/wo functional safety requirements	By design
UC9-INT-01	Interface Requirement	Realtime communication interface for sensors	Connecting sensors on the crane with the computing platform over a real time ethernet/ bus interface	Low	Industrial automation areas	By design
UC9-INT-02	Interface Requirement	OPC UA interface for control center and crane	Crane controller and crane must support OPC UA server interface	High	standardization of functional safety processes for mobile machines	By design
UC9-INT-03	Interface Requirement	MQTT interface for control center and crane	Control center and crane should support MQTT interface	Low	industrial gateways, data collectors	By design
UC9-FNC-10	Functional Requirement	Drone as Sensor for object tracking	Using drone as sensor to track the lifted object and use the information as feedback for the lifting process monitor	Low	in case of demand for diversity and redundancy for functional safety systems	By simulation/demonstrator
UC9-SEC-01	Security Requirement	Secure connection to the control center and to other machines	the connection to the control center should be secured by encryption and authentication	Medium	Industrial automation systems	By design
UC9-PRF-02	Performance Requirement	Lifting process monitoring duty cycle	Duty cycle of the lifting monitoring task must be under 1s	Medium	systems with dedicated / limited reaction time	By simulation
UC9-OPR-02	Operational Requirement	Distributed control framework	Implementing a distributed control framework (in case connection to control center is lost)	Medium	Functional safety systems	By simulation
UC9-USB-01	Usability Requirement	GUI for the control center	GUI to manage the supervision and monitoring of the collaborating machines and the executed process)	High	Industrial complex user interface	By design
UC9-USB-02	Usability Requirement	GUI for the HMI on crane	GUI for the collaborative lifting function on the HMI of the crane	High	Industrial complex user interface	By design
UC9-FNC-11	Functional Requirement	AI for winch control sensor (camera/ lidar based sensor)	AI-powered sensor platform for the winch control	Medium	in case of demand for diversity and redundancy for functional safety systems, retrofit for machinery	By design / demonstrator

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Table 13 - UC9 requirements.

4 CONCLUSIONS

In this deliverable we updated the state-of-the-art analysis of the cyber physical systems already presented in deliverable D8.1. New details related to the scientific area of indoor localization and proximity detection have been provided and a new section focused on time synchronization in distributed sensing has been added. This analysis identifies the most innovative technologies and methodologies adopted for the digitalization of the industrial sector, with a specific focus on the use cases that will be developed in WP8.

Adopting the methodology for the requirements elicitation, defined in D8.1, a second step of use case analysis has been carried on. The analysis allowed to finalize the elicitation process of functional and non-functional requirements of WP8 use cases, already presented in a preliminary version in D8.1.

The final requirements will be adopted for the modelling and design of WP8 use cases, will contribute to guide the design of the horizontal technologies that will be developed in WP1 – 6 and will represents the reference term for the use cases evaluation and validation phases.

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6 APPENDIX

A - Link to other documents/WP/tasks

This section provides a list of documents, work packages and tasks linked to this deliverable.

ID	Description
Task 8.1	Responsible for the preparation of this deliverable.
Task 8.2	Receives requirements as an input for the use case modelling and design.
WP 1, 2, 3, 4, 5, 6	WP8 requirements represent an input for the development of WP1-6 specific technologies.

Table 14 - Link to other documents/WP/tasks.

B – Definitions, acronyms and abbreviations

Definitions, Acronyms & Abbreviations	Description
AI	Artificial Intelligence
APS	Advanced Planning and Scheduling system
BLE	Bluetooth Low Energy
BPMN	Business Process Modelling and Notation
DBMS	Data Base Management System
DCTS	Distributed Consistent Time Synchronization
DSC	Differential Scanning Calorimetry
ERP	Enterprise Resource Planning
FEMA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
HMI	Human-Machine Interface
IoT	Internet of Things
IIoT	Industrial Internet of Things
IR	Infrared
ML	Machine Learning
NDI	Non Destructive Inspection
NTP	Network Time Protocol

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PLC	Programmable Logic Controller
PN	Petri Nets
RFID	Radio-frequency identification
ROI	Return on Investment
RSSI	Received Signal Strength Indicator
SPARQL	SPARQL Protocol and RDF Query Language
TPSN	Timing Synchronization Protocol for Sensor Networks
UWB	Ultra-Wide Band

Table 15 - Definitions, acronyms, and abbreviations.

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