Project number: 826276

CPS4EU

Cyber Physical Systems for Europe

D8.1 – USE CASE REQUIREMENTS v1

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

Dissemination level: Public

This project has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 826276

Version	Date	Author (name – company)	Comments
V1.0 20.02.10	10/02/2020	D.Ansaldo, N.Rebella, G.Caminale, S.Martorana – LDO M. Scholz, C.Mieth – TRUMPF L.Petrak, S. Khalifa – WIKA P.Azzoni - ETH G.Fenza – UniSA	Released to reviewers
V2.0 20.02.19	19/02/2020	D.Ansaldo, N.Rebella, G.Caminale, S.Martorana – LDO M. Scholz, C.Mieth – TRUMPF L.Petrak, S. Khalifa – WIKA P.Azzoni - ETH G.Fenza – UniSA	Release for final review
V2.0 20.02.19	27/02/2020	P. Gougeon - VALEO A. Dupret - CEA	

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1 INTRODUCTION

1.1 *Purpose*

Deliverable D8.1 outlines the state of the art of cyber physical systems, providing an update of the innovative technologies and methodologies applicable to the industrial automation field (see §0) and to WP8 Industry Automation Use Cases.

The document illustrates the methodology adopted for the requirements elicitation obtained from the use case analysis (see §3).

Finally, for each Industry Automation use case in WP8, the document provides (see §4):

- a preliminary description of the use case, focusing on the main goals, on the environment where it will be deployed and on the related processes;
- a preliminary list of functional and non-functional requirements.

1.2 *Scope*

The following WP8 Industry Automation Use Cases will be addressed:

- UC1 - Material Flow Analytics and Simulation (TRUMPF)
- UC2 - Mobile CPSs (WIKA)
- UC3 - Automatic Vacuum System (LEONARDO)
- UC4 - Trimming Quality Improvement (LEONARDO)
- UC5 - Thermoplastic Production Line Monitoring (LEONARDO)
- UC6 - Aircrafts Health Management System (LEONARDO).

1.3 *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 1 - Link to other documents/WP/tasks.

1.4 *Definitions, acronyms, and abbreviations*

Definitions, Acronyms & Abbreviations	**Description**
AI	Artificial Intelligence
DSC	Differential Scanning Calorimetry
HMI	Human-Machine Interface
IR	Infrared
ML	Machine Learning

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NDI	Non Destructive Inspection
PLC	Programmable Logic Controller
RFID	Radio-frequency identification
ROI	Return on Investment
UWB	Ultra-Wide Band
IoT	Internet of Things
IIoT	Industrial Internet of Things

Table 2 - Definitions, acronyms, and abbreviations.

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 that are indexed on Scopus.

The description points out areas of interest, emerging technologies, and methodologies, starting from the introduction to the fourth industrial revolution. One of the main results of this study is a mapping of the results at the state of the art with respect to Use Cases (UCs) of WP8.

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. The literature review illustrates the results of the state-of-the-art analysis and provides some insights by mapping possible solutions and/or methodologies to WP8 Use Cases.

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), saw as a system that interrelated 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, lead 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 analysed in real-time for decision-support systems.
2) Advanced Manufacturing Solutions. Regard the adoption of robots able to deal with complex tasks that can also collaborate with workers.
3) Simulation. Actually, 3D simulations of products, materials, and production processes support the product design phase. However, in the future, they could 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.

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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, resource-saving, cost reduction, and velocity.
8) Additive Manufacturing. It principally regards the adoption of 3D printing in, for example, prototyping or additive production. That returns in 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 could be useful to give instructions during a process or a more comprehensive vision about a piece 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.

In reality, the state of the art of the European industry is different. Real-time data access in production is very vital, whether it is related to products, processes, or machines operating in the factory. Traditionally, real-time information access for procedures was not available at the shop floor level. In case of a change in processes or actions, workers or machines have to wait until instructions are manually transferred or data is loaded in the production system. Future factories demand a close integration between ERP and shop-floor and real-time access of data at production level for real-time execution. Data collected from machines and business processes is filtered, analysed, 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 analyse 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 1):

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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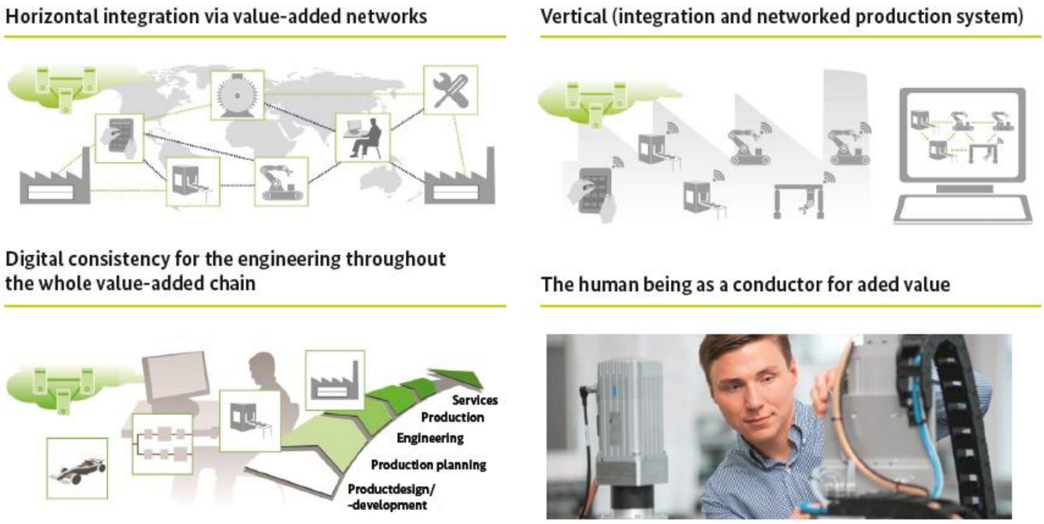

Figure 1 - Relevant aspects of Smart Manufacturing [2].

Considering the equipment hierarchy of an enterprise shown in Figure 2, 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 regards the complete enterprise, which consists of the shop floor level for production and the office floor level for the organization of the company.

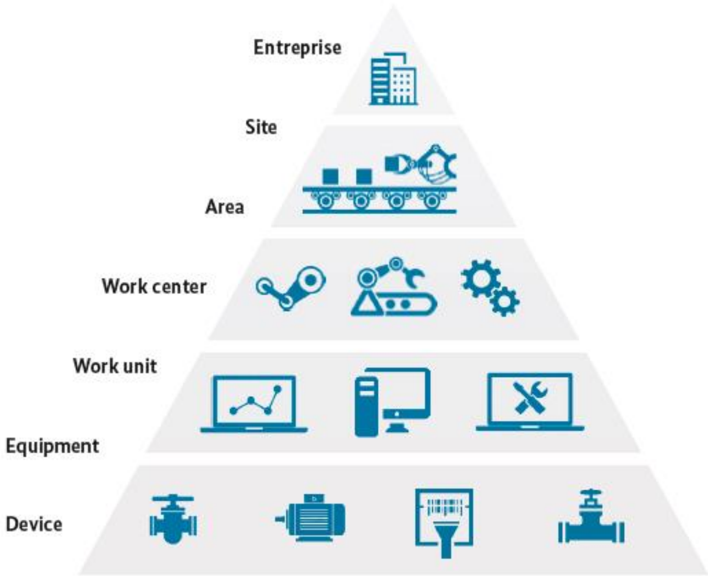

Figure 2 – Equipment hierarchy of an enterprise.

Likewise 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 a number of manufacturing devices deployed in control systems environments connected to the Internet (either intentionally or unintentionally) greater than 500.000 [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 local and global scheduling of 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, analyse it with quality statistic algorithms materials to understand the main root causes of defects. To complete the cycle, the CPS, reacting to different conditions, will be able to modify machine parameters so to avoid the damage or defect (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 aircraft and perform the following high-level functions:
    - Troubleshooting: support to aircraft failure management and fixing
    - Trend Monitoring: management of aircraft data to monitor aircraft system behaviour and performances
    - Preventive and Predictive Maintenance: definition of maintenance tasks, according to aircraft system monitoring, in order to anticipate failures
    - Fleet Spare Management: prediction of spare parts needs 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 current knowledge about a topic by collecting and analysing 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 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 3. As visible, in the last four years, the attention to ICPS is 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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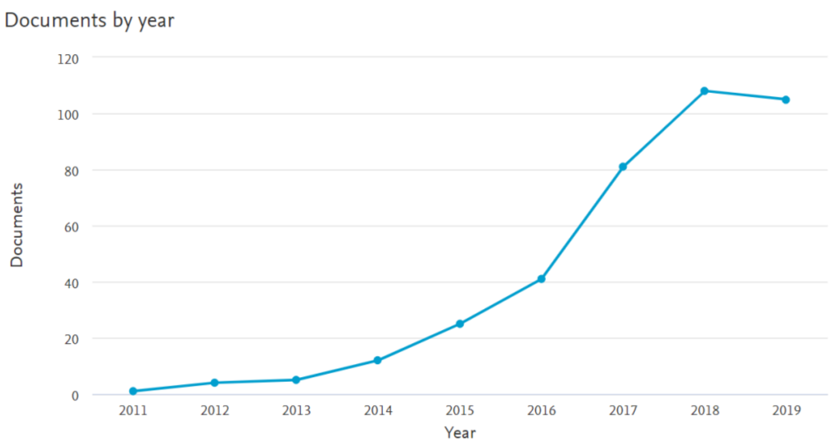

Figure 3 – Timeline about works publishing.

Considered documents mainly concern "Engineering" and "Computer Science" subject areas (Figure 4). 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 German and Spain, while the most involved authors are: Garcia Marcelo and Marcos Marga, both from Universidad del Pais Vasco, Spain.

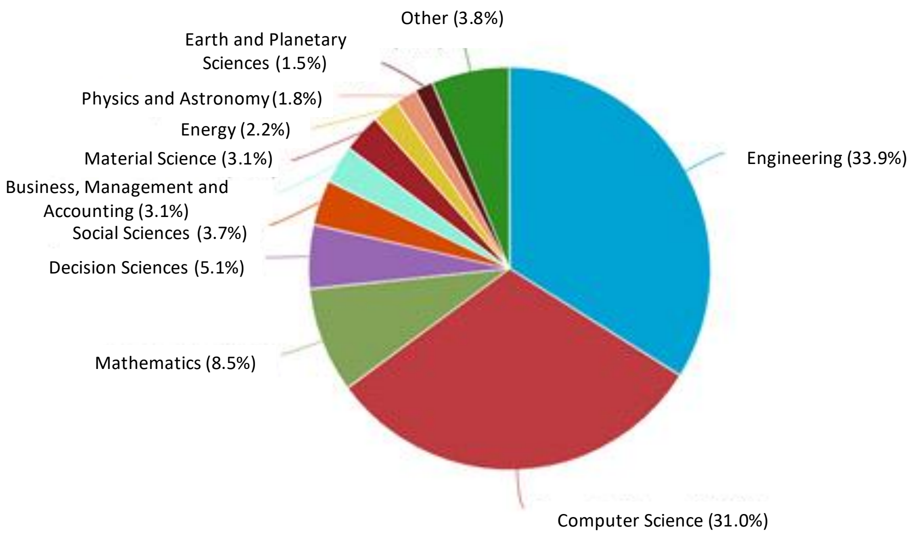

Figure 4 - Literature works by subject area.

The document analysis consists of two steps: (1) reading of title and abstract to decide if it is really coherent with the topic; (2) reading of 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 focus on specific are of interest considered most 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.

Subsequent sections will propose, for each introduced area of interest mainly existing (or emerging) solving approaches at the state of the art.

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2.4.1 Digital Twin

Digital Twin, as a replica of a physical entity, enables its simulation and, jointly, 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 5).

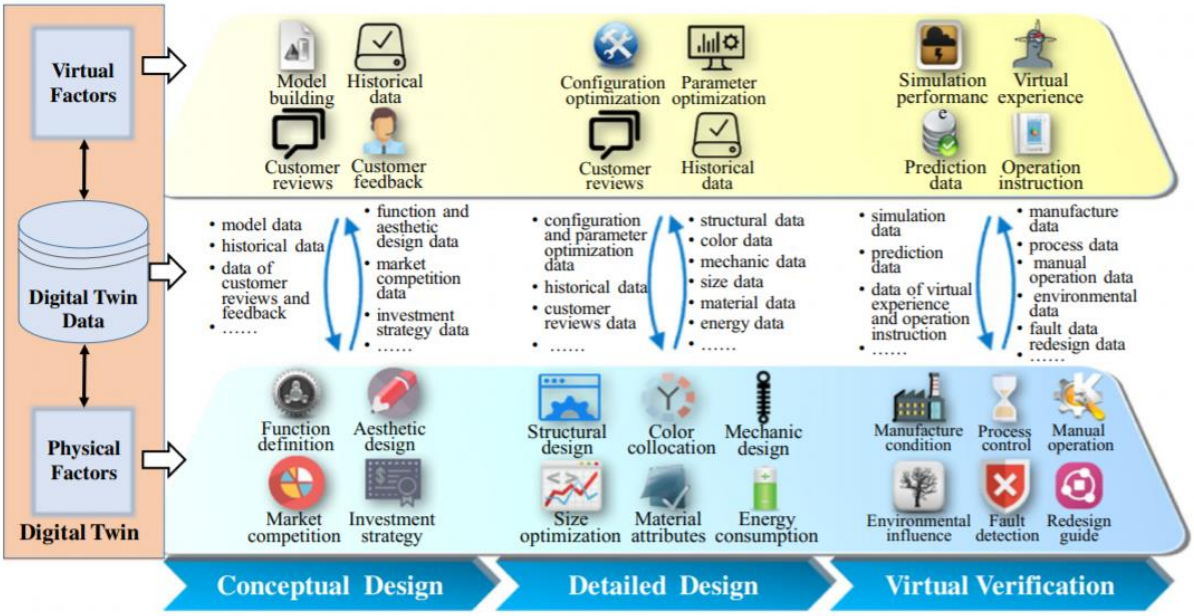

Figure 5 - Digital twin-based product design [6].

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 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 following: 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, understands the completion time of a job and, eventually makes a rescheduling [14].

2.4.1.2 Real-time controlling

Classic industrial control applications (Networked Control Systems) mainly consists 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

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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].

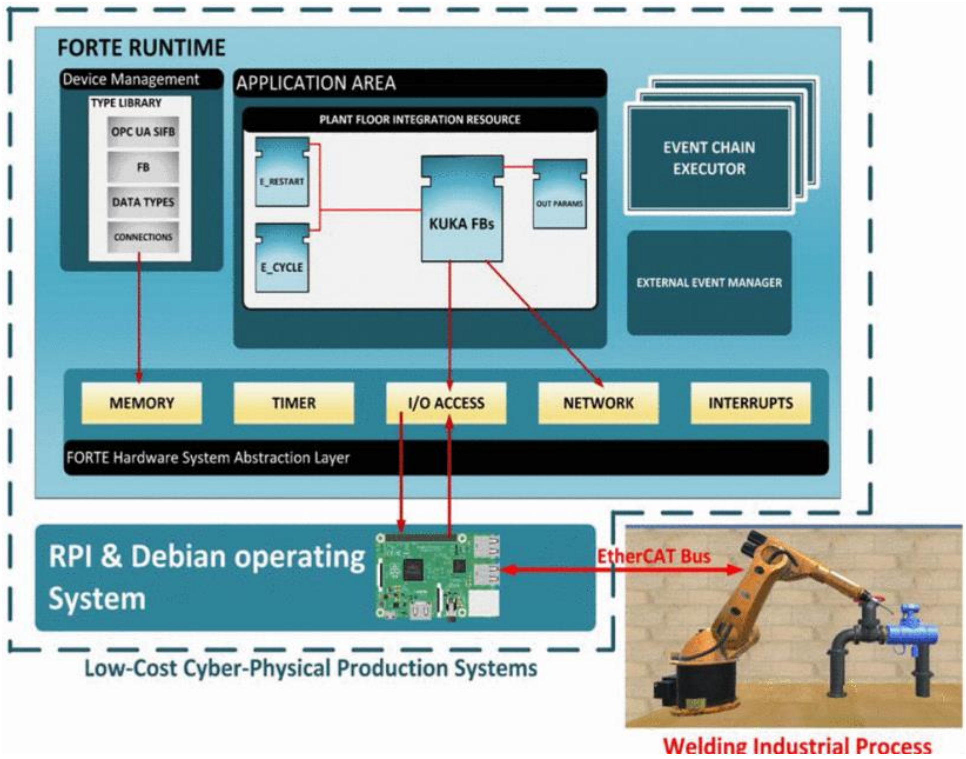

Figure 6 - Control robot architecture [20].

2.4.1.3 Forecasting

Forecasting (or prediction) activities analyse raw data to understand the system behaviour and predict future events. It is part of the advanced analytics strictly correlate 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].

Regarding the methodologies behind the decision-making process, the most popular are ones based on the Group Decision Making (GDM) process. For example, the Multiple Criteria Decision Making (MCDM), whose steps are: (1) identifying the problems, (2) constructing the preferences, (3) evaluating the alternatives, and (4) determining the best ones [27]. Otherwise, the Analytical Hierarchy Process (AHP) is a holistic approach that allows measuring the coherence between the evaluation metrics and the suggested alternatives by the team, 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].

[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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Furthermore, Ansari et al. [30] introduce 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 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, a simulation of the system and the related GUI used for showing faults to humans (Figure 7).

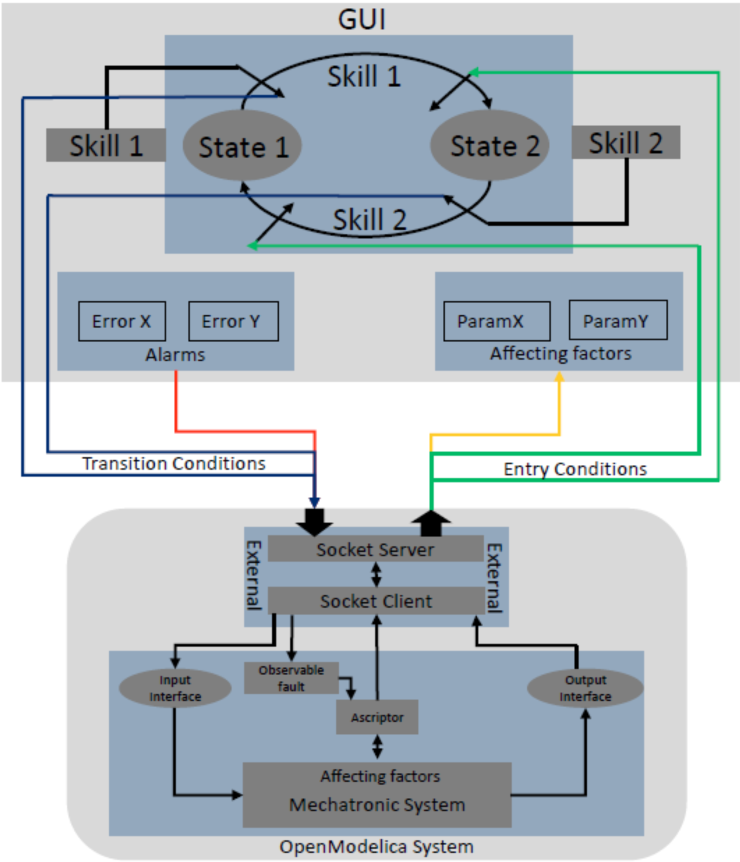

Figure 7 - Interactive fault ascription with a digital twin [32].

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 behaviour for the human.

Main 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.

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

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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 8, 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 business logic. Once the data input 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, develop them with preferred language, test and calibrate and then compile them back into the DBMS-centric implementation through the plug-ins approach.

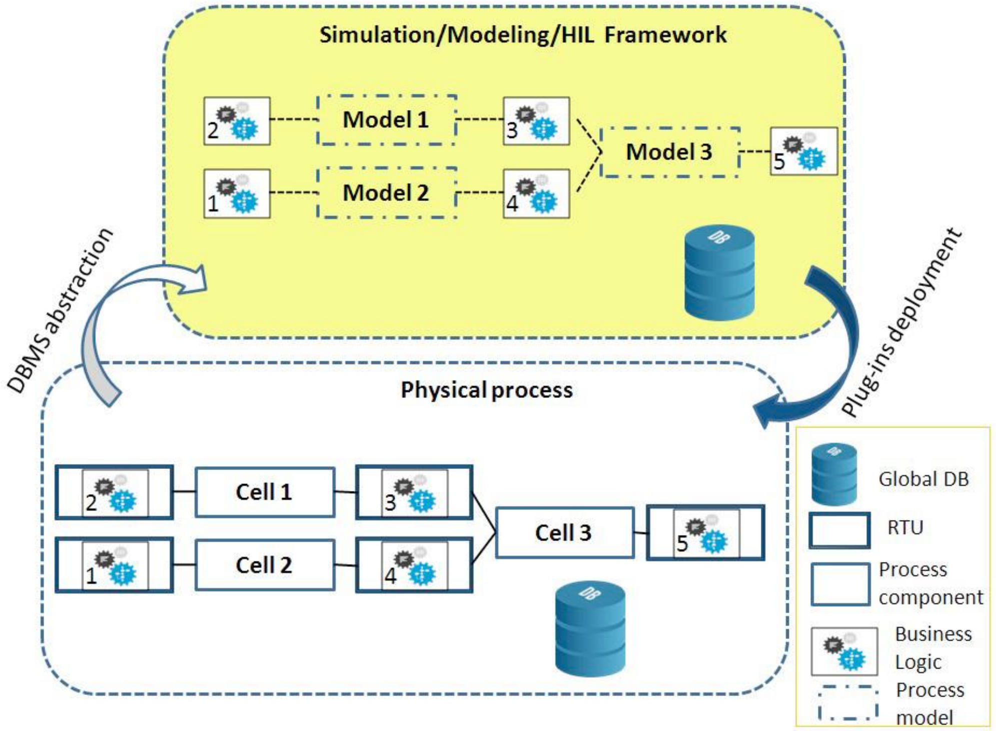

Figure 8 - DBMS abstraction and development framework.

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].

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

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

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

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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 behaviour.

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 9 (i.e., data acquisition and processing, condition assessment and diagnostic, fault prognostics and decision support, human-machine interface (HMI)) [46].

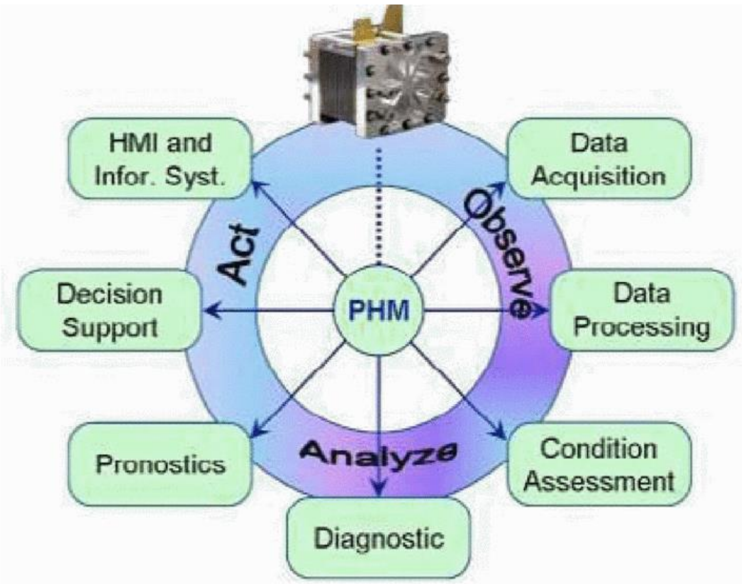

Figure 9 - PHM Architecture [46].

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 10):

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 analysing machine data to generate fleet analytics).

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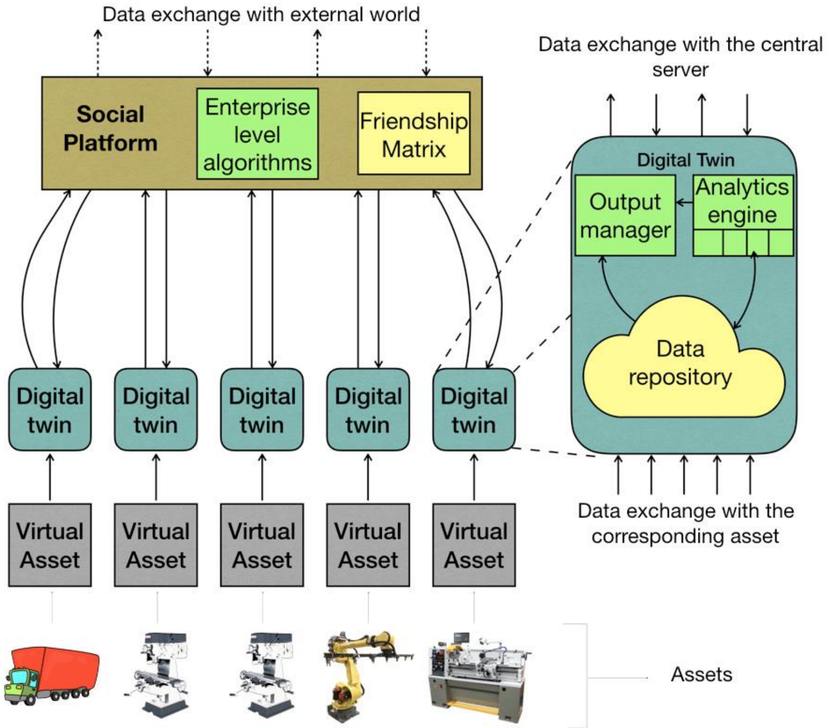

Figure 10 - A Multi-Agent System architecture for Collaborative Learning [44].

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 as a crucial aspect. The emerging of the integrated network of smart automation devices, cloud services, cloud platforms, and enterprises, new problems of interoperability rise. In this sense, Figure 11 highlights the difference between this type of integration and a hierarchical model. Matters related to interoperability regard inconsistencies among data formats or standards, compatibility between different versions of software, misinterpretation of the terminology used or in the understanding 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

[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.

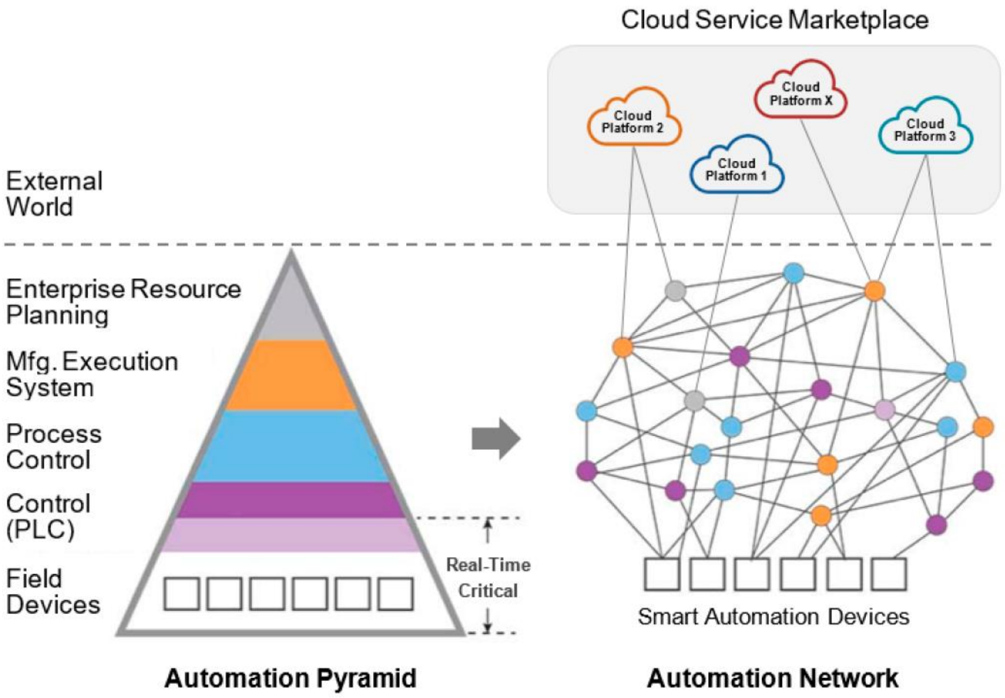

Figure 11 - Evolution of the hierarchical model of enterprise control system integration toward an integrated network of smart automation devices, cloud services, cloud platforms, and enterprises [69].

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 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 12) [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].

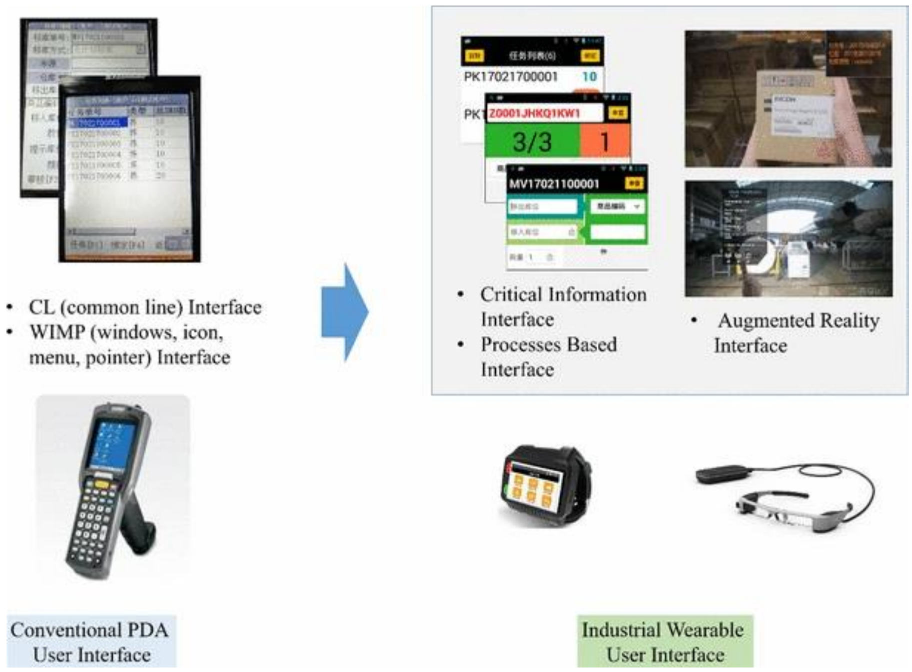

Figure 12 - Industrial wearable user interface for industrial mobility

2.4.9 Data analytics

Data analytics regards the need for methodologies of handling, retrieving, and storing 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 predicting;
- Statistic algorithms to understand dependencies among variables/sources of information (e.g., sensors).
- Decision-making algorithms to make a decision based on the real situations.

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2.4.10 Scalability

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

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

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

2.5.1 UC1 - MATERIAL FLOW ANALYTICS AND SIMULATION

The main objective of UC1 is summarized as a flexible production management of complex processes on the shop-floor. One of the main features of UC1 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, integrating MES (Manufacturing Execution Systems), PLM (Product Lifecycle Management), and ERP. The adoption of semantic data annotation and preferring the use of standards and architecture services 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, to understand the completion time, and eventually, makes a rescheduling of the activities [14]. The tracking of material flow is supported by a dedicated server or 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].

2.5.2 UC2 – 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].

2.5.3 UC3 - AUTOMATIC VACUUM SYSTEM

The objective is automating drilling activities by synchronizing two CPS (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].

Furthermore, a predictive maintenance task must understand the tip remaining useful life. In this area, several research works address predictive maintenance proposing all-inclusive solutions or experimenting 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 tip remaining lifetime should be showed to a human operator in a brief time. In this sense, preferred should not adopt cloud computing approaches exclusively.

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2.5.4 UC4 - 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 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 solutions Big Data oriented and, for example, cloud storage/computing [22].

2.5.5 UC5 - THERMOPLASTIC PRODUCTION LINE MONITORING

This use case aims to realize a CPS able to set the transformation process accurately, heating, pressing, and cooling in thermoplastic production.

The thermoplastic quality depends on multiple parameters that, in turn, influence a lot of processes. According to state of the art, the solution could regard 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 about components [16], the system could understand how setting the process. In this sense, adopting cloud storage could improve the efficiency in data management.

2.5.6 UC6 - 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 fixing solution, sometimes they 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 and deep learning algorithms are used at state of 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 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].

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3 REQUIREMENTS ELICITATION METHODOLOGY

This section reports the methodology adopted in task 8.1 to define the requirements related to the CPS4EU Industry Automation use cases. In the following paragraphs the type of requirements, the adopted notation and the requirement code conventions are described.

Requirements play major roles as they:

- Form the basis of system architecture and design activities
- Form the basis of system integration and verification activities
- Act as reference for validation and stakeholder acceptance
- Provide a means of communication between the various technical staff that interact throughout the project.

3.1 *Requirements Types*

According to the IEEE Standard Glossary of Software Engineering Terminology[10], a requirement is:

- A condition or capability needed by a user to solve a problem or achieve an objective
- A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents
- A documented representation of a condition or capability as in (1) or (2).

CPS4EU Industry Automation (WP8) Use Case requirements are classified into the following types:

Functional Requirement	A requirement that specifies a function that a system, or system component, must be able to perform. A requirement specifying **what** the overall system, or a specific component, will be able to do. Statements of services that the system should provide, how the system should react to particular inputs and how the system should behave in particular situations. Among the functional requirements are also included security requirements relating to the security services offered by the system to users or other systems.
Non Functional Requirement	A requirement specifying **how** the system or component will implement its functionality. In this document the following non-functional types of requirements are considered: • Interface Requirements • Performance Requirements • Security Requirements • Operational Requirements • Usability Requirements • Policies & Compliance Requirements • Design Constraints • Ethical Requirements • Other Requirements.

Table 3 – Requirements types summary.

[10] https://ieeexplore.ieee.org/document/159342/definitions#definitions

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The following table describe each requirement type:

Requirement Type	Req.ID	Requirement Description
Functional Requirement	**FNC**	Functional Requirements describe the behaviour and information that the solution will manage. In the case of a non-system solution, the behaviour typically refers to a workflow and the information refers to the inputs and outputs of the workflow. Additionally, the requirements describe how the data will be transformed and by whom. In the case of a system solution, the functional requirements describe the features and functionality of the system as well as the information that will be created, edited, updated, and deleted by the system.
Interface Requirement	**INT**	Interface requirements define how the system is required to interact or to exchange information with external systems (external interface), or how system elements within the system interact with each other (internal interface). Interface requirements include physical connections (physical interfaces) with external systems or internal system elements supporting interactions or exchanges. External interface requirements are important for embedded systems and outline how your product will interface with other components. There are several types of interfaces you may have requirements for, including: • Hardware: Describe the logical and physical characteristics of each interface between the software product and the hardware components of the system. • Software: Describe the connections between this product and other specific software components (name and version), including databases, operating systems, tools, libraries, and integrated commercial components. Identify data that will be shared across software components. • Communications: Describe the requirements associated with any communications functions required by this product, including e-mail, web browser, network server communications protocols, electronic forms, and so on. Identify any communication standards that will be used, such as FTP or HTTP. Specify any communication security or encryption issues, data transfer rates, and synchronization mechanisms.
Performance Requirement	**PRF**	If there are performance requirements for the Use Cases under various circumstances, state them here and explain their rationale, to help the developers understand the intent and make suitable design choices. Specify the timing relationships for real-time systems. Performance requirements can refer to individual functional requirements or features (e.g. speed of response for a certain functionality).
Security Requirement	**SEC**	Security requirements are related to both the facility that houses the system(s) and the operational security requirements of the system itself. Specify the security and privacy requirements, including access limitations to the system, such as log-on procedures and passwords, and of data protection and recovery methods. This could include the factors that would protect the system from accidental or malicious access, use, modification, destruction, or disclosure.

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		In safety-critical embedded systems this might incorporate a distributed log or history of data sets, the assignment of certain functions to different single systems, or the restriction of communications between some areas of the system. Examples: • Access requirements • Integrity requirements • Privacy requirements.
Operational Requirement	**OPR**	Examples: • Delivery mode • Access mode • Availability • Maintainability • Reliability • Capacity • Scalability • Portability • Installation.
Usability Requirement	**USB**	Examples: • Appearance and style • Ease of use • Internationalization • Accessibility.
Policies & Compliance Requirement	**P&C**	These requirements identify relevant and applicable organizational policies or regulatory requirements that could affect the operation or performance of the system(s). Examples: Laws and regulations, standards, business rules.
Design Constraint	**DSG**	Define restrictions on technology, resources or techniques to be used. Example: size, weight and power constraints, environmental requirements, which identify the environmental conditions to be encountered by the system in its different operational modes.
Ethical Requirement	**P&E**	See §5.1 Ethics of CPS4EU proposal, with particular reference to the document "Ethical Aspects of Cyber-Physical Systems": http://www.europarl.europa.eu/RegData/etudes/STUD/2016/563501/EPRS_STU%282016%29563501_EN.pdf
Other Requirements	**OTR**	Any other requirement that cannot be classified with the above categories.

Table 4 – Requirements types.

3.2 *Requirement Identification*

The CPS4EU Use Case requirements will be uniquely identified by an alphanumeric code consisting of:

<Use Case ID>-<classification>-<number>

where:

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Identifier	UC#	UC Short Description and Partner Leader
<Use Case ID>	**UC1**	Material Flow Analytics and Simulation (TRUMPF): digital twin of the shop floor
	UC2	Mobile CPSs (WIKA): “cooperative lifting”, where a huge object will be lifted and moved by at least 3 mobile cranes
	UC3	Automatic Vacuum System (LEONARDO): automation of drilling activities
	UC4	Trimming Quality Improvement (LEONARDO): AI-driven analysis and modelling of trimming data to realise real time trimming automatic setting
	UC5	Thermoplastic Production Line Monitoring (LEONARDO)
	UC6	Aircrafts Health Management System (requirements only) (LEONARDO)
<classification>	**FNC**	Functional Requirement
	INT	Interface Requirement
	PRF	Performance Requirement
	SEC	Security Requirement
	OPR	Operational Requirement
	USB	Usability Requirement
	P&C	Policies & Compliance Requirement
	DSG	Design Constraints
	ETH	Ethical Requirements
	OTR	Other Requirements
<number>	A progressive number that uniquely identifies the requirement within a requirement type	

Table 5 – Requirements ID fields.

Example:

UC1-USB-01 → Use Case ID = 1, Requirement type = “Usability Requirement”, Requirement number = 01

3.3 *Requirement Principles*

The following principles apply:

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Characteristics	Specific requirements should comply with the following characteristics: • unambiguous • complete • consistent • ranked for importance and/or stability • verifiable • modifiable • traceable.
Cross-references	Specific requirements should be cross-referenced to earlier documents that relate.
Readability	Careful attention should be given to organizing the requirements to maximize readability.
IDs	All requirements should be uniquely identifiable (via ID).

Table 6 – Requirements principles.

Each requirement should also be **testable**.

Each requirement will be classified according to the following priority:

Priority	***Feature***	***How to describe it***
High	A required, must have feature.	The system **shall**…
Medium	A desired feature, but may be deferred till later.	The system **should**…
Low	An optional, nice-to-have feature that may never make it to implementation.	The system **may**…

Table 7 – Requirements priority levels.

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4 PRELIMINARY USE CASE ANALYSIS

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

4.1 *UC1 - Material Flow Analytics and Simulation*

4.1.1 Overall Description

4.1.1.1 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. visualization of material flows, 3D shop floor model enriched with semantics about machines etc.); 2) continuous online optimization of production scheduling e.g. ad-hoc routing of orders and 3) prediction of production KPI's with the help of manufacturing simulation. 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 real-time 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 UC1:

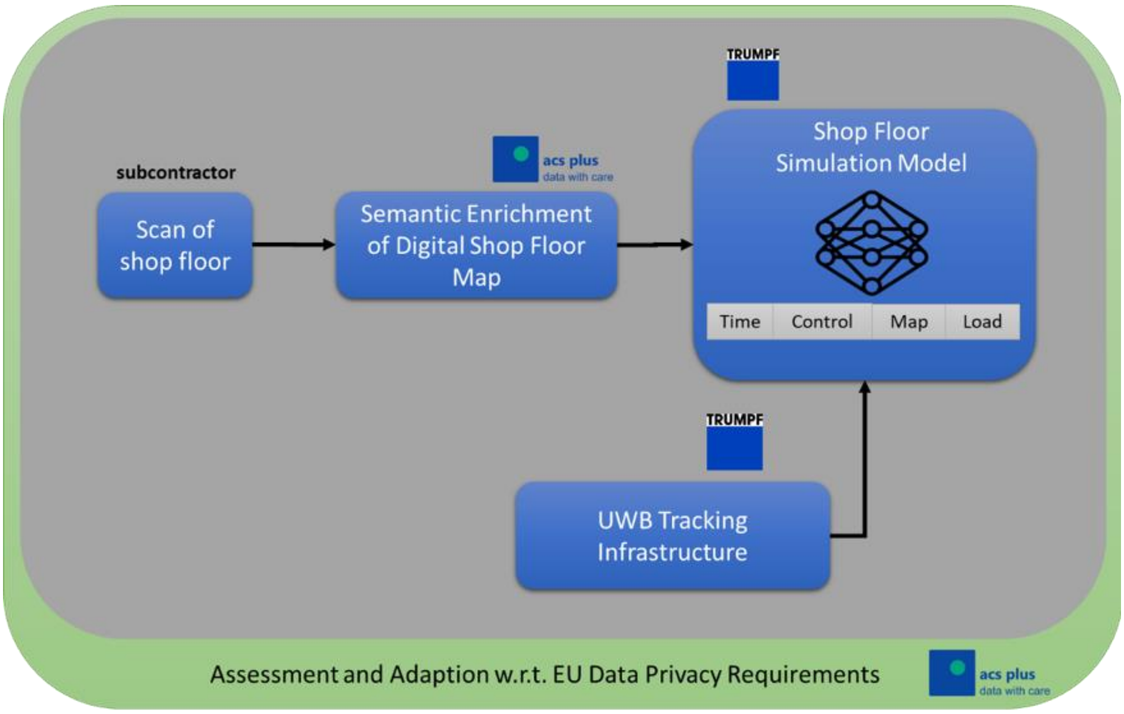

Figure 13 – UC1 overview.

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4.1.1.2 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 major functions are depicted in the following figure and briefly described below:

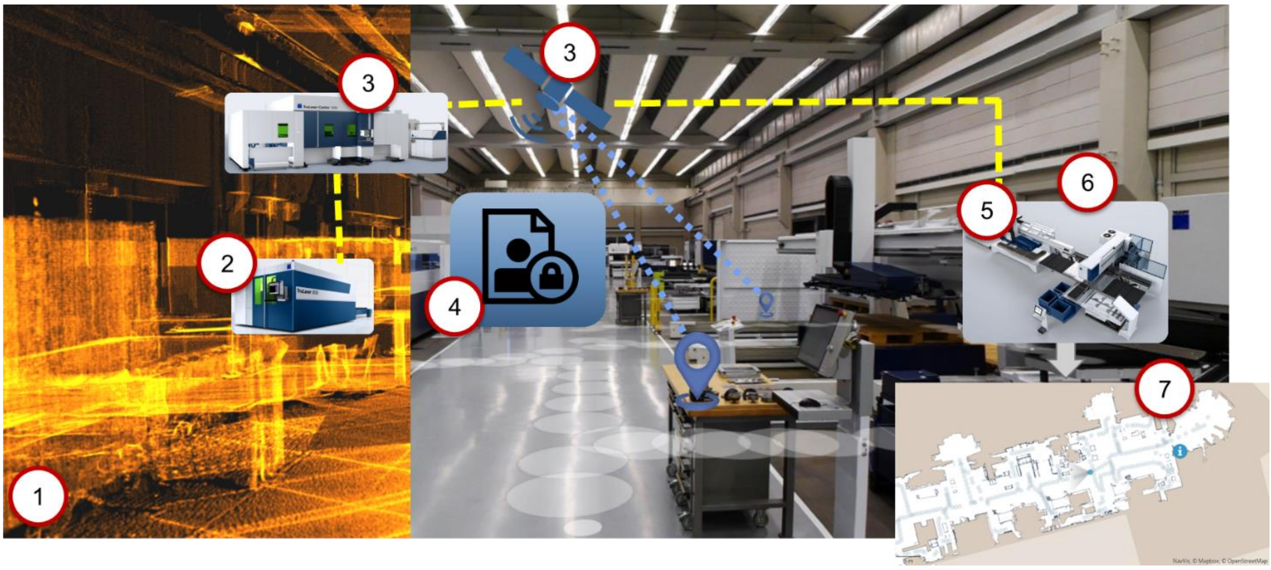

Figure 14 – UC1 major functions.

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. EU Data Privacy Requirements
5. Initial creation of simulation model based on this data
6. Continuous adaption of shop floor model-based on continuous stream of above data
7. Evaluation and interpretation of the simulation results, in order to provide feedback to the production planning system for real-time re-scheduling, re-routing and re-nesting

4.1.2 REQUIREMENTS

Requirement ID	**Requirement Type**	**Short Description**	**Description**	**Priority**
UC1-FNC-01	Functional Requirement	Detecting the type and position of TRUMPF machines given a 3D or 2D production hall scan, respectively	The position, the circumscribed cuboid and the type of the machine are to be recognized from 3D hall scan.	High
UC1-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
UC1-FNC-02	Functional Requirement	Detection of third-party machine model types	Recognizing existence and position, given a database with pictures and dimensions.	Medium
UC1-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 analysed and assessed for data privacy aspects.	Medium

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UC1-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
UC1-OPR-01	Operational Requirement	Selection of a suitable device for the creation of 2D or 3D production hall scans	Devices are acquired and assessed for their applicability for UC1-FNC-01.	High
UC1-PRF-01	Performance Requirement	2D or 3D Production Hall Scan	Create a number of 2D or 3D scans of sheet metal shop floors	High
UC1-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
UC1-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
UC1-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
UC1-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
UC1-FNC-05	Functional Requirement	Increase currency of simulation model	Analysing the continuous stream of shop floor data to detect layout changes and continuously adapt initial model	Medium
UC1-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
UC1-INT-02	Interface Requirement	Provide positioning data and auxillary 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

Table 8 - UC1 Requirements

4.2 *UC2 - Mobile CPS*

4.2.1 Overall Description

4.2.1.1 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

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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 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 local server on site or remote such as a cloud).

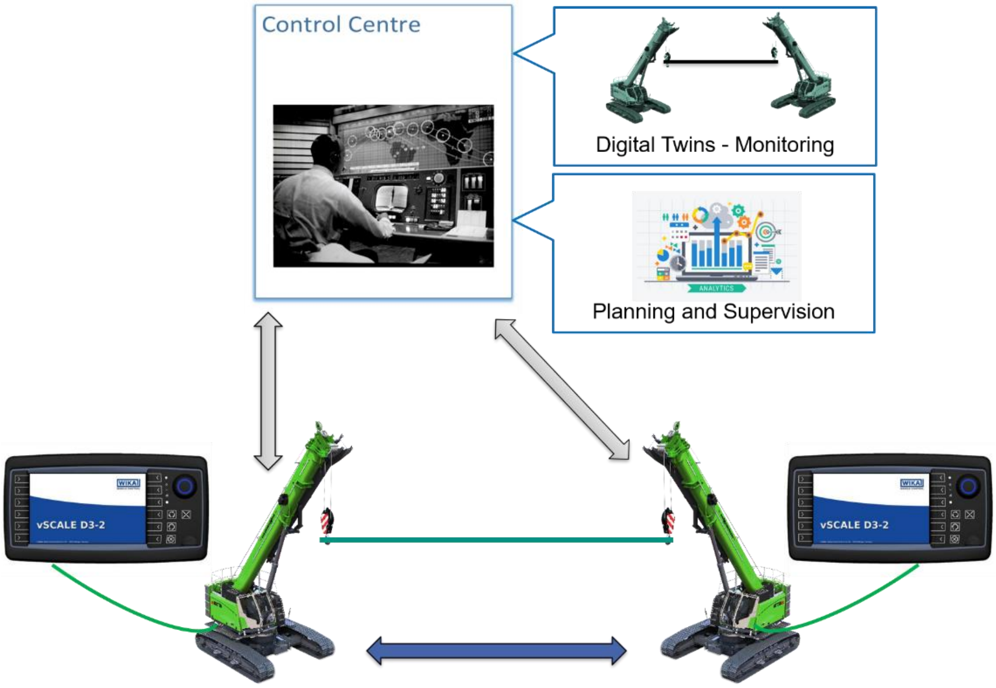

Figure 15 – UC2 overview.

4.2.1.2 Main Features

The collaborative lifting system will provide the following features:

- Lift planning:
    - Modelling and simulation of lifting process and 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.

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 crane 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 planning, which will be displayed on an HMI found in a crane operator cabin.

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

The machines will be able to communicate with the control centre, 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.

4.2.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority
UC2-FNC-01	Functional Requirement	Modelling and Simulation	Modelling and Simulation of lifting process and the used machines	Medium
UC2-FNC-02	Functional Requirement	Trajectory generation	Generating a lifting plan and missions/ trajectory for the cranes	Medium
UC2-FNC-03	Functional Requirement	Asset and process management	Machine management/ Lift process management	High
UC2-FNC-04	Functional Requirement	Contract assignment	Distribution of the missions for the machines	High
UC2-FNC-05	Functional Requirement	Autonomous lifting	Autonomous execution of the lifting process	Low
UC2-FNC-06	Functional Requirement	Machine monitoring	Machine monitoring (health conditions, safety state)	High
UC2-FNC-07	Functional Requirement	Process monitoring	Lifting process monitoring/ ensuring a correct execution of the planed lift	High
UC2-FNC-08	Functional Requirement	Winch system monitoring	Monitoring the winch control system of the crane	Medium
UC2-FNC-09	Functional Requirement	Display instruction on HMI	Display the generated instruction on HMI placed in the crane cabin	High
UC2-PRF-01	Performance Requirement	Real-time operating system	Using real time operating system (Linux-RT)	High
UC2-OPR-01	Operational Requirement	Contracts management	Framework to manage the received contacts on the mobile machines	Low
UC2-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
UC2-INT-02	Interface Requirement	OPC UA interface for control center and crane	Crane controller and crane must support OPC UA server interface	High
UC2-INT-03	Interface Requirement	MQTT interface for control centre and crane	Control centre and crane should support MQTT interface	Low
UC2-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
UC2-SEC-01	Security Requirement	Secure connection to the control centre and to other machines	the connection to the control centre should be secured by encryption and authentication	Medium
UC2-PRF-02	Performance Requirement	Lifting process monitoring duty cycle	Duty cycle of the lifting monitoring task must be under 1s	Medium

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Requirement ID	Requirement Type	Short Description	Description	Priority
UC2-OPR-02	Operational Requirement	Distributed control framework	Implementing a distributed control framework (in case connection to control centre is lost)	Medium
UC2-USB-01	Usability Requirement	GUI for the control centre	GUI to manage the supervision and monitoring of the collaborating machines and the executed process)	High
UC2-USB-02	Usability Requirement	GUI for the HMI on crane	GUI for the collaborative lifting function on the HMI of the crane	High
UC2-FNC-11	Functional Requirement	AI for winch control sensor (camera/ lidar based sensor)	AI-powered sensor platform for the winch control	Medium

Table 9 - UC2 requirements.

4.3 *UC3 - Automatic Vacuum System*

4.3.1 Overall Description

4.3.1.1 High level Use Case Description

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 carbonfiber dust that is produced. The use case will automate the movements of the vacuum system to “follow” the drill position.

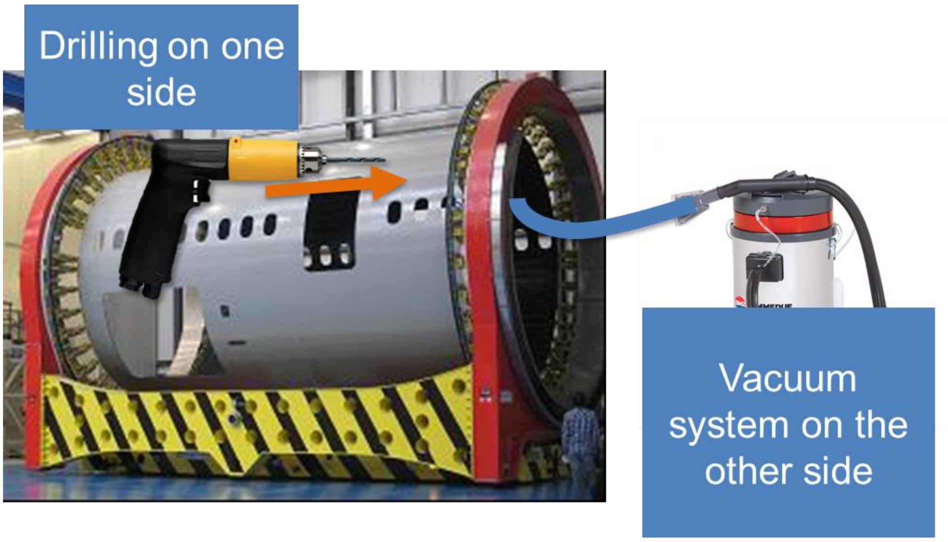

Figure 16 - UC3 overview.

The objective of this use case is to create concurrent CPSs able to synchronize their relative position and avoid any possible collision with other CPSs.

4.3.1.2 Main Features

The first CPS (**DRILL**) will be implemented on the drill motor 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 flexible rails held by suction cups, following *precisely* the position of the **DRILL** in order to vacuum the carbonfiber dust.

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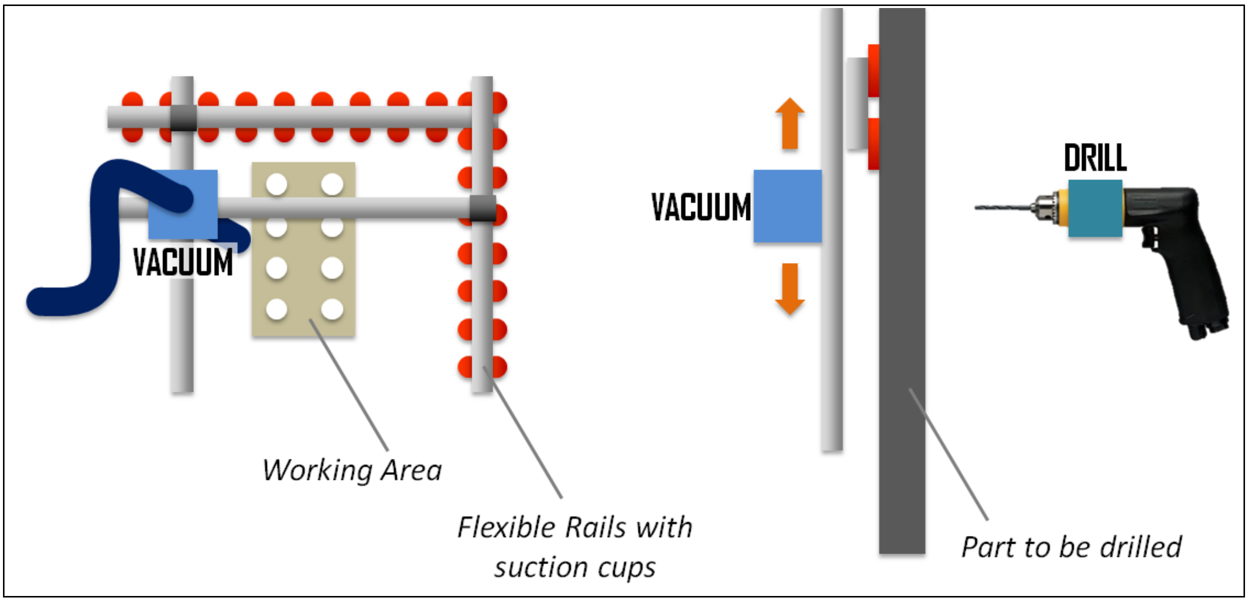

Figure 17 - UC3 components.

Furthermore, the DRILL can be equipped with a system able to identify the mounted drill bit, understand its usage and wear in order to understand when it's time to replace it.

The drills used in Grottaglie Leonardo's 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 and the economic investment needed for the tool upgrade does not justify the associated ROY. 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
- VACUUM receives DRILL position
- VACUUM calculates its relative position with respect to the DRILL, using the reference system
- VACUUM actuators move the vacuum hose on the opposite side of the DRILL
- When the VACUUM reaches its position, it begins to suck
- 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
- no objective evaluation criteria to be used, as no historical data can be analysed to produce objective standards.

The Use Case envisages a system designed to keep track of the drill bit consumption, possibly inhibiting the drill usage when specific criteria are not met.

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4.3.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority
UC3-FNC-01	Functional Requirement	Vacuum physical framework	A physical framework shall be designed and built, within the working area to enable the VACUUM to reach DRILL position. The VACUUM is clamped to the framework.	High
UC3-FNC-02	Functional Requirement	Reference system	DRILL and VACUUM shall use a common reference system for their position	High
UC3-FNC-03	Functional Requirement	Detection of positioning	DRILL and VACUUM shall be able to understand their position with respect to the coordinate reference system	High
UC3-FNC-04	Functional Requirement	Interactions between DRILL and VACUUM	DRILL and VACUUM shall communicate to exchange information on their position and to give/receive consensus	High
UC3-FNC-05	Functional Requirement	Consensus for Vacuum	VACUUM must start to suck only after it is in place (on the opposite side of the DRILL)	High
UC3-FNC-06	Functional Requirement	Consensus for drilling	DRILL perforation must be allowed only when the VACUUM is in place	High
UC3-FNC-07	Functional Requirement	Tool predictive maintenance	The drill tip wear should be estimated to predict the tip remaining useful life	Medium
UC3-SEC-01	Security Requirement	Communication Security	Communication between DRILL and VACUUM shall support data integrity and allow authentication of the two parts	High
UC3-OPR-01	Operational Requirement	Communication on edge	DRILL and VACUUM shall communicate with each other at the edge to minimise latency	High
UC3-PRF-01	Performance Requirement	Real-time communication and execution	DRILL and VACUUM must cooperate in real time (under 1s)	Medium
UC3-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

Table 10 - UC3 requirements.

4.4 *UC4 - Trimming Quality Improvement*

4.4.1 Overall Description

4.4.1.1 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[11]), analyse 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.

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

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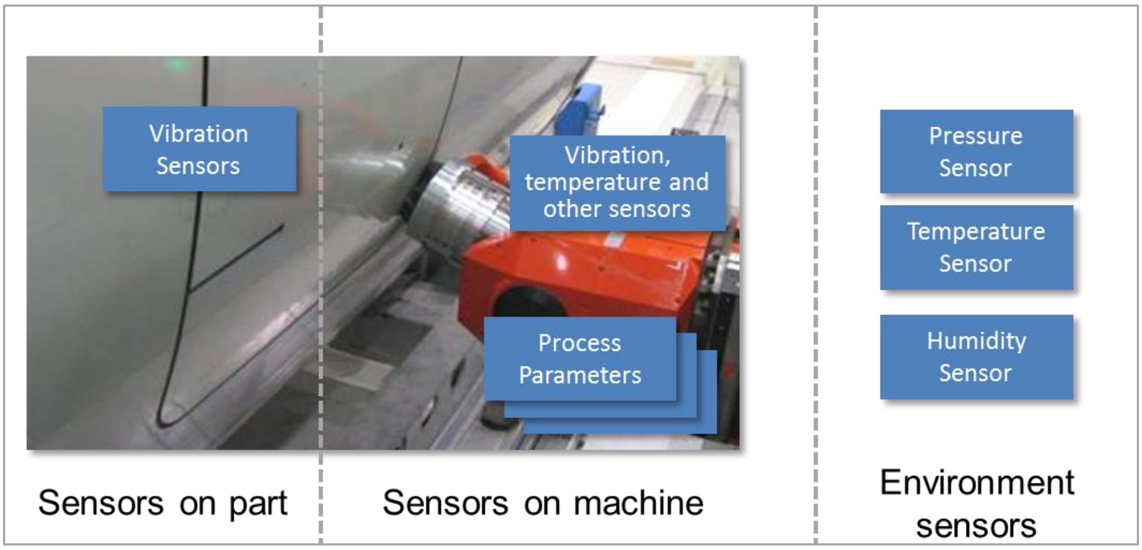

Figure 18 - UC4 overview.

4.4.1.2 Main Features

Among delamination causes 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).

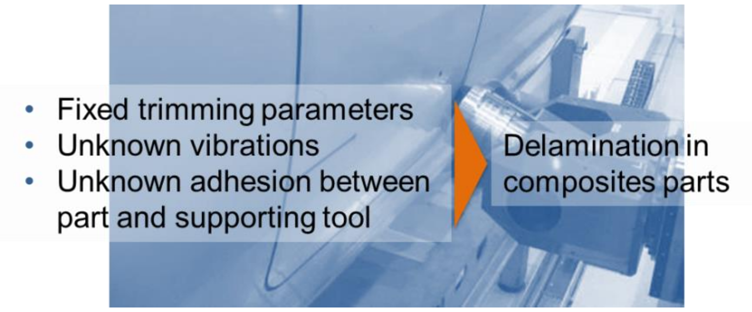

Figure 19 - UC4 delamination in composite parts possible causes.

The use case deals with 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.

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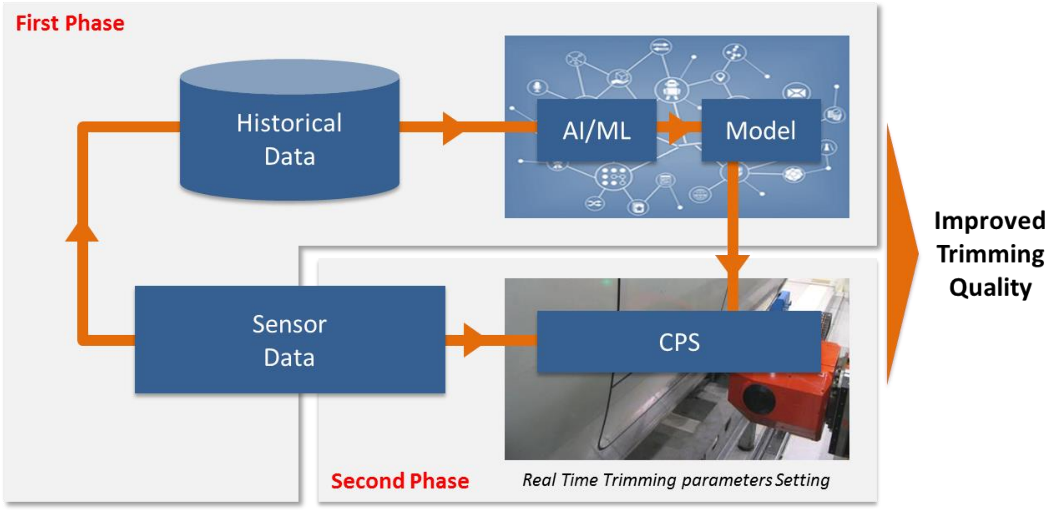

Figure 20 - UC4 first and second phases.

4.4.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority
UC4-FNC-01	Functional Requirement	Environment parameters acquisition	Information regarding environment temperature, pressure and humidity shall be measured	High
UC4-FNC-02	Functional Requirement	Vibration parameters acquisition	Vibrations shall be measured on the part being worked, on the fuselage mandrel, on the TRIMMER.	High
UC4-FNC-03	Functional Requirement	Working area surface temperature	The temperature of the area being worked shall be measured	High
UC4-FNC-04	Functional Requirement	TRIMMER parameters acquisition	The TRIMMER tip rotation, trimmer moving speed, position, shall be measured during the trimming process	High
UC4-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
UC4-FNC-06	Functional Requirement	Correlation model	Information regarding environment (temperature, pressure and humidity) shall be measured	High
UC4-FNC-07	Functional Requirement	Process Monitoring	The system should provide the operator with the optimal parameter setting according to the correlation model	Medium
UC4-SEC-01	Security Requirement	Communication Security	Support for mutual authentication, data integrity and confidentiality	High
UC4-PRF-01	Performance Requirement	Real-time communication and execution	The system should provide the operator with information in real-time (under 1sec) to enable the operator to adjust the settings of production machine	Medium
UC4-OPR-01	Operational Requirement	Interoperability	The system should be able to support various protocols and interfaces for communication at the edge and to data centre	High
UC4-FNC-08	Functional Requirement	Remote Management	The system should support remote management and software updates of firmware and business logic	Medium
UC4-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	Medium
UC4-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)	Medium

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Table 11 - UC4 requirements.

4.5 UC5 - THERMOPLASTIC PRODUCTION LINE MONITORING

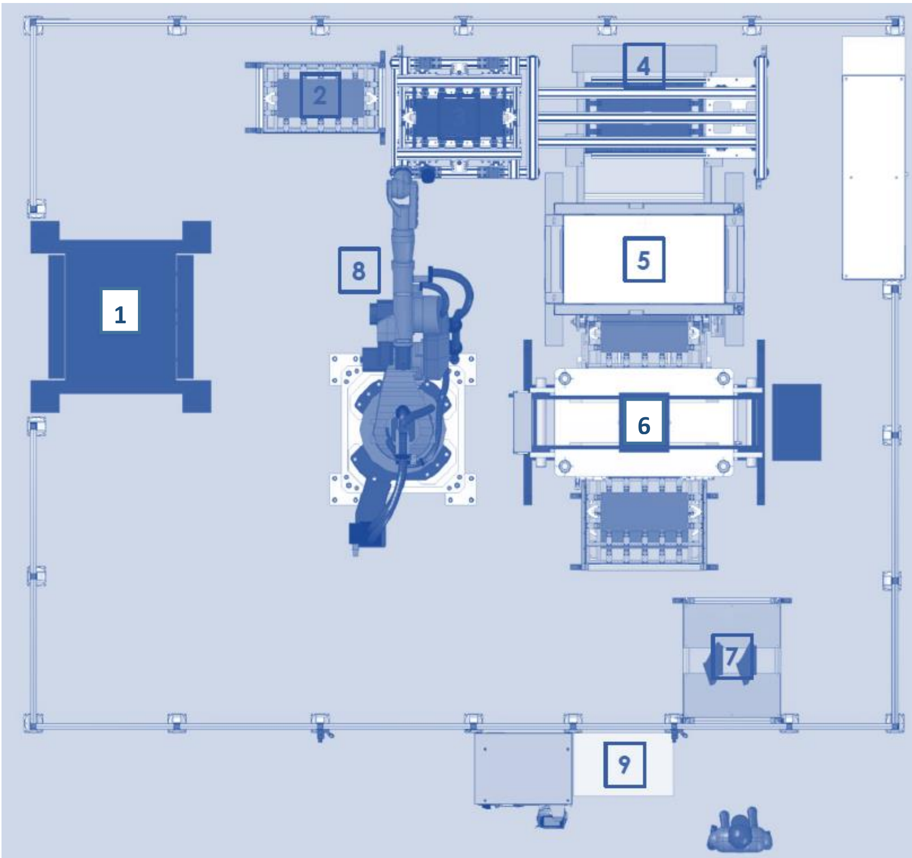
4.5.1 Overall Description

4.5.1.1 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[12]. 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 molding press
⑦ molded parts storage station
⑧ grasping station
⑨ management console

Figure 21 - UC5 production line overview

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[12] *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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4.5.1.2 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).

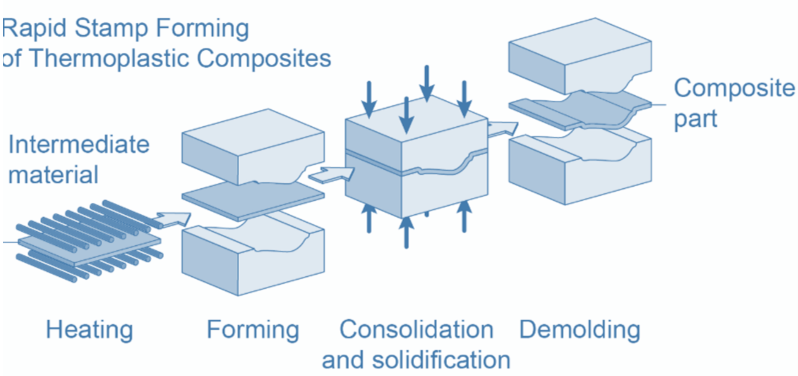


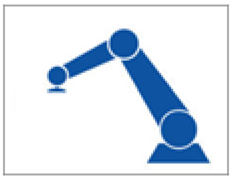
Figure 22 - UC5 stamp forming of thermoplastic composites.

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.

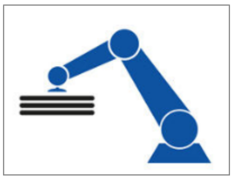
The following are the main steps of the process as will be implemented in the production line:

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.



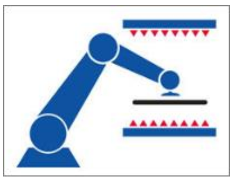
Here thermoplastic sheet is picked up and clamped into a frame. A critical step is the correct positioning of the sheet.



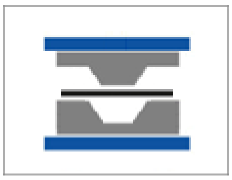
The sheet is placed into the heating device ⑤ which was previously heated to the required temperature. Here it is heated and begins to sag.

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 IR oven.



The robot arm inserts the sheet into the moulding press ⑥ and then left for a certain amount of time at a lower temperature for consolidation.



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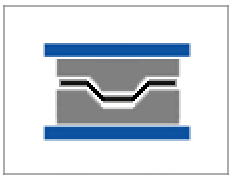
When the mould closes, the part is moulded by an hydraulic press in a process called “casting under pressure”.



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

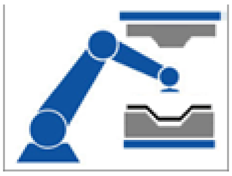


Figure 23 - UC5 production line steps.

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 (eg. 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 best quality.

4.5.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority
UC5-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
UC5-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
UC5-FNC-03	Functional Requirement	Thermoplastic sheet temperature	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
UC5-FNC-04	Functional Requirement	Thermoplastic sheet temperature	The system shall check that medium temperature is in the consented range, before the sheet is moulded	Medium
UC5-FNC-05	Functional Requirement	Environment parameters acquisition	Information regarding environment (temperature, pressure and humidity) shall be measured	High
UC5-FNC-06	Functional Requirement	Correlation model	The system shall discover the correlation between process variables and the final quality of the sheet	High
UC5-FNC-07	Functional Requirement	Process Monitoring	The system shoud provide the operator with the optimal parameter setting according to the correlation model	Medium
UC5-SEC-01	Security Requirement	Communication Security	Support for mutual authentication, data integrity and confidentiality	Medium
UC5-PRF-01	Performance Requirement	Real time communication and execution	The system should provide the operator with information in real-time to enable the operator to adjust the settings of production machine	Medium
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
UC5-FNC-08	Functional Requirement	Remote Management	The system should support remote management and software updates of firmware and business logic	High
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)	Medium

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Table 12 - UC5 requirements.

4.6 *UC6 - Aircraft Health Management System*

4.6.1 Overall Description

4.6.1.1 High level Use Case Description

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

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

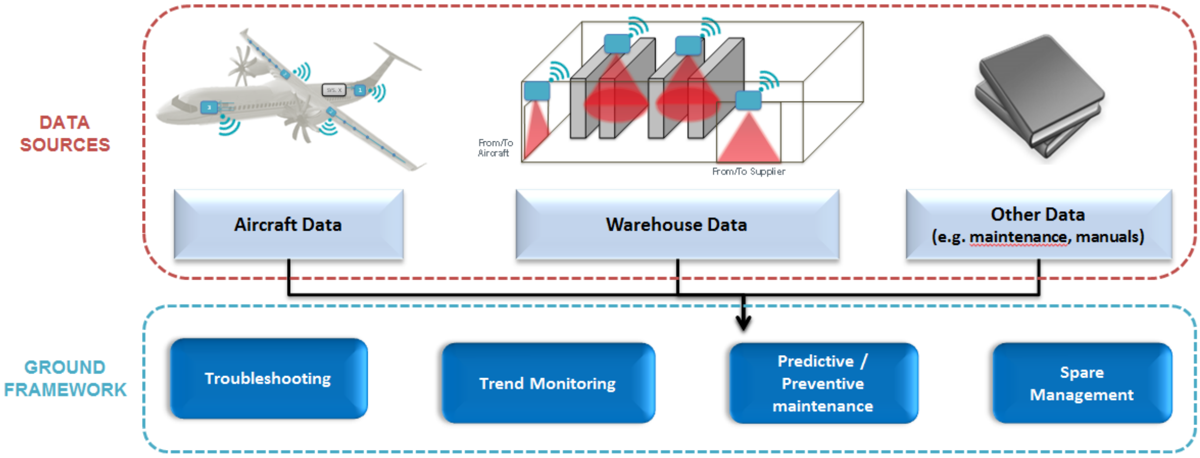

Figure 24 – UC6 overview.

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 the health status of aircraft critical parts and equipment. Failures have to be fixed as soon as possible: performance data are used to anticipate future possible failures whenever possible.

Warehouse data 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. manuals) could be handled by such a framework, but these are outside of the current CPS4EU perimeter.

4.6.1.2 Main Features

It is easy to understand that the overall picture of this use case is very complex. So in order to reduce the overall complexity, within the CPS4EU project, the focus will be on the on ground framework and in particular on the following features:

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

The AHMS onboard component deals with:

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- collecting 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

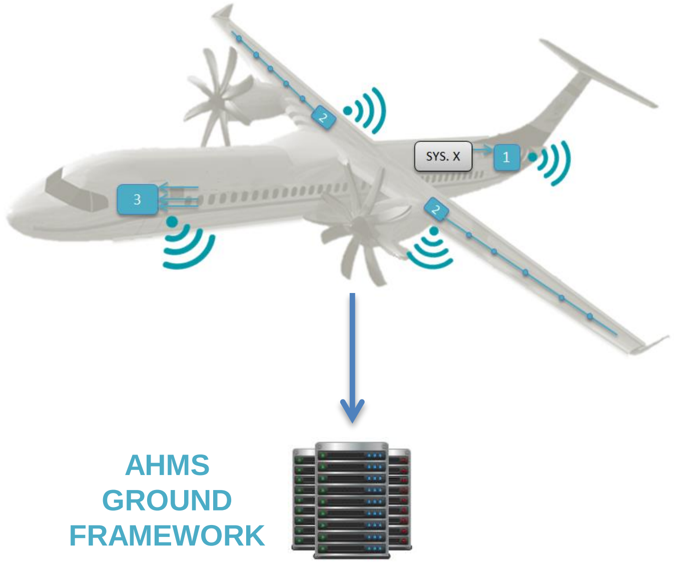

Figure 25 - UC6: CPS on aircraft.

The AHMS Warehouse Component is responsible of:

- identifying items removed/installed on aircraft for maintenance activities
- tracking items inside the warehouse or moved towards the aircraft/Supplier
- elaborating data in order to have an up-to-date status of the warehouse
- sharing collected information with Ground Framework CPS and other devices

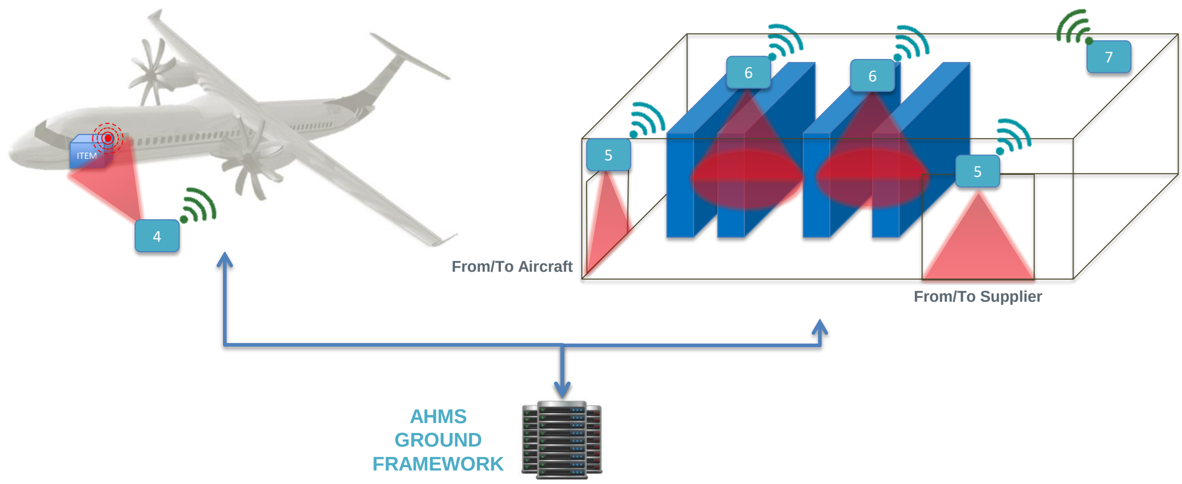

Figure 26 - UC6: CPS in the warehouse.

The AHMS Ground Framework is intended to support the following users:

- Maintenance Operators, in charge of performing the maintenance tasks according to planning;
- Engineers, in charge of analysing data and, if needed, scheduling maintenance tasks;
- Logistic Operators, in charge of managing parts transportation, optimizing spares according to the needs.

In the Ground Framework, data coming from the Aircraft and Warehouse components, are used to provide:

- the **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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- the **Engineering Department** with the capability of:
  - (Trend Monitoring) monitoring aircraft systems performance w.r.t. predefined and customizable thresholds
  - (Predictive / Preventive maintenance) setting maintenance actions anticipating possible future failure calculated following two possible approaches: comparison w.r.t. historical database or w.r.t. prognostic models able to calculate Remaining Useful Life (RUL).
- the **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.

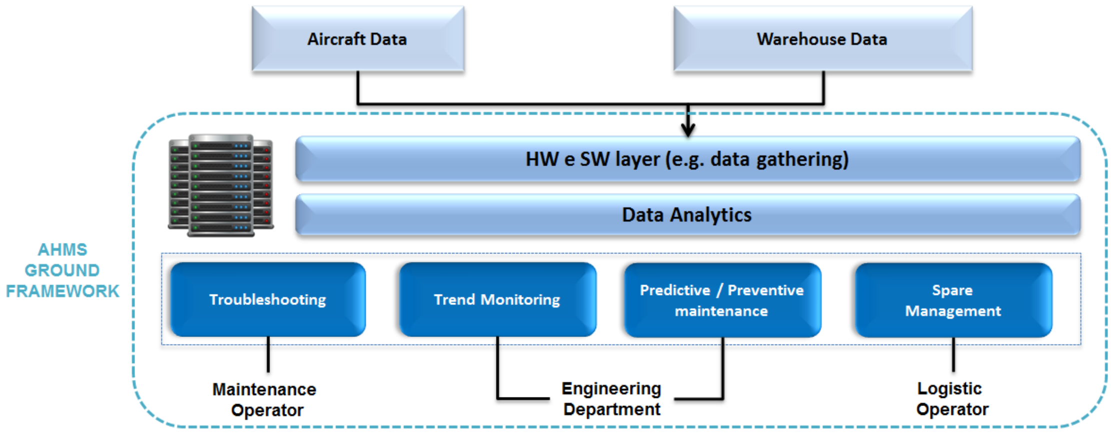

Figure 27 - UC6: AHMS ground framework.

4.6.2 REQUIREMENTS

Requirement ID	Requirement Type	Short Description	Description	Priority
	On board component			
UC6-INT-01	Interface Requirement	Connection inside the aircraft	The System shall be able to receive data from the aircraft system.	High
UC6-FNC-01	Functional Requirement	Recording data on NVM	The System shall be able to record received data on a non-volatile memory.	High
UC6-FNC-02	Functional Requirement	Computation	The System shall be able to perform computation based on data received from the aircraft system.	High
UC6-FNC-03	Functional Requirement	Modifiable algorithm	The System shall be able to perform computation using user-modifiable algoritms without impacting aircraft certification.	Medium
UC6-PRF-01	Performance Requirement	Storing data	The System shall be able to store received data and internal data of last TBD flights.	Medium
UC6-FNC-04	Functional Requirement	Algorithm upload	The Operator shall be able to upload the System user-modifiable algorithms.	Medium
UC6-FNC-05	Functional Requirement	Aircraft system data	The System shall be able to receive the following aircraft system data: identification data, configuration data, maintenance data, performance data and usage data.	High

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Requirement ID	Requirement Type	Short Description	Description	Priority
UC6-INT-02	Interface Requirement	Connection to AHMS Ground Framework	The System shall be able to trasmit the aircraft system data to AHMS Ground Framework through a wireless connection.	High
UC6-SEC-01	Security Requirement	Secure connection	The System shall provide a secure wireless connection.	High
UC6-DSG-01	Design Constraints	Power supply	The System power supply shall be compliant with the aircraft system power supply.	High
UC6-DSG-02	Design Constraints	Power consumption	The System power consumption shall be limited to a percentage (To be defined) of the aircraft system power consumption.	Medium
UC6-DSG-03	Design Constraints	Weight	The System weight shall be limited to a percentage (To be defined) of the aircraft system weight.	Medium
UC6-DSG-04	Design Constraints	Volume	The System volume shall be limited to - a percentage (To be defined) of the aircraft system volume.	Medium
UC6-OPR-01	Operational Requirement	EMC regulation	The System hardware shall be compliant with applicable EMC regulations (AC 20-190).	High
UC6-OPR-02	Operational Requirement	Environmental regulation	The System hardware shall be compliant with applicable environmental regulations (DO 160 G).	High
	Warehouse component			
UC6-FNC-06	Functional Requirement	Communication with CPS Ground Framework	The System shall be able to exchange data with the CPS Ground Framework	High
UC6-FNC-07	Functional Requirement	Item Identification	The System shall be able to identify in an automated way the items: - Inside the Warehouse - Moved from/to aircraft to the Warehouse - Moved from/to Supplier to the Warehouse To each item is applyied a component (e.g. RFID plate) that stores item identification information	High
UC6-FNC-08	Functional Requirement	Inventory Data Collection and Processing	The System shall be able to collect and pre-process inventory data before sending them to the CPS Ground Framework	High
UC6-PRF-02	Performance Requirement	Inventory Data update	The System shall be able to send updated items inventory information (e.g. stock, position, etc.) to the CPS Ground Framework each TBD minutes	High
UC6-SEC-02	Security Requirement	Secure Communication	The System communications shall be encrypted during data transfers	High
UC6-INT-03	Interface Requirement	Data and Data Flow standardization	All the Data and Data Flow shall be standardized	High
UC6-FNC-09	Functional Requirement	Environmental Conditions	The System shall be able to acquire data on the environmental conditions	Medium

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Requirement ID	Requirement Type	Short Description	Description	Priority
UC6-FNC-10	Functional Requirement	Modifiable Algorithms	The System shall be able to perform computation using user-modifiable algoritms	High
	Ground component			
UC6-INT-04	Interface Requirement	Connection with the aircraft	The System shall be able to receive data from the aircraft system on a wireless connection.	High
UC6-INT-05	Interface Requirement	Communication with the aircraft	The System shall be able to exchange data with the Aircraft	High
UC6-FNC-11	Functional Requirement	Communication with the warehouse	The System shall be able to exchange data with the warehouse about inventory items and parts supply	High
UC6-INT-06	Interface Requirement	Data and Data Flow standardization	All the Data and Data Flow shall be standardized	High
UC6-SEC-03	Security Requirement	Secure Communication	The System communications shall be encrypted during data transfers	High
UC6-FNC-12	Functional Requirement	Maintenance Model	The system should discover and implement a model to allow the automated identification of the information required to perform maintenance activities (troubleshooting, removal/installation procedures, etc.)	High
UC6-FNC-13	Functional Requirement	Trend monitoring Model	The system should identify trend deviation of critical parameters	High
UC6-INT-07	Interface Requirement	Maintenance Operator Interface	The System shall guide the maintenance operator in his troubleshooting activity	High
UC6-INT-08	Interface Requirement	Engineer Interface	The System shall provide the Engineers with trend analysis information	High

Table 13 – UC6 requirements.

5 CONCLUSIONS

In this deliverable we outlined an update of the state-of-the-art analysis of the cyber physical systems typically adopted in the domain of industrial automation. This analysis allowed to identify the most innovative technologies and methodologies adopted for the digitalisation of the industrial sector, with a specific focus on the use cases that will be developed in WP8.

We defined a methodology for the requirements elicitation, that represents a solution to collect the requirements in a coherent and homogeneous way across the use cases.

Starting from the results of the state-of-the-art analysis in conjunction with the analysis of the use cases, we adopted the elicitation methodology to identify the preliminary functional and non-functional requirements of WP8 use cases. The final requirements list will be provided in D8.2.

The preliminary requirements will be considered in task 8.2 for the modelling and design of WP8 use cases and will contribute to guide the design of the horizontal technologies that will be developed in WP1 – 6.

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