This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101069732

aerOS

EUROPEAN IOT-EDGE-CLOUD

D2.3 – Use cases manual, requirements, legal and regulatory analysis (2)

Deliverable No.	D2.3	Due Date	29-FEB-2024
Type	Report	Dissemination Level	Public (PU)
Version	1.0	WP	WP2
Description	Final version of requirements elicitation, use cases and scenarios definition and legal and regulatory analysis.		

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History

Date	Version	Change
30-NOV-2023	0.1	ToC created and announced in WP2 telco
01-FEB-2024	0.2	First content included in the document
13-FEB-2024	0.6	Second content included in the document
24-FEB-2024	0.9	Version submitted for Internal Review
29-FEB-2024	1.0	Final version submitted considering IR comments

Key Data

Keywords	Use cases, requirements, data
Lead Editor	P15 PRO – Eduardo Garro
Internal Reviewer(s)	P INF – Nikolaos Gkatzios P IQBIT – Giannis Chouchoulis

Executive Summary

This document is written in the framework of WP2 - aerOS reference architecture for the IoT-edge-cloud continuum of the Horizon Europe project aerOS (GA No 10106932). The overarching goal of aerOS is to design and build a virtualised, platform-agnostic meta operating system for the IoT edge-cloud continuum. This document depicts the efforts devoted to the refinement and increase of requirements and the description of the five use cases, also referred as pilots, of the project.

The first use case (P1) "Data-Driven Cognitive Production Lines represents the Industry 4.0 (I4.0) vertical through the intention to deploy and validate Manufacturing Autonomy Level 4 (MAL4) cognitive production processes in 4 public-private Pilot Lines (PL). This use case is divided in three different scenarios, which share among them the final goal of creating a highly flexible, sustainable (green) modular digital production lines and manufacturing of a new product in a low-volume production via the implementation of smart rapid response features in connection with self-optimization, reconfigurations ramp-up, adaptation of production line and operations. In particular, the 3 independent use case 1 scenarios are: (i) Green manufacturing (zero net-energy) and CO2 footprint monitoring, (ii) Automotive Smart Factory Zero Defect Manufacturing, and (iii) AGV swarm zero break-down logistics & zero ramp-up safe PLC reconfiguration for lot-size-1 production. Four main outcomes are expected at the end of the pilot: (1) Smart management services for zero-touch management, (2) remote metrology solution which leverages underlying meta–Operating System, (3) assembly systems in the line with aerOS approach, and (4) aerOS-based digital twin.

The second use case (P2) "Containerised Edge Computing near Renewable Energy Sources" aims at determining the impact that aerOS can have on the carbon emissions generated by the European cloud industry. The pilot will proof applicability of aerOS for set up and management of cloud-edge architectures distributed between "big" central clouds and small edge nodes, located directly at energy producing locations. To do so, the pilot is composed of two scenarios. The first focuses on deploying two federated edge nodes and a private cloud located directly at renewable energy premises (with different data sources from wind and PhV farms). The second scenario extends the federation beyond infrastructure owned by a single actor, bringing on-board multiple, independent tenants, demanding aerOS information management, cybersecurity, and data fabric services from aerOS. Three main outcomes are expected at the end of the pilot: (1) Reduction in energy consumption due to the transfer of AI and real-time analytics to the edge nodes, (2) Flexibility and scalability of the aerOS concept portability in the IoT edge-cloud continuum, and (3) Definition and implementation of energy and network conscious management tools and procedures.

The third use case (P3) "High Performance Computing Platform for Connected and Cooperative Agricultural Mobile Machinery to Enable CO2 Neutral Farming (HPCP-F)" main objective is to integrate, test and validate High-Performance Computing Platform for connected and cooperative mobile machinery farming, construction, and forestry. Such tasks in agriculture and construction work that require collecting data from different components and analyzing it whether on-board or off-board, can highly benefit from an ECU with high computing power in its overall analysis of the field work. It is divided into two main scenarios. The first scenario will optimize a large-scale production harvesting process system based on mobile machines. Three potential benefits from the usage of aerOS are identified: usage of common APIs to enable seamless application hosting and supporting the functional allocation, (ii) monitoring and real-time control, and (iii) improvement of trustworthiness via implementation of a chain of trust on embedded software. The second scenario will measure in a collaborative swarm of vehicles the energy consumption reduction due to the use of aerOS and different federation topologies.

The use case number 4 (P4) "Smart edge services for the Port Continuum" is oriented to provide a metaOS to transform maritime port container terminal operations, improving scalability through decentralization. The use case is divided into two scenarios, being the first focused on predictive maintenance of container handling equipment, and the second one concentrating on risk prevention via computer vision in the edge. Thus, four specific objectives are expected: (i) to improve the traceability of port assets, (ii) to allow the use in the terminal of heterogeneous Infrastructure Elements (IEs) (iii) to offer a predictive maintenance service integrated into the system and based on Frugal AI, and (iv) to provide a computer vision solution that can be inferred from the edge without requiring very high bandwidths. To do so, data related with cranes telemetry from their PLCs, different type of sensors will be collected for the first scenario, as well as IPTV cameras will be installed and used to perform local edge ML training and inference for the automatic identification of proper seals and surface damaged containers for the second scenario. All the data sources will be orchestrated by the aerOS communication infrastructure, being formed by different aerOS domain within the Port Continuum.

The fifth use case (P5) “Energy Efficient, Health Safe & Sustainable Smart Buildings” aims to demonstrate gains of the aerOS architecture in an edge deployment for energy efficient, sustainable, flexible and health-safe smart buildings. The main goal behind the use case is (i) to achieve swarm intelligence among the aerOS capable sensors, allowing an office to become self-organized in terms of health and efficiency, and (ii) demonstrate energy efficiency of the large buildings using real-time processing and (frugal) AI. Consequently, four main outcomes are expected at the end of the pilot: (1) Interoperability in a Smart Building, (2) Advanced networking in a Smart Building, (3) Decentralised intelligence and (4) Orchestration.

With regards to the requirements elicitation, a thorough procedure drilled down in (a) Technical Requirements and (b) Requirements coming from pilots (user and system requirements) was addressed since D2.2 and continued in D2.3. The first track (technical requirements) has been conducted using a specific template covering the domain, category, and type of requisite, specifying the technological area of the project that those refer to. A total number of 102 technical requirements were recorded, divided in data management, infrastructure virtualization and handling, security and/or privacy, network features, AI, or high-level applications and global services. Coming from pilots, a total of 74 user and system requirements were identified from all use cases / pilots (the majority were actually identified in D2.2). Out of those, 50 were considered functional requirements and 24 non-functional requirements.

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Table 1. List of acronyms

Acronym	Explanation	Acronym	Explanation
AAA	Authentication and Authorisation	NFV	Network Function Virtualisation
AGV	Automated Guided Vehicle	NP	Network provider
AI	Artificial Intelligence	OPC-UA	Open Protocol Communication Unified Architecture
AP	Application Programmer	OSS	Open Source
API	Application Programme Interface	OT	Operation Technology
AU	aerOS Application User	PCB	Printed Circuit Board
CHE	Container Handling Equipment	PCS	Port Community System
CI/CD	Continuous Integration Continuous Delivery	PL	Production Line
CMM	Coordinate Measurement Machine	PLC	Programmable Logic Controller
CMMS	Computerized Maintenance Management System	PUE	Power Usage Effectiveness
CP	Cloud Provider	QR	Quick Response
CPS	Cyber-Physical Systems	RFID	Radio-frequency identification
CV	Computer Vision	ROS	Robot Operating System
DPP	Digital Product Passport	RTG	Rubber Tyred Gantry
EAT	Embedded Analytics Tool	RUL	Remaining Useful Lifetime
ECU	Electronic Control Unit	SLA	Service Level Agreement
F	Functional	SP	Service Provider
GDPR	General Data Protection Regulation	STS	Ship-To-Shore
HLO	High-Level Orchestrator	TH	Trial Handbook
HPCP	High-Performance Computing Platform	THT	Through-Hole Technology
IAM	Identity and Access Management	TOS	Terminal Operating System
IE	Infrastructure Element	TSN	Time Sensitive Network
IP	IoT Infrastructure Provder	UE	User Equipment
IT	Information Technology	UPS	Uninterruptible Power Supply
JSON	JavaScript Object Notation	XML	Extensible Markup Language
LLO	Low-Level Orchestrator	ZDM	Zero Defects Manufacturing
ML	Machine Learning		
MQTT	Message Queue Telemetry Transport		
NEF	Network Exposure Function		
NF	Non-Functional		

1. About this document

The main objective of this document is to provide the final version of use cases and scenarios definition as well as legal and regulatory analysis. More specifically, the document offers a formal definition of use cases associated with the five vertical domains, including (i) trial general description, (ii) current problems/barriers and motivation, (iii) identification of actors involved and their participation; (iv) specification of requirements and assumptions to be fulfilled; (v) description of data sources and event flow with actor interactions aligned with aerOS approach, and (vi) determination of expected outcomes after use case execution.

In addition, the deliverable aims to disclose both functional and non-functional requirements of the aerOS platform, ensuring their clarity, completeness, and consistency. This process has followed the agile methodologies Volere and MosCoW, ensuring overall coherence across all technical stages. Through analysis of technical and business requirements, existing gaps (technical, functional, and organisational) that need to be addressed to fulfil the operational concept, approach, and goals will be identified. The requirements provided in this document will be validated throughout the project.

1.1. Deliverable context

Table 1. Deliverable context

Item	Description
Objectives	This deliverable is directly related with all objectives of aerOS. It focuses on the use cases and scenarios addressed in the project (related to O6), as well as elicits functional and non-functional requirements verifying whether they are clear, complete, and consistent (related to O1-O5).
Work plan	Deliverable D2.3 is the second and final version addressing the use cases and requirements discovery for the project. It is delivered at the same time as the first software deliverables in WP3 and WP4, as well as the first input from WP5 with regards to software integration, packaging and documentation. The use cases identified in this report will be executed along WP5 tasks, with their subsequent deliverables. The identification of requirements and use cases will serve as the driving force behind constructing the different tasks of WP2, WP3, WP4 and WP5, as well.
Milestones	The submission of deliverable D2.3 is indirectly related to the completion of milestone MS4: Use cases deployed.
Deliverables	D2.3 is directly feed from previous D2.2 deliverable, submitted in M9. It provides the final version of requirements elicitation, use cases and scenarios definition and legal and regulatory analysis. It is expected to serve as the ground truth for the concurrent and forthcoming technical deliverables: D2.6, D3.3, D4.3, D5.4.
Risks	None

1.2. The rationale behind the structure

Deliverable D2.3 is constituted by 4 sections. The main content is available in Section 2 Use cases description, and Section 3 Requirements, while Introduction and Conclusions sections at the beginning and end of the report, respectively is also provided.

Section 2 is split into five subsections, one per Pilot of the project, which is in turn split into the different approaches that describe the pilot, including business problems and barriers, partners involved, data sources, as well as objectives, requirements and outcomes of each scenario.

Section 3 summarizes both technical requirements associated with the aerOS platform, as well as user and system requirements coming from pilots. For the sake of reader easiness, the detailed lists of those requirements are provided in Appendix A and B.

Finally, Appendix C provide the Legal Framework surveys delivered to the pilot responsible.

1.3. Outcomes of the deliverable

Four main outcomes can be extracted from the deliverable:

- A review of the objectives, expectable outcomes and overall description of the scenarios. Here, it must be noted that no diminish has been performed (only improvements over the baseline set out in deliverable D2.2).
- A detailed description of every aerOS use case scenario from all pilots, including their objectives, data sources or expected results.
- A thorough analysis about the integration of aerOS approach within those use cases, considering the different technical approaches identified in parallel tasks and Work Packages.
- A comprehensive elicitation of technical and user requirements of the project, which will set the basis for the further implementation activities ahead during the rest of project's lifetime.

1.4. Lessons learnt

The lessons learnt after the period M9-M18 in the advances of task T2.2 have been varied. In this period, a refinement of the work done in D2.2 has been performed, discovering modifications required to be depicted, and new identifications to be added. The main lessons are as follows:

- Trial Handbook Methodology hinders several difficulties (such as transfer of knowledge and content from diverse files in a timely manner) that have needed to be discussed on several occasions. Slight adjustment of the delivery pace and review structure have been applied. Overall, TH Chapters have helped stakeholders to properly place their definitions and advances in a consistent manner across scenarios.
- Requirements were well captured in D2.2. However, due to the great advances in architecture, WP3 and WP4, some refinements have been needed.
- The integration (T5.1) is in a very intensive phase now, which may influence pilots' pace of advancement, affecting both D2.3 (this document) and D5.3 (delivered at the same time).
- Chapters CH1, CH2 and CH3 of the Trial Handbook of all pilots contain some information that was supposed to remain intact (and indeed, it has been the case in many points). It includes aspects such as the actors involved in pilots, the premises where the scenarios happen or the potential users and beneficiaries. However, other aspects have indeed been improved, such as the requirements, the data sources (better specified) and how aerOS maps to the different pilots, specifying the existing domains, Infrastructure Elements, basic and auxiliary services to be used, etc.
- Chapters CH4 and CH5 will be the ones evolving in the next phase of the project.

1.5. Version-specific notes

During the evolution from document D2.2 to D2.3, insightful changes have taken place within the Pilot use case scenarios, mainly on the integration of aerOS paradigm within every scenario and more primarily in the technical, user and system requirements elicitation.

In addition, due to the overlap with parallel deliverables, it was agreed among project partners to shift the original D2.2 KPIs sections and appendices to deliverable *D5.2 Integration, evaluation plan and KPIs definition*, as well as the existing software and available hardware subsection in each pilot to *D5.3 Use cases deployment and implementation*).

2. Use cases description

aerOS validates its results in five use cases, representing: (i) Industry 4.0, (ii) utilities (renewable energy), (iii) smart agriculture, (iv) port transportation and logistics, and (v) smart buildings. The following subsection presents a description of each use case that is currently underway, including its general description, current problems/barriers area, and data sources. The section also discusses the objectives, benefits, and expected results of the trial, as well as its specific outcomes. For a detailed description of existing and forthcoming hardware and software of each use case, as well as the KPIs, please refer to WP5 deliverables.

2.1. Pilot 1: Data-Driven Cognitive Production Lines

2.1.1. Trial general description

The use case aims to deploy and validate **MAL4 cognitive production processes** in **4 public-private Pilot Lines (PL)** located in: (1) INNO Didactic Factory at AIC - Automotive Intelligence Center (Bilbao, Spain), (2) MADE Competence Centre & POLIMI Industry 4.0 Lab facilities (Milano, Italy), (3) SSF open factory lab at SIPBB (Biel, Switzerland), and (4) SIEMENS INNOVATION CAMPUS in factory automation headquarter (Nuremberg, Germany). The sites offer 5000 m^2 of cutting-edge I4.0 production systems and bring together over 500 companies.

Therefore, and responding to the structure that was designed since the proposal stage, the trial is divided in four clearly differentiated scenarios. This is very relevant in Pilot 1 of aerOS, as varying groups of partners and stakeholder in the Consortium are devoted to the different scenarios. However, all of them pursue the goal of **creating highly flexible, sustainable (green) modular digital production lines** and manufacturing of a new product in a low-volume production via the implementation of smart rapid response features in connection with self-optimisation, reconfigurations ramp-up, adaptation of production line and operations.

The four scenarios are as follows. A more thorough description of each of them, together with their objectives, benefits and expected results are described in Section 2.1.3:

- ***Scenario 1 – Green manufacturing (zero net-energy) and CO_2 footprint monitoring.*** Product life cycle digital thread, and sustainability (CO_2 footprint) data models, in connection with the implementation of Digital Product Passport (DPP), enables a systemic shift towards circular economy, supporting de-manufacturing operations, optimisation of reverse logistics infrastructure and more sustainable product design. The scenario will experiment Gaia-X and **aerOS** services at PL3 (CH) to implement edge intelligence services (and analytics) in order to optimise impact and CO_2 footprint of production lines.
- ***Scenario 2 – Automotive Smart Factory Zero Defect Manufacturing.*** A ZDM approach ensuring robustness and stability of the process, deploying inline quality control among the manufacturing workflow. Remote tactile human-CMM interaction (where resilience policies and SLAs must be reached); energy efficiency monitoring and real-time machine error compensation extending 5GROWTH set-up to ensure accuracy of product quality dimensional inspection will also be showcased at PL1 (ES). The **aerOS** system will enable the seamless interaction of quality control intelligence engine with a wide range of dimensional instrumentation equipment, hybrid CMMs, arm robots or in machine-tool metrology. Considering that an Industrial IE operation failure in a manufacturing line can have major negative economic impacts, self-recovery, healing and diagnosis will be needed.
- ***Scenario 3 – AGV swarm zero break-down logistics & zero ramp-up safe PLC reconfiguration for lot-size-1 production.*** The business process incorporates the process of specific information (MES) with context information about what needs to be done, which is then fed to the edge-cloud continuum by means of SIMATIC Industrial edge apps (pub/sub schemas) to feed **aerOS**. Production flexibility (reconfigurability) is realised by on-the-fly AGVs decision making and robot path calculations. **aerOS** automatic transport and safe placement of robotic arms is safely realised with safety enabled PLCs that enrich the process with critical device data and communicate with stationary safety devices like light fences via edge. PL2 (IT) will showcase advanced logistic processes (real-time benchmarking); whereas PL4 (DE) will showcase safe and secure automation of production. Diverse IE nodes will co-exist and collaborate, orchestrated by a master node.

2.1.2. Current problems/barriers area and motivation

In order to illustrate the problems/barriers that have motivated this use case in aerOS, and according to the personalized templates of the Trial Handbook devised for the project, it was decided to utilise the following table:

First, about metrology that is required for Scenario 1, it was concluded that the current problem/barriers existing in the sector, and that will also mean a hindrance to overcome during aerOS trial were:

Table 2. Current problems and barriers in UC1 related to metrology

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Experienced metrologists are needed	Currently only highly experienced metrologists are able to adequately define the measurement strategy in the software, that is, define the point sets. Based on their great experience, they have the ability to know which regions of the piece are the most relevant.	Technical support	Lack of experienced workforce. High quantity of resources and time must be consumed for training. Loss of operational efficiency in the processes.
There is no possibility of reusing information	When the metrologists start to define the measurement strategy of a part, none of the previously performed jobs are used, the strategy is defined from scratch for each job.	Technical support	Time consuming tasks for the staff and loss of operational efficiency.
On-site operation of CMM	The operation of dimensional equipment requires a metrologist expert to be physically in the facility.	Technical support	Time consuming for metrologists. Operational inefficiencies Increased costs. Exposure to additional risks in industrial facilities.
Extrapolation of data from scratch	In the case of reuse values from another measurement, the data to program the machine is entered by hand, and this supposes a considerable loss of time.	Technical support	Time consuming tasks for the staff. Loss of operational efficiency.
Standardization	Need for standardized measurements and units of measurement	Technical support	Inefficient business and operational process. Inconsistencies in the quality of the service.
Maintenance and calibration	The equipment must maintain the accuracy of measurements over time. It requires regular calibrations and maintenance.	Technical support	Loss of efficiency. It consumes human and economic resources.
Data management/security	The security, accuracy, reliability and accessibility of the generated metrological data must be ensured.	Technical support	Data loss and breaches and exposure of confidential or sensitive information. Reputation damage and difficulties to access data.

In addition, reflecting about data management in edge, distributed, decentralized production lines in manufacturing, the problems and barriers must be analysed from another perspective. There, the current way to perform edge computing is to have independent systems inside the company that cooperates to achieve the best results possible, the current strategy to optimize the plant is utilizing a digital twin that is able to estimate some of the critical parameters changing the configuration of the devices inside the plant.

The objectives are improving the current status of the technological area introducing: (i) a more distributed (towards the edge-layers) computing power architecture that will enable real-time computing and permit to avoid transmission of huge amount of data to the cloud; (ii) a Decentralized intelligence by Frugal AI/ML system that will contribute to increase network and orchestration efficiency; (iii) enabling data interoperability and standardization for data coming from different third-party components; and (iv) an ease of use and implementation of these applications by ad-hoc APIs that enable flexibility, scalability and versatility of the whole solution.

The integration of the platform should be able to increase efficiency of the technology area, reducing costs, reducing energy consumption, reducing idle time of the components, improve interoperability and communication from different components, optimising bottlenecks.

Table 3. Current problems and barriers in UC1 related to data and edge management in production lines.

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Improve current data management	Introducing a more distributed (towards the edge-layers) computing power architecture that will enable real-time computing and permit to avoid transmission of huge amount of data to the cloud	Manufacturing	The technology will support the **reduction of waste of energy** because of the optimization of AGV travels and buffer managing. The AGV power consumption could be reduced even of 50% if the aerOS solution is able to make the system avoid some travels. Optimizing AGVs, the assembly line and quality control line buffers would lead to a **reduction of lead time**. This would lead to **Increase efficiency of production line, Decrease of idle time and costs**. Finally installing such type of solution in a production plant would lead to a high level of digitalization that would lead to a huge **increase of awareness of the production processes.**
Barrier: poor data availability	Introducing such a data dependent solution will require great amount of data. Currently the AREA in MADE has the important barrier that it is not always working. To work, MADE needs an operator that constantly operates in the area. So generating historical data could be a barrier to develop the use case. It could be necessary to simulate some data	Manufacturing	Poor data available will affect general reliability of AI/ML algorithms and general efficiency of the solution.

Challenge: asset interoperability	The introduction of aerOS platform will imply several iterations of system integration activities, as analogue assets part of the pilot come from different vendors, with consequent different interfaces with respect to the information systems logically displaced in the upper levels	Manufacturing	Lack of useful information due to the conversion of raw data formats into different ones. Possible "a posteriori" data patches could be also implemented to patch missing information from the original source.

On the other hand, one of the aspects where this use case of aerOS is focusing is on drone production lines. This is a field where several challenges can be addressed by aerOS, still posing challenges for its implementation. In the current drone production line, several machines and demonstrators are already working together and are dependent on each other. For this, they are already exchanging data from machine to machine to guarantee a seamless production of the drones. Some of the demonstrators are already equipped with power measurement devices and condition monitoring devices. One current barrier is that this data is not processed and analyzed in a common way to have a good understanding about the overall production line. If the IoT devices would be using the same IoT-Edge-Cloud for the data exchange and processing, this would be of great benefit for both parties. To be able to calculate and predict the CO2 emissions of the line, the data must be collected and analyzed on a common solution. One further barrier is the availability of data from external suppliers.

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Different solutions and approaches for processing and analysing data of a production line	No common way and solution for processing and analysing data of the different demonstrators	Manufacturing	Dashboarding and calculation of CO2 emissions rarely possible, Green Manufacturing therefore not possible
Data exchange with suppliers rarely possible	No common IoT-Edge-Cloud available for data exchange and processing with external suppliers	Manufacturing	No Data exchange with external suppliers -> calculation of CO2 emissions rarely possible, Green Manufacturing therefore not possible

Table 4. Current problems and barriers in UC1 related to managing large edge-cloud infrastructures by public entities

Broadening the scope to public entities wishing to enlarge their capacities toward production lines (and other sectors) in their regions, there are several challenges related to sustainability of digitalization strategies of large-scale cloud-to-edge deployments. Tackling the lack of proper infrastructure for cloud-edge continuum with the deployment of aerOS will broaden the technological framework that serves as the foundations for the development of the technologies that those governments could bring.

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Public cloud-edge infrastructure	As a public IT provider, NASERTIC desires to deploy public aerOS infrastructure for being exploited and leveraged by local agents that look forward on the	Infrastructure	Since NASERTIC does not have any industrial activity, aerOS' impact within the company is entirely related to the creation of a public infrastructure that is going to be at the disposal of Navarra's

	implementation of technological solutions in line with Navarra’s current sustainability & digitalization strategies.		society.

Table 5. Current problems and barriers in UC1 related to managing large edge-cloud infrastructures by public entities

Finally, some of the main challenges/barriers in the manufacturing field are those that emerge from shifting from mass production to more personalized and customized production methods, which prioritize variety and flexibility while still demanding the high efficiency of mass production. With the increasing demand for personalized production, there is a growing need to produce variable products in high volumes to meet customer demands. This requires new technological solutions that can help streamline the production process and make it more efficient while still allowing for a high level of customization. As a leader in the field of factory automation, SIEMENS (partners of aerOS) is well-positioned to develop innovative solutions that can help organizations to adapt to these changing manufacturing trends and stay ahead of the competition outside of Europe.

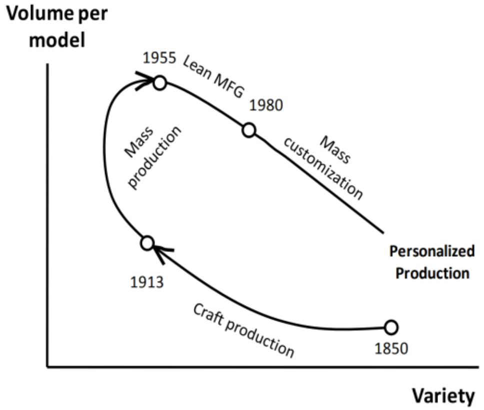


Figure 1. The evolution of production types in relation between volume per model and variety through the past 150 years

One of the biggest challenges of combining traditional and robust automation technology, often called operational technology (OT), with bleeding-edge information technology (IT) assets like perception, navigation, and manipulation is achieving interoperability and communication between the different systems. While traditional OT environment is built to be extremely reliable but also quite static in its lifecycle, IT environment that enable bleeding-edge technology for perception, navigation, and manipulation are typically developed in and dynamic and continuously iterative process. The compatibility of these different systems can be complex, requiring different protocols, languages, and processes that may not be easily integrated.

Another challenge is that traditional OT is based on programmed scripts and well-defined rules, while IT assets require complex decision-making capabilities often based on machine learning models. Due to the continuous improvement process that the operation of a machine learning model inherits, the decision making is more dynamic, less rule-based, and require continuous monitoring. Thus, it is essential to balance the traditional OT with the AI-based IT systems to avoid over-reliance on one system.

Moreover, the integration of IT assets requires specialized knowledge and skill sets that may not be readily available. As a result, organizations must ensure that their personnel are adequately trained and competent in the use and maintenance of these systems.

In summary, the challenges of combining traditional and robust OT with bleeding-edge IT assets like perception, navigation, and manipulation require careful consideration of interoperability, decision-making capabilities, security and safety, and specialized knowledge and skills. However, by addressing these challenges, manufacturers can benefit from more efficient, productive, and flexible manufacturing processes.

One of the primary advantages for solution designers on the factory shop floor of combining traditional and robust automation technology with bleeding-edge information technology assets is the increased control and flexibility to orchestrate factory assets to their needs without the additional intervention of external system integrators. This means that the solution designers can develop and implement custom solutions for the manufacturing process to meet specific requirements or challenges without depending on external experts or vendors. As a result, the solution designers can make real-time changes to the system on the factory floor, such as reprogramming the AGVs to change their routes or adjusting the robotic arms to handle different types of boxes.

Another advantage of this approach is the increased efficiency and productivity that comes with the integration of bleeding-edge information technology assets with traditional automation technology. The AI-based systems can detect and classify boxes with higher accuracy rates, leading to fewer errors and less waste. Additionally, the decentralized intelligence and communication system allows for real-time monitoring of the system, leading to quicker detection and resolution of issues that may arise.

Furthermore, the integration of information technology assets with traditional automation technology provides access to a broader range of capabilities and solutions that may not have been available before. This can lead to the development of more innovative and novel solutions for manufacturing that can improve the entire production process.

Finally, the integration of information technology assets with traditional automation technology enables solution designers to leverage existing infrastructure and knowledge, reducing the costs associated with implementing new systems. This can lead to a reduction in capital expenditure, faster implementation times, and overall increased return on investment for the manufacturing process.

In conclusion, combining traditional and robust automation technology with bleeding-edge information technology assets provides solution designers on the factory shop floor with increased control and flexibility, improved efficiency and productivity, access to a broader range of capabilities and solutions, and reduced costs, ultimately leading to a more streamlined and cost-effective manufacturing process.

From another perspective, one of the significant challenges in achieving flexible production facilities is the issue of siloed solutions provided by individual machine builders. Often, different systems within a factory operate on different proprietary protocols, making it challenging to integrate these systems into a cohesive production environment. As factories strive to increase their flexibility and adaptability, this lack of standardisation can be a significant barrier to expansion.

To address these challenges, there must be standardisation efforts across the industry, which would require machine builders and technology providers to work towards common standards that allow their systems to communicate and integrate more effectively. This would help to create more unified, interoperable production environments that can adapt more quickly and efficiently to changing market demands.

This is where the aerOS platform comes in, providing a solution that enables standardisation and continuity research across different manufacturing processes. It supports an open interface architecture that facilitates communication and data exchange between different machines, systems, and software. The platform is designed to help factories rapidly expand their production capabilities while maintaining flexibility and agility, allowing them to adapt quickly to changing market demands.

In conclusion, the challenges posed by siloed solutions provided by individual machine builders can be a significant barrier to the expansion of flexible production facilities. Standardisation efforts and continuity research, as provided by aerOS, can help to lower these barriers, enabling more rapid expansion and greater adaptability in manufacturing processes. By providing an open interface architecture and enabling seamless data exchange, aerOS is helping to create a more unified, integrated production environment that can meet the demands of a rapidly changing manufacturing landscape.

It is worth noting that aerOS is not only operating in manufacturing processes, but it operates as a middleware across different branches of data-generating assets. By providing a seamless and unified platform for data management and analysis, aerOS enables organizations to optimize their operations and gain insights into their performance across a range of industries, from energy and utilities to transportation and logistics. This broader applicability makes aerOS an even more valuable tool for organizations looking to improve their operations and gain a competitive advantage in their respective markets. With its focus on standardisation and continuity research, aerOS is at the forefront of innovation in the data management and analysis space, providing organizations with a powerful tool to unlock new insights and drive growth across multiple industries.

Table 6. Current problems and barriers in UC1 related to data and edge management in production lines.

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Transition from a static production to a flexible production	Reconfiguration and reallocation of production assets is non-trivial. A lot of engineering with different tools must be used and automated, while maintaining the same level of performance as static production assets	Engineering	Addressing new customer segments. Diverging from machine builders, towards end customers and empowerment of those.
On-demand orchestration of apps in dynamic, changing environments	Applications that use physical hardware need to be orchestrated to devices that have access to the hardware. In changing production lines, this hardware can move around, which should then change the existing orchestration.	Manufacturing	Zero touch configuration
Dynamic plant layout optimization and reconfiguration	Dynamic plant layout optimization and reconfiguration	Production Planning, Manufacturing	Less manual interaction needed, faster response times, less workforce needed
Heterogeneous and integrated communication infrastructures	Flexible and modular production systems require the sporadic relocation of resources grouped in modules, because of that, those modules are best served by wireless communication networks for their connection to the factory management or other resources. This means that networks must be built integrating wired and wireless infrastructures. Additionally, those networks must fulfil the requirements on bounded latency or packet loss often found in industrial networks.	Engineering, Manufacturing	New business opportunities for network integration solutions. Usability of current networking technology based on wired infrastructure in the future flexible factory.

2.1.3. Objectives, benefits and expected results

2.1.3.1. Use case Scenario 1: Green manufacturing (zero net-energy) and CO2 footprint monitoring

2.1.3.1.1. Description

For the use case 1 scenario data models for green manufacturing and CO2 footprint monitoring will be designed. This will be done in connection with the implementation of a Digital Product Passport (DPP), enabling a systemic shift towards circular economy, supporting de-manufacturing operations, optimization of reverse logistics infrastructure and more sustainable product design. This data models will be implemented on the assets of the extensive test and demo laboratory for Industry 4.0 of the Swiss Smart Factory. In addition to the implementation of data models and a DPP, the assets will communicate these implementations in a common way. aerOS will be used to summarize, display and analyse the collected data of the assets. The following equipment and machines will be used in the use-case where the trial takes place.

#1 Manual Workstation SETAGO - https://www.setago.io/de/setago-app/

The manual workstation SETAGO® combines hardware and software and thus enables paperless production. Create your workflows centrally on one platform and execute them independent of end devices - always focusing on the networking of individual industrial components on the store floor.

Figure 2. Manual Workstation SETAGO.

#2 Smart Conveyor

The smart conveyor is responsible for transporting the drone arms from the 3D printing farm to the quality control station. It will store in its own OPC-UA server the order data for specific parts placed in the 16 "parking spaces" engraved on the conveyor belt, each of which is linked to a QR-code representing one of the 16 spaces. In the OPC-UA server running on the PLC, the control data is written by the MES of the 3D printing farm. In addition, certain variables enable the contact logic to be applied to additional workplaces.

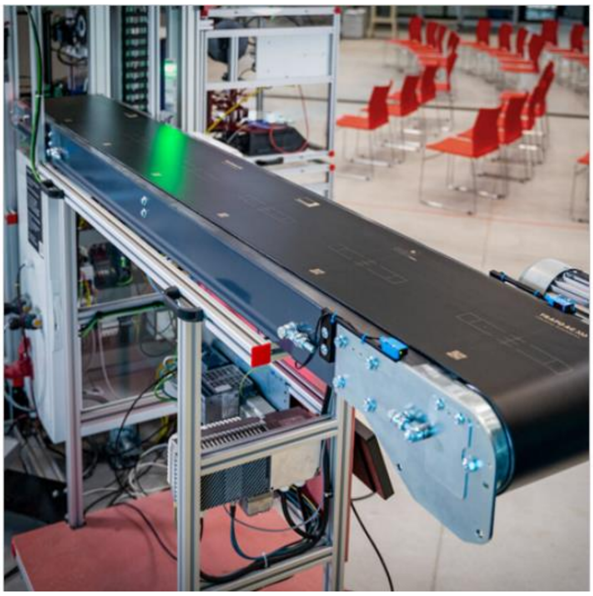


Figure 3.Smart conveyor

#3: PCB THT-Assembly (Automated Production System)

The PCB THT-Assembly station is an automated THT-soldering station which is able to solder PCB-parts on PCB's. It is responsible to solder the PCB of the drone on which electric drivers and connectors are placed. Subsystems of the station is a Stäubli robot, a Asyril sorting system, a vision system and a soldering head.

Figure 4. PCB THT-Assembly

#4: Melkus C4060 AGV

The Melkus C4060 is an AGV which is responsible for the transportation of the drones between the assets of the Swiss Smart Factory.

Figure 5. Melkus C4060 AGV.

#5: Quality control

The quality control station is responsible for checking the flatness of the 3D printed parts, using four Sylvac gauges connected by Bluetooth via OPC-UA. The low-code/no-code robot is equipped with two grippers to pick up and place the parts from the belt at the inspection station. After a successful inspection, the parts are fitted with an HF RFID tag where the necessary data is stored (order data, type of arming, colour and quality control status). Finally, the parts are placed in a box above the AGV.

Figure 6.Quality control.

Based on the described equipment in the paragraphs above, the goal is collecting data from the available equipment, which is used for the manufacturing of the lot-size one drone production. The customized configuration of the drones produced on the production line does have a direct impact on the CO_2-footprint of the drone, e.g., the material selection of the single parts of the drone, the actual environment conditions of the production line, specific individual engravings, and the delivery method selected. With aerOS, the data generated by the demonstrators will be collected and processed to measure the actual CO_2 footprint of the production for each individualized produced product.

In addition, a Digital Product Passport (DPP) can be implemented and enriched with this data. Based on the CO_2 footprint data collected from the production of each individualized produced product, the next goal is to achieve a future prediction of the CO_2 footprint of the production for each individualized produced product. Hence, this DPP will enable a systemic shift towards circular economy, supporting de-manufacturing operations, optimization of reverse logistics infrastructure, and more sustainable product design.

In a last step, the goal is to achieve a reduction of the CO_2-emission through the calculation of an optimized production path. This could include calculating the most efficient path for the Melkus C4060 AGV, which is responsible for the transportation of the drone and drone parts during production. Furthermore, the assembly and the motor production could be optimized, by learning from the data measured and predicted through aerOS.

The different implementation in aerOS will enable SSF to acquire a comprehensive understanding of the CO_2 generation of the production line. This knowledge and methodology can be transferred to other companies of the SSF network and can help them to reduce their CO_2 footprint in their own production sites.

2.1.3.1.2. Specific objectives

The objectives of this use case are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 7. Specific objectives of Use case 1 – Scenario 1

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Real-time measuring of CO_2 generated by the assets of the test – and demo platform	The assets of the drone production line in the Swiss Smart Factory are consuming energy and generating CO_2 emissions. aerOS enable the constant measuring of the emissions, by considering several factors such as energy source or amount of energy consumed	Transparent knowledge about the CO_2 footprint of every drone produced.	**Cost**	1
			Efficiency	4
			Quality	1
			Flexibility	2
			Innovation	3
			Sustainability	5
Real-time monitoring of CO_2 generated by the assets of the test – and demo platform	With aerOS the measured CO_2-emissions of the assets of the production line should be monitored in real-time in the factory. This monitoring could be also exchanged with the customer to keep him informed about the current situation.	Overview about the CO_2-emissions of the production line and the footprint of the drones produced in the factory.	**Cost**	1
			Efficiency	3
			Quality	1
			Flexibility	3
			Innovation	3
			Sustainability	5
Predicting the CO_2-footprint (production) for each individualized produced product.	By predicting the CO_2-footprint for each individualized produced product, the customer can be informed in advance about the emissions generated by his choice and can adapt accordingly. In addition, the prediction will help for a more sustainable production.	Reducing the CO_2-emissions of the production line by considering the predicted CO_2-footprint.	**Cost**	1
			Efficiency	3
			Quality	1
			Flexibility	3
			Innovation	4
			Sustainability	5

2.1.3.1.3. aerOS in Scenario 1

aerOS will be used as a data exchange, dashboarding and processing tool in the use-case of the SIPBB. aerOS will enable to communicate and collect between different kinds of assets and data in the drone production line. This enables the measurement and calculation of the CO2-emissions generated by the production line for each individualized produced product. The big advantage of using aerOS for this is that it has the ability to handle various kinds of devices with different levels of capabilities. This is exactly needed for the use-case of the SIPBB, since there is a wide variety of assets (AGV's, Manual Workstations, smart conveyor etc.) in the production line.

The main benefit regarding the implementation of aerOS services in the Swiss Smart Factory – Pilot 1 scenario 1 – concerns data exchange and data processing. aerOS will collect the energy related data generated locally – at edge level - on different stations in a common way and summarize them before analysing the data at a cloud level. This will allow to improve energy efficiency and sustainability of the supply chain, as well as optimize the production, thanks to more accurate and reliable data, such as power consumption and CO2 footprint value.

More specifically, the following objectives should be achieved through aerOS deployment in the Swiss Smart Factory:

- **Energy efficiency:**

Edge computing allows for on-site data processing, minimizing the need to transmit large amounts of data to the cloud. This reduces the energy consumption associated with data transmission and contributes to overall energy efficiency. In addition, predictive analytics would enable proactive measures to optimize production schedules, adjust equipment settings, and implement energy-saving measures before excessive energy usage occurs.

- **Production line optimization:**

Analysing data from various manufacturing processes would help to identify opportunities for optimization. By automating certain processes and adjusting production parameters based on real-time data, the company can minimize energy waste and improve overall efficiency.

- **Supply chain sustainability:**

By allowing seamless data exchange between companies and/or demonstrators, Tracking and managing the carbon footprint of raw material extraction, manufacturing processes, transportation, and distribution will be easier for companies. Therefore, monitoring and optimization of the environmental impact of the entire supply chain will be accessible to all partners involved in these steps.

- **(Remote) real-time monitoring:**

Sensors and devices implemented in the manufacturing facility can collect data through aerOS to monitor energy consumption in real-time. This data can be analysed at the edge and transmitted to the cloud for comprehensive insights into energy usage patterns during production. Furthermore, remote monitoring reduces the need for physical presence at the factory site, minimizing travel-related carbon emissions associated with on-site inspections, maintenance and troubleshooting.

- **Environmental Impact Assessment:**

Sensors and monitoring devices on the production floor can track carbon emissions associated with different stages of the manufacturing process. aerOS can then generate reports for internal analysis and external reporting, demonstrating the company's commitment to carbon reduction and allowing the implementation of a Digital Product Passport for each drone produced.

To process the collected data and make use of certain AI-capabilities for the prediction of the CO2 footprint for each individualized produced product, and to enable the reduction of the CO2-emissions generated by each individualized produced product, aerOS data fabric service will be used. In addition to the provided functionalities, the possibility of deploying self-created AI-modules in aerOS will play an important role in this use-case.

For a last, aerOS will be used to display the generated CO2-emissions and the prediction of the CO2-footprint generated by the assets of the production-line for each individualized produced product. In the Swiss Smart Factory there are several screens, which are used to display several information about the production process of a drone.

From a technical point of view, each asset of the Swiss Smart Factory (i.e. manual workstation, THT-Soldering Station, AGV, sensors etc.) represents an aerOS Infrastructure Element (IE). The whole is then considered as an aerOS and SIPBB domain, which will be connected to an external cloud and to aerOS thanks to the Nasertic host, as illustrated below.

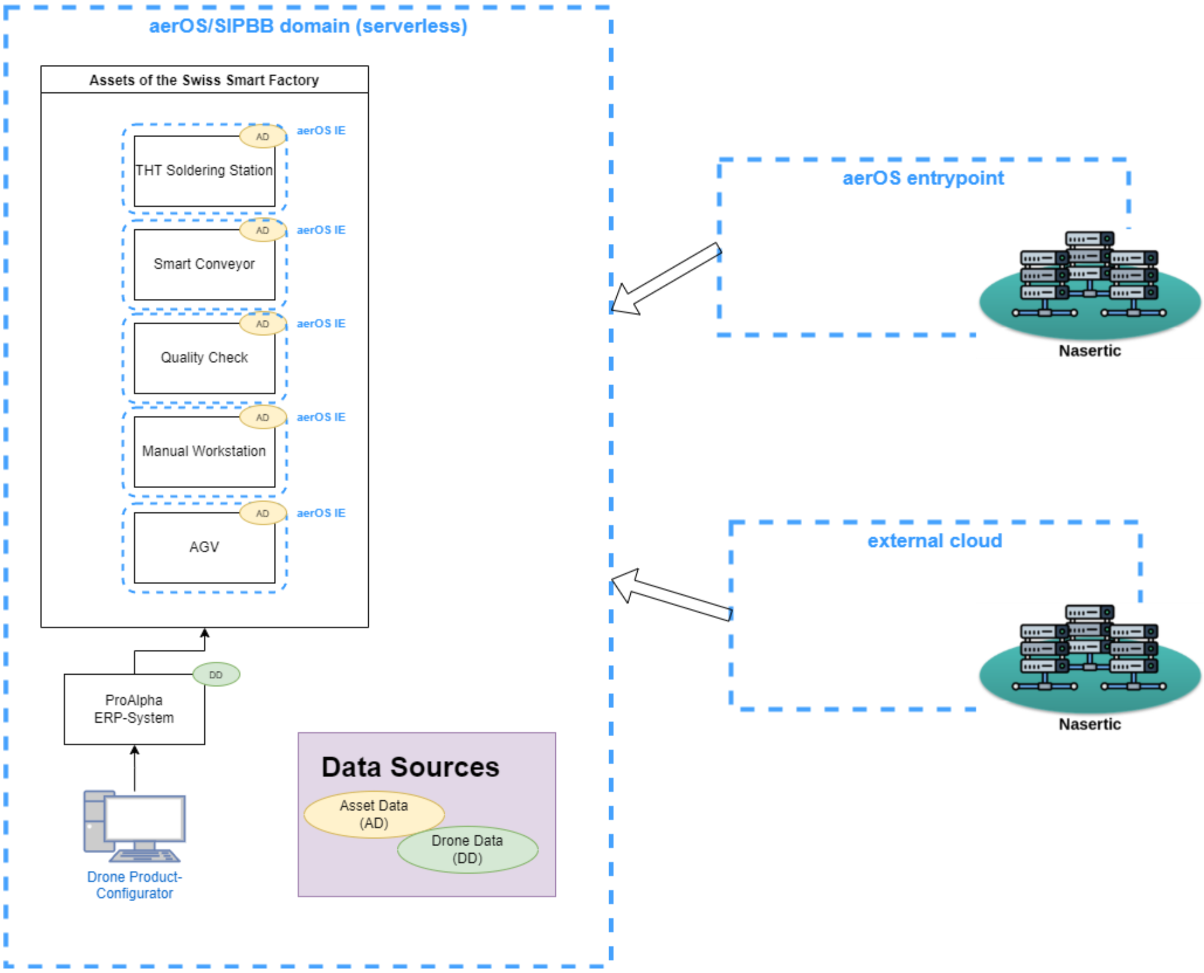


Figure 7. Mapping of aerOS in the Swiss Smart Factory infrastructure – Pilot 1 Scenario 1.

Also, a more fine-grained analysis was performed:

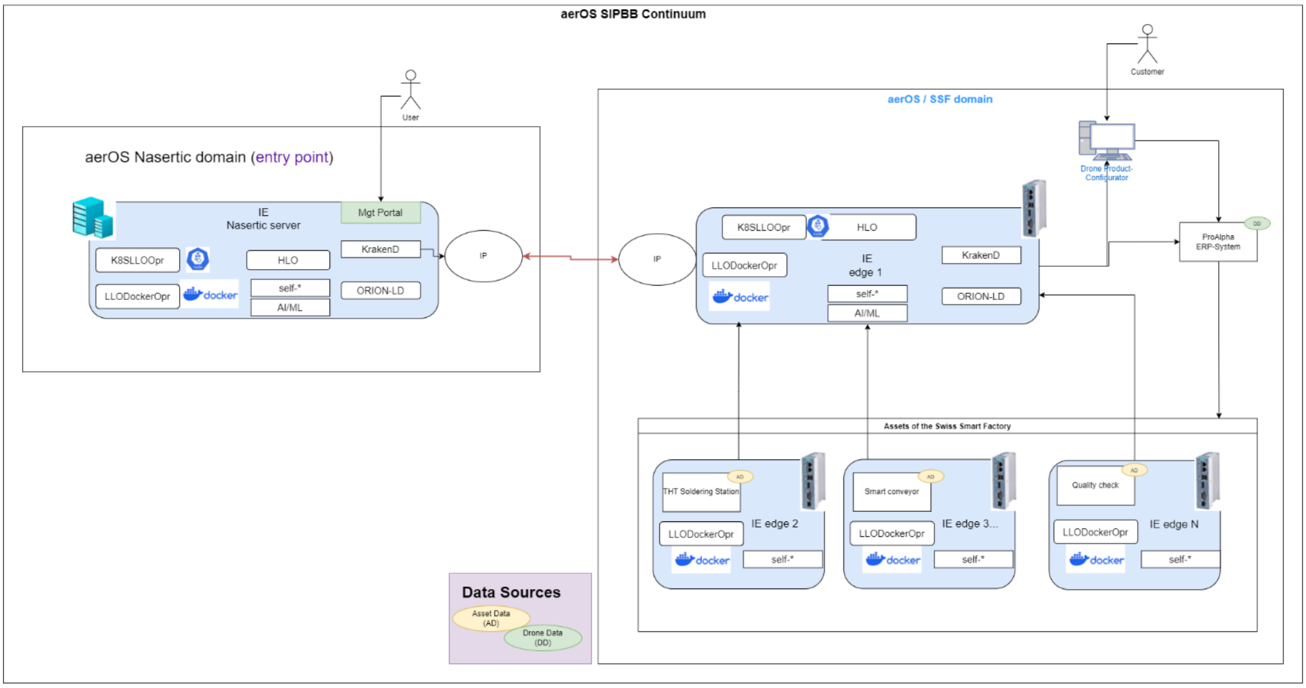


Figure 8. Mapping of aerOS in the Swiss Smart Factory infrastructure – Pilot 1 Scenario 1 (fine-grained).

As it can be seen in the figure above, during the period M12-M18, efforts have been made together with aerOS technical partners to identify the domains and the IEs that will exist in P1-Scenario infrastructure. The various components of the aerOS runtime that are already being installed and tested are also depicted in the image.

Regarding the **basic services** of aerOS that will be used in this pilot will be, as of M18, the following:

- Data Fabric
- Cybersecurity (KrakenD)
- Rest of self-elements (self API…)
- Management Portal
- Decentralised AI

In terms of custom/auxiliary services of aerOS, this scenario foresees the usage/development of the following (this will be decided and proceeded with later in the project – M21 to M36):

- Custom AI models
- Embedded Analytics (EAT)

2.1.3.1.4. Actors involved in Scenario 1

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 8. Actors involved in Scenario 1 of Use case 1

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Production line coordinator	Manufacturing	Direct	By predicting and dashboarding the CO_2-footprint of the individualized product, the coordinator of the production line can edit the line path and the production of the drones.
Salesperson	Sales	Direct	When sharing the CO_2-Footprint of the drone produced within the production line, the salesperson is affected when interacting with customers.

2.1.3.2. Use case Scenario 2: Automotive Smart Factory Zero Defect Manufacturing

2.1.3.2.1. Description

For the use case scenario 2, a Zero-Defect Manufacturing (ZDM) approach will be addressed in order to deliver semi-autonomous orchestration via remote tactile human-CMM interaction in dimensional quality control processes. “Zero-Defects” concept has been around for decades aiming at avoiding all failures and imperfections. Regarding the definition of ZDM, one of the big mistakes is to believe that this concept pressures us to produce without waste, without emissions, without accidents, without losses and without unemployment, among others. An organization must work to achieve perfection at each stage of the process, quality must be caused, not controlled, and while the definition of quality must be defined by each organization, the quality system should be considered a method of prevention and not a final stage in the process that will help us determine if the quality of the production has been as good. The industry has always seen metrology as an expensive process that does not add value, but it is in fact an essential part of the production process and part of the added value of a company: *The price of quality measurement is the price of nonconformity*.

The real need to optimise the process is starting to gain weight in companies and after a lot of effort, quality control is, right now, part of the production process. To reach this point there has been a significant change thanks to the emerging technologies and the rise of Industry 4.0: optical sensors and new data processing systems have been incorporated to contribute to shorten the time dedicated to quality management. The incorporation of these optical sensors and new software solutions, with great capacity to analyze and store data, has facilitated the natural process of acceptance of the role of metrology. To reach this reality, there has been not only a conceptual change, but a technological change that allows us to scan the parts in production and in the laboratory in an agile way. In addition, before we did not have capable systems of storing or processing as much data as we have now; Technological development has been crucial for metrology to be part of the added value of a process.

In that regard, metrological studies are used to test the tolerances of parts. The fundamental objective is the obtaining and expression of the values of the magnitude working with different instruments, methods, and appropriate measurements, with the precision required in each case. Since there are many different types of measurements, **this use case scenario will focus on dimensional measurement of components (i.e., machinery)**. More specifically, new metrological solutions are increasingly located within the production line, because it is sometimes crucial to arrive at high quality products that enhance the competitiveness of the company in sectors close to ZDM, such as the automotive or the aeronautics.

The process for the metrological analysis of a manufacturer has 2 phases:

a) the planning of the strategy
b) the programming of the machine.

Before starting to program the part point tracking, one needs to plan a strategy that depends on numerous characteristics of the physical part and parameters that the manufacturer requires. Usually, it is necessary to develop a metrological strategy for each part, observing its characteristics and parameters, only tacitly taking advantage of the information that previous similar projects have with the object of study. It is not only a waste of information, due to the difficulty of preserving the "know-how", but also a waste of time, since it requires metrologists with relatively high experience, and this can be translated as a gap in the improvement of the process and suboptimal process performance.

In today's market there are various metrological software solutions for the processing of data acquired in dimensional control. Most metrological solutions focus on the processing of information, regardless of the source of the data. Some allow control with coordinate measuring machines, being able to design and launch the scanning programs from the same interface.

The use case scenario 2 focuses on implementing aerOS components, aiming at the following goals:

- Interaction of quality control engine with dimensional equipment, arm robots, or in machine-tool metrology.

- Real-time quality control monitoring and error compensation.
- Remote tactile low latency human interaction.
- Energy efficiency monitoring.

For achieving the previous needs, the use case scenario 2 targets the implementation of aerOS capabilities in dimensional measurement of components, with the aim of promoting the manufacturing autonomy Level 4 and remote operation of CMMs. To this end, aerOS technological components will be deployed and validated in Innovalia Didactic Factory at AIC – Automotive Intelligence Center (Bilbao, Spain). Innovalia´s facilities host the development of the following competences and related technologies:

- Industrial IoT & CPPS
- Metrology
- Zero Defect manufacturing
- Business Digitalization
- Big Data & 3D Mobile Visualization
- Cybersecurity and Digital Trust

Figure 9. Innovalia Didactic Factory at AIC

Companies dedicated to the manufacture of parts and components for the automotive, aeronautical, energy, etc. sectors are receiving dimensional quality requirements and tolerances from large companies that cannot be achieved with traditional methods.

The technology that is currently being imposed for the realization of dimensional quality controls is optical technology, since it allows the acquisition of a large amount of information in a much shorter time than probing technology. As a consequence, the number of pieces controlled is much higher. On the other hand, the amount of information that is handled is much greater, a point cloud of a car door can have 15 million points; therefore, the management and calculation algorithms have to be optimized to the maximum.

Currently, the optical measurement system has its own information processing software parameterizable associated with it and depending on the operator, one result or another will be obtained, which the developers design as a “black box” making it difficult to verify how they process this information.

In the use case scenario 2, aerOS will be implemented in the dimensional measurement process, which implies the following steps:

- Set a measurement plan for the part to be measured.
- Execute the measurement machine to scan the part.
- Upload the point data to the cloud.
- Extract parameter values
- Extract measurement results to the database.
- Generation of visualization and reports.

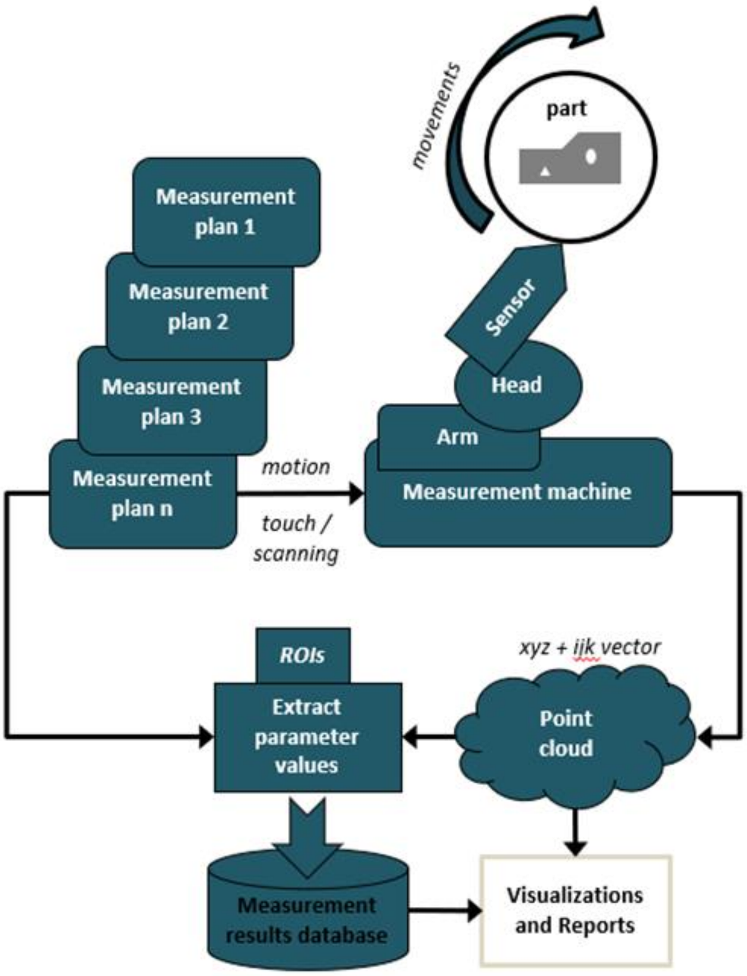


Figure 10. Actual measurement process of M3 SW

The dimensional measurement process in Innovalia involves the utilisation of M3MH work platform, which includes the components shown in the figure below. aerOS will enable the automation of the capture process and will assist in the data management and connectivity of the work platform.

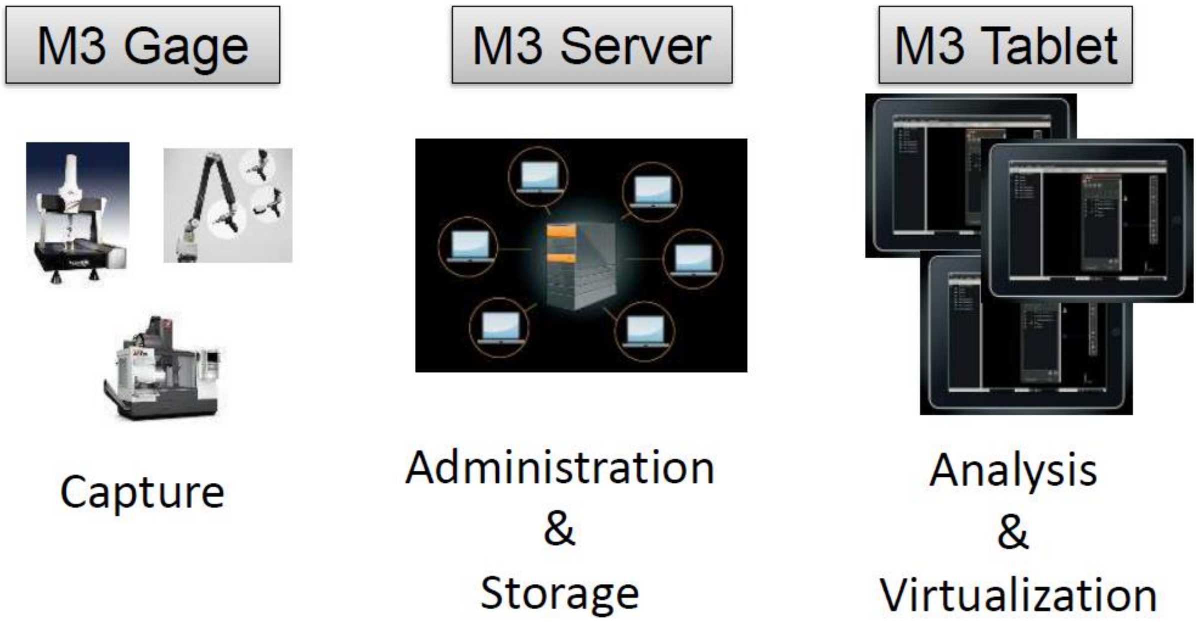


Figure 11. M3MH Work platform.

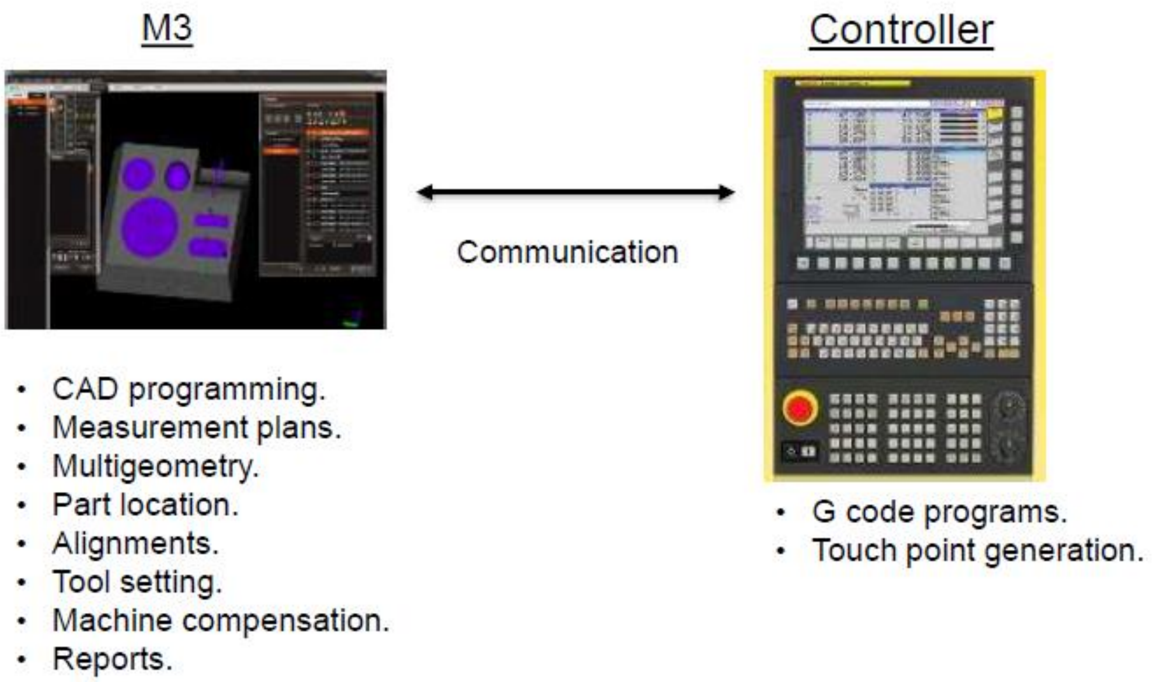


Figure 12. M3-Controller data communication.

In addition, aerOS will assist and optimise the whole process of Digital Twin creation, which is based on the following steps:

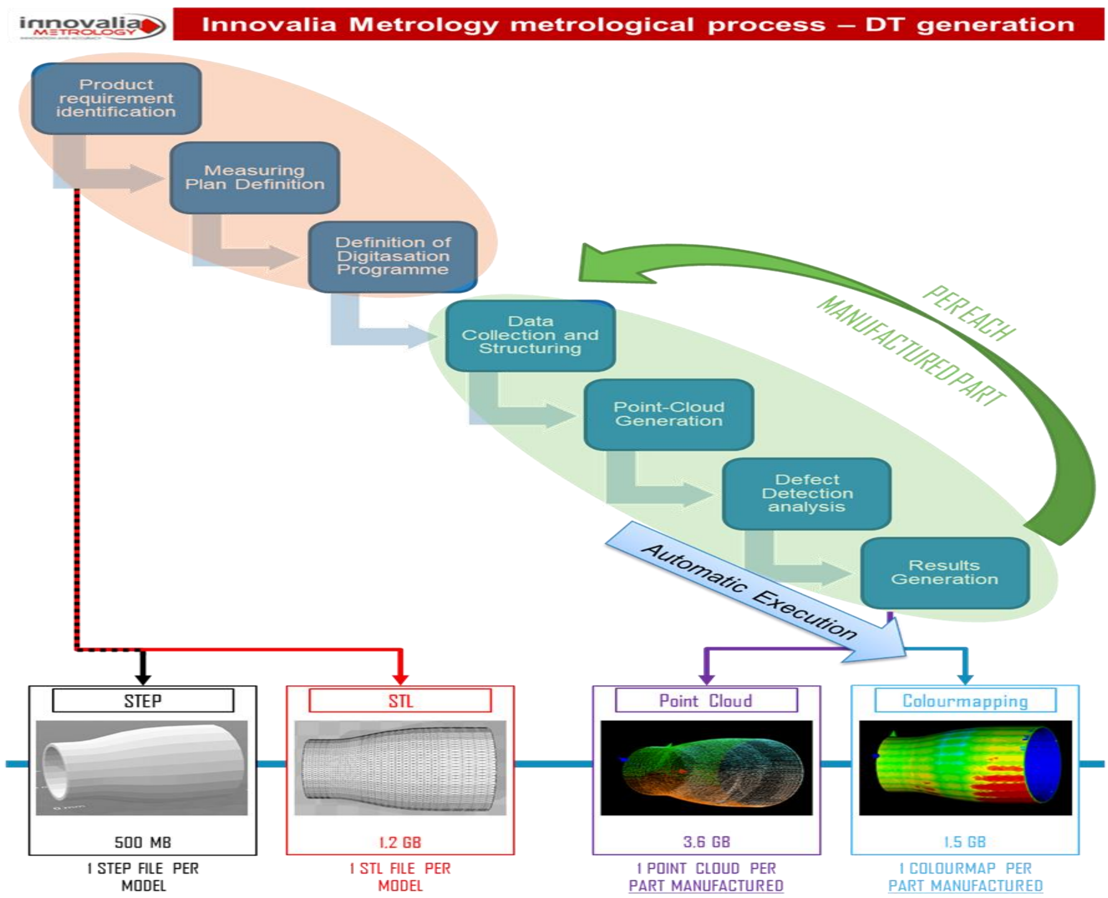


Figure 13. Digital Twin generation process.

2.1.3.2.2. Specific objectives

The global objective of the use case scenario 2 is to promote the autonomy level 4 of manufacturing processes (**MAL4**). This is defined as an autonomous and adaptive manufacturing process, and different manufacturing autonomy levels can be differentiated as follows:

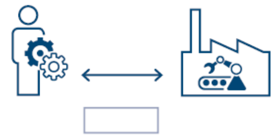
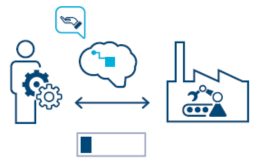
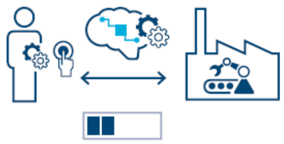
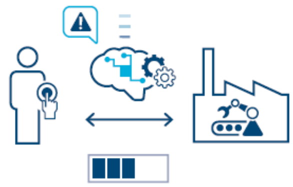
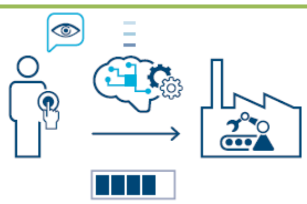
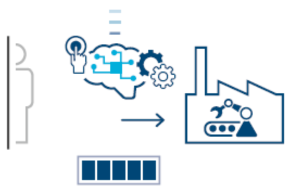
LEVEL 0		**No autonomy**, human beings have total control without any help.
LEVEL 1		**Assistance with respect to selected functions,** humans have full responsibility and make all decisions.
LEVEL 2		**Partial autonomy in clearly defined areas,** workers have full responsibility and define (some) objectives.
LEVEL 3	System-monitored environment 	**Autonomy delimited into larger sub-areas**, the system warns if problems occur, the workers confirm the solutions recommended by the system or operate at an alternative level.
LEVEL 4		**The system operates autonomously and adaptively,** within the defined limits of the system, workers can supervise or intervene in emergency situations.
LEVEL 5		**The system operates completely autonomously.**

Figure 14. Manufacturing autonomy levels

With the aim of reaching the aforementioned global objective and promote cyber physical systems (CPS), the specific objectives of the implementation of the aerOS in ZDM use case are as follows:

- <u>Remote tactile operation.</u>

Currently, the operation of CMMs is mainly carried out on-site. When it comes to the factory level, this implies that a metrologist expert must physically travel to the factory. As a consequence, there are operational inefficiencies and higher associated costs, as well as an increased risk to the operator working in hazardous areas. Aiming at the remote tactile, low latency operation, it would allow to face the aforementioned impact, requiring low latency communication protocols for reliable, fast and secure operation.

- Real-time monitoring and operation for machine error compensation, ensuring the accuracy of dimensional inspection.

The risk of false decision-making rises with higher measurement uncertainties. Since measuring is comparing, measurement is a physical process in which an iteration takes place between the object being measured and the instrument used for it. The result - the measurement - has to be collected and interpreted by the metrologist. Therefore, the ensemble will be subject to two types of influences: individual, inherent to the metrologist, and instrumental, arising from the method and the measuring device. Both will be the cause that exact knowledge of the magnitude is never possible, since the imperfection of the senses of the metrologist and the equipment used will always create an uncertainty in the value obtained and, consequently, a discrepancy between the exact value and the real, whose measure is the error interval.

The uncertainty associated with the instrument can be controlled through calibration; however, this is not the case for the uncertainty due to the metrologist.

- Avoidance of errors.

Error conditions often occur when one or more process parameters deviate significantly from the expected value and the quality of the process degrades. The sensitivity of the process to these variations in operating conditions depends on the point in the measurement process at which they occur, as well as the specific characteristics of a particular process disturbance.

Information from process parameters can be used to monitor the condition of a measurement operation, as well as to provide a process control signal to a feedback algorithm. If any of the key process parameters deviate, an error occurs.

- Promote the automation of measurement process.

The achievement of MAL4 requires the automation of metrology process as part of manufacturing process. It involves the use of real-time, low latency orchestration of Infrastructure Elements (e.g., robotic arms, scanners…) to improve the accuracy and efficiency of measuring and recording physical dimensions and parameters. Automated metrology systems can help streamline and optimize various stages of the measurement process, from data collection and analysis to reporting and quality control.

One of the most important challenges related with the automation is related with the management of the large amounts of data that needs to be managed and processed in order to act upon physical elements.

A more particularised list of objectives of use case scenario 2 is described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 9. Specific objectives of Use case 1 – Scenario 2

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Remote tactile operation	Remote tactile, low latency operation, requiring fast response communication protocols for reliable, fast and secure operation.	High operational efficiency Improved safety for metrologists.	**Cost**	5
			Efficiency	4
			Quality	2
			Flexibility	5
			Innovation	3
			Sustainability	3
Real-time monitoring and operation for machine error compensation, ensuring the accuracy of dimensional inspection	Fast response compensation, real-time data analysis.	Consistence in the quality of the service. It saves human and economic resources	**Cost**	4
			Efficiency	4
			Quality	5
			Flexibility	5

			Innovation	5
			Sustainability	4
Avoidance of errors	Real time data monitoring and analytics will allow early detection of deviations and act upon them.	Consistence in the quality of the service. Higher reputation among customers.	**Cost**	4
			Efficiency	5
			Quality	5
			Flexibility	3
			Innovation	3
			Sustainability	4
Automation of measurement process	Promote MAL4 cognitive production lines by the automation of measurement process.	Higher productivity and manufacturing efficiency Consistence in the quality of the service Avoidance of human errors Improved safety	**Cost**	5
			Efficiency	5
			Quality	4
			Flexibility	5
			Innovation	5
			Sustainability	4

2.1.3.2.3. aerOS in Scenario 2

In the use case scenario 2, aerOS is expected to be used for the following purposes:

- Data management: aerOS will provide CMM metrological data management (point clouds…), providing interoperability and traceability.
- Networking: workload communication and load-balancing within CMMs, self-* capabilities during CMM operation.
- Hardware resources registry, CMM updates detection, registering of the status of CMM elements.
- Artificial Intelligence (AI): AI will be used to optimize the sequence of a CMM measurement process and the orchestration of its resources.
- Analytics: aerOS is expected to provide advanced analytics on the performance of CMM resources, anomaly detection and predictions.
- Cybersecurity: aerOS will provide the latest cybersecurity toolset to protect CMM machines and its operation.
- Privacy: provide privacy in CMM access to the network
- Trust and Data Sovereignty: aerOS will provide mechanisms and technologies to ensure trust in CMM communications and data transfer.
- Policy Services: providing remote access and authorisation control to the CMM equipment.
- Management toolset: aerOS will provide a management toolset to the CMM equipment, promoting its predictive maintenance and dynamic management of CMM components and resources.
- Master Database: the CMM equipment will provide metrological and CMM components performance data to the master Database of aerOS.
- Task Collector: aerOS will provide decomposed task requests to the CMM equipment.
- Task assignment: aerOS will assign tasks to the CMM equipment based on AI and ML techniques.

This will promote the improvement and the quality of the functionalities offered by the metrological software M3MH, which are shown in the figure below:

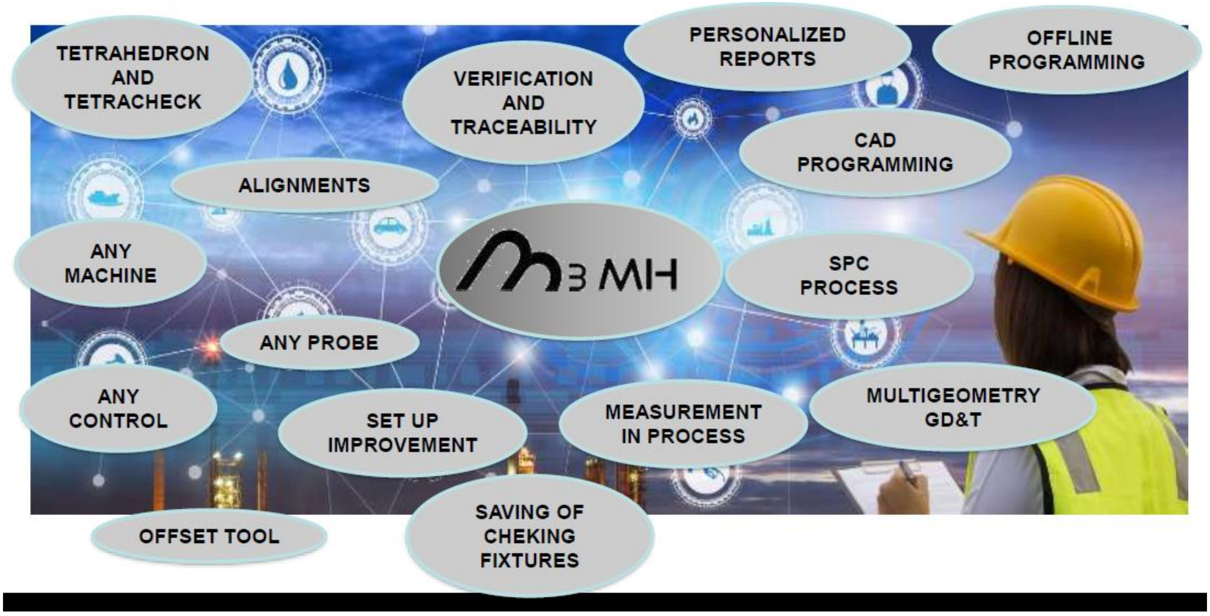


Figure 15. M3MH improved functionality with aerOS

The deployment of aerOS continuum in the Innovalia pilot is depicted in the picture below. The deployment will consider various domains. The aerOS NASERTIC environment will host the basic aerOS services in a Linux environment that will coexists with the windows virtualised environment required to operate M3.

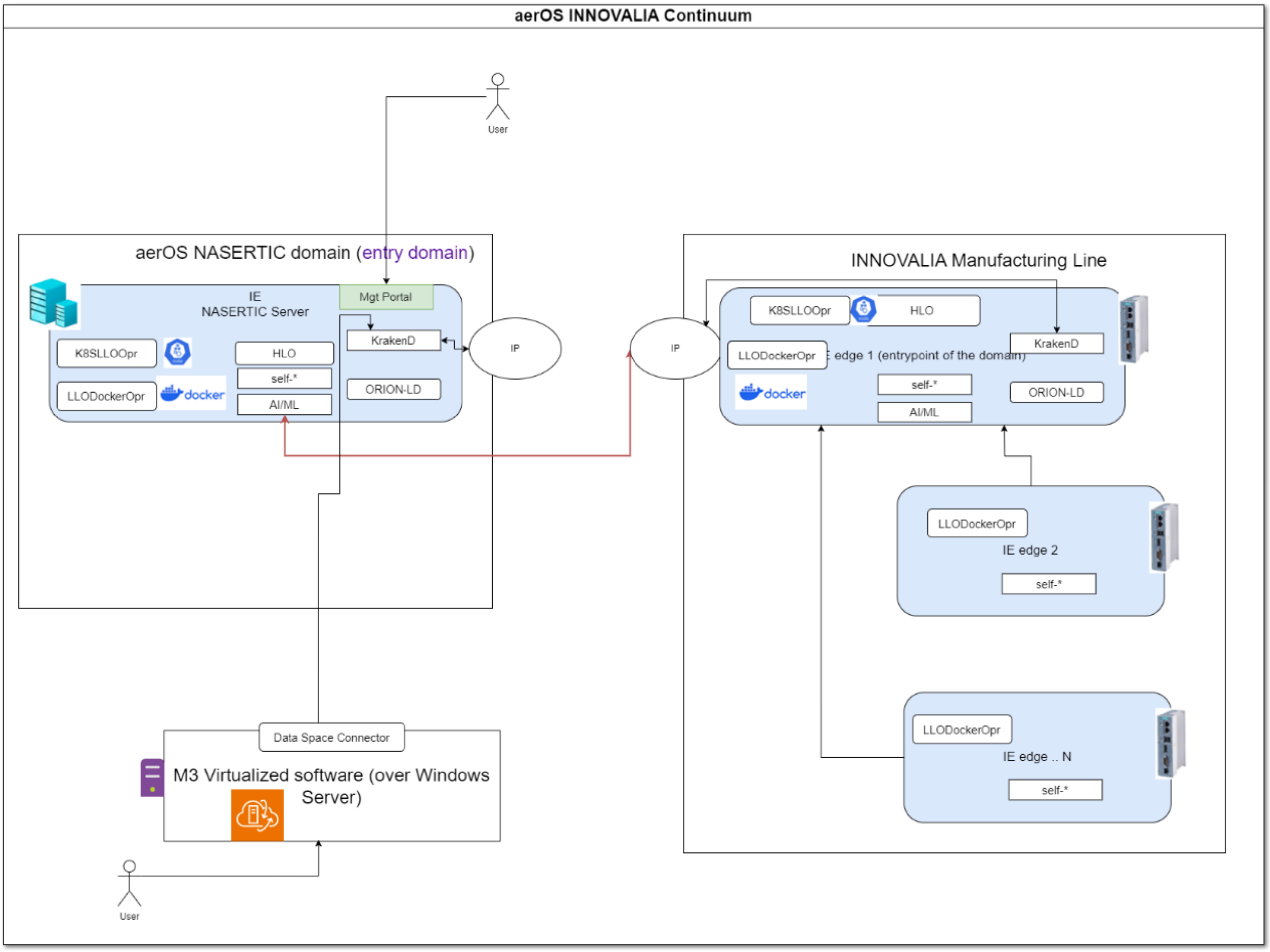


Figure 16. Mapping of aerOS in the Innovalia infrastructure – Pilot 1 Scenario 2.

The deployment of the continuum services in the NASERTIC environment will consider the operation of the High Level Orchestration services to orchestrate the assets and services in the INNOVALIA domain of the continuum that will host the metrology equipment in the manufacturing facilities. Edge devices in the manufacturing environment will host the Low Level Orchestration Docker operation services and self* services that will optimise the operation of near-edge operation of the autonomous quality services for production metrology.

On both NASERTIC (cloud) domain and INNOVALIA (edge/IoT) domains AI/ML services will be deployed to deal with the cognitive management of the metrology service continuum. The entry point in the edge/IoT domain will host the K8S management services that will deal with registrations as well as monitoring and configuration aspects of that domain.

Security and ID services to connect the virtualised M3 environment with the metrology continuum will be dealt with KrakenD services managed by the aerOS metaOS. Data brokering will be facilitated by Orion-LD OSS brokering services.

User of the metrology continuum will be gained via the M3 virtualised services, whereas metrology continuum management and configuration will be gained via the aerOS portal hosted in the NASERTIC (cloud) domain.

2.1.3.2.4. Actors involved in Scenario 2

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 10. Actors involved in Scenario 2 of Use case 1

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Metrologist	Manufacturing	Direct	The use case will enable the metrologist to balance their workload. Moreover, it will protect them from exposure to industrial facilities' hazards, as the remote operation will avoid the need for workers to travel to the site

2.1.3.3. Use case Scenario 3: AGV swarm zero break-down logistics & zero ramp-up safe PLC reconfiguration for lot-size-1 production

2.1.3.3.1. Description

Use case scenario 3 is primarily conducted by partners SIEMENS, MADE and POLIMI. It represents a real Digital Factory, where digital technologies are integrated with a Lean vision of logistics and production processes. The area exploits, in a real production line, the advantages deriving from the use of digital tools such as Industrial IoT, Cloud, Data Analytics, Collaborative Robotics, Virtual Commissioning, Product and Process Digital Twins. A concrete demonstration of how these new technologies are the enabling factors for the innovation of processes, products and the 4.0 operator is expected, making it possible to create and sustain the company's competitive advantage.

This scenario of pilot 3 is formed by two sub-cases:

SIEMENS sub-case

Description of the pilot areas:

The trial is being conducted in the Siemens TechHall in Nuremberg, which is equipped with various assets essential for implementing the required functionalities. The setup includes three small Automated Guided Vehicles (AGVs) that have autonomous navigation capabilities and can lift and transport items such as pallets or boxes to different work areas. In addition to these, there is a larger AGV equipped with a robotic arm, enabling it to perform more complex tasks.

Furthermore, the setup features two mobile robotic arm modules. These modules are designed to be portable and can be transported by the small AGVs to different locations within the workspace. Once in place, they can perform a variety of tasks using their robotic arms.

All assets in the TechHall are interconnected through Wi-Fi, providing seamless communication between them. They are also connected to the internet and a powerful server located within the TechHall. This network setup ensures efficient coordination and data exchange among the various components involved in the trial.

Goals:

The overall final objective is to build a flexible production system that is modular, efficient, and can adapt to changing manufacturing conditions. The focus is on creating a cyber-physical system that uses automated guided vehicles (AGVs) and robotic arms in combination with decentralized intelligence and communication technology supported by computational resources called SIMATIC Industrial EDGE. The system will allow for the detection and classification of packaging boxes using AI technology running on external hardware accelerators for increased accuracy and efficiency. The AGVs will pick up the boxes and deliver them to the operation site, where the robotic arms will integrate them into the factory line. Overall, the project seeks to offer flexible and modular possibilities in manufacturing that are often not possible with current state-of-the-art static production systems. The trial will measure the efficacy of this system in terms of feasibility and robustness, thus paving the way for the adoption of a novel cyber-physical system that can improve the manufacturing process.

The main goal is to explore how a production line can be flexibly adapted by modifying a specific process step for a particular task, and seamlessly transitioning back to the previous production line using a decentral intelligent cloud system called EDGE. The Connectivity between all components can be achieved due to a fast, secure and modern 5G Network.

The production steps that could be modified and transitioned among are:

- *Step 1*: An AGV is assigned to perform tasks on a specific production line, ensuring the smooth flow of operations.
- *Step 2*: The AGV receives a notification to collect three new packets from the post station, which contain important components for an ongoing production task.
- *Step 3*: At this moment, the AGV downloads the associated software package from the cloud and is enriched with a functionality that enables the detection of physical packets on a pallet.
- *Step 4*: Thanks to the new software package, the AGV is now able to recognize the packages and their size through its integrated camera using AI algorithms. Since such algorithms are very GPU-intensive, they are calculated by outsourcing the algorithms in the cloud. Due to the fast 5G connectivity, cloud computing has hardly any latency.
- *Step 5*: Using advanced sensors and visual recognition systems, the AGV locates an appropriate point in its production line where it can safely interrupt its current task.
- *Step 6*: AGV Drives to the Post Station and Collects the Packages with precise navigation and motion planning algorithms based on local resources on the device. The AGV autonomously drives to the post station, ensuring a safe and efficient path. It collects the three packages containing the required components.
- *Step 7*: AGV Utilizes Robotic Arm to Unpack the Payload Equipped with a versatile robotic arm, the AGV efficiently unpacks the payload from the packages, ensuring careful handling of delicate components and materials.
- *Step 8*: AGV Transports the Payload to the Target Destination Using its integrated mapping and path optimization algorithms, the AGV navigates through the production environment to deliver the payload to its designated target destination.
- *Step 9*: AGV Returns to its Primary Production Line and Resumes Work Upon successful delivery, the AGV retraces its path back to its primary production line. It carefully integrates itself back into the workflow and resumes its original tasks, ensuring minimal disruption to the overall production process.
- *Step 10*: The AGV can detach the robotic arm and all the other physical components to continue with different tasks, e.g., to charge its battery or picking and placing another object to another place, while the detached physical components proceed with its actions at their current station.

Aspects to Note: The AGV prioritizes safety by adhering to predefined safety protocols and utilizing obstacle detection systems. The motion planning algorithms ensure smooth and efficient movement, minimizing any potential collision risks. Non-Destructive Inspection techniques may be employed during the payload unpacking process to ensure the integrity and quality of the components. Additionally, security measures such as authentication protocols and encrypted communication channels are implemented to protect sensitive data and prevent unauthorized access. This use-case scenario showcases the benefits of incorporating robotics into flexible production lines, enabling efficient adaptation to changing tasks while ensuring safety, motion optimization, non-destructive inspection, and security throughout the entire process.

Figure 17. AGV can be configured with a wide variety of hardware.

Figure 18. The AGV can detach itself and act similar to a pallet truck.

MADE and POLIMI sub-case

Description of the pilot areas:

MADE Area

Use case area in MADE represents a real Digital Factory where digital technologies are integrated with a Lean vision of logistics and production processes. The area exploits, in a real production line, the advantages deriving from the use of digital tools such as Industrial IoT, Cloud, Data Analytics, Collaborative Robotics, Virtual Commissioning, Product and Process Digital Twins. A concrete demonstration of how these new technologies are the enabling factors for the innovation of processes, products and the 4.0 operator, making it possible to create and sustain the company's competitive advantage.

The Digital Twin allows to thoroughly analyze the characteristics of the production process and the product, prevent design errors and predict final performance. At the same time, it becomes an enabling technology for new methods of analysis and business models. The Lean 4.0 systematic approach defines a lean and Agile factory where to implement several “4.0” technologies, tracking waste and reducing its generation.

Logistics 4.0 solutions exploit IoT, RFID and advanced automation technologies to create an efficient, coordinated flow of material and a flow of information useful for the control and continuous improvement of the system.

The asset – Hardware

The experiment is representative of a manufacturing company producing valves for Oil & Gas. Inside the factory there is a production line, consisting of:

- 5 axis numerical control machine (workshop) and smart warehouse (pick to light)
- Warehouse 4.0
- Manual assembly station 4.0
- Automatic assembly station and quality control

Inside the factory, handling is entrusted to two AGVs and a 4.0 roller conveyor. Two collaborative robots are integrated into the production cycle to support valve handling and assembly activities. An area dedicated to continuous improvements.

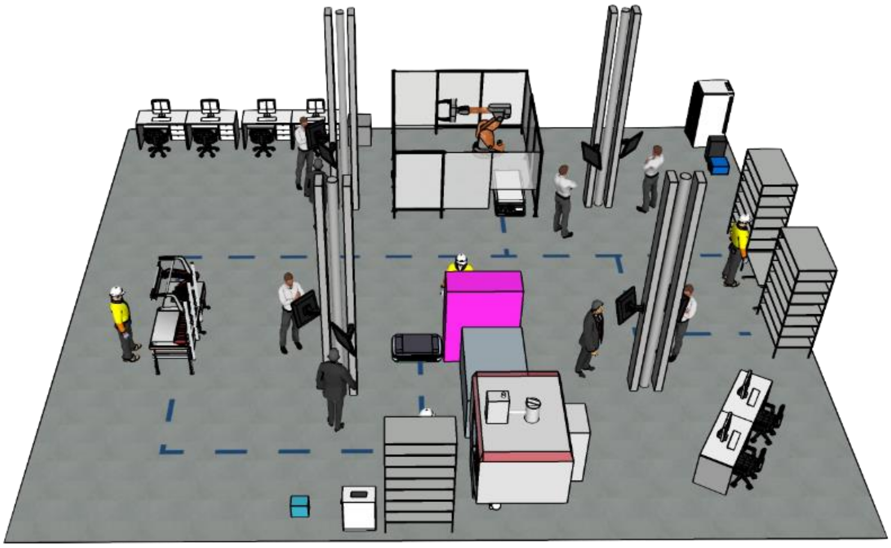


Figure 19. Manufacturing company producing valves for Oil & Gas

Process of the digital 4.0 factory

The use case simulates a digital factory where Oil&Gas valves are produced.

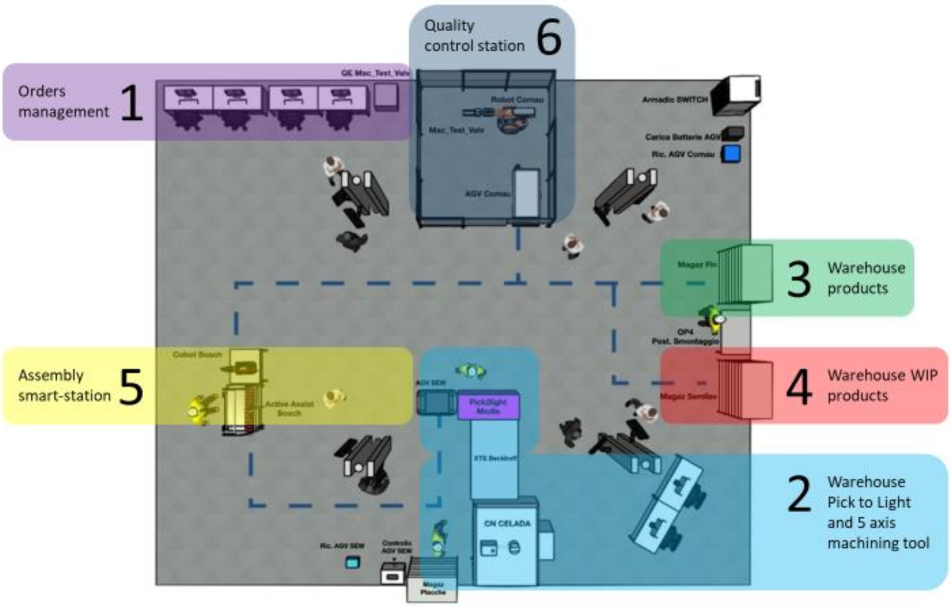


Figure 20. The 6 zones of the digital factory.

The use case presents basically 6 zones:

- ZONE 1 – Orders management
- ZONE 2 – Warehouse Pick to Light and 5-axis machining tool
- ZONE 3 – Warehouse products
- ZONE 4 – Warehouse WIP products
- ZONE 5 – Assembly smart-station
- ZONE 6 – Quality control station

Phase 1 - The use case process starts at zone 1 where the orders of the valves are generated. In this stage the orders data are simulated and stored in a Database.

Phase 2 - Depending upon the orders the production phase starts with loading in AGV 1 of a piece of valve in zone 3, and at the same time with the production of a special plate machined by a 5-axis machining tool in zone 2.

Later, this plate following a smart quality control system goes automatically to a smart warehouse called Pick to Light, in which there are almost all the components needed to assemble correctly the valve. In this phase an operator guided by the smart warehouse put the right components in AGV 2 (this has fixed trajectory).

Phase 3 - Once loaded, both AGVs depart to the same 4.0 assembly area, the one in zone 5. The valve is assembled from the operator in the smart assembly area with a guided and interactive way.

Phase 4 - Then, when completely assembled, the valve is loaded onto the AGV 1 which is programmed to go directly into the testing area (zone 6) where there is a robot which positions the valve in the pneumatic testing device which puts in pression the valve to test it.

Phase 5 - After the test the valve is repositioned in the AGV again and this goes back to the warehouse in zone 3 or 4 depending on the test result (simulates that the valve is taken to another department ready for sale or for scrap if it did not pass the test).

POLIMI Area

POLIMI Is a part of the MADE use-case. It plays the part of a simulated outsourced manufacturing location. In case the Production at MADE manufacturing location is constrained. MADE outsources a part of its production to POLIMI. This Production outsourcing is simulated in the POLIMI Industry 4.0 Lab. The POLIMI lab is fully equipped with a small production plant (manufacturing dummy mobile phones) and an AGV for material handling and transportation. The case is comprised of the following Phases:

Phase 1 - The outsourced production scenario is triggered when there is some congestion at MADE production plant. In such a condition a notification is sent from MADE to POLIMI Lab which triggers the production simulation.

Phase 2 - After the reception of the order/notification the Production Manager at POLIMI Lab must accept the order to begin production.

Phase 3 - After the order has been accepted, a notification is sent to AGV to retrieve raw Material from designated Area (simulated warehouse).

Phase 4 - An operator Loads the AGV and presses a button to indicate completion of the operation.

Phase 5 - The AGV transports the material to the production Line.

Phase 6 - The line operator unloads the material and after the completion of this operation He starts the production of the specified number of valves (simulated by the dummy phones) .

Phase 7 - Once the Order is complete the production the operator indicates the completion of the order in the system which triggers the AGV again to retrieve the finished products from the line.

Phase 8 - The AGV then transports the material to the other designated Area (Outbound bound logistics) which is meant to simulate dispatch to made. Once this final trip of the AGV is completed, A notification is sent to MADE to indicate the Dispatch of completed orders.

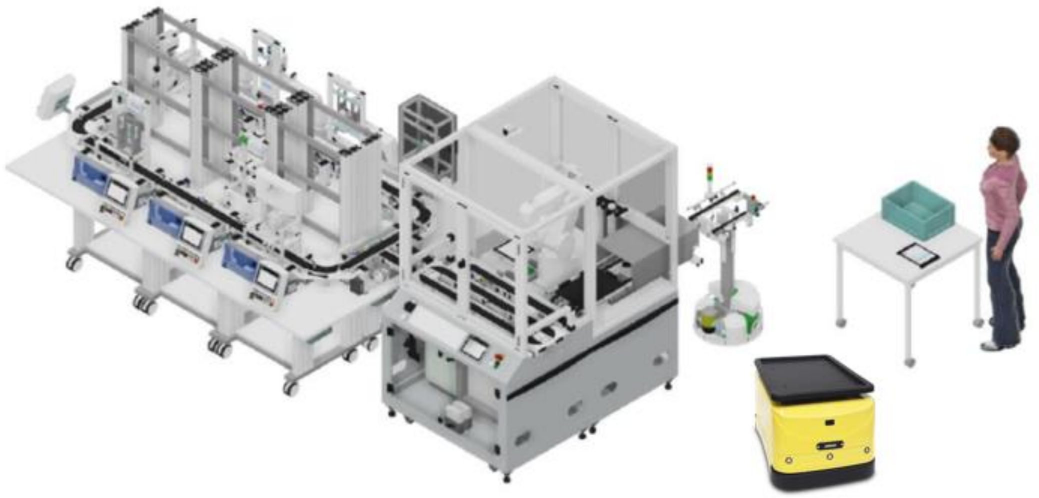


Figure 21.Use case scenario 3 of Pilot 1 in MADE factory.

Goals:

Goal of Area 1 (MADE)

The AGV results to be busy most of the time. One solution to optimize it could be introducing data based analysis and AI/ML based orchestrator to optimize AGV travels based on the assembly capacity of the line and to the quality control area one. Here one of the problems is that the AGV leaves the loading area even for a single valve once the order has arrived. The problem is that if another order arrives immediately after there is no way to save a trip to the AGV and on the other hand the system does not consider the bottlenecks dictated by the assembly capacity and the testing capabilities. This theme is currently not managed, or rather it is simulated via the Digital Twin and the system should be manually reprogrammed to be more efficient. I could be interesting to try to introduce artificial intelligence which, using historical data on orders and the maximum capacity of the plant, estimates how many valves it makes sense to take on an AGV trip and try to get close to saturation in assembly and testing.

Goal of Area 2 (POLIMI)

We can assume a scenario in which one of the internal supply chains is saturated, and we decide to outsource production by loading it onto the other: the sharing of logistics data (position of the AGV and reference of the order in charge) would allow real-time tracking of the 'order. If it is possible to predict the saturation of the lines, we can implement a make-or-buy scenario. Enabling the buy decision could be simulated in POLIMI Lab. In this scenario, POLIMI Industry 4.0 Lab will play the part of an external company where a simulated production scenario will be exhibited using an AGV for material transport and a production line for simulating the manufacturing of valves.

2.1.3.3.2. Specific objectives

TECHNICAL OBJECTIVES

Optimising AGV travels and a smart make or buy scenario, the company will for sure have decreased energy consumption, reduction of lead time of the product, increase efficiency of production line, decrease of idle time and increase awareness of the production processes that will for sure lead to decrease of costs, reduced time to market, increase of reliability of the company due to a better performing production chain.

SOCIAL OBJECTIVES

The solution will allow for better management of critical situations inside the plant, such as plant blocks due to exaggerated saturation, that would lead to better security and work life for employees, managers and operators.

1. Flexible usage of factory assets like a robot arm
2. Reduce the risk of workplace accidents by eliminating the need for manual lifting and handling of boxes.
3. Enhance agility and adaptability by using aerOS to seamlessly manage the software and hardware resources needed for the task.
4. Optimize network capabilities to ensure the uninterrupted operation of the AGV, robot arm, and AI vision software.

The use case scenario aligns with these objectives by automating a previously manual and potentially risky task. By using AI vision and automated machinery, the process becomes more consistent, and efficient. This aligns with the objective of improving efficiency. The use of machinery and automation also reduces the risk of workplace accidents. Ultimately, sustainability is enhanced by reusing existing production assets in multiple working areas, while decreasing investment costs and ensuring flexibility.

The specific objectives of this use case are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 11. Specific objectives of Use case 1 – Scenario 3

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Optimizing AGV travels	The AGV results to be busy most of the time. One solution to optimize it could be introducing data-based analysis and AI/ML based orchestrator to optimize AGV travels based on the assembly capacity of the line and to the quality control area one. Here one of the problems is that the AGV leaves the loading area even for a single valve once the order has arrived. The problem is that if another order arrives immediately after there is no way to save a trip to the AGV and on the other hand the system does not consider the bottlenecks dictated by the assembly capacity and the testing capabilities. This theme is currently not managed, or rather it is simulated via the Digital Twin and the system should be manually reprogrammed to be more efficient. I could be interesting to try to introduce artificial intelligence which, using historical data on orders and the maximum capacity of the plant, estimates how many valves it makes sense to take on an AGV trip and try to get close to saturation in assembly and testing.	Optimizing AGV travels and a smart make or buy scenario the company will for sure have decreased energy consumption, Reduction of lead time of the product, increase efficiency of production line, Decrease of idle time and Increase awareness of the production processes that will for sure lead to Decrease of costs, reducing time to market, Increase of reliability of the company due to a better performing production chain.	**Cost**	4
			Efficiency	5
			Quality	3
			Flexibility	2
			Innovation	4
			Sustainability	4
Flexible usage of factory assets like a robot arm	To leverage aerOS's rescheduling capabilities for optimizing the use of factory assets, such as a robotic arm, in various production scenarios (e.g., box un-palletizing). This approach prevents the unnecessary purchase of new resources, thereby saving costs and reducing idle time. The factory assets like a robotic arm have a specific task to do. Due to aerOS rescheduling capabilities, the factory gets instructed to free that asset for a short period.	This saves cost and does not create the need to buy new resources that would not be used efficiently (long wait periods until next product arrives). The use case scenario demonstrates the effective application of aerOS in reallocating the robotic arm for diverse	**Cost**	4,5
			Efficiency	3,8
			Quality	2,5
			Flexibility	5
			Innovation	4
			Sustainability	5

	In this period the asset can be used in a completely new production use case scenario (e.g., box unpalletizing) This saves cost and does not create the need to buy new resources that would not be used efficiently (long wait periods until next prod-uct arrives)	tasks. This aligns with the objectives of cost reduction, efficiency, quality improvement, enhanced flexibility, fostering innovation, and sustainability.		
Enhance agility and adaptability by using aerOS to seamlessly manage the soft-ware and hard-ware resources needed for the task.	To achieve new business models and efficient utilization of hardware resources through the flexibility offered by aerOS. This includes the deployment of dedicated software solutions for specific tasks, enhancing quality and efficiency.	Changing software and rescheduling hardware resources does use resources most efficiently. The scenario showcases aerOS's ability to dynamically manage software and hardware resources, enabling the factory to adapt quickly to changing demands. This enhances operational agility and adaptability, meeting the objectives of cost efficiency, quality, flexibility, innovation, and sustainability	**Cost** **Efficiency** **Quality** **Flexibility** **Innovation** **Sustainability**	5 4,3 4 5 4 5
Optimize net-work ca-pabili-ties to ensure the uninterrupted operation of the AGV, robot arm, and AI vi-sion software.	The flexibility and modularity of the factory design, requires the integration of wireless and wired infrastructure to build up the communication networks that the different re-sources require. Those integrated and heterogenous net-works must addition-ally provide guarantees of bounded latency and packet loss, needed for achieving high availa-bility of the connect-ed resources. To ensure uninterrupted operation of AGVs, robotic arms, and AI vision software through the integration of robust and responsive communication networks. These networks are designed to offer high availability with minimal latency and packet loss.	Changing software and rescheduling hardware resources does use resources most efficiently. In the described scenario, the smooth coordination and communication between the AGVs, robotic arm, and AI systems exemplify the effective implementation of optimized network capabilities. This aligns with the objectives of cost efficiency, high operational quality, flexibility, innovation, and sustainability in the factory's operations.	**Cost** **Efficiency** **Quality** **Flexibility** **Innovation** **Sustainability**	5 4 4 5 4 5
Reduce risk at workplace	To minimize human operator risks in intense working environments by increasing automation.	The scenario illustrates how automation, particularly the use of AGVs and robotic arms, reduces the need for manual intervention in potentially hazardous tasks, thereby aligning with workplace safety objectives.	**Cost** **Efficiency** **Quality** **Flexibility** **Innovation** **Sustainability**	2 1 2 0 0 0

2.1.3.3.3. aerOS in Scenario 3

This scenario of pilot 3 is formed by two sub-cases:

SIEMENS sub-case

Siemens' exploration of aerOS within their innovation lab in Nuremberg presents several advantages, promising to revolutionize manufacturing processes:

1. **Enhanced Flexibility in Production Lines:** The research enables a shift from isolated small processes to integrated production chains. This integration offers greater flexibility and adaptability, allowing factories to swiftly adapt to changing market demands.
2. **Customized Manufacturing (Lot Size 1)**: It facilitates 'Lot size 1' production, where manufacturing processes are customized for individual customer needs. This enhances customer satisfaction and the quality of the final product.
3. **Space Efficiency in Production Environment:** By reducing the need for static production lines, the flexible production setup can save significant space, leading to more efficient and cost-effective utilization of manufacturing areas.
4. **Decreased Maintenance Time:** The reduced reliance on specialized equipment and machinery minimizes maintenance time, thereby boosting overall productivity.
5. **Efficient Use of Robotic Technology**: The deployment of versatile robotic arms could lessen the requirement for human-operated workspaces and extend operational hours, maximizing operational efficiency and productivity.

In summary, Siemens' research into aerOS in their Nuremberg lab equips manufacturers with the means to rapidly and effectively adjust to market changes, enhance production efficiency, lower costs, and improve product quality.

aerOS is a decentralized system that provides the flexibility and adaptability to meet the changing needs and requirements of organizations. In some cases, these needs may require not only software, but also hardware solutions. For example, an automated guided vehicle (AGV) needs to pick up a mobile robot arm and deliver it to the operation area with the packages. Once the robot arm arrives, it needs to be reconfigured with new software through aerOS to perform an unpacking task.

To support this task, aerOS can seamlessly add the necessary hardware and software resources (skills) to the IEs. This includes not only the robot arm as an asset, but also the software needed to control it and enhance it through AI. aerOS can also provide the AGV with the capability to deliver the robot arm to the operation area, ensuring a seamless transition from one task to another.

Additionally, aerOS can retune the local 5G network capabilities to maintain service availability during this specific transition. By doing so, aerOS ensures that the network can support the increased demand for resources during the unpacking task. This helps to maintain a high level of service quality for users of the system.

Also interesting is the sub use case of aerOS equipping the AGV with AI technology utilizing onboard hardware accelerators to detect boxes and deliver to the operation:

1. The AGV is equipped with onboard hardware accelerators and cameras that allow for the detection of boxes through AI technology.
2. The aerOS software orchestrate the detection process by selecting the necessary hardware resources and providing the software resources.
3. The AI technology is trained to detect and classify boxes according to specific parameters, such as size, shape, or color; tailored for the specific box pickup use case.
4. Once the boxes are detected, the AGV picks them up and navigates to the operation site using the onboard AI technology and aerOS software.
5. At the operation site, the robot arm is now needed for the further succession of the complete task. This is done by the AGV and communicating with the respecting factory line providing the robot arm.

6. In order to activate the skill of integrating the boxes into the factory line, the robot arm needs different software skills orchestrated by aerOS.
7. After completion of the task, the robot arm is returned to its previous working slot by the AGV. Also, the software needed for the previous work of the robot arm is reallocated by aerOS, disengaging further use of the specific box unloading software.

Overall, this process relies on the integration of onboard and external hardware accelerators, AI technology, and aerOS software to enable the AGV to detect, pick up, and deliver boxes to the operation site while seamlessly coordinating with the factory line equipment.

Underlying software assets and functionalities are provided either by Siemens proprietary software solutions or open-source software assets from ROS.

The strength of aerOS lies in its ability to be tailored to specific requirements. As new tasks arise, aerOS can modify the installed apps to meet them, ensuring that the system stays up-to-date with the latest needs and requirements. To effectively manage these changes, SIEMENS is utilizing aerOS optimization algorithms. These handle the allocation of new and the re-allocation of existing tasks over a changing infrastructure automatically using e.g., Mixed Integer Programming and Deep Reinforcement Learning.

As it can be seen in the figure below, during the period M12-M18, efforts have been made together with aerOS technical partners to identify the domains and the IEs that will exist in P1-Scenario infrastructure:

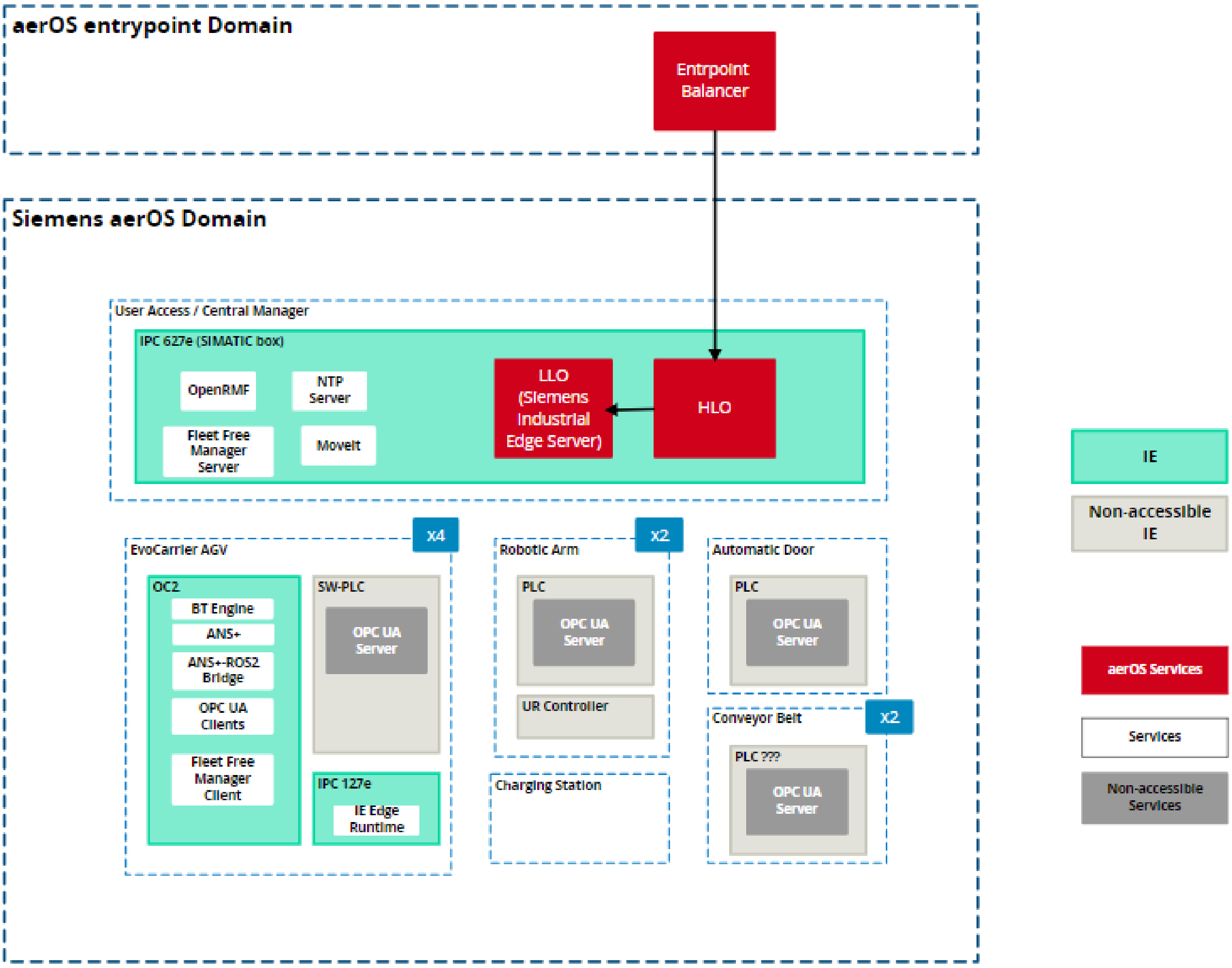


Figure 22. Mapping of aerOS in the Siemens infrastructure – Pilot 1 Scenario 3.

MADE and POLIMI sub-case

The following are the issues encountered that aerOS is helping overcome thanks to the different basic and auxiliary services:

- AGVs are busy most of the time, but their trips are not optimized.
- They leave the loading area even for a single valve, leading to unnecessary trips if another order arrives soon after.
- The system doesn't consider bottlenecks in assembly and testing capacity.

Proposed Solution:

- Introduce an AI/ML-based orchestrator to optimize AGV travel based on:
    - Assembly line capacity
    - Quality control area capacity
    - Historical data on orders and plant capacity
- Aim to:
    - Reduce unnecessary trips
    - Get closer to saturation in assembly and testing
    - Improve overall efficiency

Additional Idea:

- Predict line saturation and implement a "make-or-buy" scenario:
    - If a line is saturated, outsource production to another line.
    - Share logistics data (AGV position and order reference) for real-time tracking.
    - Simulate the "buy" decision in POLIMI Lab.

Benefits:

- Reduced AGV travel time and energy consumption
- Improved production efficiency and throughput
- Increased responsiveness to changing order demands

As it can be seen in the figure below, during the period M12-M18, efforts have been made together with aerOS technical partners to identify the domains and the IEs that will exist in P1-Scenario infrastructure. The various components of the aerOS runtime that are already being installed and tested are also depicted in the image.

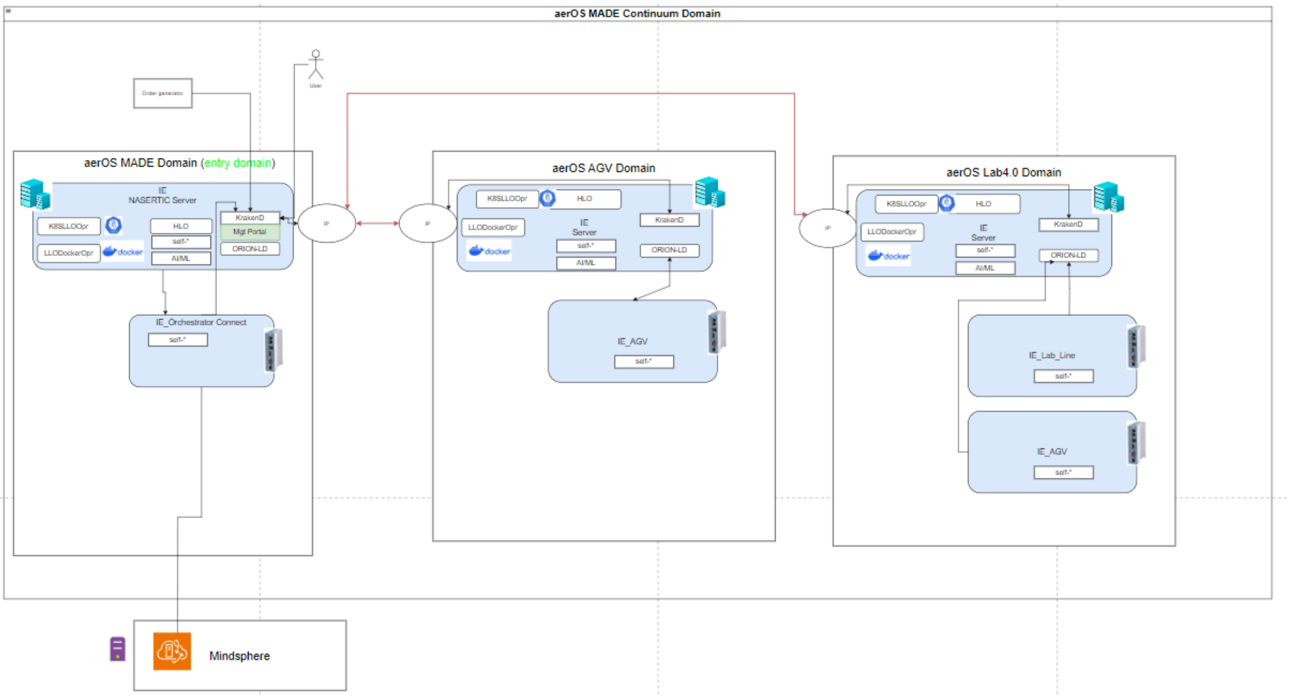


Figure 23. Mapping of aerOS in the MADE/POLIMI infrastructure – Pilot 1 Scenario 3.

Regarding the **basic services** of aerOS that will be used in this pilot will be, as of M18, the following:

- Cybersecurity
- Data Fabric
- Orchestration

- AI models
- Management portal
- Self-capabilities

In terms of custom/auxiliary services of aerOS, this scenario foresees the usage/development of the following (this will be decided and proceeded with later in the project – M21 to M36):

- Serverless execution of services (EAT)
- Frugal AI
- Trust management

2.1.3.3.4. Actors involved in Scenario 3

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 12. Actors involved in Scenario 3 of Use case 1

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
System integrator	Manufacturing	Direct	Deployment and configuration of aerOS tools and interfaces into the physical assets and ICT infrastructure of pilot plant
Blue Collar Workers	Unpalletizing	Direct - Less work	The work is replaced by a robot arm and the Blue Collar Worker can focus on other more sufficient tasks in the production
Manufacturing	Factory Engineering	Direct - Keep more flexibility in mind when designing production assets like robot arms and working areas (e.g. unpalletizing area)	Factory assets now can have multiple purposes. This introduces new challenges in engineering mechanical interfaces while lowering the number of overall assets to maintain
Management	Restructuring / adaptability	Direct	New possibilities to interact with existing factory assets

2.1.3.4. Common Infrastructure Pilot 1 use case scenarios

All the aforementioned use case scenarios of Pilot 1 will be commonly hosted in a cluster provided by Nasertic in order to deploy a subset of the services they require for their scenarios to run. Figure 24 depicts this behaviour. As exemplified, in order for a service to run, a number of microservices must be deployed. The owning partner of each service is represented with a different colour, and all the microservices that make up such service are depicted as boxes filled with the colour of the owner. In the figure a subset of those microservices to be hosted in NASERTIC are conveyed. Thus, for a service to work, part of the images will be deployed in NASERTIC's domain while the remaining images will be deployed on the premises of the owning partner. With this overarching setup for the Pilot 1, the aerOS' federation & orchestration functionalities will be validated.

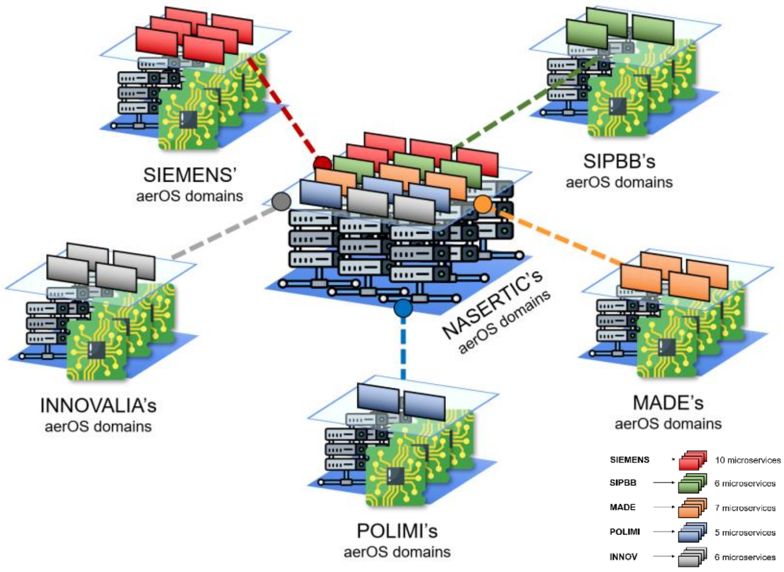


Figure 24. Role of NASERTIC's infrastructure within Pilot 1.

2.1.4. Data sources

The data sources that have been detected so far to be used in the Pilot 1 of aerOS are as follows. The next list reflects only a summary of the minimum aspects detected so far:

Data sources

- Product drone related data (CO_2-footprint, colours, size, type, etc.). JSON accessible via API endpoint upon request.
- Process asset data for calculating CO_2 footprint reachable via OPC-UA, API endpoint and MQTT.
- Machinery data for calculating CO_2 footprint reachable via OPC-UA, API endpoint (delivering JSON) and MQTT (machines: Melkus AGV, Motor Production, PCB THT-Assembly, Manual Assembly Workstation, Ambient Temperature & Humidity, measurement of SSF hall).
- Sensor data and 3D metrological data that are stored in a data lake of the pilot, and can be accessed via API Endpoint, File Extract, SQL data access and OPC-UA SDK.
- Status of the machines through sensors accessible via API endpoints.
- Digital twin (of the production line) estimations.
- AGV monitoring data (JSON received via MQTT protocol)
- UR5 monitoring data (accessible via PROFINET bus, OPC UA interface or MQTT protocol)

2.1.5. Requirements of the trial

Below there is a list of the specific requirements identified for this trial. A full list of all the requirements gathered for Pilot 1 are available in Appendix B.

- Real time data management and response
- Computing resources (cloud & edge)
- Low latency communication between edge devices and with cloud
- Secure communications between edge devices and with the cloud
- Compatibility among heterogeneous devices and industrial machinery
- Interoperability of the technology, which enables a various kind of data, IoT-Devices and interfaces.
- Support for various types of devices, even at different levels
- Real time dashboarding of processed and/or collected data
- Integration with Existing Systems
- Ease of re-configuration
- Virtual Test simulation

- AI/ML models choice
- AI/ML model setup
- Efficient Task Rescheduling and Allocation
- Advanced Object Recognition and Handling
- Implementation of Time-Sensitive Networking (TSN) for Synchronized Operations
- Support for “on-demand” real-time critical service operation and configuration

2.1.6. Specific measurable outcomes of the trial

After the completion of the activities of the pilot, when fulfilling the objectives above by the partners of the use case, the expected outcomes of the trial are as follows:

- Secure industrial edge management services for green manufacturing & logistics.

Result: Meta Operating System running in a manufacturing production line.

The implementation of aerOS for green manufacturing and logistics will enable local data processing at the edge of the network, reducing latency, bandwidth and storage costs, and improving data security and privacy. It will allow centralized management of all connected edge devices and applications, which reduces maintenance and updating costs, enhances security patches, and enables scalability and flexibility, leveraging advanced analytics and AI to optimize environmental impact of production processes and their performance.

- Smart management services for zero-touch ZDM

Result: Metrology solution which leverages underlying meta–Operating System (aerOS).

The implementation of aerOS will enable the use of advanced metrology solutions and inspection tools to monitor and control the quality of products and processes in real time. This will allow the integration of big data analytics, artificial intelligence, and digital twins to detect and prevent defects, optimize production parameters, and reduce waste and rework, providing a platform for developing and deploying customized metrology applications and solutions for different industry types and use cases, based on state-of-the-art technologies and open-source software.

- Safe industrial edge automation services & self-optimisation reconfiguration services

Result: Assembly systems in the line with new software installed (aerOS)

aerOS will enable local and secure data processing at the edge of the network, which improves data security, privacy, and latency, thus allowing centralized management of all connected edge devices and applications, which enhances security patches, scalability, and flexibility. In addition, the self*- components of aerOS will enable the use of self-optimizing functions to monitor and control the quality of products and processes in real time, and to adapt to changing production targets and customer needs. Thus, it will allow the integration of reconfigurable tooling and fixtures to support flexible and versatile assembly systems for different products and variants.

- Increase the data processing capacity of the IoT edge-cloud continuum for smart manufacturing services.

Result: Digital Twin fed by aerOS features.

The implementation of aerOS will enable faster and more reliable data processing at the edge of the network, where IoT devices generate and consume data, reducing latency, bandwidth, and storage costs, thus allowing seamless integration and orchestration of edge and cloud computing resources, where users can leverage cloud-based services and platforms for advanced analytics, artificial intelligence, and digital twins to optimize production processes and performance. aerOS will provide a flexible and scalable computing continuum that can support workload mobility and adaptation to different industrial scenarios and requirements, such as security, privacy, reliability, and efficiency.

As expected benefits, aerOS will allow manufacturing lines (represented by MADE, POLIMI, INNOVALIA, NASERTIC and SIEMENS) to:

- Reduce the energy consumption associated with data transmission and contributes to overall energy efficiency. In addition, predictive analytics would enable proactive measures to optimize production schedules, adjust equipment settings, and implement energy-saving measures before excessive energy usage occurs.
- Identify opportunities for optimization by analyzing data from various manufacturing processes, leading to automatization of certain processes and adjusting production parameters based on real-time data.
- To remote monitoring, reducing the need for physical presence at the factory site, minimizing travel-related carbon emissions associated with on-site inspections, maintenance and troubleshooting.
- Improve the performance of CMM operation, reducing the time and costs for quality control processes.
- It will promote the industrial automation level, reducing the human intervention and allowing the self-monitoring of a process.
- Increased efficiency and productivity due to the use of on-demand AI technology that can detect and classify boxes.
- Reduced risk of workplace accidents since the AGV is equipped with onboard sensors and cameras that can detect and avoid potential hazards on its path.
- Enhanced flexibility and adaptability to changing factory line conditions, as the AI technology can be retrained to detect new types of boxes or handle different tasks as needed.
- Reduced labor costs as the AGV can perform tasks that would otherwise require human intervention, leading to a more cost-effective and efficient operation.

With respect to AGV in SIEMENS sub-use case:

a. Increased Efficiency and Productivity: The deployment of on-demand AI technology, capable of detecting and classifying will significantly enhance operational efficiency. This technology ensures accurate and swift identification and handling of items, leading to increased productivity.

b. Enhanced Workplace Safety: The AGVs are equipped with advanced sensors that enable them to detect and navigate around potential hazards. This capability substantially reduces the risk of workplace accidents, creating a safer environment for both machinery and human operators.

c. Improved Flexibility and Adaptability: The AI technology's ability to be retrained for different tasks allows for enhanced adaptability to changing conditions on the factory floor. Whether it's handling different types of objects or adjusting to new operational tasks, this flexibility ensures the production line can quickly adapt to various requirements.

d. Reduction in Labor Costs: By automating tasks traditionally performed by humans, such as material handling and sorting, the use of AGVs and robotic arms leads to significant labor cost savings. This automation not only reduces the manual workload but also contributes to a more cost-effective and streamlined operation.

Implementing aerOS in a flexible production environment, augmented by AGVs, AI technology, and robotic arms, will result in a more streamlined and efficient manufacturing process. This integration leverages both onboard and external hardware accelerators, leading to improvements in accuracy, safety, and productivity, thereby enhancing the overall effectiveness of the manufacturing operations.

2.1.7. Legal framework

During the course of task T2.3 (Legal and regulatory analysis and governance specification), several actions have been performed in order to identify the legal framework surrounding activities in Pilot 1 (available in D2.2). Besides that, a thorough analysis of the legal and regulatory aspects affecting the different scenarios of Use case 1 was performed, outputting the following results:

EU-wide regulations

- EU GDPR: European General Data Protection Regulation (2016). Data privacy law which applies to any organization that processes the personal data of EU residents, regardless of where the organization is located. The regulation aims to protect the fundamental right to privacy by setting out strict rules on how personal data must be collected, processed, stored, and deleted. The GDPR requires organizations to obtain explicit consent before collecting and processing personal data, provides individuals with the right to access and correct their data, and mandates that organizations report data breaches to authorities within 72 hours.

- EU Directive 2014/53: regulatory framework established to ensure the safety and compatibility of radio equipment placed on the EU market. It covers a wide range of radio equipment used for communication, broadcasting, remote control, and signal processing, as well as their accessories and components. The directive sets out essential requirements for conformity assessment, market surveillance, and the placing of CE marking on compliant equipment. It also includes provisions for the protection of privacy and personal data, as well as measures to ensure traceability of equipment to its manufacturer or importer. The main objective of the directive is to ensure that all radio equipment placed on the EU market is safe, does not cause interference with other equipment or networks, and meets the necessary standards for health and safety. Since this is a directive, each country transposed it into national laws, which will later be covered for each demonstrator.
- EU NIS Directive 2016: cybersecurity law that aims to increase the security and resilience of network and information systems across the European Union. As it is a directive, it requires EU member states to establish their own national framework for the security of network and information systems, and to designate competent authorities to oversee and enforce these frameworks. The directive also requires operators of essential services and digital service providers to take appropriate measures to manage the risks to the security of their networks and information systems. Again, due to this regulation being a directive, each country transposed it into its national legislation system.

National-wide regulations

Scenario 1: Green manufacturing (zero net-energy) and CO2 footprint monitoring

Since use case site of Scenario 1 takes place in Switzerland, the following regulations apply:

- Ordinance on Telecommunications Installations (OTI) and "Radiocommunication Ordinance": these laws are homologue to EU Directive 2014/53, but since Switzerland is not a member of the EU it did not directly transpose it. Instead, Switzerland adopted these two ordinances, issued by OFCOM (Swiss Federal Office of Communications), which set out the requirements for the placing on the market and the use of radio equipment in Switzerland.
- About data regulation: Switzerland has its own data protection law (FADP - Federal Act on Data Protection), which regulates the processing of personal data by setting out rules for the collection, use, and disclosure of personal data by both private and public sector organizations. Of course, if a Swiss organization should process personal data of EU individuals, the EU GDPR applies, as it has extraterritorial effect.
- Federal Act on the Protection of Critical Infrastructure: law that aims to protect critical infrastructure and essential services in Switzerland from cyber threats and other risks. It is homologue to EU NIS Directive 2016.

Scenario 2: Automotive Smart Factory Zero Defect Manufacturing

Since Use case site of scenario 2 2 takes place in Spain, the following regulations apply:

- General Telecommunications Law: regulates telecommunications services and networks. It sets out rules for the management, operation, and use of telecommunications networks and establishes the regulatory framework for the Spanish telecommunications sector. The law defines the roles and responsibilities of various public and private entities involved in the provision of telecommunications services and includes provisions related to the allocation and use of radio frequencies, the protection of consumers' rights, and the promotion of competition in the telecommunications sector.
- Royal Decree-Law 188/2016: implementation of EU Directive 2014/53. The decree establishes the regulatory framework for the placing on the market of radio equipment in Spain and sets out requirements for the conformity assessment, labeling, and market surveillance of radio equipment. It also includes provisions related to the use of radio frequencies and electromagnetic compatibility to

ensure the efficient functioning of the internal market for radio equipment and the protection of public health and safety.

- Royal Decree-Law 12/2018: implementation of EU NIS Directive 2016.

Scenario 3: AGV swarm zero break-down logistics & zero ramp-up safe PLC reconfiguration for lot-size-1

Since Use case site of Scenario 3 takes place in 2 production lines, one in Italy and another in Germany, the following regulations apply:

Germany

- German Radio Equipment Act (FTEG): implementation of EU Directive 2014/53.
- Act on the Federal Office for Information Security and on Information Technology in Federal Administration (BSIG): implementation of EU NIS Directive 2016.
- Telecommunications Act (TKG): regulates the provision of telecommunications services and networks, the allocation of radio frequencies, the protection of personal data and privacy, and the consumer rights of telecommunications users.

Italy

- Legislative Decree No. 128 of 2016: implementation of EU Directive 2014/53.
- Legislative Decree No. 65 of 2018: implementation of EU NIS Directive 2016.
- Codice delle comunicazioni elettroniche: regulates the provision of electronic communications services and networks, including fixed and mobile telephony, internet access, and broadcasting. It sets out the rules on access to and use of network infrastructure, interconnection, numbering, spectrum management, and radio frequency allocation.

2.2. Pilot 2: Containerised Edge Computing near Renewable Energy Sources

2.2.1. Trial general description

Use case 2 will be driven by partners CloudFerro (CF) and Electrum supported by SRIPAS as technical partner targeting applicability of **aerOS for carbon aware computing**. It will determine impact project's results can have on the carbon emissions generated by the European cloud industry. It will also verify aerOS ability to set up and manage dynamic federation of heterogeneous infrastructure resources.

This pilot will address the management of containerized edge data centres developed by CF and located directly at renewable energy sources, connected to the smart infrastructure and providing cloud continuity. It will be deployed and validated at renewable energy centres operated by ELECT, in Poland.

The pilot will proof applicability of aerOS for the set-up and management of cloud-edge architectures distributed between "big" central clouds and small edge nodes located directly at energy producing locations, gathering information and events from the deployed smart devices. The edge nodes will have connectivity to the private cloud infrastructure of CF.

By pursuing these goals, we will verify how aerOS answers needs highlighted by EU in European Green Deal and Europe fit for the digital age priorities. Both initiatives signify growing need for sustainable solutions in edge-cloud industry. Energy intensive nature of traditional data centres makes it less and less feasible to expand operations by buying, or building, more space, as indicated by DAIRO. Traditionally, resource-demanding services (e.g., AI) have been deployed in the cloud. Thus, approaches based in decentralized edge devices, such aerOS, may improve performance. By leveraging aerOS, cloud industry will be able to take advantage of potential benefits for including numerous far and near edge nodes located at renewal energy producing locations, (thus, rapidly scaling operations), while keeping computing/storage capacity due to orchestration capabilities.

The trial will require deployment of hardware and software components at multiple locations. For efficiency, there is the intention to leverage existing "big" traditional cloud infrastructure operated by CF and compliment it with containerized edge nodes. While CF's traditional clouds are a mature technology, that undergoes incremental changes, the containerized edge nodes are still in development. Their architecture may change substantially overtime.

Clouds to hold part of the trial are located in TIER 3 complaint data centres with PUE (power usage effectiveness) between 1.5 and 1.7. Exact efficiency will depend on cloud selected. On the component level, CF's infrastructure is built using state-of-the-art, industry leading parts and solutions. From server grade GPUs (A6000s and A100s) to Supermicro motherboards to power supplies.

Current vision for the **containerized edge data centre** architecture involves singular UPS (uninterruptible power supply – energy container to support 15 minutes of operation) per 6 physical server racks in a single edge node. Within these 6 racks we will install between 20 and 40 compute nodes and several storage nodes.

On the **system level** planned cloud edge system will range from **OpenStack** that manages traditional clouds with CEPH for storage to **bare metal Kubernetes** deployments in the edge nodes. It is yet to be decided what storage solution will be applied in the distributed edge nodes.

The trials will take place at the hybrid or single source DER installation (two locations), where the case of containerized data centre and its power management system will be tested. Electrum will design and install the required power connection infrastructure with the hybrid power management controller for the data centre (Grid, ESS and PV/Wind generators).

The data sources include energy meters, weather sensors and data concentrators that collect multiple power parameters from all electronics devices installed at given facility. Electrum will provide the Renedium Master Power Controller - responsible for calculations of active and reactive power of whole plant. Renedium 1.0 is a regulator certified to meet NC RfG requirements, used to regulate active and reactive power of the entire facility according to various criteria. Additionally, Electrum will provide the industrial edge computer with neural network accelerator to test the Company's distributed architecture platform – EMACS2.0 - Virtual Power Plant.

2.2.2. Current problems/barriers area and motivation

aerOS Consortium, represented in this use case by CloudFerro and ELECTRUM, see emergence of edge computing as a way of building more sustainable and optimized cloud computing services. There is the plan of the cloud provider in the Consortium (CF) to geographically and topologically distribute computing resources in a network of edge nodes. In this vision, a single node will have a power consumption between 50 and 100 kW (what translates to 5 to 10 server racks), that can be powered by a single windmill or PV farm. It will allow CF to enforce a new paradigm: instead of moving Watts of Power, we will move Bits of Data. With this approach, CF can lower the carbon footprint of certain infrastructure and platform services and offer a solution for the problem of energy grid congestion/overload.

At the moment CloudFerro is in the process of developing and building its cloud-edge system. MVP (minimal viable product) of the service that leverages edge computing is to be launched in the Q1-2024. It has been defined as a serverless data processing engine, dedicated to batch-type of applications. At first, CloudFerro will be the main customer of this service. CF's satellite Earth Observation data repository and related workload will be able to saturate initial set of edge nodes. In next steps, there is the plan to introduce more stakeholders from the European space industry, followed by customers representing other domains.

Although, in preparatory activities, there have been identified a number of risks and barriers in regulatory, technical and managerial domains. However, it is believed that with the support of the innovations by aerOS, all these will be successfully overcome.

Table 13. Current problems and barriers in UC2

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Procurement	Long delivery times for IT components	Purchasing	Risk mitigated by updating milestone dates
Supply chain disruption	Current and future supply chain disruptions can slow down technology development and deployment of the pilot	Purchasing	Risk of reduced adoption
Shortage in Professional Competencies	A shortage of competent professional personnel and competition with industry leaders in this regard can slow the development and deployment of the system and drive costs up.	Technical support	Lower production capacities and outdate of skills and competences
Interoperability	Interoperability between technology stacks owned by different stakeholders is a must to enable operations on a large scale.	Manufacturing	Integration issues resulting in diminished turnover.
Regulatory Landscape and Cross-Territorial Consistency	Deployment of services in a geographically distributed edge-cloud system can be limited by specific national/regional norms and laws. Localized rules or regulations could slow down or prevent deployment of the system.	Manufacturing	Adjustment to regulation prevents from expanding.

2.2.3. Objectives, benefits and expected results

In the following sections there is a thorough description of each one of the scenarios from Pilot 2.

2.2.3.1. Use case Scenario 1: Green Edge Processing

2.2.3.1.1. Description

Green Edge Processing scenario aims to deploy two federated edge nodes and a private CF cloud located directly at renewable energy premises and connected to different smart devices and data sources from wind and PhV farms operated by ELECTRUM. Managing the system shall be performed in energy, network and self-conscious manner, measuring the reductions provided (benchmarking of parameters based on real-time own analytics in the IE) in the orchestration of tasks deployed in the edge instead than in the cloud (e.g., AI). With the changes in requirements for computing resources, available energy or network throughput, aerOS will facilitate rapid changes (self-scalability, self-automation) in task distribution though orchestration (managing topology, tasks and services).

The primary goal of this use case, apart from creating and managing cloud-edge continuum, is to **test aerOS capacity for carbon-aware computing**. By shifting movable compute tasks between different locations, based on current and projected energy availability, we want to manage carbon footprint of our services. This includes edge nodes powered by windmills or photovoltaic farms, and traditional "big" data centers powered by energy from the grid with green certificates. To do it, scheduling with real-time adjustments that can take into account changing circumstances every hour or so is required. Another logical step to do is shifting computing tasks across time. There is the aim of having aerOS using predictions about how heavy workload will be, and what type of energy will be available to create task queues. Of course, not every type of computing job can be managed this flexibly. Fortunately, CF as the operator of the biggest Earth Observation data storage and management platform in Europe, deals on every-day basis with abundance of batch-type of processing tasks.

At the moment, CF offers its users "*Data Generation-as-a-Service"* that allows them to process satellite images/measurements using any of the pre-selected applications. This processing is performed in two modes:

- Best-effort: free of charge service with a limited pool of resources allocated to it. New orders are placed in a queue based only on time, no SLA are provided.
- On-demand: Commercial service, that gives user the ability to set the desired time for execution of the processing.

Both modes are deployed on Kubernetes cluster in CF's traditional cloud.

For the **Green Edge Processing** scenario, there is the aim of defining and deploying a new service. It will allow users to execute their own applications (delivered as docker images) for batch processing of Earth Observation data. There will be no moderation in the application content. As in the case of VMs of other container-based services, there will not be direct access to it. In their requirements, users will be able to define how fast they need the results, where (topologically and geographically) processing should be performed and what should be the renewable energy usage rate for their processing. Depending on these factors, price will be automatically determined.

Most important characteristic of a task in this service is its limited execution time. In order to efficiently populate the system, there is the need of having workload that is movable and in batches. It comes with an additional advantage and requirement: efficient usage of available cloud resources. This kind of service does not allow for over commitment of resources, typical for big clouds. To keep it commercially viable, there is the need of utilising (thus, selling) resources at a much higher rate. Our current estimations suggest that the desired level of consumption is north of 80%.

2.2.3.1.2. Specific objectives

The objectives of this use case are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 14. Specific objectives of Use case 2 – Scenario 1

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Carbon footprint reduction and increased CPU utilization	Ability to process data when and where the carbon footprint of the activity is the lowest.	Mitigation of carbon emissions generated by cloud&edge services. Positive environmental impact that mitigates the risk of slowing down the deployment of European ICT resources, due to new regulations. Decreased costs of operations for service providers, by maximizing use of cheaper, renewable energy.	**Cost**	1
			Efficiency	1
			Quality	1
			Flexibility	2
			Innovation	2
			Sustainability	2

2.2.3.1.3. aerOS in Scenario 1

aerOS will support the management and utilization of IoT-edge-cloud infrastructure by introducing the concept of computational continuum and smart orchestration. It will enable to deploy applications in the continuum and execute computational jobs in a reliable and adaptable manner. The aerOS Server would be reading data from our SCADA database table (lakehouse architecture) and managing access permissions for any data recipient or sharing client.

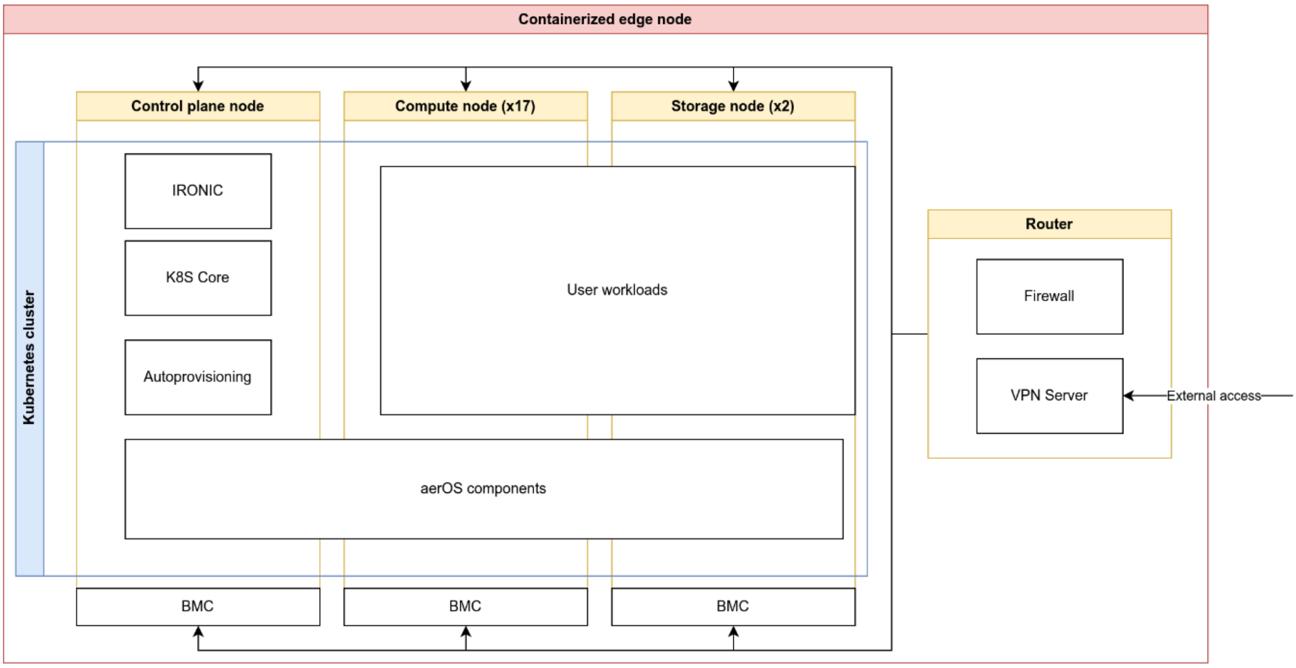


Figure 25. aerOS in scenario 1 of Use case 2

It will allow specific applications to benefit from frugal techniques in improve energy efficiency:

- aerOS will be used for distributing, monitoring and relaying tasks of stateless processing, allowing execution of batch or FaaS-like activities among a pool of near and far-edge nodes located at ELECTRUM renewable energy premises (e.g., wind/photovoltaic farms, hydro energy, or high-capacity batteries).
- aerOS will make use of heterogeneous information in the orchestration and scheduling model (master DB and registry will be needed along the task collector and distributor), boosting the energy and resource optimization. aerOS will allow for definition and implementation of energy and network conscious management tools and procedures.
- aerOS capability to manage dynamically changing infrastructure environment will be tested.

- Proposed application shall also result in lower capital intensity of the system, allowing the operator to abandon redundancy at a node level, and assuring it on system wide level, as tasks of a failing node can be transferred to an operational one.
- aerOS will enable managing the system in energy, network and self-conscious manner allowing for reductions in real-time analytics efficiency.

2.2.3.1.4. Actors involved in Scenario 1

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 15. Actors involved in Scenario 1 of Use case 21

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Clients/End-user	Any	Direct	Must align his/her workload to specific requirements of aerOs managed processing.
Data Providers	Management	Indirect	Must enable data source for aerOS workload to interaction with.
Business Development	Marketing & Sales	Direct	Must define aerOS-related product/service and include it in its offering.
SysAdmin	Engineering	Direct	Must implement and maintain aerOS capabilities
Developer/Integrator	Engineering	Direct	Must implement aerOS across the continuum
User support	Support	Direct	Must incorporate aerOS functionalities into its practices, prepare and perform relevant staff training.
Energy source owner	Management	Indirect	Must review its business model and align it with aerOS consumption mode.

2.2.3.2. Use case Scenario 2: Secure federation of edge/cloud

2.2.3.2.1. Description

This use case considers the aerOS capability to create secure ad-hoc resource federations composed from heterogeneous edge nodes and traditional “big” clouds. It will build on top of the use case scenario 1, and extend the federation beyond infrastructure owned by a single actor. Simultaneously, it will on-board multiple, independent tenants and execute unmoderated (thus, not trusted) workload provided by these tenants. It means that the main challenges of this scenario are in security and data and information management domains. Secure federation scenario will leverage aerOS functionalities that will be developed within WP3 and WP4 – Work Packages that tackle cybersecurity and data privacy. Additionally, integrating 3rd party-owned resources will verify aerOS’ interoperability.

2.2.3.2.2. Specific objectives

The objectives of this use case are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 16. Specific objectives of Use case 2 – Scenario 2

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Security across the federation	Resilience of the cloud-edge federation against breaches	Introduction of new providers to the federation is easier, thus limits the cost of operations. It also increases the trust of stakeholders in the system. Streamlining	**Cost**	3
			Efficiency	1
			Quality	5

		activities	**Flexibility**	2
			Innovation	2
			Sustainability	1
Separation between tenants / security of users	Measures of digital separation of physical infrastructure to accommodate multiple tenant	Better management of users, access control and less risk of threats and vulnerabilities	**Cost**	3
			Efficiency	1
			Quality	5
			Flexibility	2
			Innovation	2
			Sustainability	1

2.2.3.2.3. aerOS in Scenario 2

The main focus of this use case scenario will be on testing and verifying aerOS meta-operating system's basic unit capabilities - Infrastructure Element. These IEs will be the building block that provides virtualization layer, over heterogeneous infrastructure resources. It will provide runtime environments for the remaining elements of the systems as well as for the user applications. The crucial requirement in this scenario (comparing to scenario 1) is tenant separation. We understand it as an ability of IE (or wider aerOS) to create secure, individual environments for multiple users within common infrastructure nodes. These environments should be able to accommodate un-moderated workload – user can provide application containerized services without supervision of the system administrator.

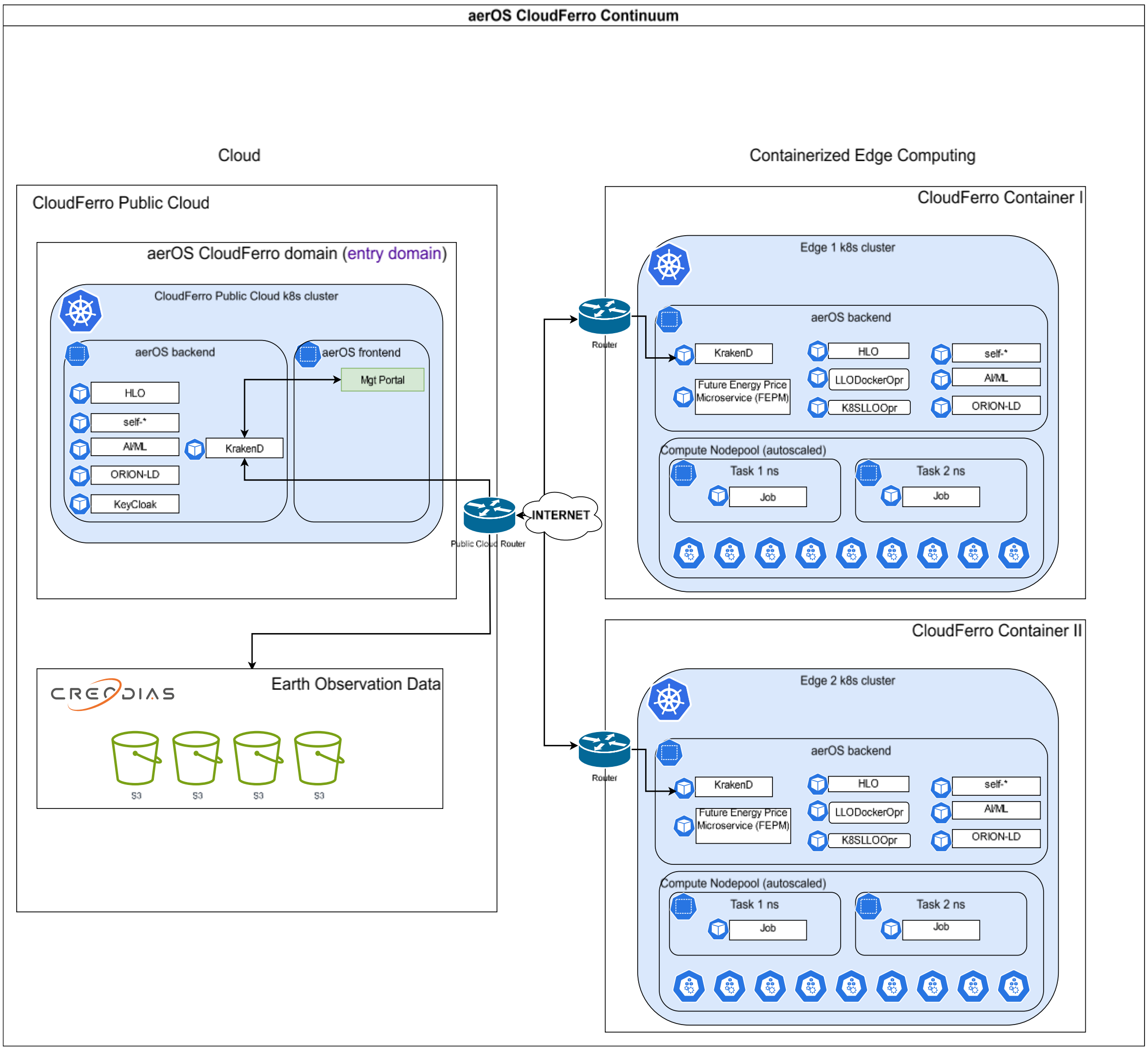


Figure 26. aerOS in scenario 2 of Use case 2.

Additionally, the IEs will be interoperable in their deployments (as per aerOS requirements). Scenario 2 foresees federation of varied infrastructure resources, especially at the edge. Moreover, aerOS will be used not only to virtualize bare metal servers. It will also be used to connect big clouds – managed with established cloud software – or edge nodes with a virtualization layer already existing (e.g.: Kubernetes on Ironic). The current list (M18) of aerOS components that are planned to be used in the scenario 2 is:

- aerOS AAA components, including IAM – identity and role management
- Self-* suite for autonomous management
- Federated Orchestration
- Traceability provided by semantic tools and other features of aerOS Data Fabric
- Security, Privacy and Trust

2.2.3.2.4. Actors involved in Scenario 2

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 17. Actors involved in Scenario 2 of Use case 2.

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Technical Support	Maintenance	Direct	Must prepare and conduct workshops for staff

Management	Administration/strategy	Indirect	Must include use of aerOS in the strategic planning
System architect	Technical Development	Direct	Must include aerOS capabilities in the system architecture
Sales	Marketing & Sales	Direct	Must devise new product/service aimed at edge node providers
System administrator	Maintenance	Direct	Must learn aerOS capabilities and prepare relevant monitoring practices
Security expert	Security & Compliance	Direct	Must review aerOS security approach and synchronize with company practices accordingly

2.2.4. Data sources

The data sources that have been detected so far to be used in the Pilot 2 of aerOS are:

Data sources

- Earth Observation data from Copernicus and Sentinel (JSON and XML in an access to be selected via S3 API endpoint)
- User provided custom data from API endpoints.
- Energy consumption data of computing machines received via MQTT.

2.2.5. Requirements of the trial

Below there is a list of the specific requirements identified for this trial. A full list of all the requirements gathered for Pilot 2 as a whole, are available in Appendix B.

- Scheduling with real-time adjustments support
- Shifting computing tasks across time
- Support for execution of user applications/jobs
- Application/job conditions definable by the user
- Support for movable workload in batches
- Meta-operating system deployment Portability
- IAM
- Traceability
- Tenant separation
- Security rules and policies
- Interoperability

2.2.6. Specific measurable outcomes of the trial

After the completion of the activities of the pilot, when fulfilling the objectives above by the partners of the use case, the expected outcomes of the trial are as follows:

- Reduction in energy consumption due to the transfer of AI and real-time analytics to the edge nodes. And
- Flexibility and scalability of the aerOS concept portability in the IoT edge-cloud continuum.

Result: Meta Operating System running in the edge data centres of a cloud provider company.

- Definition and implementation of energy and network conscious management tools and procedures.

Result: Tools that can be used by Energy Operators.

As expected benefits, aerOS stakeholders and partners involved in the Use case 2 (SRIPAS, CF and ELECTRUM) will have:

- It will promote the reduction of carbon footprint and CO_2 emissions in containerized data centres.
- Technological expertiseExperience in real environment deployment will be a learning opportunity and possibility to evaluate lab tested solutions for the team and company.
- Collaboration on an up-to-date problem coming from developing industrial area

2.2.7. Legal framework

During the course of task T2.3 (Legal and regulatory analysis and governance specification), several actions have been performed in order to identify the legal framework surrounding activities in Pilot 2 (available in D2.2). In addition, as part of the legal framework to be considered as requirement for Pilot 2, some local requirements were identified and are documented in the next paragraphs:

Electrical engineering, design, construction and testing performed in this Use case 2 shall comply with the latest applicable laws, decrees, administrative regulations, standards and technical regulations. All the installations shall be realized in accordance with the standards of professional practice and in respect of the specifications and local standards.

Monitoring and Control System should be manufactured, tested and shall be operated in accordance with the latest edition of the corresponding standards listed below:

- IEC 61000 Electromagnetic compatibility (EMC)
- IEC 60068-2 TC 104 - Environmental conditions, classification and methods of test
- IEC 61724 Photovoltaic system performance - Part 1: Monitoring
- IEC 60529 IP ratings
- IEC 62262 Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)
- IEEE 1379-2000 Recommended Practice for Data Communications Between Remote Terminal Units and Intelligent Electronic Devices in a Substation
- IEC 60870-5-series Telecontrol equipment and systems - Part 5: Transmission protocols
- IEC 61850 Communication networks and systems for power utility automation IEC 61400-26-1 Time based Availability for Wind Turbines
- IEC 61400-26-2 Production based Availability for Wind Turbines

Listed in this chapter, standards and specific codes should be treated as minimum requirements but should not be limited to (this statement will be bear in mind by pilot partners during all the execution of the trial). Monitoring and Control system should be manufactured and tested to comply with national and local regulations and should fulfil requirements of the local Grid Operator. In case of any discrepancies between the specifications and other documents, the more stringent specification requirements should be applied. The proposed solution should be given in good time to the Owner or Engineer for review.

2.3. Pilot 3: High Performance Computing Platform for Connected and Cooperative Agricultural Mobile Machinery to Enable CO2 Neutral Farming (HPCP-F)

2.3.1. Trial general description

Use case 3 will be driven by partners John Deere and TTControl targeting to develop a High-Performance Computing Platform (HPCP) for Connected and Cooperative Mobile Machinery, which has the potential to reduce the CO2 footprint in areas like agriculture, construction, or forestry. The HPCP use case will be deployed and validated in John Deere's European Technology Innovation Centre in Kaiserslautern.

The target is to develop a proof-of-concept of a HPCP, providing a machine-to-machine connectivity from everywhere for a large-scale agricultural production system on one side, but also delivering certain real-time performance still navigating the overall system remotely and controlling (i.e., supervising) execution of the agricultural work process. The required network connectivity everywhere and always is still a challenge. Edge computing in connection with locally limited and temporary networks will be needed as enabler for autonomous machine fleets.

Connected and cooperative agricultural mobile machinery is a key to synchronize and optimize the mobile machinery work. This use case will contribute to enabling sustainable farming solutions for energy optimisation and noise reduction. The developed solution will be capable to e.g., perform computational tasks in support of demonstrating fully electric swarm of vehicles safely and securely operating in platooning or other swarm combinations. The solution will bring higher performance and connectivity capabilities vs. existing solutions brought to the mobile machinery. Using IoT services also edge computing is foreseen for more critical tasks like e.g. field borders in the overall system to enable real-time control.

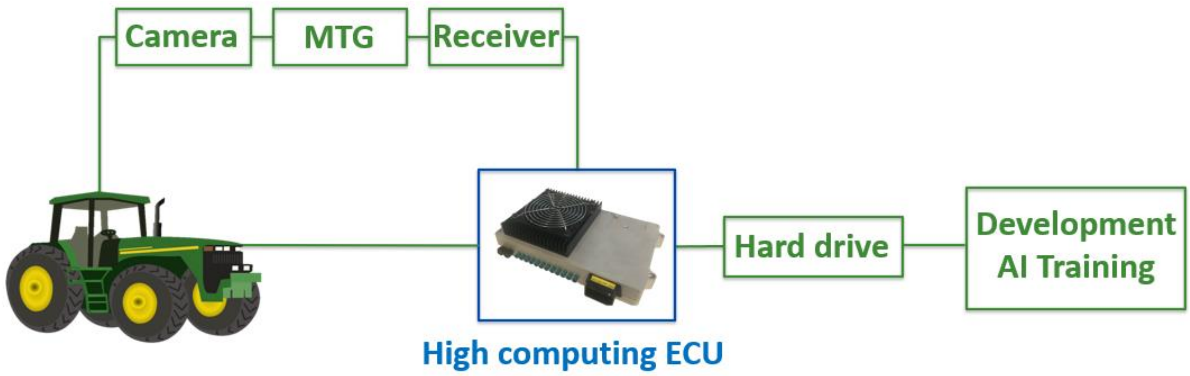


Figure 27. Preliminary setup of the demonstration of the HPCP Use Case (Pilot 3)

The main objective of the HPCP use case is to integrate, test and validate High-Performance Computing Platform for connected and cooperative mobile machinery farming, construction, and forestry. The proposed robust and flexible solutions need to provide M2M connectivity from everywhere for large-scale production systems; real-time performance with low latency networking; federated AI capabilities to improve performance in the edge and data management including autonomy (self-automation), ownership (trust for origin needed), storage and interoperability. This use case will contribute to enabling operation solutions for road building and sustainable farming with optimized energy input.

In particular, the pilot is for analyzing the already existing field work and finding a room for improvement via the provided Electronic Control Unit (ECU) with high computing power from TTControl. Such tasks in agriculture and construction work that require collecting data from different components and analyzing it whether on-board or off-board, can highly benefit from an ECU with high computing power in its overall analysis of the field work aiming for optimization and performance enhancement.

Faster and optimized field work based on analyzing data that requires high computing power such as images with the help of the incorporated ECU with high computing power. This will help enabling elevation of the features of an existing field work that has been performed manually.

- Collecting and analysing various types of data from different data sources (components that are usually connected to the machine/vehicle), such as positioning and location information via the receiver, network status and type via a cellular modem, images via cameras. This will result in a detailed knowledge about the running system and make the end user's job easier, faster, and smoother.
- Shifting to automated field monitoring will result in shorter completion times.
- Giving a chance for the end user to focus on other tasks that require attentive observation and management and prioritize their daily tasks.

For achieving the previous, it is expected that the pilot will carry out the next actions:

- Collecting data from different sources (images, location, network status).
- Connect to a display for convenient human machine interaction.
- Data from cameras as well as operating instructions from cloud must be processed in a semi real-time manner.
- Improving the quality of field work e.g., by automating some of the time-consuming tasks.
- Optimising machine work and reducing the added error of manual tasks
- Improving the end-user's experience
- Impact of machine learning and artificial intelligence techniques to be analysed.
- Real-time data analysis for large-scale mobile machinery system
- Proof-of-concept for a crop monitoring system on board that analysis live data flow.
- Deployment and validation of the TTControl's prototype connecting to the John Deere's devices.
- Investigation of the applicability of the aerOS edge meta-operating system SW architecture and compatibility of the designed use case with the overall architecture of aerOS.

2.3.2. Current problems/barriers area and motivation

Digital transformation in Agriculture, Construction, and Forestry is quickly progressing. Especially, Precision Operation (e.g. in farming known as "Precision Farming") offers a pathway towards reducing inputs, maximizing quality of production and in farming also yields. Digitalization allows integrated control of machines involved in production. At the same time, the operating mobile machines needs to interact with other production systems, sensors, and information services. Edge computing, in connection with limited / temporary networks (as connectivity in rural areas has strong limitations), will enable the deployment of intelligence without permanent connectivity to the cloud (self-dependability).

A key enabler for optimized operation of machine fleets is synchronization and optimization of the work of all mobile machines (e.g. tractors, implements, combines in farming, pavers, rollers and trucks in road building, or forest harvesters and forwarders in forestry). Current systems, e.g., connected and cooperative mobile machinery, are pushed to resources limits, in tasks like data access and processing, ensure data privacy and security or provide continuity to the cloud. In-vehicle edge nodes (e.g., JD edge), interacting with smart devices, networking components and compute continuum, will get benefited with the support provided by an IoT edge-cloud continuum solution. Applications of the aerOS system achievements can be applied in multiple business areas such as farming, construction, and forestry.

Especially but not exclusively, in farming aerOS can enable significant improvements of inputs through smart control and by this, the usage of the aerOS architectural concept might increase sustainability significantly.

The described use case of crop monitoring, as an example, is being performed manually by farmers at the moment. Crop monitoring is a time-consuming task that will also consist of errors when it is performed manually, such as overlooking weed in the middle of healthy grass. Performing this task in an automated way with the help of AI training using images in the field and the help of the provided ECU with a high computing power, will significantly enhance user experience and will create an overall more sustainable solution than the one present at the moment.

In order to further illustrate the problems/barriers that have motivated this use case in aerOS, and according to the personalized templates of Trial Handbook devised for the project, it was decided to utilise the following table:

Table 18. Current problems and barriers in UC3

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Data collection	AI models require a large amount of data to be trained properly and perform in the way it is expected to	Mobile machinery (e.g. farming machines, or construction machines)	More time required to obtain the information, larger resources and skills and efforts for labelling.
Live data analysis	Analysing data in real-time and comparing it to an existing trained model is a challenging task that require high processing capabilities	Mobile machinery (e.g. farming machines, or construction machines)	Huge investments, steep learning curve, time, resources and efforts. Integration issues.

2.3.3. Objectives, benefits and expected results

In the following sub-sections, there is a thorough description of each one of the scenarios in Pilot 3.

2.3.3.1. Scenario 1: Cooperative large-scale producing

2.3.3.1.1. Description

The first scenario of Use Case 3 will optimize a large-scale production harvesting process system based on mobile machines. Data from sensors (e.g., machine sensors, geo-positioning, cameras, radar) as well as operating instructions from cloud will be safely and securely processed. The basic development will be done on a sophistically selected machine fleet. A demonstration will be carried out with a mobile machinery vehicle. An IoT edge-cloud continuum approach will be adopted for the orchestration of services (AI/ML-based assignment), optimization of data autonomy (with semantics) of a swarm of vehicles, each equipped with own far edge node executing aerOS (IE registry will play a key role here) and connected to the smart devices and sensors of the vehicle. Developed solution will be capable to e.g., perform computational tasks to support the demonstration of the future swarm of vehicles safely and securely operating in platooning (up to TRL5), governed by a robust policy engine, which will be integrated and validated in the John Deere's functional prototype vehicle.

2.3.3.1.2. Specific objectives

The objectives of this use case are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 19. Specific objectives of Use case 1 – Scenario 1

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Optimizing	Analysing data that requires high computing power such as images with the help of the incorporated ECU with high computing power	Elevation of field work that has been performed manually. Shorter completion	**Cost**	3
			Efficiency	5
			Quality	5
			Flexibility	5

field work[1]		time.	**Innovation**	5
		Saving human effort for more attentive demanding tasks	**Sustainability**	5

The main objective of this scenario is to analyze the already existing field work and find a room for improvement using the Electronic Control Unit (ECU) with high computing power from TTControl provided to John Deere. Such tasks in agriculture and construction work that require collecting data from different components and analyzing it whether on-board or off-board, can highly benefit from an ECU with high computing power in its overall analysis of the field work aiming for optimization and performance enhancement.

2.3.3.1.3. aerOS in Scenario 1

In order to understand the role of aerOS to realize this scenario, a series of steps are now planned.

First, TTC's prototype will be deployed in the John Deere experimental vehicle to ensure a proper connectivity and functioning of interfaces. The execution of the SW and sensor data from John Deere would be a critical testing phase to validate the performance, and if needed, necessary adaptations to be implemented. The subset of the tasks of this scenario described above require real-time execution and finding of proper allocation of tasks to optimize data communication latencies. Several parameters will be utilized to monitor e.g., energy consumption, resource allocation while performing data communication, or similar. The exact parameters for the evaluation, i.e., KPIs, are defined for two integration phases (Alpha and Beta).

There have been identified three potential areas of the benefits from the usage of the aerOS architecture concept (see figure below): (i) usage of common APIs to enable seamless application hosting and supporting the functional allocation, (ii) monitoring and real-time control or capabilities of the system in support of the time-aware execution of the tasks, and (iii) improvement of trustworthiness via implementation of a chain of trust on embedded software level which is needed for the future certification of TTC's products with regards to security measures (ISO/SAE 21434 standard to be considered). These are only few currently defined benefits from the usage of aerOS. As Linux-based approach for e.g., the monitoring of tasks / services is used, that will allow to investigate further relevant for Pilot 3 services or functionality from the project which could be potentially used.

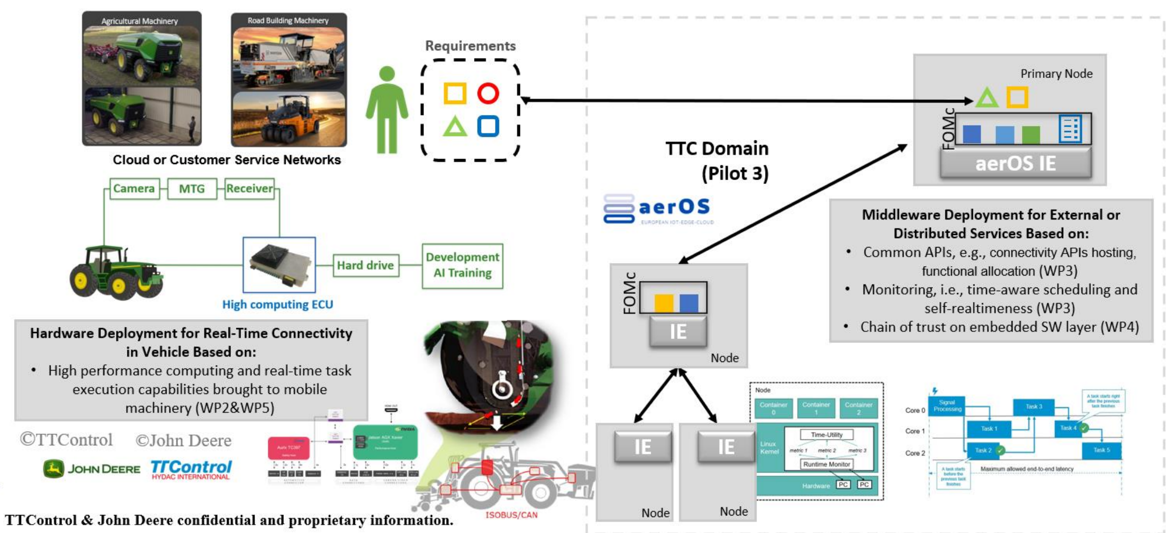


Figure 28. aerOS in scenario 1 of Use case 3.

[1] The assessment of impact and effect value is performed for a single vehicle. In case of platooning (i.e. a swarm of vehicles operating with a joint goal), these positive effects might be at least multiplied by a number of vehicles or more (automated operation excluding a driver for each of the vehicle has also a large impact which is, however, hard to calculate precisely).

From a technical point of view, a mapping to aerOS design principles was made. The figure below represents this analysis:

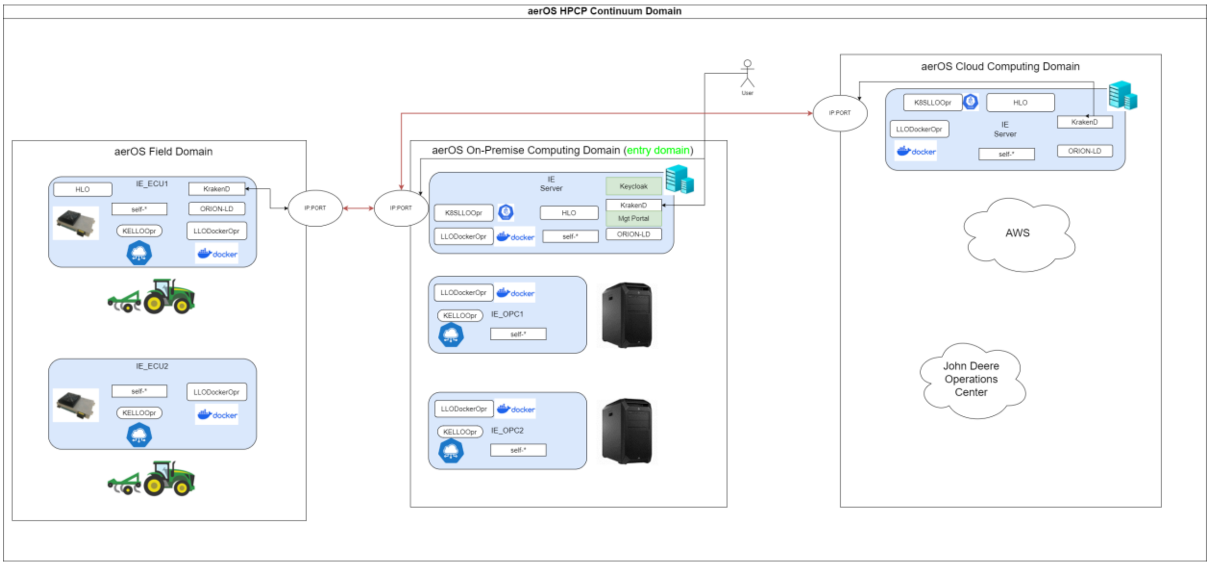


Figure 29. Mapping of aerOS in the Pilot 3 Scenario 1.

As it can be seen in the figure above, during the period M12-M18, efforts have been made together with aerOS technical partners to identify the domains and the IEs that will exist in P1-Scenario infrastructure. The various components of the aerOS runtime that are already being installed and tested are also depicted in the image.

2.3.3.1.4. Actors involved in Scenario 1

Potential actors in real-world application scenario can be specified as below. However, please note, that none of human will be included / affected during the project for the demonstrator as Pilot 3 will be deployed in a lab.

Table 20. Actors involved in Scenario 1 of Use case 3

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Blue Collar workers (Farmers)	Agriculture	Direct	Shorter completion time of field work
Clients (Farm owners)	Agriculture	Direct	Shorter completion time of field work

2.3.3.2. Scenario 2: Basis for CO2 neutral intelligent operation (e.g., farming, construction, forestry)

2.3.3.2.1. Description

Basis for CO_2 neutral intelligent operation (e.g. farming, construction, forestry): deploying of tasks in the edge, it is possible to reduce the latency and reaction time, by using low-latency networks like e.g. 5G. The benefit is also related to the energy consumption when transferring AI and real-time embedded analytics, what may reduce the CO_2 impact. The scenario will measure in a collaborative swarm of vehicles the energy consumption reduction due to the use of aerOS and different federation topologies, considering how AI-supported approaches affect performance.

Figure 30. Data analysis at JD in scenario 2 of Use case 3

Other relevant considerations for describing scenario 2 of Use case 3 are the following:

- Data from sensors as well as operating instructions from cloud must be safely and securely processed
- Deploying of tasks in the edge
- Reduce the latency and reaction time, by using low-latency networks (e.g. 5G), the benefit is also related with the energy consumption when transferring AI and real-time embedded analytics, what may reduce the CO_2 impact.
- The scenario will measure in a collaborative swarm of vehicles the energy consumption reduction due to the use of aerOS and different federation topologies.
- Analyse Impact of AI "affecting".

2.3.3.2.2. Specific objectives

Data and information from multiple devices and at least one autonomous or semi-autonomous mobile machines are processed on-the-go. aerOS-technology can principally be deployed to conventional commercial vehicles as well as to electrified machinery. In the case of electric machines, CO_2 emissions from direct energy consumption can be reduced to zero. Further energetic improvements can be achieved by more precise operation and coordination with regard to optimized trajectories, positioning, and speed of one or more machines. Applications can be carried out at higher accuracies positively impacting overrunning surfaces and reducing outputs.

The objectives of this specific scenario are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 21. Specific objectives of Use case 3 – Scenario 2

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Connected machine and sensor/device data	Massive data transfer and handling between mobile machinery and infrastructure for highly precise off-board operation	Reduced number of cabs: • Lower weight • Reduced workload (1 operator of multiple	**Cost**	3
			Efficiency	4
			Quality	3
			Flexibility	3

		machine) • Path/trajectory planning optimized	**Innovation**	5
			Sustainability	4

2.3.3.2.3. aerOS in Scenario 2

The deployment of aerOS in this scenario is envisaged same as in scenario 1 (Section 2.3.3.1.3).

2.3.3.2.4. Actors involved in Scenario 2

Potential actors in real-world application scenario can be specified as below. However, please note, that none of human will be included / affected during the project for the demonstrator as Pilot 3 will be deployed in a lab.

Table 22. Actors involved in Scenario 1 of Use case 3

ACTOR	B$ AREA	IMPACT	IMPACT DESCRIPTION
Operator in the Operations Center at JohnDeere	Mobile machinery and agriculture in particular	Indirect	Optimizing the operation of a fleet for energy consumption and CO_2 reduction
End users with access to e Operations Center at JohnDeere	Mobile machinery and agriculture in particular	Indirect	Optimizing the operation of a fleet for energy consumption and CO_2 reduction

2.3.4. Data sources

The data sources that will be used in the Pilot 3 of aerOS are as follows.

Data sources

- Field monitoring real-time image data (JPEG) provided by forward and backward camera sensors for on-board processing based on an AI model (also in batch dumping). It also provides JSON metadata that includes e.g., time stamp, resolution and raw pixel values.
- Real-time geopositioned location of vehicle monitoring (CSV) provided by GNSS receiver and connected via CAN bus. It will provide structured data containing time stamp, and latitude and longitude coordinates of vehicle.
- Information about field conditions and previous treatment / operations on the specific field (JSON/CSV). It will be provided in real-time (1 update per second, or via network API request). It will also provide structured data containing previous field treatments and weather data.
- Information about current vehicle status, e.g., power level, engine status, etc., and vehicle system configuration (JSON/CSV). It will be acquired in real-time (1 update per second) via CAN bus.

2.3.5. Requirements of the trial

Below there is a list of the specific requirements identified for this trial. A full list of all the requirements for Pilot 3 as a whole are available in Appendix B.

- Low-latency communication between system components
- Compatibility between different types of devices in the built system
- Compatibility between the built system and the overall architecture of aerOS
- (Semi) real-time data analysis
- Local processing of data flow

2.3.6. Specific measurable outcomes of the trial

After the completion of the activities of the pilot, when fulfilling the objectives above by the partners of the use case, the expected outcomes of the trial are as follows:

- Fully automated safe and secure execution at the edge node of the vehicles swarm.

Result: Vehicles equip new software – HPCP and aerOS.

The pilot will demonstrate the process optimization in a closed loop of control ("vertical integration") ensuring fully automated safe and secure execution at the edge (e.g. being integrated in the vehicle leading the swarm) of instructions generated and provided from the cloud to the platoon leader of the swarm.

- IoT edge-cloud continuum.

Result: Meta Operating System now exists, abstracting underlying computing resources.

Creation of a IoT-environment providing real time, high bandwidth, and low latency connectivity in temporary networks based on next generation electronic building blocks of a safe and secure platform for more the execution of advanced automation application to support a grid-connected electric tractor system and control the swarm machines.

- Enlarged open edge ecosystem.

Result: Standard API for managing the continuum and creating new functionalities upon.

Enlarge open edge ecosystem of the aerOS project the pilot consortium focuses on standard-based interfaces (e.g. GMSL2) and widely available software elements (e.g. Linux-based) by integrating and orchestrating several applications for demand as services to enable the uptake of midcaps, SMEs and start-ups developing the relevant functions or services.

As expected benefits, aerOS will allow stakeholders of the agricultural machine use case (represented by JohnDeere and TTC) to have, at least (but not limited to):

- Faster and optimized field work based on analyzing data that requires high computing power such as images with the help of the incorporated ECU with high computing power. This will help enabling elevation of the features of an existing field work that has been performed manually.
- Collecting and analyzing various types of data from different data sources (components that are usually connected to the machine/vehicle), such as positioning and location information via the receiver, network status and type via a cellular modem, images via cameras. This will result in a detailed knowledge about the running system and make the end user's job easier, faster, and smoother.
- Shifting to automated field monitoring will result in shorter completion times.
- Giving a chance for the end user to focus on other tasks that require attentive observation and management, and prioritize his/her daily tasks.

2.3.7. Legal framework

During the course of task T2.3 (Legal and regulatory analysis and governance specification), several actions have been performed in order to identify the legal framework surrounding activities in Pilot 3. Germany, where the use case will take place, is aligned with all relevant European directives.

The legal framework of Pilot 3 is now available (it was not included in D2.2). It can be found in Appendix C.

2.4. Pilot 4: Smart edge services for the Port Continuum

2.4.1. Trial general description

The Smart edge services for the Port Continuum Use case (pilot 4) will be driven by the Industrial partner EUROGATE and the scenarios will be deployed and validated in the container terminal located in the Port of Limassol (EGCTL), the largest port in Cyprus, handling more than 90% of the container volume of the island, reaching approximately 300.000 TEUs per year. The terminal operates 24/7, servicing almost all container vessels of the island. Technically, EGCTL will be supported by partner Prodevelop (PRO) and the Cyprus University of Technology (CUT).

The equipment of the terminal consists of more than 35 rubber gantry cranes (straddle carriers), 5 empty container handling equipment, 10 terminal tractors and 5 Ship-To-Shore (STS) cranes. Two of the cranes were commissioned in 2019, are of type Super Post Panamax and have the capacity to handle two containers at a time (twin mode).

The Eurogate group develops and operates an in-house Terminal Operating System (TOS) which covers all operating aspects of the terminal, including vessel planning, cargo handling, cargo moves and machinery instructions, customs and Port Community System (PCS) interface and handling of dangerous goods. EGTL also operates a third-party maintenance management system.

Figure 31. Eurogate Container Terminal in the Port of Limassol – aerOS Use case 4

EGCTL has since starting operations, pioneered in the upgrade of the connectivity of the port systems, achieving a reduction of container clearance time from 24 hours to 15 minutes and an average import container delivery time of 20 minutes. Both of these achievements are a testament to the commitment of EGCTL to optimizing terminal operations and target of further improving the resilience of the terminal and the speed of operations.

In the above context, EGCTL is in the process of digitizing and automating more operations processes, such as creating an automated truck gate process. aerOS will be the starting point in creating scalable IoT infrastructure that the Terminal can build and expand in the future, as it is expected to connect more than two hundred devices in the next 5 years. The trial aims to generate the necessary know-how in deploying scalable IoT systems and create a testing ground for AI technologies which can then be deployed both terminal wide and group wide (i.e., in one of the other twelve Eurogate terminals).

The Use case 4 has been divided in 2 scenarios (that will be described below) that, jointly, pursue the achievement of four objectives:

- Objective 1: To provide a digital platform for the port which can improve the traceability of assets in the terminal yard. To do so, proper data acquisition, transmission, and storage services should be guaranteed by aerOS.
- Objective 2: To support a heterogeneous set of Infrastructure Elements compliant with aerOS, from the lightweight IoT gateways such as RPis, up to the most-capable cloud servers (either private or public ones). Therefore, the minimum requirements for running aerOS operating system should not be very high.

- Objective 3: To provide a very accurate predictive maintenance service based on frugal AI models that are embedded in the aerOS stack.
- Objective 4: To provide a computer vision solution that can be inferred from the edge without requiring very high bandwidths. The aerOS orchestration should be smart enough to manage when these functionalities can be carried out in the edge devices dynamically, according to the actual IEs' capabilities.

2.4.2. Current problems/barriers area and motivation

Port container terminals and their logistic infrastructures are essential to keep the world-developed areas. At present it is considered that more than 90% of the world's trade is carried by sea[2]. Hence, the impact of this strategic sector on the quality of life of worldwide citizens is crucial, as freight transport is a powerful key driver for job creation and economic growth. Promoting innovation on efficiency, sustainability and safety of the port-container industry is a fundamental issue. In particular, the significant economic growth before and after the global COVID-19 pandemic crisis, as well as the increase of cargo volumes, have driven maritime ports into developing their capacities in unexpected ways. Shipping lines have always been the main stakeholders pressing for continuous port efficiencies, with new challenges arising coming from the strengthened ocean carrier alliances and the increased ship dimensions. On the one hand, shipping alliances, as a means of capacity rationalization, lead to further concentration and to decreased number of ports to call. Therefore, less ports are being required to serve more ships. On the other hand, those pressures are to intensify more as the dimensions of ships are continuously increasing. The average size of new containerships delivered has increased from an average of 1k TEUs (Twenty-feet Equivalent Units) in the 1970s to 7.7k TEUs ordered today[3]. As bigger ships mean also bigger volumes to be loaded/unloaded within small time-windows, this is also consequently impacting transferring congestion pressures towards container terminals[4]. Thus, this evolution has provided remarkable needs for the appropriate performance of container handling and logistics. However, operational missing links and bottlenecks remain, including among others performance inefficiencies, labor accidents, increased energy consumption as well as pollutant and Greenhouse gas emissions[5].

In parallel, the advancement of new digitization paradigms such as Cloud-Edge Computing, Internet of Things (IoT), Big Data, and Machine Learning (ML), have created new possibilities for the industry, leading to the well-known concept of Industry 4.0. In regards of the cargo handling industry, Industry 4.0 services, also known as Port 4.0, could improve processes by connecting all equipment and systems in real time, thus enabling seamless data exchanges. Under these new conditions, more automated and interoperable solutions could be achieved by the sector with less risk, at a lower cost, and faster lead-time. The aim of aerOS Pilot 4 is to provide and successfully test a cloud-edge continuum distributed system for container terminals that will efficiently tackle the mentioned challenges. aerOS shall provide an intelligent meta-OS for transforming container terminals' operations, using real data as a mechanism to support decision making and the generation of new incomes. Whereas the low latency applications, timely decisions and human-centric interaction are not possible with the cloud-centric architectures, aerOS will provide a cloud-edge continuum approach with secure services, allowing the industrial companies to alleviate the recurrent need to send the data to a central node, react faster to certain critical events deploying AI/ML close to the point of interest, extreme scale data governance and services, and improve scalability through decentralization.

In order to further illustrate the problems/barriers that have motivated this use case in aerOS, and according to the personalized templates of Trial Handbook devised for the project, it was decided to utilise the following table:

[2] International Maritime Organization, 2019. IMO profile
[3] M. Wackett, Global fleet capacity to bulge as more containerships are delivered in 2018, 2018.
[4] L.Nightingale, Tesco raises concern over bigger boxships, 2015.
[5] O. Merk, and T.T. Dang, Efficiency of World Ports in Container and Bulk Cargo (oil, coal, ores and grain), Paris, OECD Publishing, 2012.

Table 23. Current problems and barriers in UC4

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Poor data and telemetry digitization and analytics	Ports have a lot of equipment which provides sensor data, but these data are not stored and further used for decision making	Management/ Technical support	The lack of digitalization does not allow to gather insights for either better operational efficiency or reducing risky working situations
Fixed preventive maintenance periods	Cranes have a predefined maintenance time measured in hours (1000h), but sometimes there is a failure before period elapsed, and the port stops operations until crane's component is fixed.	Management / Technical support / Accounting / Warehousing	A larger time required to repair the equipment because the spares might not be available.
No computer vision features	There are several cameras installed across the port, but their video streams are not sufficiently exploited.	Management / Sales / Technical support / Customer relationships	Ports do not provide an automated quality check form about containers' status to their customers. If it is done manually, the required time for it is very high

2.4.3. Objectives, benefits and expected results

In the following sub-sections there is a thorough description of each one of the scenarios in Pilot 4.

2.4.3.1. Scenario 1: Predictive maintenance of Container Handling Equipment

2.4.3.1.1. Description

Any industrial equipment wears out eventually, but if it is well-maintained, it would probably last longer. Originally, reactive maintenance was the regular process, which essentially addressed the repair of a piece of machinery only after it was broken down. However, it had many overhead costs that could be avoided. To name a few, the cost of unplanned maintenance due to equipment faults included a considerable amount of time wasted for responding to emergencies and diagnosing faults, so that would result in loss of production, as well as higher costs for parts commissioning and shipping. Preventive maintenance "looks ahead" to stop breakdowns before they occur by scheduling regular preventive maintenance cycles. With proper planning, technicians can ensure the best working conditions and prolong the expected life span for the equipment. In detail, preventive maintenance has traditionally been done using SCADA systems set up with human-coded thresholds, alert rules, and configurations about when machine conditions are at a state of needed repair or even replacement. However, either time-based or usage-based preventive maintenance may be addressing problems that do not exist, as maintenance is performed regardless of identified issues, leading to although planned, increased unnecessary downtimes. Furthermore, preventive maintenance requires a larger inventory management for replacement parts. Aiming at exploring options for improving maintenance strategies, and thanks to utilizing condition monitoring equipment and machine monitoring sensors, the performance assessment of assets can be realized with a more real-time, data-driven analytics approach. This new approach, namely predictive maintenance, utilises real-time health status knowledge and assessment, enabling the prediction of faults before they occur, thus not having to wait for equipment to breakdown (i.e., reactive maintenance), nor carrying out maintenance when it is not necessary (i.e., preventive maintenance).

With regards to the port continuum pilot, due to heavy loads, long periods of use, and a wide variety of weather conditions, Container Handling Equipment (CHE) (such as STS cranes, RTG cranes, Straddle carriers, or reach stackers) require an optimal maintenance process. However, the traditional preventive maintenance semi-manual approach does not consider more complex dynamic behaviours of CHEs, or the contextual data relating to the operational process at large. According to the previous needs, an accurate predictive maintenance system is pursued. Thanks to the latest advancements on Artificial Intelligence (AI), the implementation of machine learning (ML)-based solutions is seen as the next-step functionality that can lead predictive maintenance to major costs savings, higher predictability, and increased availability. The novelty of aerOS project becomes apparent when reviewing the state-of-the-art literature of AI predictive maintenance applied to the maritime sector. There is a current lack of scientific literature about AI in general, and ML models in particular, applied for the development of predictive maintenance solutions to container terminal machinery. Thus, while predictive maintenance as a tool is already being used in other sectors, terminal ports have still a long way to go into the digitalisation journey in order to benefit from implementing the proposed solutions to their machinery. The goal is that the trained ML algorithms will enable to detect anomalies and test correlations while searching for patterns across the various data feeds from OT (sensors, PLCs), and IT (TOS, CMMS, weather condition). But for that, like most ML works, sufficient historical data and expert knowledge will be needed to understand previous failures reasoning. This also includes general features, such as mechanical properties, average usage, and operating conditions.

The following components of the **STS cranes** will be used for the predictive maintenance tests on aerOS:

- Trolley Wire Rope Enlargement Warning: An early warning system will be put in place that monitors the discrepancy between the distance the limit switches of the trolley wire rope were positioned on the travel length of the boom with the distances that were stored in the first calibration of the machine. The warning system will predict in advance when it becomes faulty, allowing the Technical Department to plan for this issue before any undesired working condition.
- Motor Filter Condition: Currently, there is no analogue sensor measuring the temperature of the motor itself. Thus, a sensor monitoring ambient temperature and current load of the motor will be used to detect if the ventilation system is behaving adequately or requires replacement of the filter. The alerts will be recorded by the CMMS software, and this will allow to use previous Dates/Times when the filters were replaced so that the system will be able to predict further replacements in advance.
- Motor Bearings Condition: Monitor motor speed as well as load and motor bearing housing temperature to determine if the bearings of the motor have degraded and require replacement (Sensor required).
- Motor load sharing from Hoist: Measure variability between the 2 motors, master and follower hoist motor to monitor that they share the load equally. This could indicate a misalignment of one of the motors, coupling degradation, motor degradation or closed loop control issue (Speed Encoder, Parameters, Inverter etc.).
- Tensioning Aux Cylinder Pressure Monitoring: This would check when the deviation between the 2 cylinders has increased greatly or avoid the disparity and notify personnel to check the wire ropes.
- Load Cell deviation: Monitor the health of the load cell by comparing the 2 existing channels in each of them and predict the failure to drift of the measurement system.

The following components of the **Straddle carriers** will be used for the predictive maintenance tests on aerOS:

- Generator engine efficiency: To calculate and monitor efficiency genset system by measuring power delivered to the engine in terms of fuel l/h and electrical energy produced. To do so, three main data inputs will be monitored: engine fuel consumption, engine load, engine speed, engine torque, generator output, and outdoor temperature.
- Genset vibrations: To monitor vibration on genset and predict if this is related to genset mounting failures, or engine injector issues. The main variables to be recorded are: genset vibration, generator output frequency, and generator output load.
- Suspension/Wheel Hub issues: To monitor the drive system of the straddle carrier during operation and send warnings if the system is behaving abnormally. The system should provide the main reason that could be due to e.g., suspension failing, tyres, etc. It will take into account not only machine inclination, but also load height, machine side frame speed difference, wheel hub/suspension vibrations or if it is transporting a container or not.
- Hydraulic system: Hydraulic Pressure Instability can indicate issues in the system, accumulator or pressure regulators that are faulty. Several pressure transducers will be placed on the machine to

measure the system and alert if there is an anomaly based on the machine operation, including also parking brakes engaged or not, spreader motion ON/OFF and outdoor temperature.

- Engine Temperature Issues: Monitor key values of the engine to predict degradation and failure of components such as Coolant Pump degradation, Radiator degradation. The engine temperature combined with the engine load and external temperatures can provide indications on the above component failures/degradation.
- Brake Temperature Issues: Monitor key values of the brakes to predict degradation and failure of components such as Brake Cooling Pump degradation, Radiator degradation, filter clogging, failure of seals that mix the hydraulic fluid with the brake cooling fluid. The brake cooling temperature combined with the brake pressure applied and external temperatures can provide indications on the above component issues.
- Inverter Temperature Issues: Monitor Temperature of Inverters based on inverter loads and outdoor temperature conditions to predict overtemperature due to clogged filter or faulty cooling fan operation.
- Engine Boost Pressure Issues: Monitor key values of the boost pressure, by monitoring boost pressure, intake temperature, engine load, engine speed and predict issues related to leakage of the boost circuit, degradation of the turbo, or degradation/failure of the intercooler.

2.4.3.1.2. Specific objectives

The general objective of use case scenario 1 is **to validate different frugal AI models[6] to (i) predict remaining useful lifetime (RUL) of assets with regression models, and (ii) predict failure within a given time window with classification models** for **STS cranes** and **straddle carriers**. This can help to reduce downtime, increase efficiency, and save costs by reducing the need for regular manual inspections.

The system should also be able to provide real-time alerts to the users and system administrators when maintenance is needed. By using frugal AI models, the system can be more lightweight and less computationally intensive, which can be beneficial in situations where resources are limited. The envisioned frugal ML models of aerOS to be performed on the edge, would analyse the data on premise in real-time, reducing the amount of data to be transferred to the cloud, which in-turn would save businesses money on cloud storage costs.

Three frugal ML models[7] will be considered: "input frugality", "learning process frugality" and "model frugality". This general objective can be split into small specific objectives:

1. To retrieve telemetry data from 2 straddle carriers and 2 quay cranes every second. At the time of writing this handbook, tyre pressure, vibration, hydraulic pressure, acceleration, road vibrations, oil and fuel levels, and power measurements have been discussed.
2. To correlate the aforementioned telemetry data with the proprietary software solutions used in the terminal. In particular, the operational activities collected in the Terminal Operating System (TOS) and the Computerized Maintenance Management System (CMMS) will be properly integrated following an exchange of data with the secure, trusted aerOS services.
3. To develop, test, and validate different frugal AI models for providing advance insights of probable faults for the 4 CHEs being monitored. Both regression and classifications ML algorithms will be considered for the specific use case.

A more particularised list of objectives of scenario 1 of Use case 4 is described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 24. Specific objectives of Use case 4 – Scenario 1

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
CHE telemetry	To retrieve telemetry data from	The access to real-time telemetry	**Cost**	2

[6] Frugal AI refers to the use of simpler, more efficient models that can run on resource-constrained devices, such as those used in IoT gateways or embedded systems, which can learn with less data.

[7] M. Evchenko, J. Vanschoren, H. H. Hoos, M. Schoenauer, M. Sebag, "Frugal Machine Learning", Nov. 2021 https://arxiv.org/abs/2111.03731

data acquisition	2 straddle carriers and 2 quay cranes every second	data of the CHEs in the port will allow terminal managers to carry out better and more informed choices, leading to a higher operational efficiency of the terminal.	**Efficiency**	5
			Quality	3
			Flexibility	1
			Innovation	5
			Sustainability	1
Connection to TOS and CMMS	To collect work instruction data and maintenance tasks, warnings and faults data from the Terminal Operating System (TOS) and Computerized Maintenance Management System (CMMS), respectively.	The access to historical TOS and CMMS data will allow terminal managers to improve the decision-making process, leading to a higher operational efficiency of the terminal.	**Cost**	2
			Efficiency	3
			Quality	4
			Flexibility	1
			Innovation	5
			Sustainability	1
Frugal-AI models for predictive maintenance	To train, test, and validate frugal predictive maintenance AI-models (both, regression and classification) with the CHE telemetry data, and maintenance data.	The development and deployment of predictive maintenance solutions will allow to avoid unexpected machinery faults, which will reduce repair costs, as well as equipment downtime.	**Cost**	4
			Efficiency	5
			Quality	4
			Flexibility	1
			Innovation	5
			Sustainability	3

2.4.3.1.3. aerOS in Scenario 1

Even having enough data, the selection, training, and inference process of the most suitable ML model for the computing capabilities of the Infrastructure Elements (IEs) of the use case is critical. Distributed orchestration is considered in aerOS as a keyway of optimizing the speed and performance of predictive analytics by performing ML locally, since even though cloud computing can support predictive analytics solutions, carrying out these models on a remote server leads to potential latency issues, which may cause delayed response maintenance times.

The below diagram sketches the expected architectural deployment for the two Pilot 4 use case scenarios. As it can be seen, the pilot plans to differentiate up to 4 different aerOS domains. For use case scenario 1, both aerOS STS domain, as well as aerOS SC domain are expected to collect data from sensors and the machine's PLC and performing basic pre-processing. Thus, they will be formed mainly by far-edge devices. Edge processing will be performed for local ML training and inferencing for identifying the need for predictive maintenance. In addition, aerOS STS domain will act as the entry domain, and will include all the distribution management and orchestration services from aerOS in the server being deployed in EUROGATE premises. Finally, cloud resources (CUT and Video domains) will be used for more intense ML training and testing, mainly for use case scenario 2.

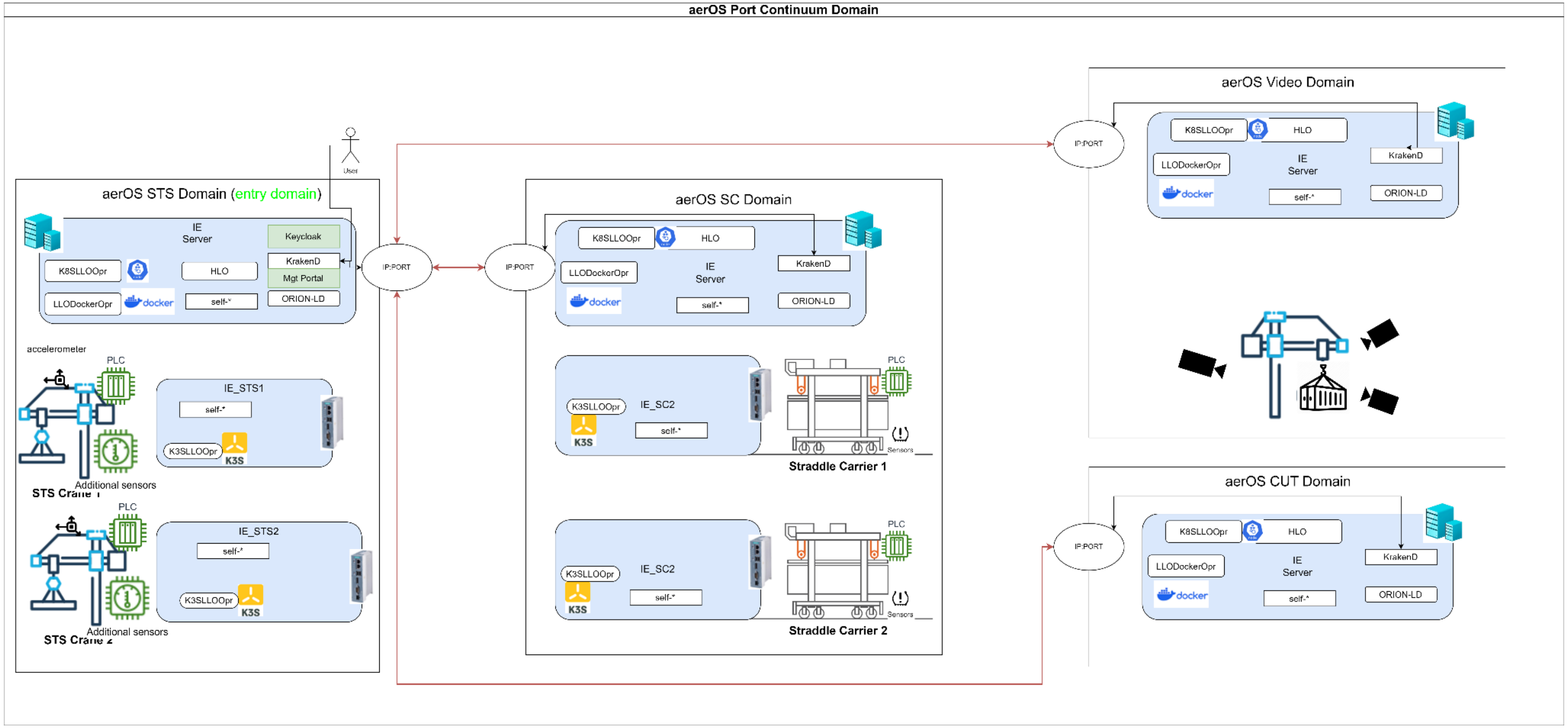


Figure 32. Port Continuum use case scenarios of aerOS.

2.4.3.1.4. Actors involved in Scenario 1

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 25. Actors involved in Scenario 1 of Use case 4

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Container terminal board	Management	Indirect	Extending lifespan of cranes will reduce capital expenditure on new CHEs, as well as increase terminal productivity
Container terminal maintenance department	Maintenance	Direct	The predictive maintenance service will allow maintenance team to optimize their work, reducing unexpected faults
Crane drivers	Operations	Direct	The reduction of unexpected faults will increase the cranes lifespan and smooth operation, consequently, drivers' safety and satisfaction
Technology provider	IT	Direct	An accurate AI/ML service will be implemented, becoming part of the product portfolio

2.4.3.2. Scenario 2: Risk prevention via Computer Vision in the edge

2.4.3.2.1. Description

Influenced by the advancements and technologies generated by the well-known fourth industrial revolution (Industry 4.0)[8], maritime port digitalisation (also known as Port 4.0) is considered as one of the key pillars for addressing several operational efficiency challenges. Port 4.0 refers to the process by which digital technologies are integrated into the operations and management of ports and terminals. Therefore, cutting-edge technologies are employed to drive autonomous operations and assist humans to follow the right business and operational decisions. Among others, it involves the use of technologies such as Autonomous Systems, the Internet of Things (IoT), Computer Vision (CV), Big Data, or Artificial Intelligence (AI).

Within this digitalization journey, AI has the potential to revolutionize the maritime industry. It will allow terminal operators to optimize resource allocation, reduce congestion, or improve turnaround times. Computer Vision (CV) is a rapidly growing field of AI that has many potential advantages in various industries[9]. One significant advantage of CV is its ability to automate visual inspection processes. With the help of CV algorithms, it is possible to automate quality control, defect detection, and inspection processes, resulting in increased accuracy, speed, and cost-effectiveness. This can be particularly useful in manufacturing and industrial settings, where visual inspections are critical to ensure product quality and safety.

One of the main data sources for the terminal comes from the camera systems. Thanks to the explosion of customizable IPTV cameras, the captured video streams combined with CV can be used for improving different aspects in the port. In particular, it is crucial to keep track of the continuous flow of in-and-outgoing containers. Missing one container might lead to high costs. The second use case scenario of the pilot 4 is based on the development, integration and validation of different frugal-AI CV algorithms on the edge. IPTV cameras to be installed at the terminal yard or at the STS cranes when loading and unloading the vessels. This use case will allow the terminal to automatically identify containers with damages, and to check for the existence of container seals without the need of human intervention. These two features will be offered to container terminals'

[8] Fotios K Konstantinidis, Nikolaos Myrillas, Spyridon G Mouroutsos, Dimitrios Koulouriotis, and Antonios Gasteratos. 2022. Assessment of industry 4.0 for modern manufacturing ecosystem: A systematic survey of surveys. Machines 10, 9 (2022), 746

[9] Fotios K Konstantinidis, Spyridon G Mouroutsos, and Antonios Gasteratos. 2021. The role of machine vision in industry 4.0: an automotive manufacturing perspective. In 2021 IEEE International Conference on Imaging Systems and Techniques (IST). IEEE, 1–6.

customers, providing an added value from the quality check point of view. In addition, the automated and low-latency analyses of those video streams on the edge will avoid human mistakes and at the same time reduce safety risks, achieving a secure, and trustable environment for workers.

The details of the two applications of CV are described next:

Broken seals / unsealed containers

One of the major applications of use case scenario 2 is to detect broken seals or absence of seals on containers, and differentiate between properly sealed and unsealed containers. Similar applications of computer vision have been applied to different projects, and their outputs are closely related to the main goal of the second use case. The objective is to discern sealed from non-sealed containers, which will enhance the quality control of the terminal yard operations. The innovation proposed is, thus, the application of this technology to a different goal from the examples found in the literature, but in close relation with them. Furthermore, there is the plan to build a CV-based model for achieving higher accuracy in properly detecting the seals on the back side of containers, which can be a challenging task (as presented in Figure 33).

Figure 33. Example of detection of broken-sealed container for scenario 2 of Use case 4

Container surfaces damages detection

Frequent use and stacking of containers can lead to various damages such as cracks, cuts, holes, deformations, and dents. The manual methods for early detection of damage have several weaknesses, such as low efficiency, slow speed, low accuracy, and high cost, which affect the efficiency of the port and cause economic losses. Therefore, the second major application of use case scenario 2 is to develop a CV-based method capable of detecting various damages of containers. The detection of damage to containers requires an efficient CV model instead of conventional detection models because they have some complexities. For example, there are multiple views of the container sample image, which leads to differences in the damage features for the same container. On the other hand, the difference in the damage features of different categories is not obvious, which makes training models difficult. Finally, weather, light, and other factors can cause interference during sampling.

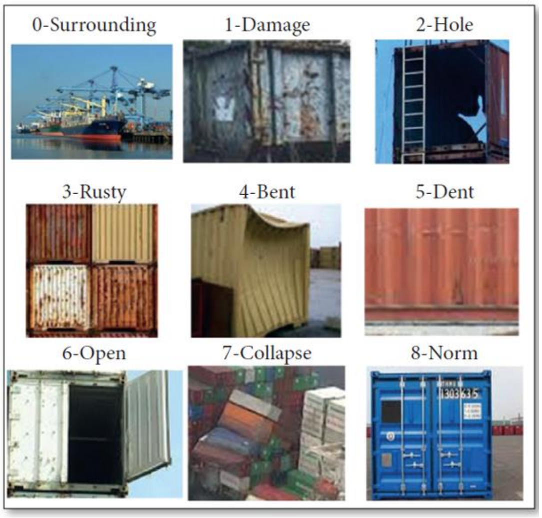


Figure 34. Different type of container surface scratches

2.4.3.2.2. Specific objectives

The general objective of use case scenario 2 is to provide a CV solution that can be inferred from the edge without requiring very high bandwidths. The aerOS orchestration will manage when these functionalities can be carried out in the edge devices dynamically, according to the actual IEs capabilities. This general objective can be split into small specific objectives:

Table 26. Specific objectives of Use case 4 – Scenario 2

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
IPTV camera installation	To procure and install different IPTV cameras with enough resolution, local storage, and customization capabilities	The installation of IPTV cameras at the quay side of the port will allow to capture the processes of loading/discharging containers of vessels.	**Cost**	2
			Efficiency	2
			Quality	4
			Flexibility	1
			Innovation	3
			Sustainability	2
Collect video streams from installed IPTV cameras	The video streams captured from the IPTV cameras should be properly collected for a long period of time in a sufficiently large storage service.	A large dataset is needed in order to allow AI practitioners to carry out the proper data annotation and ML training required for getting accurate ML algorithms	**Cost**	4
			Efficiency	3
			Quality	4
			Flexibility	2
			Innovation	3
			Sustainability	3
Frugal-AI models for object detection	To train, test, and validate frugal AI-models for detecting wrongly sealed containers, as well as containers' surfaces damages (classification NN are the main point of interest).	The development and deployment of CV solutions will provide an added value from the quality check point of view of the terminal SLAs. In addition, the automated and low-latency inspection of the containers will avoid human mistakes and at the same time reduce safety risks, achieving a secure, and trustable environment for workers.	**Cost**	2
			Efficiency	4
			Quality	5
			Flexibility	4
			Innovation	5
			Sustainability	4

2.4.3.2.3. aerOS in Scenario 2

The integration of use case scenario 2 diagram is shown in the corresponding section of use case scenario 1. We refer the reader to that section for deeper insights.

2.4.3.2.4. Actors involved in Scenario 2

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 27. Actors involved in Scenario 2 of Use case 4

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Container terminal board	Management	Indirect	Detection of sealed and non-sealed containers will help in making decisions; also, it helps in reducing human presence

			at an area with high safety risks. Eventually, it will help in enhancing the productivity of terminal, as humans need 30 seconds to 01 minute to check the seal but CV based system will do this task in couple of seconds (i.e., 2-5 seconds).
Container terminal maintenance department	Maintenance	Direct	Early detection of damages in containers can help to resolve the small issues before any big loss.
Crane drivers	Operations	Direct	Based of damage detection using computer vision-based models, they can carry damaged containers with more care to avoid any further loss of container contents.
Technology provider	IT	Direct	An efficient computer vision-based model will be implemented, becoming part of the product portfolio.

2.4.4. Data sources

The data sources, existing software and hardware that have been detected so far to be used in the Pilot 4 of aerOS are as follows. The next list reflects only a summary of the minimum aspects detected so far. A far more thorough description is included in the current stage of the Trial Handbook (online) of the pilot. In addition, it is worth noting that these descriptions will be fully disclosed in the next deliverable of this task (T2.2, deliverable D2.3):

Time-series data of the Quay cranes and Straddle Carriers of the EUROGATE Limassol port that will be stored every second, directly obtained from the PLC through MQTT or HTTP.

- Data from the tyre pressure monitoring system, vibration, hydraulic pressure, and acceleration sensors, road vibration sensors, oil and fuel levels, and power measurements. This data will be collected and handled at the far-edge (IoT Gateway) level.
- Terminal Operating System (TOS) data, to be used for feeding operational insights as well as training and validating predictive maintenance algorithms.
- Maintenance data from the Computerized Maintenance Management System (CMMS) exported as XLS and retrieved from APIs to gather information about the assets to be regularly maintained in the port, including equipment, materials, but also maintenance schedule and assigned workers.
- Video streams from yard IPTV cameras, including live video (via RTMP protocol) feed and file extracts (MPEG4-only for training purposes).

2.4.5. Requirements of the trial

Below there is a list of the specific requirements identified for this trial. A full list of all the requirements gathered (in M9) for Pilot 1 as a whole are available in Appendix B.

- Develop aerOS IE that integrates data telemetry from cranes into aerOS Data continuum
- Integration of TOS with aerOS
- Integration of CMMS into aerOS
- Monitor Trolley Wire Rope Enlargement
- Motor Filter Condition
- Motor Bearings Condition
- Motor load sharing from Hoist
- Tensioning Aux Cylinder Pressure Monitoring
- Generator engine efficiency
- Genset vibrations
- Inclination issues

- Hydraulic system
- AI models for PdM should meet a minimum R2
- Integration of IPTV camera streams in aerOS
- Container plate identification
- Detection of damaged containers
- Detections of holes in containers
- Detection of wrongly sealed containers
- AI algorithms for CV should process at least 10 frames per second
- AI models for CV should meet a minimum R2

2.4.6. Specific measurable outcomes of the trial

After the completion of the activities of the pilot, when fulfilling the objectives above by the partners of the use case, the expected outcomes of the trial are as follows:

- Integration of live data from the container terminal.

Result: High-level meta-OS system up and running

- Integration of assets for predictive maintenance

Result: A tool (with GUI) provided to the Port Managers based on benefits provided by aerOS.

Real-time integration between HW and SW terminal assets for proper predictive maintenance.

- Data collection supporting AI

Result: Solid, robust, standardised, available, Big Data dataset

Dataset of telemetry data from quay cranes and straddle carriers that is big enough to support training, testing, and validation of Predictive Maintenance models.

- Predictive maintenance

Result: AI models for crane predictive maintenance

Frugal AI models for crane predictive maintenance alerting including classification and regression models such as decision trees, random forest, KNN, Binary recursive models, etc.

- Edge models

Result: PdM services properly working at the edge.

- Recording of containers

Result: Solid, robust, standardised, available, Big Data dataset

Dataset of images from IPTV cameras recording containers during load/unload operations (large enough to support training, testing, and validation of Computer Vision models).

- Computer Vision

Result: Computer Vision models working

Computer Vision models (YOLOV, Inception, ResNet50, EfficientNet) for the detection of damaged containers, wrongly sealed containers, or other scratches needed for risk prevention purposes.

- CV services

Result: A set of CV services manageable via aerOS

Computer vision services properly working at the edge IEs.

As expected benefits, aerOS will allow stakeholders of maritime port use case (represented by EGCTL) to be able to:

- Achieve full end-to-end traceability of assets and procedures
- Allow to take better decisions by improving the availability of the information and the way it is presented to the staff.
- Reduce manual interactions, automatizing as much as possible the input of traceability data in such a way that any service develop within the framework of aerOS may benefit from the insights that data can provide
- Increase efficiency and reduce costs by implementing real-time tracking and monitoring of assets in the terminal yard through the use of IoT and AI technologies.
- Improve communication and collaboration between stakeholders.
- Reducing idle periods due to unplanned maintenance operations of cranes and straddle carriers and the automatic detection of container IDs and structural checks to detect damages.
- Enhanced security services, guaranteeing overall customer satisfaction.
- Enhance its ability to analyse and optimise its performance by collecting and analysing data on the usage and performance of equipment.
- Implement security measures on the state of the containers.
- Beneficial for security, as different organizations may have different requirements for data privacy and ownership.
- Up-to-the-minute health status knowledge, enabling not to wait for equipment shutdown to occur (i.e., reactive maintenance), nor carrying out maintenance when it is not necessary (i.e., preventive maintenance).
- Help to prevent downtime, increase efficiency, and save cost by reducing the need for regular manual inspections.

2.4.7. Legal framework

During the course of task T2.3 (Legal and regulatory analysis and governance specification), several actions have been performed in order to identify the legal framework surrounding activities in Pilot 4 (available in D2.2). Besides that, a thorough analysis of the legal and regulatory aspects affecting the different scenarios was performed, outputting the following results:

Sectorial regulations (Maritime Ports):

- Maritime ports - REGULATION (EU) 2015/757, 29 April 2015 and amending Directive 2009/16/EC - monitoring, reporting and verification of carbon dioxide emissions from maritime transport. This legislation motivates the need of the presented solutions to reduce carbon dioxide emissions.
- Maritime transport - DIRECTIVE 2009/29/EC, April 2009 amending Directive 2003/87/EC - so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community.

Technologies:

- Data - Data Act Document SEC(2022)81 (EU) - haring non-personal data that is generated through the use of connected product or related service by a user from the data holder to the user or a designated third-party data processor authorized by the user. Also relevant to prevent vendor lock-in with cloud and edge providers due to technical incapacity for switching limiting market growth and innovation.
- Platform services – Digital Markets Act {SEC(2020) 437 final} - Applies to core platform services provided or offered by gatekeepers to business users established in the Union or end users established or located in the Union, irrespective of the place of establishment or residence of the gatekeepers and of other law otherwise applicable to the provision of service. Aims to end unfair restrictions imposed by large-scale platforms, including cloud computing platforms, to reduce lock-in effects and increase innovation. Important for the implementation of services and analytics in the cloud-edge continuum developed in aerOS.

- Digital Services - Digital Services Act {SEC(2020) 432 final} - aims to contribute to the proper functioning of the internal market for intermediary services and set out uniform rules for a safe, predictable and trusted online environment, to protect fundamental human rights . Sets out obligations on intermediary information society services to ensure the proper functioning of the internal market and a safe, predictable and trusted online environment in which the fundamental rights enshrined in the Charter are duly protected.
- Artificial Intelligence – Artificial Intelligence Act {SEC(2021) 167 final} - aims to provide clarity around what can and cannot be done with AI in the European Union. It established harmonized rules for the placing and using AI on the market, and prohibits certain practices. It outlines specific requirements and obligations for operators. It also provides harmonized transparency rules for AI systems intended to interact with natural persons, emotion recognition systems and biometric categorisation systems, and AI systems used to generate or manipulate image, audio or video content. Finally, it sets out the rules on market monitoring and surveillance.

Products:

- Computer vision solutions - REGULATION (EU) 2016/679, and repealing Directive 95/46/EC (General Data Protection Regulation) - Any person recorded in the video streams needs to be anonymize protection of natural persons with regard to the processing of personal data and on the free movement of such data.
- Computer vision solutions – Cypriot Data Protection Act. Law 125 (I)/2018 (Cyprus) - Any person recorded in the video streams needs to be anonymized. Protection of Natural Persons with regards to the processing of personal data and for the free movement of such data. The law states that the processing which is carried out by a controller or a processor for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes shall not be used for taking a decision which produces legal effects concerning the data subject or similarly significantly affects them.

2.5. Pilot 5: Energy Efficient, Health Safe & Sustainable Smart Buildings

2.5.1. Trial general description

This use case, driven by partners COSMOTE (COSM), NCSRD, FOGUS, INF and UPV, aims to demonstrate gains of the aerOS architecture in an edge deployment for energy efficient, sustainable, flexible and health-safe smart buildings. The use case considers deployment and validation in an office enterprise building of COSMOTE (Athens, Greece).

A wide number of sensors and actuators with the aerOS capabilities must be deployed to measure energy, luminosity, CO2, humidity, temperature, motion detection, and desk occupancy. The data collected by these sensors, together with the algorithmic criteria set to minimize energy consumption and maximize health measures is capable to determine the appropriate clustering of employees in the offices and deduce the recommended employees seating. Specifically, the system by considering: (i) the metrics received by the sensors; (ii) the employee's data, such as position in the organization's structure and team membership; (iii) historical data on energy consumption, CO_2 emissions per office segments; and (iv) one's previous seating preferences; will select the appropriate office and allocate the most suitable seat(s), and proceeds to direct the employee with the help of a Web App.

At the same time, the sensors data are to be exploited to actuate appropriately the ventilation, heating and air-condition systems as well as to control luminosity. Swarm intelligence among the aerOS capable sensors shall allow them to cooperate in a decentralized manner and collectively manage each room's condition, so that the office becomes self-organized in terms of health and efficiency.

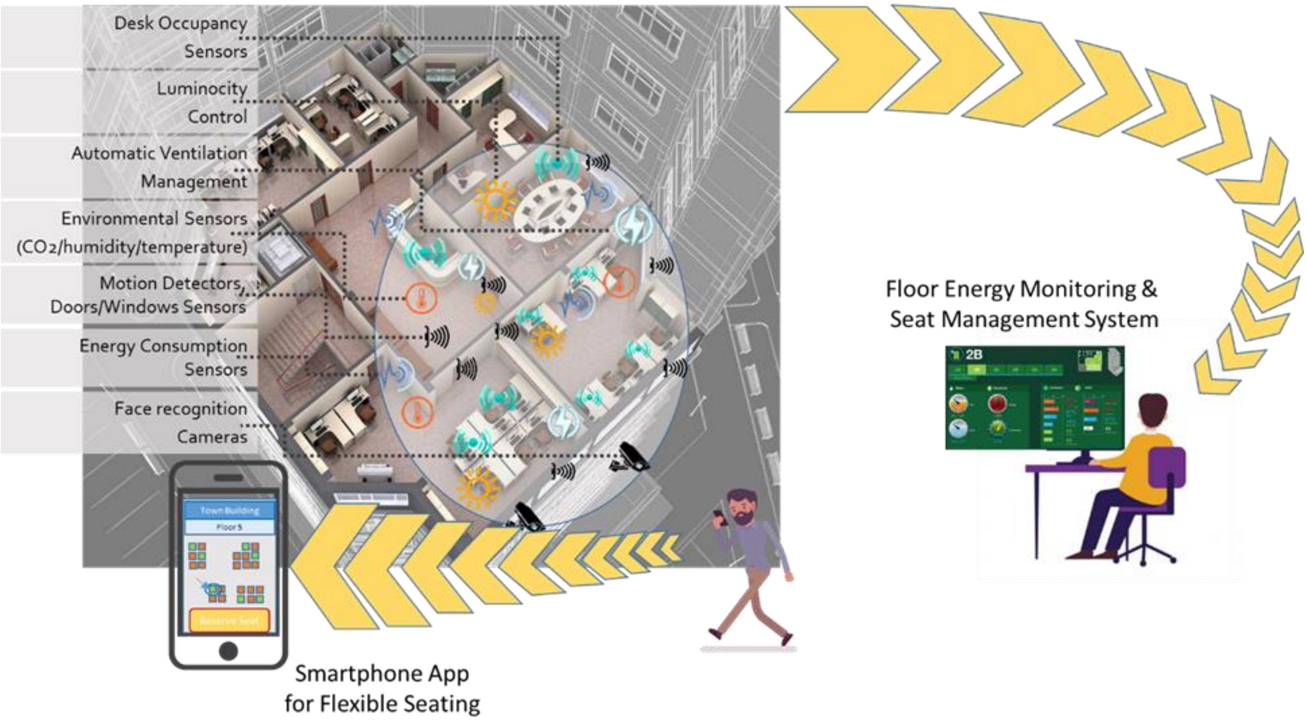


Figure 35. Overview of Use case 5

Finally, a user management interface available to the building facility managers, depicts monitoring dashboards presenting in real-time the energy consumption and health/safety KPIs set for each segment of the building and in total with flexible historical reference. In this way, the use case stands as a complete prototype of the target system envisaged for the aerOS paradigm.

The implementation shall leverage the IoT solution prototyped by COSMOTE R&D and already installed in residences and COSMOTE's telecom sites. The architectural layout of the solution is com-posed of: (a) A wide range of commercial (and custom) end-devices/sensors, (b) Multi-purpose IoT gateways for the support of a wide range of Use Cases, (c) A backend cloud infrastructure, enabling gateway/device management, data storage, data processing, (real-time and historical) data visualization, cloud-based dashboards (WebGUI). The solution is based on open-source software and commercial hardware, it offers an open API for data retrieval.

The aerOS proposal for Energy Efficient, Health Safe & Sustainable Smart Buildings is unique and presents innovative solutions to business and IOT challenges:

- An extensive number of IoT sensors are deployed in the Smart Buildings ecosystem, generating/processing huge amount of data that are only valid for the location they originate from, yielding their transmission and collection for central processing meaningless and wasteful. The distinctive infrastructure characteristics of each building rationalize the autonomous and decentralized decision-making at the edge with the use of the aerOS nodes intelligence, and the effects are instantaneous and tactile.
- With multiple IoT vendors and solutions, tech integration, so that sensors, systems, analytics work in sync, becomes a considerable obstacle. Applying the aerOS architecture that stands as a unique abstraction layer, the end-to-end integration can be achieved easily embracing the strategic IoT sourcing of each enterprise to offer an adaptable solution that can bridge heterogeneity.

With regards to the **global objectives of the Use case 5**, Energy Efficient, Health Safe & Sustainable Smart Buildings Use Case aims to exhibit how the aerOS platform agnostic meta-operating system for the IoT-cloud-edge continuum can be applied in the Smart Buildings applications domain. Three specific objectives are set:

- Objective 1: Implement the aerOS architecture in Smart Buildings market to optimize the efficiency and safety of enterprises based on process and data autonomy and self-orchestrated IoT ecosystems.
- Objective 2: Demonstrate energy efficiency of the large buildings using real-time processing and (frugal) AI.

- Objective 3: Use 5G and smart network components like NFV and NetApps to extend aerOS capabilities.

2.5.2. Current problems/barriers area and motivation

Enterprise buildings can save energy by using advanced sensors and automated controls in HVAC (Heating, Ventilation and Air Conditioning), plug loads, lighting, as well as advanced building automation and data analytics. Buildings that have advanced controls and sensors along with automation, communication, and analytic capabilities are known as smart buildings. In a fully-fledged smart building, the building systems are interconnected using information communications technologies (ICT) to communicate and share information about their operations. At the same time in the last years, the Coronavirus pandemic disruptively affected the traditional work norms, stranding previously crowded office buildings. Trying to ignite the economy recovery process, more and more companies have adopted a strategic return to the workplace, embracing flexible working and mobile workspaces. Rather than trying to fit as many people as possible into a workspace, so that to maximise utilisation of shared commodities and infrastructure in the quest of efficiency, companies seek to maximise the space between workers and perhaps rotate between a remote and in-office working model to facilitate a safer shared environment. Evidently, the post-pandemic workplaces have become large open spaces with no fixed seating per employee; and desks are to be allocated to employees on demand and daily. As such, proper employees' placement, social distancing, and energy efficiency, along with business and personal preferences and work habits becomes a complex and dynamic task. In this transformation towards flexible, safe and sustainable workplaces, IoT technology and Analytics through the aerOS capabilities can offer a unique, autonomous solution towards safe and sustainable workplaces. That solution, as depicted in Figure 36, can be deployed in a diverse set of buildings, embracing diverse IoT solutions aligned to the IoT sourcing strategy of each enterprise.

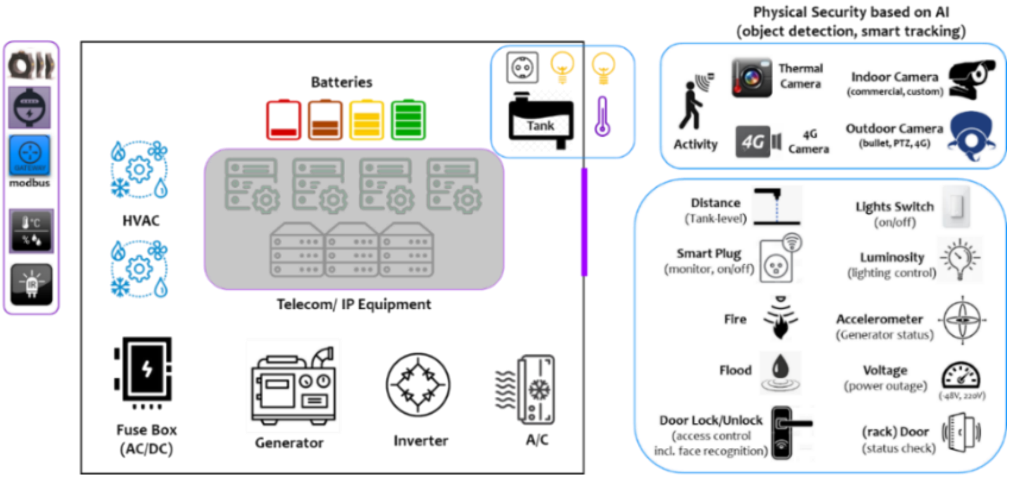


Figure 36. Smart buildings IoT architecture

In order to illustrate the problems/barriers that have motivated this use case in aerOS, it was decided to utilise the following table:

Table 28. Current problems and barriers in use case 5.

CHALLENGES or BARRIERS	DESCRIPTION	AREA	IMPACT IN THE COMPANY
Reduce operational costs by saving energy and space in a wide range of geographically dispersed buildings owned or rented.	COSM owns and needs to maintain a lot of buildings, geographically dispersed and with a variety of use and occupancy, in the most cost-effective manner	Management	The distributed, orchestrated and dynamic nature of aerOS pilot 5 directly responds to the company's challenge to maintain in the most efficient manner the buildings occupied.
The solution must instantly integrate and	Interoperability is a key issue for the smart building systems development	Purchasing	By leveraging the openness and interoperability of the aerOS

incorporate state-of-the-art components	process that leads to limiting options used to specific vendors' products, that needs to be avoided.		architecture, a lot of cost savings can be achieved as components can be plugged-in / integrated with minimum effort.
Data Privacy and Security	Collect and manipulate user data in a secure manner that protects personal information, while enabling smart decision making and recommendations based on that data.	Management / Technical Support	Demonstration of aerOS nature in Pilot 5 through autonomous and decentralised decision-making at the edge.
The chatbot should be able to communicate with the aerOS elements	The chatbot needs to have access to information from the building sensors and the recommendation system in order to present them to the employees.	Product Development	A further development and an extension of the chatbot's capabilities will be achieved in order to be able to communicate with devices from aerOS ecosystem.
Test the aerOS IoT-cloud-edge computing continuum solution in real scenarios	UPV plays a key role in the development of the technical components of aerOS, especially with the ones related with the IoT-cloud-edge computing continuum. It is essential for the partner to deploy and test the developed solution in a real scenario with multiple challenges to be solved.	Technical support	By providing technical support in the deployment of the pilot, UPV will test the developed technological components in the project and enhance its knowledge regarding IoT-cloud-edge computing continuum scenarios and its capabilities to solve real-word challenges.

2.5.3. Objectives, benefits and expected results

In the following sub-sections there is a thorough description of each one of the scenarios in Pilot 5.

2.5.3.1. Scenario 1: Intelligent Occupational Safety and Health

2.5.3.1.1. Description

The global smart buildings market has been booming, with a growth rate of more than 32%[10], based on the promise of big cost reductions - 18% cut on the office energy costs- and improved operational efficiency –as smart sensors and data analytics automatically detect and instantaneously react to workspace alterations, equipment faults and environmental changes. During the next couple of years, organizations will focus on the data enabled by IoT platforms to drive real results and commercial real estate will reach large-scale implementations of IoT applications[11], significantly transforming their **Operational Efficiency & Energy Management** processes.

At the same time, the Coronavirus pandemic disruptively affected the traditional work norms, stranding previously crowded office buildings. Trying to ignite the economy recovery process, more and more companies consider a strategic return to the workplace, embracing flexible working[12] and rotation between a remote and in-office working model, revolutionizing the **Human Resources Management** process through virtual, intelligent & mobile workplaces.

Addressing both aspects, the purpose of this scenario is to use sensors that cooperate in a decentralized manner to collectively manage each building room's conditions in the working environment. Also, determine the appropriate clustering of employees in the offices and deduce the recommended employees seating keeping in

[10]https://www.pwc.com/us/en/industries/capital-projects-infrastructure/library/scaling-up-smart-buildings.html
[11] https://www.rfidjournal.com/a-look-into-2019-smart-cities-and-smart-buildings
[12] https://www.workdesign.com/2020/12/2021-trends-the-mobile-workplace/

mind that the goal is to minimize energy consumption and maximize health measures, considering the following aspects per business process:

- **Operational Efficiency & Energy Management**

In the business world operational efficiency is necessary to reduce costs, and energy consumption is put in the spotlight. While some measures are collectively adopted, the level of automation and intelligence in most buildings is still low. In an open space building, the first thing we currently do to minimize the energy consumption is to reduce the use of lighting. This can be achieved by turning on/off the lights at certain times (working hours) i.e., turn on/off the lights after 8am/8pm respectively, modified, though, to accommodate cleaning/security personnel. With the help of Passive Infrared Sensors (PIRs) the lights can be automatically turned on when motion is detected and off if there is no motion for i.e. 30 minutes or even keep the lights on only in corridors. The same rule can then be applied during working hours in empty rooms (in case of motion detection turn lights on). Moreover, during working hours lights can be turned on/off based on cloud coverage and ambient light levels: in case of adequate daylight there is no need for extra lights. Furthermore, with the use of switches we can control the heating in the common areas and the workspaces used based on automations. More specifically, the switches controlling the heating can turn on/off at certain times during cold and hot months. When the heating is on, the temperature can be set to 20-25 degrees Celsius, which according to ENERGY STAR is the ideal balance of comfort and energy efficiency.

- **Human Resources Management and Mobile Health-Safe Workspaces**

Following the Coronavirus pandemic, a key consideration in work environments becomes the social distancing and the concern for optimizing air quality conditions. The process up to now is rather arbitrary and fixed and is mainly agreed among the occupants of each room, thus not versatile, and optimum. The scenario assumes building a system for employees' placement, considering various environmental and energy related criteria as well as behavioral preferences and the employee's feedback. On top of that, the system could prioritize positioning the same team members in the same space. The system can identify which desks are occupied through smart interpretation of motion sensors (PIRs) data.

Notable indicators of air quality are CO_2 and PM2.5 levels. High levels of these in a room should trigger actions. A smart light bulb can use different colors to depict the changes in the air quality of the room and an air purifier can be turned on to restore the gases to normal levels. Moreover, pushover alerts to the facility managers can provide instructions to open a window taking into consideration indoor - outdoor environmental conditions (mainly temperature and/or humidity) and whether the A/C or heating is on. These measurements involve sensors located at certain zones and not the average measurements of all sensors located in a room and the recommendations/automations should refer to these specific zones. If there is no way to "fix" the air quality, then another room should be considered for the next employees to come, since moving the already stationed employees would affect the working conditions and is not recommended. We could monitor the room conditions and refer newcomers to other rooms before the conditions deteriorate.

Additional features include automation for the purpose of the system's maintenance to guarantee the reliability of the overall solution. Such automation can include pushover/push bullet alerts notifying for low battery levels if the sensor's battery drops below a certain threshold (i.e. 30%). Dashboards depicting each room floor plan and the deployed sensors, as shown in Figure 37 can offer monitoring and visualization of the data in real time, as in the example of

Figure 38. Finally, a time-series forecasting system can process the historical energy and environmental data, feed them to proper machine learning algorithms to predict and visualizing future energy and environmental data of each workspace/floor, including suggestions based on these. This service would interest both the employees, as they would acquire information fast and reliably, draw conclusions, gain consciousness by developing a better understanding of the workspace's energy distribution and environmental conditions, and the facility managers, as they would have all the sensor information readily available and, on top of that, overview on a larger scale all the rooms/floors on the network. Having such a powerful tool for prognosis at their disposal, the facility managers could adjust, and act accordingly, and not only economize, but contribute to the overcoming of the energy crisis issue.

Figure 37. (WebGUI/Dashboard) | Interactive Floorplan.

Figure 38. (WebGUI/Dashboard) Measurements Depiction Sample

2.5.3.1.2. Specific objectives

The objectives of this use case are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 29. Specific objectives of Use case 5 – Scenario 1

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Exhibit the portability and interoperability gains proposed by the aerOS concept in the heterogeneous IoT sensors market.	The IoT market is extremely diversified, with a wide range of heterogeneity both in protocols, data artifacts (attributes and values), as well management capabilities.	Through the implementation of the aerOS architecture, the components of the system become aerOS nodes and mask heterogeneity therefore allowing the instant (plug & play), automated deployment and expansion of the IoT solution.	**Cost**	5
			Efficiency	5
			Quality	4
			Flexibility	4
			Innovation	3
			Sustainability	4
Definition and implementatio n of latency controlled	Mesh networking and 5G technologies shall be deployed in the IoT solution for the efficient communication	Reliable communication is critical in various layers (sensors, application components and users) and the aerOS architecture	**Cost**	2
			Efficiency	5
			Quality	4

distributed smart networking components.	among the aerOS nodes as well as the humans involved in the use case.	considers an all-encompassing efficient communication framework.	**Flexibility**	4
			Innovation	3
			Sustainability	4
Definition and implementation of distributed explainable AI components for aerOS	The pilot decentralizes the intelligence necessary to maintain a safe and sustainable working environment by implementing an edge solution to reduce heavy centralized processing and unnecessary data communication.	The solution can work autonomously to the level of granularity required (per room, floor, building, cluster of buildings) with analogous computational resources that can be scaled-in/out on demand as part of the aerOS node principles.	**Cost**	5
			Efficiency	4
			Quality	3
			Flexibility	5
			Innovation	5
			Sustainability	2
Definition and implementation of smart orchestration for the IoT-edge-cloud continuum	Smart orchestration is key to manage and maintain the environment, targeting the aerOS nodes deployment and provisioning coupled with necessary wireless network configurations, updates in distributed intelligence criteria and prioritization, as well as means to provide business critical monitoring information.	Automation and expandability are key to any IoT solution, especially when targeting reliable autonomous operation. With the aerOS architecture, the most optimum deployment and utilization of resources, as well as recovery in case of incidents is assured.	**Cost**	2
			Efficiency	5
			Quality	5
			Flexibility	5
			Innovation	4
			Sustainability	2

2.5.3.1.3. aerOS in Scenario 1

The use case aims to exhibit how the aerOS platform agnostic meta-operating system for the IoT-cloud-edge continuum shall be applied in the Smart Buildings market to optimize the efficiency and safety of enterprises through autonomous and self-organised IoT ecosystems.

The combination of the Energy Efficient, Health Safe & Sustainable Smart Buildings and aerOS concepts is unique and presents innovative solutions to business and IoT challenges:

- An extensive number of IoT sensors are deployed in the Smart Buildings ecosystem, generating/processing huge amount of data that are only valid for the location they originate from, yielding their transmission and collection for central processing meaningless and wasteful. The distinctive infrastructure characteristics of each building rationalize the autonomous and decentralized decision-making at the edge with the use of the aerOS IE's intelligence, and the effects are instantaneous and tactile.
- With multiple IoT vendors and solutions, tech integration, so that sensors, systems, analytics work in sync, becomes a considerable obstacle[13]. Applying the aerOS architecture that stands as a unique abstraction layer, the end-to-end integration can be achieved easily embracing the strategic IoT sourcing of each enterprise to offer an adaptable solution that can bridge heterogeneity.

The aerOS-enabled system developed as part of the use case will transform existing energy-efficiency IoT applications by:

- Deploying the aerOS architecture by bundling application components as aerOS nodes and identifying the appropriate placement and scaling of the application components for far-edge, edge, or cloud processing. The use of configuration management and orchestration as well as self-* operations are fundamental enhancements.
- Investigating the AI principles and technologies (e.g., explainable AI and frugal AI) to implement the external, application-specific, AI requirements of the system.

[13] [2] https://www.pwc.com/us/en/industries/capital-projects-infrastructure/library/scaling-up-smart-buildings.html

- Exploring the abstraction layer, and meta-data modelling techniques (e.g., FIWARE) as proposed by aerOS, to achieve interoperability and extensibility.
- Incorporating the seamless integration of various communication types and network deployments (e.g. 5G and WIFI6) as envisaged by the aerOS network architecture.
- Both software and hardware resources of Pilot 5 need to be mapped to the aerOS run-time, as depicted in the figure below.

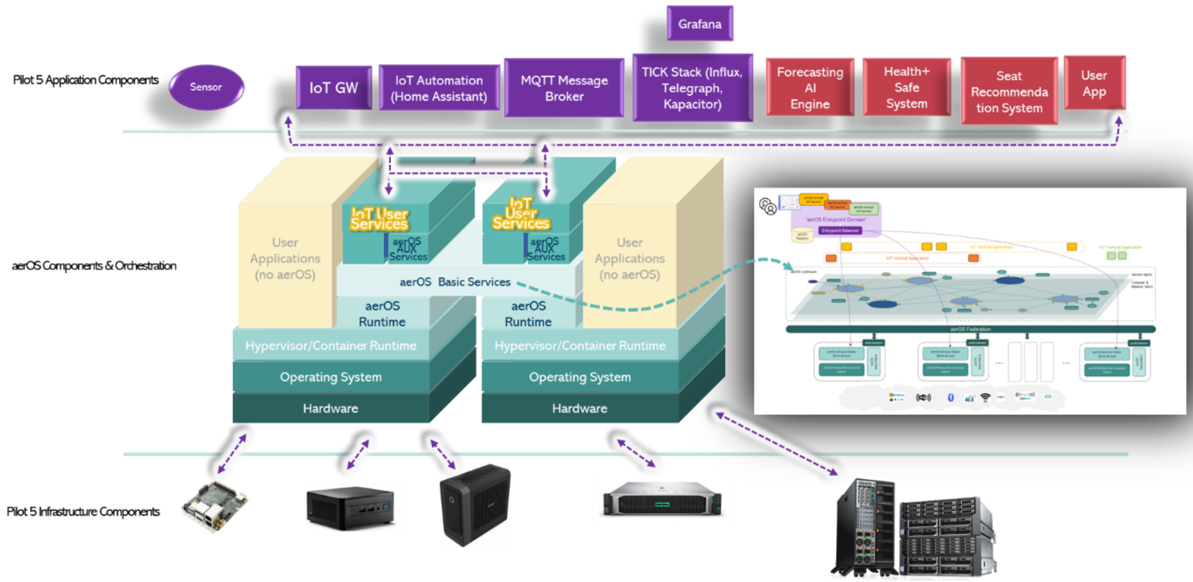


Figure 39. Intelligent Occupational Safety and Health Application Architecture in aerOS infrastructure

The use case will evaluate and incorporate the following **core aerOS modules:**

- **Data Fabric**: The primary concern is around (i) syntactic and semantic interoperability of the sensors' data, to facilitate annotation and translation to a selected ontology, tackling the wide heterogeneity of data formats, which are currently vendor and sensor specific, that makes the seamless integration of different sensors in the same solution a cumbersome task. Also (ii) effective storage for data persistence (iii) data lineage and traceability (iv) data access and verification for sharing data to/from other platforms are applicable. This will be achieved by exploring the applicability of Task 4.1 and 4.2 developments.
- **Network and Compute Fabric:** Deployment automation to scale efficiently, considering technologies to communicate workloads in domains providing load-balancing is relevant, as due to the high number of IoT components to be dispersed high-availability, reliability and efficient management and distribution of resources is important. This will be achieved by exploring the applicability of Task 3.1 and 3.2 developments.
- **Service Fabric:** Services to facilitate the realisation of the distributed architecture, including (i) resources indexing and discovery as well as (ii) runtime observation, registering of nodes status and tailored logging, are important to achieve high-availability, efficient utilisation of local resources. This will be achieved by exploring the applicability of Task 3.3 and 3.5 developments.
- **Security, Privacy & Trust:** Since the use case is designed to be deployed in common/public workspaces and collects information that directly or indirectly affect the humans in place, security is critical as the system needs to ensure the authenticity and integrity of data sources and artefacts. These features will be evaluated by exploring the applicability of Task 3.4 and 4.5 developments for the below technical components of Cybersecurity Toolset, Privacy and Trust and Data Sovereignty.
- **Autonomous (self-*) Management:** Orchestration and configuration management including dynamic provisioning/upgrading of the components of the solution, is pivotal for the ecosystem that the application targets, that can span to hundreds of residents and/or buildings. As such tools delivered by aerOS for maintenance, management, re-configurability regarding software, smart network and service components are very important. These features will be evaluated by exploring the applicability of Task 3.3.

- **aerOS decentralised AI:** AI capabilities at the edge, respond to the use case demand to build distributed (e.g., per building) autonomous and intelligent IoT solutions. Explainability is important since the outcome of the use case's AI recommendation engine influences the end-users work life. Frugal AI, to reduce energy/resources while training the energy efficiency and health-safe data models is also important, so that to deliver efficiently the appropriate AI models per building without waiting for large amounts of sensor's data to be collected. These features will be evaluated by exploring the applicability of Task 4.3 and 4.4 developments for Frugal AI with Explainability (FAI).

The aerOS stack definition builds upon **the concept of Federated Orchestration** as an important architectural dimension, that is important to develop and scale the aerOS IEs and domains ecosystem. In the context of the Pilot 5 application, Federated Orchestration has an obvious fit, and federation can be considered either among the autonomous buildings (supporting customers that own or manage many properties) to dynamically share available resources in an optimum manner, or even among different application owners/domains to interoperate for a common cause, such as federated learning and establishment of best practices. The incorporation of the aerOS decentralised federation orchestration, decomposed to LLO (Low-level-Orchestrator) and HLO (High-level Orchestrator) functionalities is appropriately supported in the Pilot 5 domains.

The basic mapping of the envisaged use case implementation and placement of components within the aerOS domain model is depicted in the figure below. Two basic pilot domains are perceived. The Pilot 5 Main/IoT Domain, and the Pilot 5 Application Domain:

- The Main/IoT Domain serves as the pilot's Entry Domain and contains all the basic aerOS components necessary to attach to the federated aerOS environment, incorporating the MgtPortal. The Main Domain incorporates the IoT components, and the management of the sensors and Home Assistant devices of the Pilot.
- The aerOS Application Domain, that contains the backend application components, such as the Tick framework, the AI components, the recommendation system, and the User Application.

It is noteworthy that the proposal for two separate domains, IoT and Applications domain, is provisional acknowledging that the placement as well as the life cycle, management, and configuration of the components per domain can be in different and should abide to different operational and service-level requirements.

Nonetheless, based on the HLO-LLO placement heuristics, it is acceptable that the Application Domain can be incorporated within a single domain, the Pilot aerOS Entrypoint Domain.

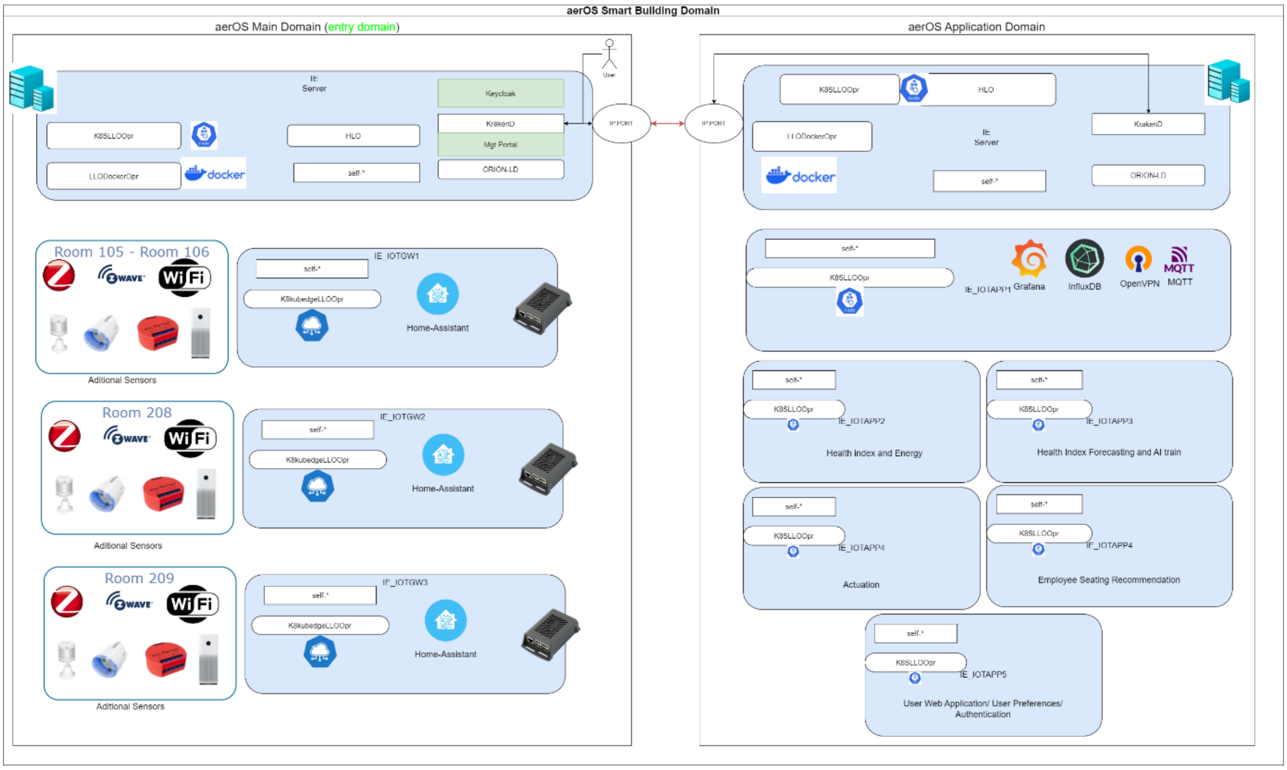


Figure 40. Intelligent Occupational Safety and Health Application Architecture in aerOS domains.

Considering the Data Lake resulting from the Pilot5 architecture, this is graphically depicted in the figure below and explains how the data communication flow between the pilot 5 components.

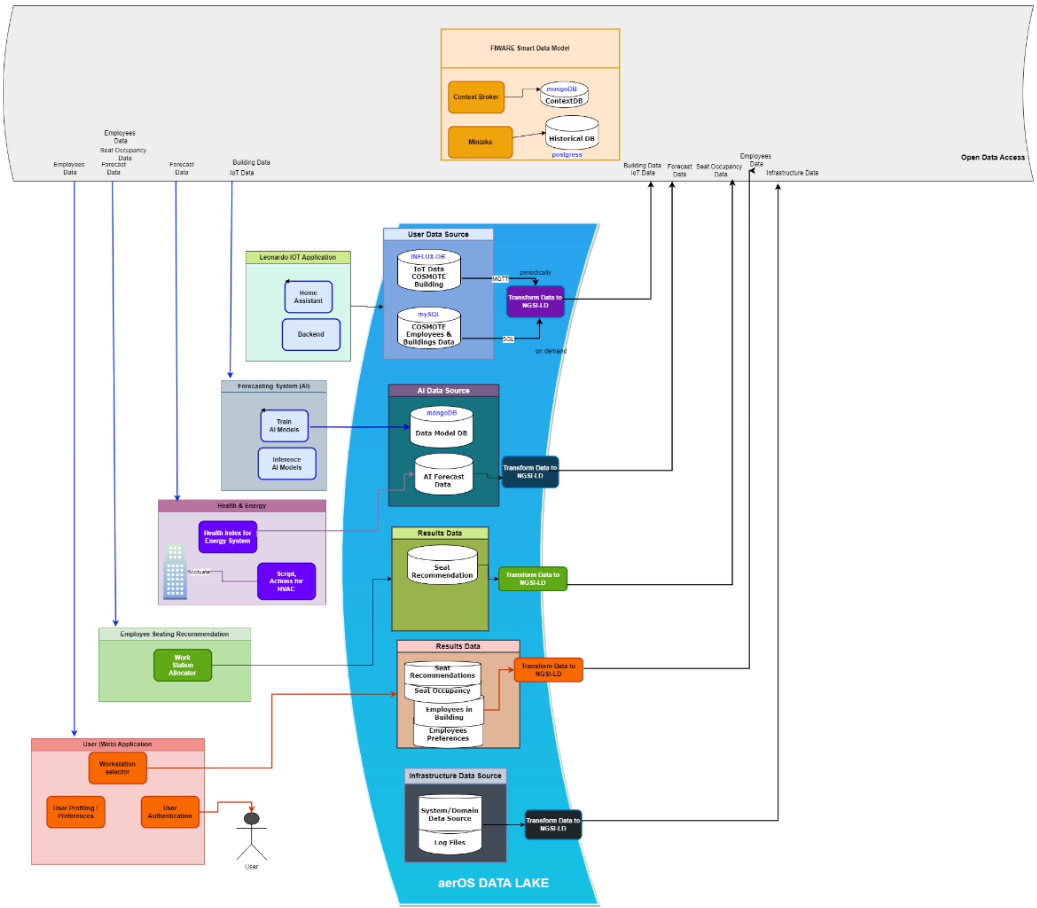


Figure 41. Intelligent Occupational Safety and Health Application Architecture in aerOS domains

2.5.3.1.4. Actors involved in Scenario 1

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 30. Actors involved in Scenario 1 of Use case 5

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
End-user/Employee	Any	Direct	Must approve to his/her smart workspace placement, and abide to the recommendations and instructions of the system
Customer/Property owner	Management	Indirect	Must invest in system intelligence to increase efficiency and reduce costs
IT Operations	Technical Support	Direct	Must implement & support aerOS capabilities
Facility Manager	Technical Support	Direct	Must comply with aerOS recommendations
System Provider (Developer/Integrator)	Engineering	Direct	Must implement aerOS nodes capabilities (e.g., AI, orchestration, interoperable semantic & syntactic data ontologies e.g.)
IoT Vendor	Manufacturing	Indirect	Must implement aerOS nodes capabilities (e.g., AI, orchestration, interoperable semantic & syntactic data ontologies e.g.)
Data Scientist	Engineering	Direct	Must explore explainable & frugal AI towards data models that are specific to each building needs

2.5.3.2. Scenario 2: Cybersecurity and data privacy in building automation

2.5.3.2.1. Description

The second scenario of Use Case 5 will build on top of use case scenario 1 and transfer and integrate aerOS components which will be developed within work packages 3&4 regarding Cybersecurity and data privacy. Components that will support secure access to IoT processes deployed within building working areas, and governance procedures to enable supervised and authorized sharing of IoT generated data, will be deployed to frame with trust mechanisms the IoT, smart building solution, within COSMOTE premises. Beyond security mechanisms integration within smart buildings management system, the 5G network infrastructure, provided and deployed within COSMOTE area, will be used to demonstrate aerOS capabilities secure extension regarding user and third-party applications access to services and data from the core network.

Within use case 1 and in the process of optimizing energy efficiency and health safety and sustainability of smart buildings a multitude of heterogeneous sensors will be deployed within COSMOTE pilot smart buildings. These sensors will record a huge amount of data which will be transferred to edge cloud infrastructure not only to be stored but to also be analysed and used as input to AI models. Output of AI services will both guide decisions and actions to be transferred to other far-edge devices, the actuators, to further configure working space conditions, and will also provide recommendations to users regarding their working conditions and placement. Additionally, as data is the fuel of algorithms and decisions these data will also have the possibility to be shared among IEs that may submit requests to reuse these data or obtain trained models based on these data or get policies developed based on these data.

Carefully reading the above process it is obvious that IoT systems deployed, on top of aerOS infrastructure elements (IE), are increasingly interconnected and although they enable automation, optimization, and monitoring of building functions such as HVAC, lighting, security, this increased connectivity also creates new security risks and vulnerabilities. Insecure communication channels and weak authentication mechanisms make them vulnerable to data eavesdropping or even permit data poisoning. The inclusion of several devices and systems and multiple parties (owners, managers, applications etc) introduce the possibility of unauthorized access to data and processes that may produce critical decisions regarding the current working conditions and building operation. Unattended devices without the possibility to provide updates are left exposed to security exploits. Except from the possible risks coming from IoT data and processes exposure it is equally important to have in mind the risks that emerge due to the aerOS orchestration capabilities that are provided so that every aerOS IE (node) can be accessible for resources orchestration and monitoring. Every IE exposes some capabilities to either receive orchestration commands regarding deployments, connectivity etc or to provide resources that could support external processes. These exposed capabilities, provided as exposure API, if not properly secured can introduce obvious risks regarding third parties intervention both to aerOS IE environment but also to the hosting network segments too.

Additionally in the ground of scenario 2 of use case 5, there is the goal to provide secure extension of aerOS capabilities with the integration of 5G network facilities, operating at COSMOTE premises, and the use of 5G and smart network components such as network exposure functions (NEF) and network applications (NetApps). Now in 5G networks there is limited-service exposure and although 5G networks have a wide range of services and capabilities, it is quite challenging for external applications to access and utilize these services effectively. Within the second scenario, the goal is to provide NEF (emulated) deployment, with the support of aerOS ecosystem, which should be able to provide standardized interface and make it easier for external applications to discover and access 5G network services. From a security aspect, with the proliferation of devices and applications connected to 5G networks, security has become a critical concern and secure standards to access core network services information are critical. Finally, as vendors and operators involved in the 5G ecosystem, and new services and applications are emerging interoperability between network and flexibility to accommodate new use cases are a demand. The deployment of a NEF emulator, which can authenticate and authorize the requests according to the policies set by the network operator, of NetApps that will interact with NEF to request network resources and services on behalf vertical applications are planned within this second use case 5 scenario.

2.5.3.2.2. Specific objectives

. The objectives of this use case are described using the table below, which aims at explaining their impact and their effect in value (being 1 no significant and 5 very significant).

Table 31. Specific objectives of Use case 5 – Scenario 2

OBJECTIVE	DESCRIPTION	IMPACT	EFFECT OF VALUE	
Exhibit the cybersecurity and data privacy capabilities of aerOS.	The outcomes of the WP3 and WP4 of AerOS will be demonstrated in this pilot in the COSMOTE buildings.	aerOS services are strictly controlled and access to underlying services which provide federation and orchestration capabilities and information are not openly accessed.	**Cost**	3
			Efficiency	4
			Quality	4
			Flexibility	2
			Innovation	4
			Sustainability	3
aerOS secure extensions capabilities will be demonstrated using the 5G network deployed in COSMOTE.	The 5G network infrastructure deployed within COSMOTE area, will be used to demonstrate AerOS capabilities secure extension regarding user and third-party applications access to services and data from the core network.	Access to data provided by 5G core network functions is of importance for developing user centric applications. At the same time, it is critical to manage and provide controlled access to user data provided by core network.	**Cost**	4
			Efficiency	3
			Quality	4
			Flexibility	4
			Innovation	4
			Sustainability	2
Securely	From the generation of data by	Access to data produced from	**Cost**	2

transfer data between AI algorithms using the aerOS capabilities	the IoT sensors until their productive use towards the intelligence capabilities of the building, data transfers are a lot and go through a lot of different stations. Secure manipulation of these data for the feeding of the AI algorithms will be demonstrated using the capabilities of AerOS.	smart building application is controlled and only granted to authorized users and deployed AI services. As a result, benefits provided by AI applications, which provide automated building management, are incorporated and at the same time it is ensured that these privileged capabilities, and data, are securely exposed to strictly authorized to, AI data, consumers and recommendation providers.	**Efficiency**	4
			Quality	4
			Flexibility	3
			Innovation	3
			Sustainability	3
The safe deployment of exposure APIs that demonstrate the security of the AerOS Orchestrator	Exposed capabilities from IEs, provided as exposure API, if not properly secured can introduce obvious risks regarding third parties intervention both to AerOS IE environment but also to the hosting network segments.	aerOS orchestrator provides access to underlying computing resources. Controlled access to these services ensures that resources provisioning is controlled at all times. Access to aerOS orchestration is only provided to registered and authorized users.	**Cost**	3
			Efficiency	3
			Quality	3
			Flexibility	2
			Innovation	3
			Sustainability	3

2.5.3.2.3. aerOS in Scenario 2

The basic unit within the aerOS meta-operating system for the IoT edge-cloud continuum is the Infrastructure Element. Although this is not going to be extensively analysed here, the basic principles of an IE element is that it provides the appropriate virtualization layer, which can operate over a variety of hardware resources, which provides the runtime environment where core components are deployed to enable the complete management and orchestration of underlying resources, providing thus network connectivity, processing and storage capabilities and supporting IoT applications deployment as close to the edge as needed. Although aerOS IE is much more than this, it is a prerequisite that all these operations regarding both meta-operating system resources orchestration and user IoT services management should be performed within a trusted environment where no one can tamper with the resources operating to form the edge-cloud continuum and user data and IoT services cannot be accessed without having the explicit permission from the owner. Thus, Cybersecurity components designed and developed within WP3 & WP4 regarding data encryption, authentication and authorization will be deployed and their functionality will be tested in this, second, use case 5 scenario.

Single sign-on technique, based on OpenID protocol will be deployed enabling users and applications to authenticate and access IE resources and IoT services using a single set of credentials centrally registered and managed. Next in order to control who can access resources and data and what actions can perform over each resource an Authorization engine will be deployed. This engine will provide the tools to define policies, namely the policy definition point, and based on these policies each request will be validated before being allowed to operate on requested resources. Following diagram, Figure 42 is presenting a schematic diagram of authentication and authorization process. All entities requiring access to IE data and deployed services should first identify themselves, acquire some authorization enabling capability token and then permitted (or not) to specific services or data. Needless to say, that all communications and data exchanges will be secure and private based on endpoints encryption enforcement.

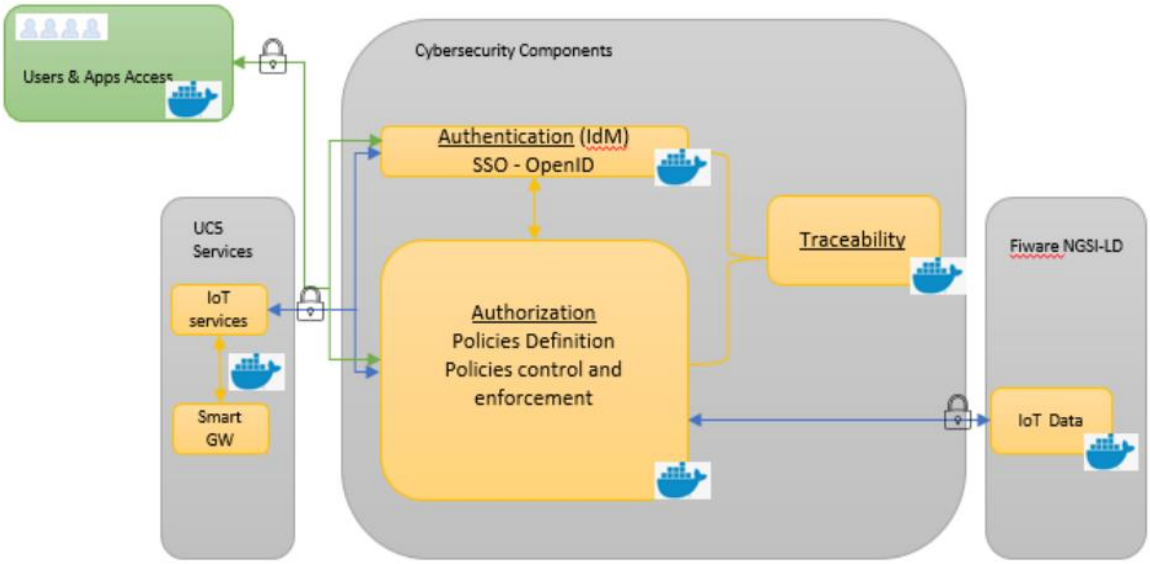


Figure 42. Authentication schema of aerOS in Use case 5, scenario 2

For the 5G scenario, targeting to extend aerOS capabilities, which will integrate services regarding either deployments over radio connections or deployments exposing 5G core capabilities and data for the benefit of vertical applications a topology very similar to the following one will be deployed.

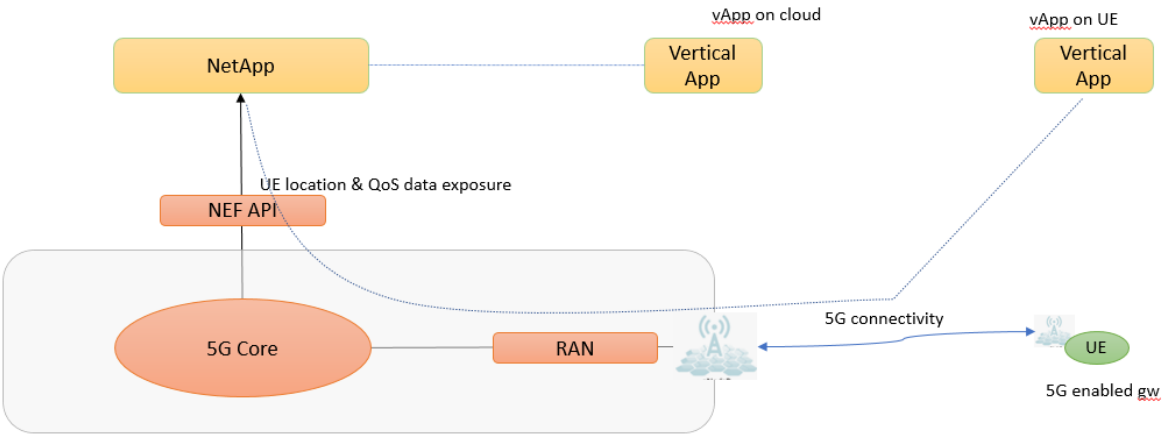


Figure 43. Tentative composition of 5G components deployments in scenario 2 of Use case 5 in aerOS

In this case a smart gateway is upgraded with 5G connectivity module and it will be connected to 5G network. The core components that will be deployed and managed within aerOS ecosystem will be the NEF emulator, 2 Network Applications and 2 Vertical Applications. A brief description of the role and the deployment mode of these is provided in the next paragraphs.

The **Network Exposure Function (NEF) emulator** is a key component in the 5G core network architecture, that will be deployed and managed (LCM) within the aerOS IE, and will be used to provide a secure and controlled interface for third-party applications that need to access services and data from the core network. NEF will act as a safe intermediary between the core network and external applications, and will enable them to access network services and data while enforcing security and access controls.

Network applications (NetApp), deployed and managed (LCM) within aerOS IE, will abstract and streamline the communication of vertical applications (vAPPs) with the 5G Core (5GC). It will be deployed within IE either as a FaaS or a container workload and will operate as a wrapper of 5G/NEF Northbound APIs to expose services through Business APIs. The deployed NetApp will allow vertical applications to be developed/upgraded (and take advantage of the 5G exposure capabilities) without changing integral parts of their software, they will only consume the business APIs.

The **vertical application (vApp)** will either be deployed within the UE (i.e the 5H enhanced smart gw) or have a placement somewhere else within the COSMOTE edge aerOS IE. It will consume the NetApp business interfaces making requests which will be translated to 3GPP specified API calls and when the necessary computations and data manipulation are completed these business APIs will transfer the information to the vertical application.

These components and a schematic of their, layered, interaction is presented in the following figure:

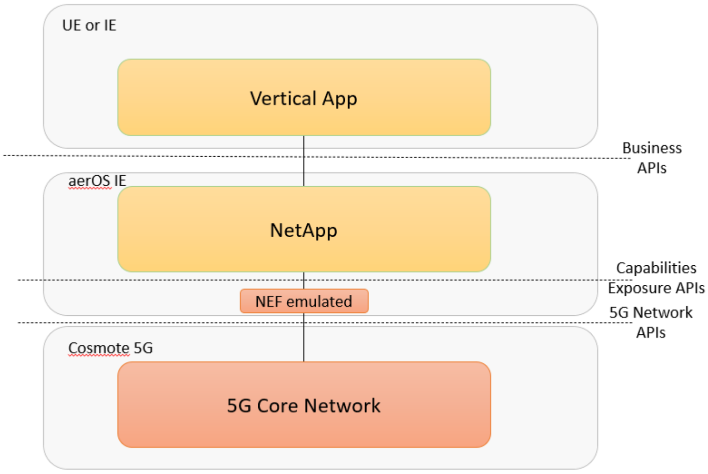


Figure 44. NEF-NetApp-vApp aerOS supported interaction.

The scope of this implementation of 5G integration within the second scenario is to extend aerOS capabilities by providing standardized interface and make it easier for external applications to discover and access these 5G network services. This extension will "run" on a secure and controlled interface when accessing services and data from the core network as dictated by aerOS architecture.

2.5.3.2.4. Actors involved in Scenario 2

The actors involved of this use case have been collected following the table below, representing the actors involved, business area impacted, together with the type of impact and what it consists of.

Table 32. Actors involved in Scenario 2 of Use case 5

ACTOR	B$ AREA	TYPE OF IMP.	IMPACT DESCRIPTION
Managers	Management	Direct	Managers will have the ability to securely monitor the building operations in terms of health and efficiency. The data of the building and its employees will be private and protected from potential risks, as well as be kept confidential and anonymized.
IT Engineers and Network Administrators	IT	Direct	Responsible for ensuring the always correct functioning of the infrastructure and communication channels. Continuously monitoring the IoT infrastructure and ensuring its proper operation against vulnerabilities. Responsible for addressing cybersecurity threats.
Building Employees	All office operations	Direct	Managers will have the ability to securely monitor the building operations in terms of health and efficiency. The data of the building and its employees will be private and protected from potential risks, as well as be kept confidential and anonymized.

Third Party Vendors	Various	Direct	Third party colleagues or users of the COSMOTE infrastructure will need to adapt, update their standards, and ensure compatibility with the aerOS ecosystem.

2.5.4. Data sources

The data sources to be used in the Pilot 5 of aerOS are as follows:

- Sensor-generated environment monitoring data (Temperature, luminosity, Air quality, C02, MQ135 gases, Motion, door sensor…) feeding an InfluxDB timeseries database (thus, accessible in JSON and SCV via API).
- Metadata of sensors' transmission (protocol-specific parameters, link quality parameters such as RSSI and SNR, app data transferred, availability, battery, name…) available through InfluxDB.
- Data and metadata of gateways' transmission (similar to the above).
- Configuration management and monitoring data (resource utilization data exposed by the K8s resources based on the usage of Prometheus, such as network latency, memory usage, CPU…). Both periodic and triggered by events, if needed.

2.5.5. Requirements of the trial

Below there is a list of the specific requirements identified for this trial. A full list of all the requirements gathered (in M9) for Pilot 5 as a whole are available in Appendix B.

- Far Edge and Edge storage capacity
- Cloud storage capacity
- Support any IoT sensor type and protocol
- Automatic service recovery upon system or network loss
- IoT Data Collection and processing fully automated, reliably transferred in a configurable manner
- IoT system automatic configuration management
- User-friendly monitoring of system health and remote management
- Scalability to Support Mass Deployments
- Data Analytics & Decision Making at the Edge
- APIs for 3rd Parties/Stakeholders
- Gateways and Base Stations Heterogeneity
- Web app for end user-system interaction
- Occupancy policy
- Message aggregation policy at gateway-level for lower overhead
- Gateway functionality for harmonizing heterogeneous data
- Distributed deployment of workloads/services along the continuum
- Meta-operating system deployment
- Portability
- Data privacy annotation
- Identity management
- Cybersecurity policies definition & enforcement
- Traceability

2.5.6. Specific measurable outcomes of the trial

- Interoperability in a Smart Building.

Result: Smart Building solution with extension and interconnection capabilities

To exhibit portability and interoperability gains proposed by the aerOS concept, which stands as a unique solution to integration pains of existing heterogeneous IoT sensors market.

- Advanced networking in a Smart Building

Result: Mesh network system governed by aerOS

Outcome 2: Definition and implementation of latency controlled distributed smart networking components; Mesh networking and 5G technologies shall be deployed for efficient communication among the aerOS IE.

- Decentralised intelligence

Result: Platform where AI models run dynamically and execute all the way around the continuum

Outcome 3: To decentralise intelligence towards a safe and sustainable working environment. Federated learning at the edge, intelligence close to event and data sovereignty are integral characteristics of the use case definition.

- Orchestration

Result: Meta Operating System as the single point where orchestrator is ordered.

Outcome 4: Smart orchestration targeting wireless network configurations, updates in distributed intelligence criteria and prioritization, and business critical monitoring information is a key enabler.

As expected benefits, aerOS will allow Smart Building stakeholders (represented by COSMOTE in aerOS) to enjoy of the following benefits derive from the aerOS nodes intelligence, and its architecture:

- Smart building technologies can provide facilities operators with the tools to anticipate and proactively respond to maintenance, comfort, and energy performance issues, resulting in better equipment maintenance, higher occupant satisfaction, and reduced energy consumption and costs.
- The pilot proposes a unique combination of energy-efficient and health-safe buildings by utilizing a distributed AI approach for proper employees' placement, addressing social distancing and energy efficiency, along with business and personal preferences and work habits, a complex yet all and more necessary demand, as companies, after the Corona-virus pandemic adopt hybrid office/home working scenarios and mobile desk workplaces.
- The pilot is built exploiting to the maximum open-source, community best-practices and as such is a state-of-the-art cost-effective, future proof solution.
- The pilot is IoT-technology agnostic and can dynamically adopt and adapt to changes in infrastructures using automated orchestration solutions.
- The pilot deployment can dynamically scale-in and out (e.g., add/remove rooms, floors and buildings) and integrate in a bigger ecosystem (e.g. federate with other smart buildings solutions) by leveraging the distributed autonomy, federated architecture and interoperability assured by aerOS node principles providing flexibility to support customers' target infrastructures and business plans.

2.5.7. Legal framework

During the course of task T2.3 (Legal and regulatory analysis and governance specification), several actions have been performed in order to identify the legal framework surrounding activities in Pilot 5 (available in D2.2). that, a thorough analysis of the legal and regulatory aspects affecting the different scenarios of Use case 1 was performed, outputting the following results:

Sectorial regulations (Telecommunications):

- HDPA (Greece) - By complying to the regulations fair access to services, and user/data protection is guaranteed.

- GDPR (EU) – Protection of user data.

Technological regulations:

- IoT – Law 4961/2022 (Greece) - Constitutes a primary, but high level endeavor in view of the forthcoming and more detailed EU legislation on new technologies.
- IoT – EU Connected Communities initiative (EU) - This initiative concerns the IoT development infrastructure, and aims to collect information from the market about existing public and private connectivity projects that seek to provide high speed broadband, more than 30 Mbps.
- IT Systems & Networks – HCA, Law 4727/2020 (Greece) – Cybersecurity and privacy.
- IT Systems & Networks – Directive (EU) 2019/1024, Directive (EU) 2018/1972, EU NIS Directive-2016 – Cybersecurity and privacy.
- 5G Technology – EETT (Greece) – Regulate the efficient use of spectrum, and ensures fair market competition.
- 5G Technology – 3GPP, ETSI, BEREC (EU) – Set the specifications for functional suitability and devices compliances to EC standards, facilitates interoperability among operators.

Usage of products:

- Open-source software is used (MQTT, Home Assistant, K8s). aerOS partners in Use case 5 will be sure to comply with proper licensing and noticing whenever making results public.

3. Requirements

The elicitation of requirements is key in a Research and Innovation Action to ensure the proper coverage of the goals set out for the project. In addition, a thorough procedure for establishing technical, user and system requirements will ensure a more efficient conduction of the technical and pilot activities across the WPs of aerOS. In this section are reported the main aspects related to those procedures, drilled down in (a) Technical Requirements and (b) Requirements coming from pilots (user and system requirements). While in this chapter an overall explanation of the results is provided, the actual list of requirements can be found in Appendix A and Appendix B.

3.1. Technical requirements

A number of 102 technical requirements were recorded following the methodology described in deliverable D2.2.

While the full list of technical requirements gathered till M18 of the project **is included in the Appendix A**, this section shows a statistical summary of the results obtained so far.

Summary of the technical requirements presented in are the result of recording refined revision of the requirements already identified in the deliverable D2.2. This has been done by performing cross checking and updating of the list by the different technical partners of aerOS. After studying the technical goals and tasks of aerOS and understanding the current standpoint of developments and the findings made so far, the effort has been focused on improving the definitions, the classification, the priority, etc.

As a conclusion, the requirements identified in M9 are still relevant. However, in several parts of the project, more requirements have been necessary to be included (those that are highlighted in blue in the list of Appendix A). Specifically, **36 new requirements** have been identified and described in the period M9-M18.

In the following graphs, some statistics are shown regarding the recorded requirements; presented based on the area they refer to, the roles they concern, the domain they refer, the category they address, their type and priority. As it can be seen, the majority of requirements gathered are Non-Functional ones, prioritized as Must-have and mostly referring to Data, Infrastructure, AI, Security and Meta-OS areas of the aerOS project. However, there are recorded requirements for almost every area, role, domain, and category within the scope of the project.

The requirements per **area** have been:

Table 33.Summary of aerOS technical requirements per type.

Requirement type	Quantity
Data	24
Infrastructure	16
AI	17
Security	11
Meta-OS	11
Application	3
Development	6
Services	3
Network	6

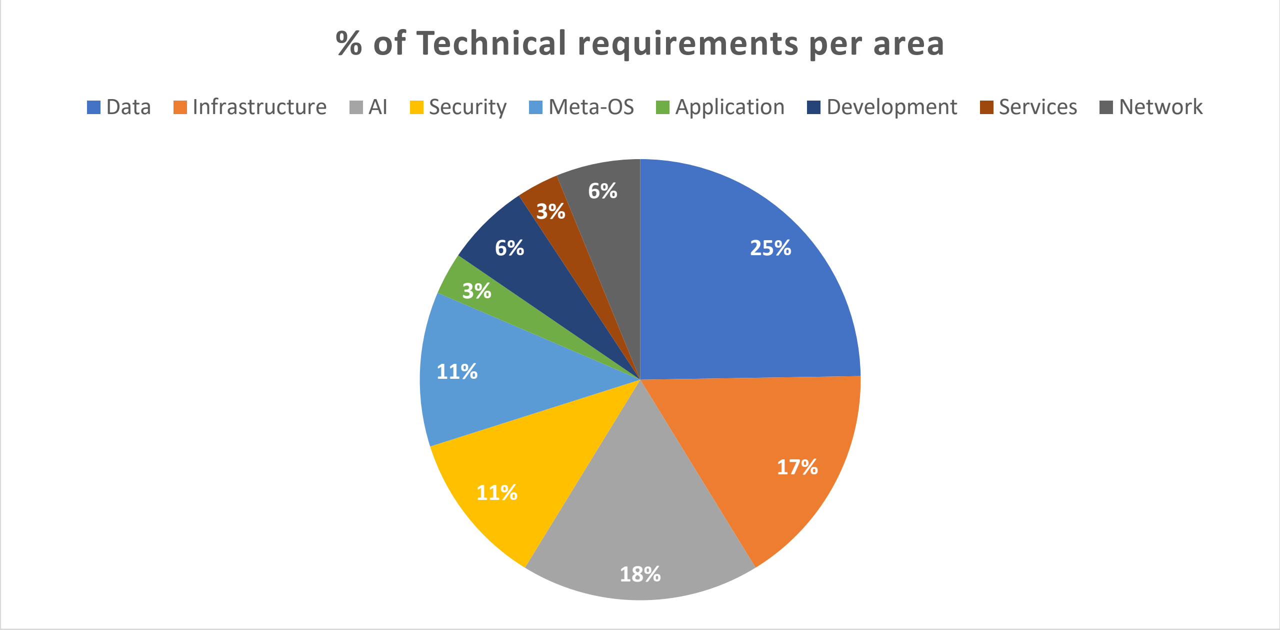


Figure 45. Graph representing the technical requirements per area

The requirements per **role** have been:

Table 34. Summary of aerOS technical requirements per role.

Requirement role	Quantity
ALL roles	39
Service Provider (SP)	45
Application Programmer (AP)	29
aerOS Application User (AU)	25
IoT infrastructure provider (IP)	24
Cloud infrastructure provider (CP)	19
Network provider role (NP)	20

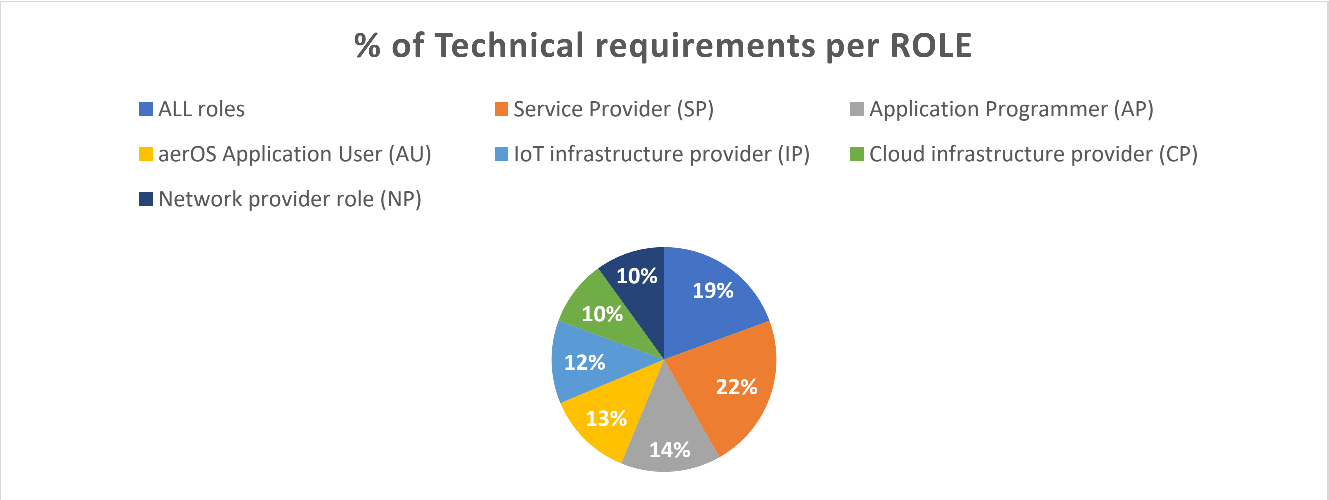


Figure 46. Graph representing the technical requirements per role

The requirements per **domain** have been:

Table 35. Summary of aerOS technical requirements per domain.

Requirement domain	Quantity
ALL domains	16
Continuum	64
Application	3
Edge	6
NIoT	1
Network	2

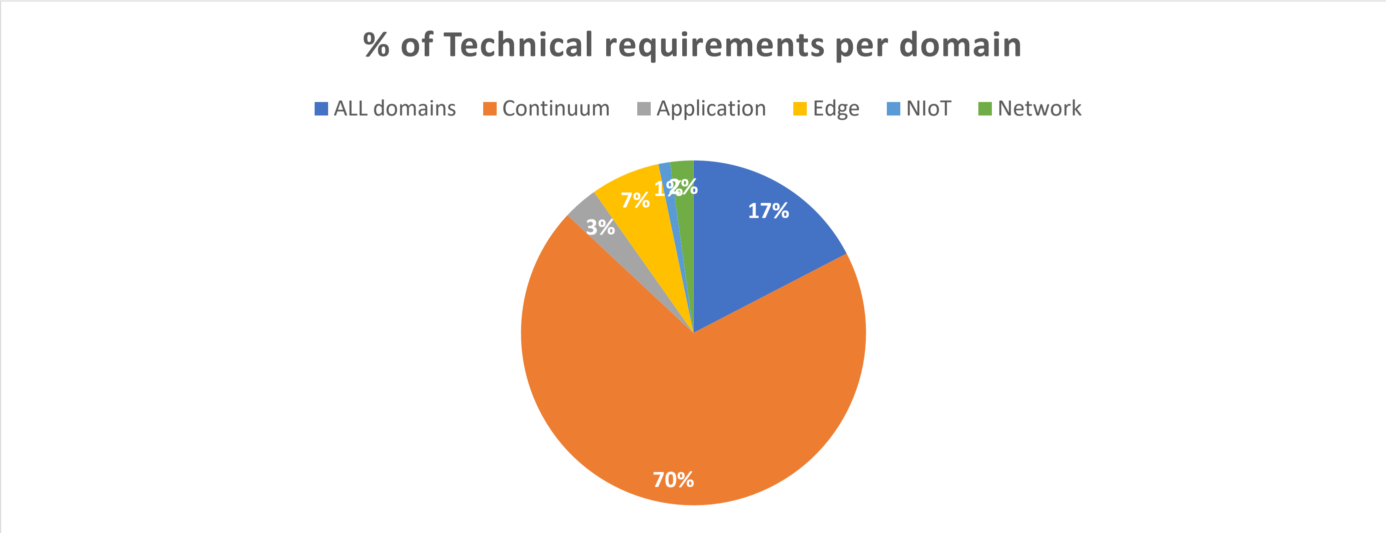


Figure 47. Graph representing the technical requirements per domain

The requirements per **category** have been:

Table 36. Summary of aerOS technical requirements per category.

Requirement category	Quantity	Requirement category	Quantity
General aspects	24	Usability	5
Security	15	Development	1
Availability	17	Data models	3
Performance	18	Flexibility	1
Privacy	9	Extensibility	1
Data Quality	12	Automation	2
Accessibility	13	Interoperability	1
Maintainability	8		

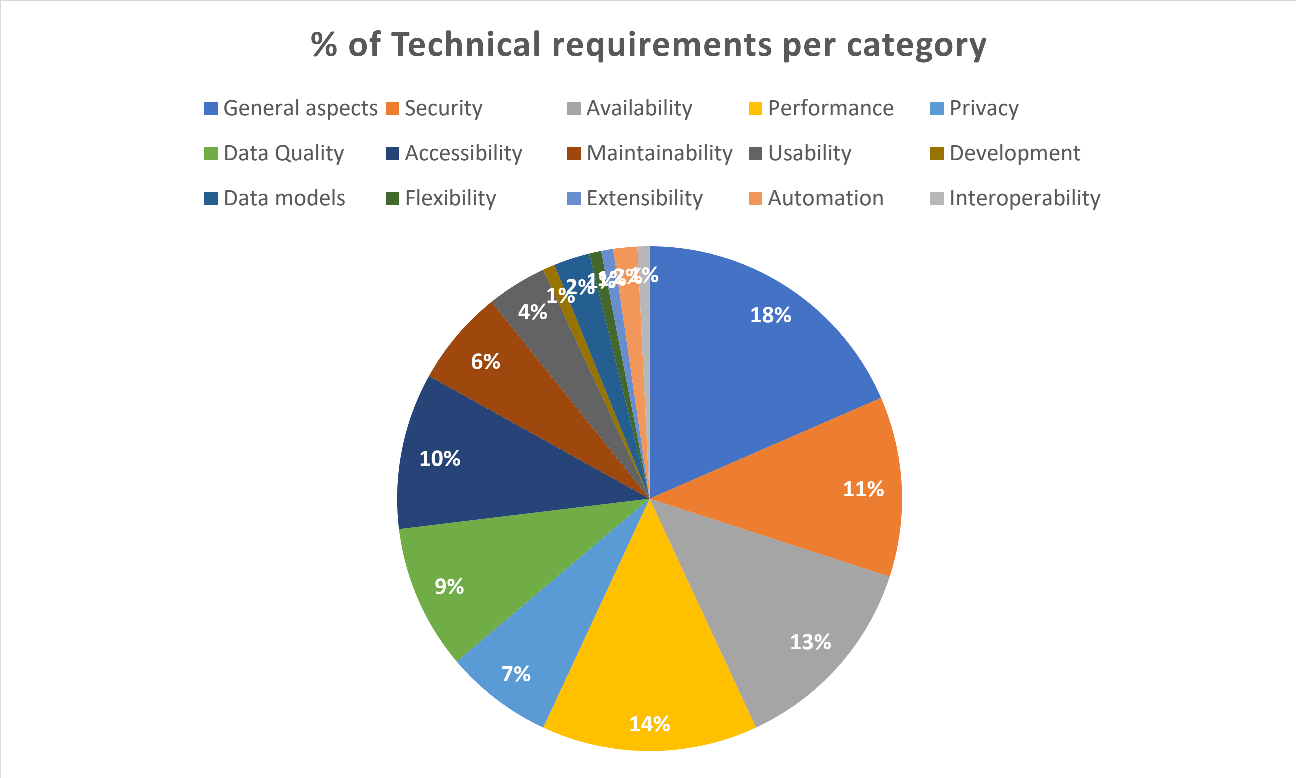


Figure 48. Graph representing the technical requirements per category

The requirements per **classification** have been:

Table 37. Summary of aerOS technical requirements per classification.

Requirement classification	Quantity
Functional	26
Non-functional	72
Constraints for design	4

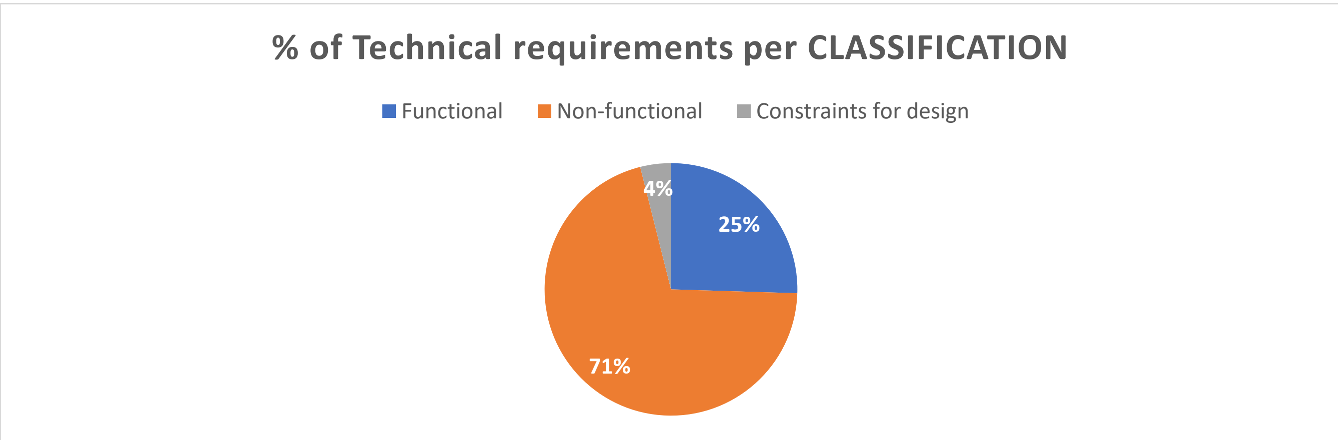


Figure 49. Graph representing the technical requirements per classification

The requirements per **priority** have been:

Table 38. Summary of aerOS technical requirements per priority.

Requirement priority	Quantity
Must	71
Should	32
Could	2

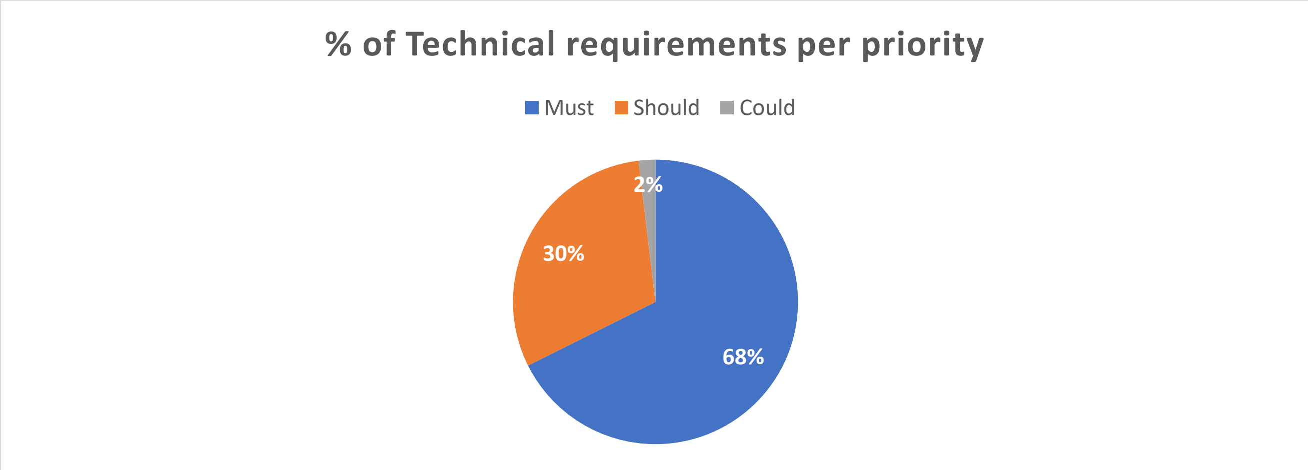


Figure 50. Graph representing the technical requirements per priority

As a written summary of those:

aerOS is seamlessly integrating various edge technologies into a homogeneous continuum (e.g., KubeEdge, AI models, network interfaces and components, APIs, security, distributed trust…). Computing and storage resources can be located anywhere in the network (thanks to the two-staged orchestration and the federation of the continuum), defining an expanded network compute fabric that spans over (any fragment of) the entire path between (constrained) devices and cloud(s). Resources available in the compute continuum, are geo-distributed and migrate over time while some of them are part of a dynamic infrastructure. aerOS is leveraging concept of services as a "unifying abstraction", across resources (i.e. any physical or virtual IoT edge-cloud continuum resource, from device to far-edge, edge or cloud); across multiple infrastructure domains and service levels, supporting federation. aerOS is advancing towards an efficient orchestration of services (thanks to smart allocation engine powered by several AI strategies) in a heterogeneous continuum of resource federation, as opposed to single-domain orchestration (where the orchestrator has full control over resources; while multi-domain orchestration requires coordination across domains.

aerOS is exerting research efforts to support future hyper-distributed applications, delivering intelligence on demand. High level intents will be able to be defined by users (via the aerOS portal) in a declarative way to specify applications and service's needs, as well as consumed services will be translated in an intelligent and automatic manner to permit efficient deployment and orchestration.

A common meta operating system for the IoT edge-cloud continuum is being designed and developed, which will be able to orchestrate hyper-distributed applications over a heterogeneous and segmented/federated IoT edge-cloud continuum. The proposed aerOS meta-operating system is being designed to be hosted in a flexible and fully orchestrated virtualisation/containerisation-based environment and to be deployable on different levels of the architecture, across the IoT edge-cloud continuum. It will be made available to the community (as soon as it is ready) in the form of containerised S/W modules (accompanied by comprehensive documentation and adoption guidelines) that can be executed on top of any operating system of any component of the architecture providing typical services of an operating system, e.g., abstractions, low-level element control, commonly used functions or message-passing between processes.

aerOS has created the aerOS runtime that can be (and is) executed in different infrastructure elements of the IoT edge-cloud continuum enabling distributed AI and decentralized orchestration of services across IoT edge-cloud continuum. Also, aerOS has been designed in a modular way, where all IEs, basic services and auxiliary services leverage a powerful toolset of Open APIs to provide network, resources, data and services to fully enable programmability feature in the IoT edge-cloud continuum. aerOS' Data Fabric allows for distributed data management to deliver a true meta–Operating System, where data is discoverable everywhere (data catalogue), but exposed in a secured and trusted manner (sovereignty and governance). Also, aerOS innovatively proposes automated mechanisms for data annotation and translations, opening the door to diverse verticals and standards (e.g., SAREF, SmartDataModels…) to be natively supported following aerOS strategies. All of this is being achieved while permitting direct access to data sources (through the metadata) and event-generating processes without sacrificing aggregated data analysis and insights. Several aspects of aerOS are utilising (semi)autonomous approaches, like mechanisms for self-adaptation and self-healing of the Infrastructure Elements, based on self-observation (self-awareness).

aerOS (via the AAA delivery) introduces a holistic cross-layer solution for cybersecurity, while supporting federated and distributed data governance. The management of the aerOS infrastructure is planned to be as automated as possible (via the custom CI/CD scripts and the DevPrivSecOps methodology), with minimum manual intervention. Security analysis and Privacy analysis are now an integral part of the Software Development Life Cycle.

Among services that can be executed in an aerOS deployment, AI pipelines stand out, being proposed as a continuous action governed by MLOps principles and technology. aerOS components allow for the execution of these AI pipelines, originating from both internal use cases (supporting aerOS mechanisms) and external use cases (originating from applications). Users will be able to specify requirements related to execution of AI pipelines according to a pre-established data model. Data models that shall support AI requirements and pipeline definitions should be extendable and adaptable to new cases. aerOS is being designed to be able to process large amount of information at the edge and decide which information needs to be transmitted to a central cloud server for further storage and processing. aerOS shall support explainability of models and provide mechanisms for tackling data frugality.

aerOS will handle data generated by heterogeneous sources and support data processing tasks performed within the system towards supporting data autonomy. aerOS is offering mechanisms for defining (compound) data sources (after employing the LOT methodology and automated annotation) and creating data-flow topologies based on streams. Because of the high heterogeneity of aerOS deployments, interoperability based on semantics and semantically represented/annotated data and data flows is being embedded in the continuum through add-ons to the Data Fabric. aerOS should be able to semantically annotate "raw" data to enable/empower its semantic interoperability mechanisms. Furthermore, aerOS syntactic interoperability solution should allow for user defined extensions; hence, it should have a modular and "parametrised" architecture.

3.2. User and system requirements

As indicated in the previous section, while functional requirements are defined to clarify the system's subject matter, the non-functional requirements refer to the behavioural properties that the specified functions must have, such as performance, usability, etc. Both functional and non-functional aerOS requirements listed below are result of intensive communication among stakeholders, as their analysis has been performed for all pilots separately.

While the full list of technical requirements gathered until M18 of the project **is included in the Appendix B**, this section shows a statistical summary of the results obtained so far.

User and system requirements in aerOS come directly from an analysis performed within each of the 5 pilots of the project. The requirements are presented in comprehensive tables as result of recording refined revision of those already identified in the deliverable D2.2. This has been done by performing cross checking and updating of the list by the different stakeholders (and technical partners involved) in the pilots of aerOS. After studying the overall goals, objectives, etc. of each scenario and after understanding the current standpoint of developments and the findings made so far, the effort has been focused on improving the definitions, the classification (functional vs non-functional), the priority, etc.

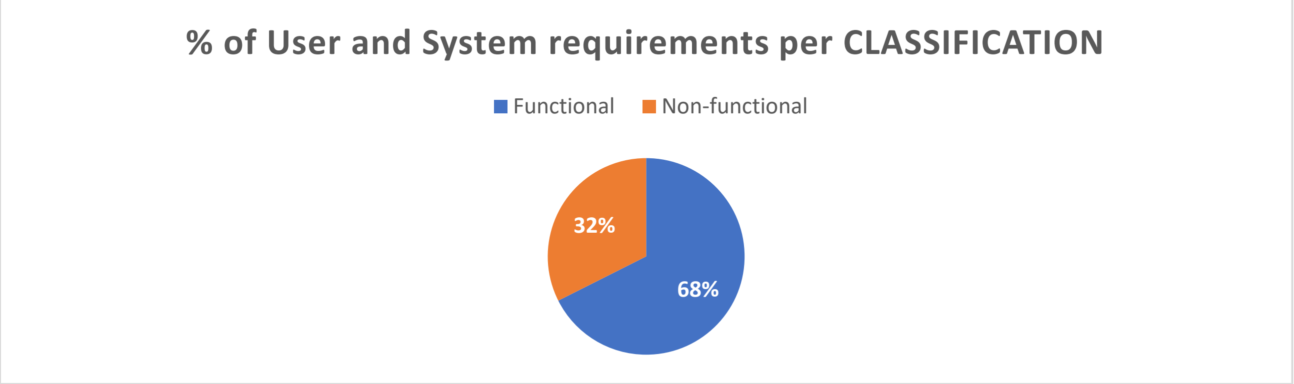
As a conclusion, the requirements identified in M9 are still relevant. However, in most pilots, new requirements have been necessary to be included (those that are highlighted in blue in the list of Appendix B). Specifically, **20 new requirements** have been identified and described in the period M9-M18.

Currently, the project has **74 pilot-related requirements**. In the following graphs, some statistics are shown regarding the recorded requirements; presented based on their classification (functional or non-functional), the type (user or system requirements) and their priority (must, could, should, would…). As it can be seen, the majority of the requirements gathered are Functional ones, prioritized as Must-have and mostly referring to System. However, there is a substantial amount of non-functional requirements and user requirements.

The requirements per **classification** have been:

Table 39. Summary of aerOS user and system requirements per classification.

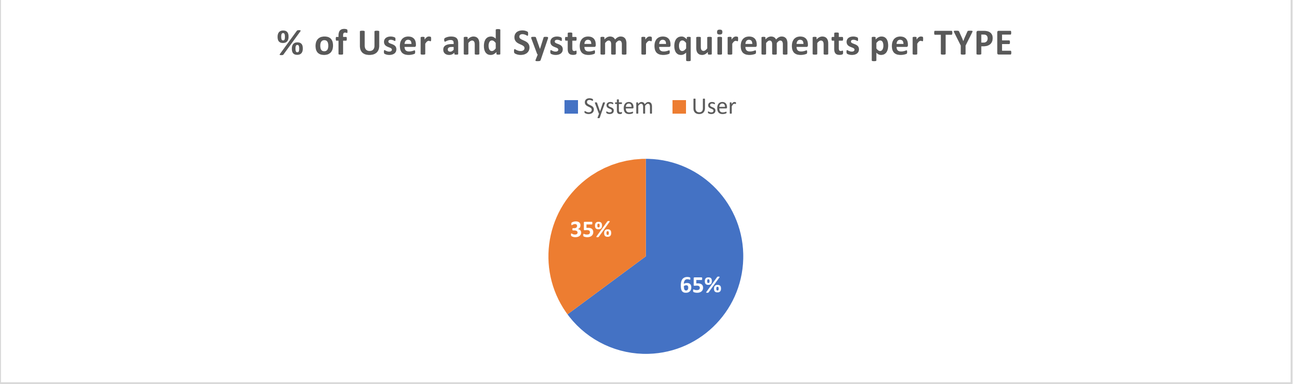
Requirement classification	Quantity
Functional	50
Non-functional	24



The requirements per **type** have been:

Table 40. Summary of aerOS user and system requirements per type.

Requirement type	Quantity
System	48
User	26

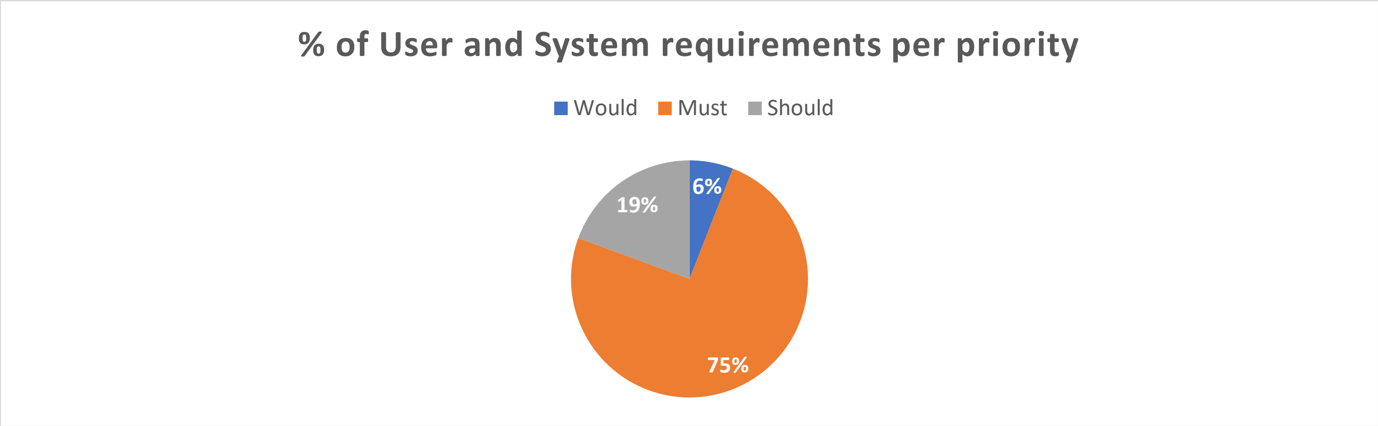


The requirements per **priority** have been:

Table 41. Summary of aerOS user and system requirements per priority.

Requirement priority	Quantity
Would	4
Must	50

Should	13
Could	6



4. Conclusions and future work

Deliverable D2.3 extends the five use cases of the project with respect to the first version provided in the Grant Agreement and the most up-to-date version from D2.2, as well as refines the technical and user requirements of these use cases. The main conclusions drawn from each use case, also defined as pilot, in the project are:

The *Data-Driven Cognitive Production Lines* use case has been divided in three different scenarios, which share among them the final goal of creating highly flexible, sustainable (green) modular digital production lines and manufacturing of a new product in a low-volume production. aerOS will be used as a data exchange, dashboarding and processing tool in the use-case scenario 1. For the second use case scenario, aerOS will provide CMM metrological data management, workload communication and load-balancing, advanced AI-based analytics on the performance of CMM, and the latest cybersecurity and privacy toolset, among others.

The *Containerised Edge Computing near Renewable Energy Sources* use case will assess the impact on carbon emissions generated by the European cloud industry. aerOS will be managed for setting up and managing distributed cloud-edge architectures located directly at energy producing locations. Whereas the first scenario focuses on deploying two federated edge nodes and a private cloud located directly at renewable energy premises, the second scenario extends the federation, bringing on-board multiple, independent tenants. The primary role of aerOS is to guarantee the information management through the HLO and LLOs distributed orchestration, along with the cybersecurity of the upcoming data fabric provided by the AAA suite of aerOS.

The *High-Performance Computing Platform for Connected and Cooperative Agricultural Mobile Machinery to Enable CO2 Neutral Farming* use case will validate a HPCP for farming, construction, and forestry sectors. Such tasks in agriculture and construction work that require collecting data from different components and analysing it whether on-board or off-board, can highly benefit from an ECU with high computing power. Three potential benefits from the usage of aerOS are identified in the two scenarios of this use case. On the one hand, it is expected to use common APIs approach from the project to enable seamless application hosting and supporting the functional allocation. On the other hand, the monitoring and real-time control capabilities of the system will allow to support time-aware execution of the tasks. Finally, the trustworthiness improvement of aerOS, via the implementation of a chain of trust, will permit the future certification of embedded software and products with regards to security measures.

The use case *Smart edge services for the Port Continuum* is oriented to boost the digitalization of maritime port container terminal operations with a first scenario focused on predictive maintenance of container handling equipment, and the second one concentrating on risk prevention via computer vision at the edge. To do so, the lightweight requirement of aerOS orchestration will allow the use in the terminal of heterogeneous Infrastructure Elements (IEs), capable of inferring Frugal AI models, without requiring very high bandwidths with a central node. All the data sources will be orchestrated by the aerOS communication infrastructure, being formed by different aerOS domains within the Port Continuum.

The *Energy Efficient, Health Safe & Sustainable Smart Buildings* use case aims to provide energy efficient, sustainable, flexible and health-safe smart buildings. The main goal behind the use case is to achieve swarm intelligence among the aerOS capable sensors, allowing office to become self-organized in terms of health and efficiency, and by using real-time processing and (frugal) AI to improve energy efficiency of the large buildings. Applying the aerOS architecture that stands as a unique abstraction layer, the end-to-end integration can be achieved easily. Furthermore, incorporating the seamless integration of various communication types and network deployments (e.g. 5G and WIFI6) is envisaged by the aerOS network architecture.

With regards to the requirements elicitation, a thorough procedure drilled down in (a) Technical Requirements and (b) Requirements coming from pilots (user and system requirements) was addressed since D2.2 and continued in D2.3. A total of 176 requirements have been elicited, divided in 102 technical and 74 coming from the stakeholders of aerOS. It is expected that all of them will be validated in the second half of the project by means of the technical WP3, WP4, and WP5 work packages.

A. Technical Requirements table

Table 42.aerOS technical requirements.

ID	Refers to	Name	Description	Role	Domain	Category	Type	Pri-ority	Rationale	Acceptance Criteria
TR-1	INFRASTRUCTURE	Homogeneous seamless integration of diverse edge technologies	Seamlessly integrate various edge technologies into a homogeneous continuum	ALL	Continuum	Interoperability Accessibility	NF	M	Seamless integration of different edge technologies achieving homogeneity across the continuum	Common homogenous access agnostic to the edge technology
TR-2	INFRASTRUCTURE	IoT edge-cloud continuum resources	Computing and storage resources can be located anywhere in the network, defining an expanded network compute fabric that spans over (any fragment of) the entire path between (constrained) devices and cloud(s)	ALL	Continuum	Availability Accessibility	NF	M	Computing and storage resources can be located anywhere in the network; IoT, Edge, Cloud	Accessibility to orchestratable resources at any domain
TR-3	APPLICATIONS	Hyper-distributed applications support	Support future hyper-distributed applications, delivering intelligence on demand (when/where needed)	ALL	App Continuum	General	NF	M	Support of scalable distributed applications execution where parts of application run in different domains of the continuum delivering effectively required intelligence	Distributed application constructed as a service chain where each scalable component runs at the aggregated continuum
TR-4	META-OS	Meta-operating system for the IoT edge-cloud continuum	Provide a common meta operating system for the IoT edge-cloud continuum, which will be able to orchestrate hyper-distributed containerized applications over a heterogeneous and segmented/federated IoT edge-cloud continuum	ALL	App Continuum	General	NF	M	Provide a meta-operating system to make possible scalable distributed containerized applications constructed as service chains to effectively execute over offered resources across the continuum. This requires orchestration of distributed application execution over distributed continuum resources.	Scalable distributed applications constructed as service chains effectively execute over offered resources across the continuum

ID	Refers to	Name	Description	Role	Domain	Category	Type	Pri-ority	Rationale	Acceptance Criteria
TR-5	META-OS	Meta-operating system host environment	The proposed aerOS meta-operating system will be hosted in a flexible and fully-orchestrated containerization based environment	IP CP NP	Continuum	General	NF	M	A containerization environment provides the required flexibility to host a distributed meta-operating system where applications will be executed across the continuum.	Applications execute in a fully orchestrated containerization environment hosting the distributed across the continuum meta-operating system.
TR-6	META-OS	Meta-operating system deployment - Portability	The envisioned meta operating system will be deployable on different levels of the architecture, across the IoT edge-cloud continuum. It will consist of containerized S/W modules that can be executed on top of any operating system of any component of the architecture providing typical services of an operating system, e.g., abstractions, low-level element control, commonly-used functions or message-passing between processes	IP CP NP	Continuum	General	NF	M	Enable components at each part of the continuum to provide orchestratable resources for apps and services deployment.	aerOS can be executed on top of any operating system of any component of the architecture.
TR-7	META-OS	Meta-operating system orchestration and AI enabler	aerOS will have ability to be executed in different infrastructural components of the IoT edge-cloud continuum enabling distributed AI and orchestration of services across IoT edge-cloud continuum.	ALL	Continuum	Performance Availability Data quality	NF	M	Provide an environment for deploying distributed AI mechanisms as well as hyper distributed containerized applications and services.	Distributed AI mechanisms as well as hyper distributed containerized applications and services are efficiently deployed over the continuum.
TR-8	META-OS	Meta Operating System modularity	aerOS will be implemented as containerized modules, executed on top of any operating system of an Infrastructure Element (IE) of the IoT edge-cloud continuum, e.g., a smart device, IoT gateway, edge node or network component	IP CP NP	Continuum	General	NF	M	Take advantage of containerized technology for ease of deployment, isolation, performance, personalization and expandability.	aerOS is implemented as containerized modules and executed on top of any operating system of an Infrastructure Element of the continuum.

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TR-9	NETWORK	Network programmability in the IoT edge-cloud continuum	aerOS should leverage the powerful toolset of openAPIs on network exposure and APIs for network management and orchestration to fully enable programmability feature in the IoT edge-cloud continuum	NP	Continuum	General	NF	M	Enable smart networking capabilities for performance, availability, resilience, security.	Programmability is supported across the continuum.
TR-10	INFRASTRUCTURE	Dynamic resources	Resources available in the compute continuum, are geo-distributed and migrate over time while some of them are part of a dynamic infrastructure	IP CP NP	Continuum	Availability	C	M	Support and exploit the dynamicity of the environment.	Seamless access to resources
TR-11	DATA	Data autonomy	aerOS will handle data generated by heterogeneous sources and support data processing tasks performed within the system towards supporting data autonomy	ALL	Continuum	Security Privacy Availability Data quality	NF	M	Support the heterogeneity of the environment and the data sources to provide for data autonomy.	Data autonomy is realized across the continuum.
TR-12	APPLICATIONS	Usage requirements	High level intents are defined by users (i.e., developers, service consumers, data providers, administrators) specifying needs, in terms of QoS and geo-scope. By leveraging these views, aerOS will orchestrate services in an intelligent and automatic manner	ALL	Continuum	General	NF	M	Provide an efficient and agnostic to the complexity of the operations way to fully exploit the benefits of the continuum.	High level intents are defined by users and efficiently reflected in deployments.
TR-13	DATA	Distributed data management	aerOS will allow for distributed data management to make user-side applications more intelligent and proactive, and to provide foundation for hyper-distributed applications and services, closer to data	ALL	Continuum	Performance Availability Data quality	NF	M	Efficiently support distributed data management to facilitate intelligent hyper-distributed applications and services.	Distributed data management is illustrated and it is exploitable by applications and services.

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			sources and event-generating processes without sacrificing aggregated data analysis and insights							
TR-14	INFRASTRUCTURE	Federation	aerOS will leverage concept of services as a "unifying abstraction", across resources (i.e. any physical or virtual IoT edge-cloud continuum resource, from device to far-edge, edge or cloud); across multiple infrastructure domains and service levels, supporting federation	IP CP NP SP	Continuum	General	C	M	Enable sharing of resources across multiple domains.	Resources across distinct administrative domains and from edge-to-cloud are accessible in a unified way.
TR-15	META-OS	Self* mechanisms	Several aspects of aerOS will utilize the (semi)autonomous approaches, in particular these will include mechanisms for self-adaptation and self-healing of the Infrastructure Elements, based on self-observation	IP CP NP SP	Continuum	Performance Availability Maintainability	NF	S	Support self-adaptation and self-healing of infrastructure elements to automate processes and reduce complexity.	self-adaptation and self-healing of infrastructure elements is realized.
TR-16	META-OS	Security mechanisms of an Infrastructure Element	Nodes connected to the aerOS continuum shall be able to scan their own internal network, through (semi)autonomous mechanisms, for unwanted network situations such as DDoS attacks, etc.	IP CP NP SP	Continuum	Security	NF	S	Enables adding an extra layer of security to the nodes of the continuum to detect and prevent network attacks directed towards the Infrastructure Elements	The self-security element has been realised and network threats to the node have been successfully prevented
TR-17	META-OS	Mechanisms for recovery and (re)configuration of a continuum node	Nodes connected to the aerOS continuum that have sensors connected to them shall be able to analyse the health status, the data sent by the sensors and the configurations applied to recover these sensors from anomalous states or incorrect configurations, in case the sensors are not working properly	IP CP NP SP	Continuum	Performance Availability Maintainability	NF	S	Enables automated (re)configuration and curation of Infrastructure Elements to reduce process complexity and increase process automation	Self-healing and self-configuration mechanisms have been realised and the Infrastructure Elements are able to recover from abnormal states of operation or incorrect or inappropriate configurations.

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TR-18	META-OS	Communication interface of the Infrastructure Elements	Computing nodes connected to the aerOS continuum shall have a communication system (API) between the node and the surrounding environment to send/receive data and apply operations	IP CP NP SP	Continuum	Security Accessibility	NF	M	Allows a connection to be established with the Infrastructure Elements of the aerOS continuum to apply actions on them and allow them to send/receive information about certain actions	The self-API mechanism has been realised and it is possible to establish a connection to the Infrastructure Elements
TR-19	META-OS	Adaptability of the Infrastructure Elements	Through self-monitoring, the nodes of the continuum will be able to detect possible future anomalies, applying prevention and anticipation techniques to avoid service interruptions and remain operational and available for as long as possible	IP CP NP SP	Continuum	Availability Reliability	NF	S	The node will be able to anticipate possible errors or lack of resources in the near future in order to avoid them and remain operational	The self-optimisation and adaptation mechanism has been realised and it is possible to keep the node operational longer and in a better state of health
TR-20	META-OS	Applicability	The aerOS approach will be generic and directly applicable to any vertical, cross-vertical business process, and several different physical or virtual platforms	ALL	App Continuum	General	NF	M	Efficiently support a wide range of diverse vertical use cases.	Diverse use cases may be implemented using the aerOS solution.
TR-21	SECURITY	Cross-layer cybersecurity	aerOS should introduce a holistic cross-layer solution for cybersecurity, while supporting federated and distributed data governance.	ALL	App Continuum	Security Privacy Availability Data quality	NF	M	Provide a holistic security solution across each continuum and along federated continuums.	A cross-layer, cross-domain cybersecurity solution is implemented.
TR-22	SERVICES	Multi-domain services orchestration	aerOS should efficiently orchestrate services in a heterogeneous continuum of resource federation, as opposed to single-domain orchestration (where the orchestrator has full control over resources; while multi-domain orchestration requires coordination across domains	IP CP NP SP	Continuum	General	NF	M	Efficiently orchestrate services in a heterogeneous continuum of resources federation.	Services are efficiently orchestrated in a heterogeneous continuum of resources federation.

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TR-23	INFRASTRUCTURE	Infrastructure resilience	aerOS should adapt to abrupt network changes, with the orchestrator rerouting traffic and resources allocation within IoT edge-cloud continuum	IP CP NP SP	Continuum	Availability Performance	NF	M	Efficiently adapt to the dynamicity of the environment to provide uninterrupted services deployed on the continuum.	Infrastructure proves resilient to the dynamicity of the environment.
TR-24	INFRASTRUCTURE	Network infrastructure resilience	aerOS must adapt to unexpected changes or errors in the network. The aerOS orchestration systems, together with the (semi)autonomous self-orchestrator mechanism of the nodes, must be able to reroute network traffic and resource allocation to other Infrastructure Elements of the computing continuum	IP CP NP SP	Continuum	Performance Availability Reliability	NF	M	Efficiently adapt to the dynamicity of the environment to provide uninterrupted services deployed on the continuum	Infrastructure proves resilient to the dynamicity of the environment
TR-25	INFRASTRUCTURE	Resource availability	aerOS should make sure there is always appropriate amount of resources available per infrastructural element	IP CP NP SP	Continuum	Availability Performance	NF	M	Eliminate the possibility of resources starvation at each infrastructure element.	Scarcity of resources is efficiently avoided.
TR-26	INFRASTRUCTURE	Resource availability of a computing node	(Semi)autonomous aerOS self-scaling mechanisms must always ensure that enough resources are available on the computing nodes connected to the continuum	IP CP NP SP	Continuum	Availability Performance	NF	M	Eliminate the possibility of resources starvation at each infrastructure element	Self-scaling of Infrastructure Elements is realised and scarcity of resources is efficiently avoided
TR-27	INFRASTRUCTURE	Proximity of resources	aerOS should support delivering computing resources close to edge devices, considering communication latency	IP CP NP SP	IoT Edge	Performance Availability Data quality	NF	M	Support closer to the edge deployment of services and app components.	Close to the edge services and app components deployments are achieving low latency solutions.
TR-28	DATA	Context awareness	aerOS should support the ability to provide information about (edge) , considering heterogeneity as a drawback to deal with	IP	IoT Edge	General	NF	M	Enable context awareness as the ability of the heterogeneous IoT devices to gather information about their environment at any given time and adapt behaviors accordingly.	IoT devices are able gather information about their environment at any given time and adapt behaviors accordingly.
TR-29	INFRASTRUCTURE	Architecture modularity	aerOS architecture should be modular, to fully exploit encapsulated functionalities including new modules easily	ALL	Continuum	General	NF	M	Built a flexible and easily expandable architecture.	Architecture follows a modular design.

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TR-30	INFRASTRUCTURE	Support of containerized infrastructure technologies	It must be possible for the aerOS system to be installed in any computational environments supporting any containerized environement and demonstrate integration support to most prevailing open source containers engines, being clustered or not.	CP IP	Continuum	General	NF	M	The aerOS should be installed in enterprise-level computational infrastructures with minimum constraints	Demonstrate the installation of aerOS in containerized environments
TR-31	INFRASTRUCTURE	Basic Infrastructure Manageability	The aerOS infrastructure must comply and execute centrally defined (enterprise-level) policies (e.g. scheduled patch upgrades, security hardening)	CP IP	Continuum	General	NF	M	The aerOS system must follow well-defined policies for configuration management across the whole continuum	Demonstrate the infrastructure configuration policies definition and execution
TR-32	INFRASTRUCTURE	aerOS Monitoring	The aerOS system must include a monitoring infrastructure and depict health to relevant stakeholders	ALL	Continuum	General	NF	M	The aerOS system must ensure best-performance operation	Existence of monitoring dashboard
TR-33	INFRASTRUCTURE	aerOS monitoring mechanisms	(Semi)autonomous mechanisms based on self-observation will be used to determine the health status and performance of Infrastructure Elements connected to the aerOS computing continuum	IP CP NP SP	Continuum	Performance Availability Reliability	NF	M	The aerOS system must guarantee optimum performance, high availability and reliability	Self-awareness, self-diagnose and self-realtimeness of Infrastructure Elements is realised
TR-34	INFRASTRUCTURE	Infrastructure management automation	The management of the aerOS infrastructure should be as automated as possible, with minimum manual intervention	ALL	Continuum	General	NF	M	With a huge number of infrastructure elements, manual actions are a prohibiting factor as they relate to an error-prone and time consuming process	Depict the utilization of automation engines for configuration support
TR-35	APPLICATIONS	Declarative applications requirements	There should be a declarative way to specify the application's infrastructural requirements and consumed services	IP SP	Continuum	Flexibility Extensibility	NF	M	Ensuring infrastructure and service specification consistency and simplicity across the continuum	A blueprint should be sufficient to specify all the required infrastructure and service components across the continuum
TR-36	NETWORK	Services visibility across virtual network links	Once virtual links are established between infrastructure components, services should be visible across the link	IP SP	Network	Accessibility	NF	M	Ensuring services access across virtual networks	Interaction between services across the architecture should be possible and configurable

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TR-37	INFRASTRUCTURE	Automated workload execution on IoT Devices	The architecture should allow automated setup and upgrade of IoT devices through workload specification	IP SP	IoT	Automation	NF	S	Ensuring automation on the edge devices	A blueprint should be sufficient to accurately specify the workloads to be executed in all or part of the edge devices
TR-38	DATA	(semi) real-time data analysis support	Support analyzing live data in a timely manner and give a response back with the required/suggested action	AL L	Continuum Network	Performance Maintainability	NF	S	Depending on the situation: timely data analysis could improve the quality of work and automating some of the tasks that are currently handled manually	Data analysis /decision making through aerOS's edge
TR-39	NETWORK	Low latency communication between system components	System latency should be monitored to ensure a low latency communication between deployed application components	NP	Edge	Performance Reliability	NF	S	Observing overall system latency	Defining a tolerable overall system latency
TR-40	NETWORK	Low latency communication between system components	System latency should be controlled from the (semi)autonomous self-monitoring systems of the Infrastructure Elements and kept below an acceptable limit to ensure communication between all components of the deployed application or service	NP	Continuum	Performance Availability Reliability	NF	S	Monitoring of the overall system latency to keep it below the limit and to meet the requirements of the applications or services deployed on the nodes	Defining a tolerable overall system latency
TR-41	DATA	Syntactic interoperability	"Out of the box" aerOS data infrastructure should provide support for the most commonly used data formats: JSON, XML, CSV, …	AP AU SP	App Continuum	Usability	F	S	aerOS data pipelines shall support most commonly used data formats	Data pipelines support most commonly used data formats
TR-42	DATA	Extensible syntactic interoperability	aerOS syntactic interoperability solution should allow for user defined extensions. Hence, it should have a modular and "parametrized" architecture.	AP SP	App Continuum	General	F	M	aerOS data-level interoperability mechanisms shall be extensible	aerOS syntactic interoperability solution allows for user defined extensions
TR-43	DATA	Composable data topologies	aerOS should offer mechanisms for defining (compound) data sources and creating data-flow topologies based on streams.	AP AU SP	App Continuum	General	F	M	aerOS shall provide mechanisms for defining data sources and data flows	Mechanisms for defining data sources and data flows are provided

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TR-44	DATA	Reactive data streams handling	Stream processing mechanisms should be created using tools and techniques ensuring "reactivity", i.e., allowing asynchronicity with non-blocking back pressure.	AP AU SP	Continuum	Usability	NF	S	aerOS stream processing should follow the Reactive Streams principles	Stream processing mechanisms are provided
TR-45	DATA	Semantic data annotation	aerOS should be able to semantically annotate "raw" data to enable/empower its semantic interoperability mechanisms.	AP SP	App Continuum	Usability	F	S	aerOS shall provide mechanisms for semantic annotation of "raw" data	Mechanisms for semantic annotation of "raw" data are provided
TR-46	DATA	Streaming semantic annotation	Since most data handled by aerOS will have a streaming nature, the semantic annotation mechanisms should offer full support for data streams.	AP SP AU	App Continuum	General	F	M	aerOS semantic annotation should be capable of processing data streams	Semantic annotation is capable of processing data streams
TR-47	DATA	Semantic interoperability	Because of the high heterogeneity of aerOS deployments, it should use an interoperability solution based on semantics and semantically annotated data and data flows.	AP SP AU	Continuum	Data quality	NF	M	aerOS shall enable semantic interoperability	Semantic interoperability is provided
TR-48	DATA	Semantic translation	To achieve interoperability, aerOS shall employ efficient semantic translation mechanisms, e.g., based on an enhanced version of the Inter Platform Semantic Mediator (IPSM) semantic translator.	AP SP AU	App Continuum	General	F	M	aerOS semantic interoperability shall utilize semantic translation	Semantic interoperability utilizes semantic translation
TR-49	DATA	Core data models/ontologies	aerOS Core data models, as the basis for the aerOS internal data flow/exchange should be based on a set of carefully selected ontologies.	AP SP AU	Continuum	Data quality	NF	S	Whenever feasible, aerOS Core data models design should be based on well established ontologies	aerOS Core data models design is based on well established ontologies
TR-50	AI	AI task execution in the continuum	Providing execution environment utilizing heterogenous IE is one of the objectives of aerOS. Among tasks that can be executed in an aerOS deployment should be AI-related tasks.	AP SP AU	App Continuum	General	F	M	aerOS shall enable commissioning and execution of AI jobs using resources available in the continuum.	AI tasks must be executed in the continuum on the IE that matches the user-defined requirements.

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TR-51	AI	Support for non-centralized data processing	aerOS shall be able to process data at the edge and decide which information needs to be transmitted to a central cloud server for further storage and processing.	AP SP	App Continuum	General	C	M	aerOS shall support AI tasks without centralized data processing. Where required, transmission of information to the cloud shall be kept to a minimum from the point of view of bandwidth, as well as security.	A selected AI task must be executed in such a way that training data does not leave a local device, e.g. federated learning implementation.
TR-52	AI	Models deployed in the continuum	aerOS shall support models deployed in different places in the continuum doing predictions. It is the responsibility of a model developer to minimize the model size.	AP SP	App Continuum	General	F	M	AI in aerOS can be envisioned as a process of model training using the available infrastructure or using ready models to support internal or pilot-related functionalities. Predictions may be done on IE "in different places" in the continuum including resource-restricted devices.	At least one IE has running service with deployed model that is used for prediction based on data sent to or available at this IE.
TR-53	AI	User requirements for AI tasks	Users shall be able to specify requirements related to execution of AI tasks according to a pre-established data model.	AP SP AU	App Continuum	Usability Data models	F	M	To be able to effectively use the continuum and execute tasks on resources that best match requirements users shall be able to provide information about the task.	Values for at least 5 parameters describing an AI task to be executed can be specified by the user.
TR-54	AI	AI-related data models adaptability and extendibility	Data models that shall support AI requirements and workflow definitions should be extendable and adaptable to new cases.	AP AU	App Continuum	Data models	NF	S	Large amount of possible use cases / algorithms / models / data may be utilized with aerOS architecture which requires the possibility to describe them using aerOS metadata.	There is a possibility to add new attributes to the existing data models without need to change the already implemented logic for the attributes that existed in the model before.
TR-55	AI	Compliance with frugal AI paradigm	When possible and required by the user, execution of AI tasks should be aligned with the concept of frugality.	AP SP AU	App Continuum Edge	General	NF	M	aerOS is designed for edge-cloud continuum which requires mechanisms that can deal with nodes (IEs) with limited resources. This shall be considered when designing and implementing AI-based mechanisms especially close to the edge by applying frugality where necessary.	For AI implemented in aerOS (internal or external) at least one frugal technique for AI shall be present.

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TR-56	AI	Support for data frugality	aerOS shall provide mechanisms for tackling data frugality (small amount of training data and/or labels).	AP SP AU	App Continuum Edge	General	NF	M	aerOS is designed for edge-cloud continuum which requires mechanisms that can deal with nodes (IEs) with limited data available for model training. This shall be considered when designing and implementing AI-based mechanisms especially close to the edge by applying frugality where necessary.	For AI implemented in aerOS (internal or external) at least one frugal technique directed at limited data for AI shall be present.
TR-57	AI	AI tasks orchestration	aerOS shall provide mechanisms for AI tasks orchestration to provide reliability.	AP SP	App	Reliability	NF	M	AI tasks (e.g. training of models) can be executed in a distributed way (e.g. federated learning) which requires orchestration including: task execution and monitoring. This should increase the reliability provided by the system.	The AI tasks can be executed in a distributed way. aerOS mechanisms are used to provide reliability.
TR-58	AI	AI tasks monitoring	aerOS shall provide mechanisms for task execution monitoring.	AP SP	App	Usability Reliability	NF	S	AI tasks can be long running and the aerOS-based system shall provide means to check the current status.	There is a possibility to check the status of AI tasks that was commissioned to be executed in aerOS-based system.
TR-59	AI	Reliable AI task execution	aerOS shall react to changes in the environment to provide a reliable AI execution environment.	AP SP AU	App Continuum	Reliability	NF	M	The edge-cloud continuum can include resources with various capabilities, connectivity and stability. There shall exist mechanisms to adapt the AI task execution to current state of the environment to increase the reliability.	The AI task that was commissioned to be executed in aerOS-based system can be finished even if some unpredicted changes in the environment happened (for which aerOS has some mitigation and reaction techniques).
TR-60	AI	AI tasks user requirements to resource matching	aerOS shall be responsible for matching user requirements to capabilities of resources available in the continuum.	AP SP AU	App	General	NF	M	User shall have the possibility to define AI task-related requirements and, on the other hand, IEs in the continuum have their configurations and capabilities. These information shall be matched to select best place to execute the job in the continuum using aerOS orchestration.	User can commission AI tasks execution to the continuum without knowledge of underlying physical infrastructure or selecting specific IEs.

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TR-61	AI	AI task description	User shall be able to specify characteristics of the AI task covering algorithm, required data and resource configuration restrictions.	AP SP AU	App	Data models	NF	S	User shall have the possibility to define AI task-related requirements with respect to a predefined data model.	aerOS provides a mechanism and data models to define AI tasks to be commissioned to an aerOS-based system.
TR-62	AI	Internal and external AI support	aerOS components shall allow for execution of AI tasks originating from internal use cases (supporting aerOS mechanisms) and external use cases (originating from applications).	ALL	App Continuum	General	C	M	aerOS shall enable to execute AI tasks specific to pilot applications but may as well use AI to enhance its internal mechanisms.	There is at least one scenario for internal AI and one for external AI in aerOS.
TR-63	AI	Explainability support	aerOS shall support explainability of models.	AP SP AU	App Continuum Edge	General	F	M	To enhance the trustworthiness of the whole solutions selected AI should be explainable or interpretable.	At least one AI application scenario includes explainability or interpretability.
TR-64	DATA	Data cataloguing	Metadata about the available data sources and the data they provide	AU SP	Continuum	Data quality	F	M	Data consumers within aerOS (either users or aerOS internal services) need a way for discovering the data that are available in aerOS continuum	Standard interface that exposes the data catalog towards data consumers
TR-65	DATA	Data collection	Automated ingestion of data in the data infrastructure	ALL	Continuum	Accessibility	F	M	Data infrastructure must orchestrate and automate the collection of data from their data sources on behalf of data consumers	Mechanisms for collecting data which will be implement based on the nature of the target data source
TR-66	DATA	Data privacy labeling	Annotation of sensitive data such as Personal Identifiable Information (PII)	ALL	Continuum	Privacy Security	F	C	Definition of data governance policies for data access must consider sensitive data	Mechanism for annotation of data as sensitive

ID	Refers to	Name	Description	Role	Domain	Category	Type	Pri-ority	Rationale	Acceptance Criteria
TR-67	DATA	Data provenance	Metadata about history of data in a data pipeline	ALL	Continuum	Data quality Security	F	S	Tracing the history of data throughout its life cycle is needed for providing trust in the data	Mechanism for collecting provenance information about data
TR-68	DATA	Context-aware data access	Definition of data access policies based on context information related to the target data and the data consumer	ALL	Continuum	Privacy Security	NF	S	Data access policies must be defined with a fine-grained level based on context information	Access control mechanism for defining data access policies based on the role of the consumer and the context of the target data
TR-69	DATA	Distributed data management	Management of data across different data infrastructure instances	ALL	Continuum	General Performance Standards	NF	M	Distributed data management throughout the continuum is needed in order to scale and adapt in dynamic data exchange scenarios	Standard mechanisms and interfaces to enabled distributed data infrastructures
TR-70	DATA	Data integration	Combination of data from different heterogenous data sources	ALL	Continuum	Accessibility Standards	NF	M	Data consumers will greatly benefit from having a holistic view of data across the continuum	Mechanisms to adapt collected data into a unified data model based on the semantics of the data
TR-71	DATA	Data-as-a-product	Management of data as a product that can be easily shared among consumers	ALL	Continuum	Accessibility Standards	NF	M	Exposing data following the Findable, Accessible, Interoperable, Reusable (FAIR) principles to enable interoperability among data consumers in the continuum	Standard interfaces and standard data models to facilitate interoperability
TR-72	SECURITY	Cybersecurity tools	Implementation of cybersecurity tools that will support the DevPrivSecOps procedures of aerOS	ALL	ALL	Security Privacy	NF	S	The cybersecurity tools are essential for DevPrivSecOps	Sufficient cybersecurity tools to support the DevPrivSecOps procedures

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TR-73	SECURITY	Privacy-preserving functions	Deployment of functions that aim at the protection of privacy by protecting sensitive data from unauthorized access	ALL	ALL	Privacy	NF	S	Protection of sensitive data from unauthorized access	Mechanisms for the protection of sensitive data from unauthorized access are realized
TR-74	SECURITY	Trust establishment	Employment of mechanisms to establish trust within aerOS ecosystem	ALL	ALL	Security Trust	NF	S	Trust establishment in aerOS	Trust score calculation and trust management are realized
TR-75	SECURITY	Cybersecurity policies	Establishment of cybersecurity policies to define who can do what and when	ALL	ALL	Security	NF	S	Cybersecurity policies to enhance and maintain the security of aerOS	Policies that define who can do what and when are realized
TR-76	SECURITY	Security and management of identity and access in aerOS	Integration of Keycloak with OpenLDAP provides a comprehensive solution for secure authentication, authorization and user management	ALL	ALL	Security Trust	NF	M	Keycloak with OpenLDAP provides a robust, flexible, and comprehensive security solution. It combines Keycloak's modern identity management and access control features with OpenLDAP's powerful directory services.	The synchronization between Keycloak and OpenLDAP is crucial for maintaining data integrity and ensuring that authentication and authorization processes run smoothly.
TR-77	SECURITY	Security features to protect API's	High performance API Gateway that provides several features to enhance the security of aerOS API infrastructure. The implementation is based on KrakenD	ALL	ALL	Security Privacy	NF	M	KrakenD, as an API Gateway, provides a range of security features to protect APIs from various threats.	The effectiveness in securing an API infrastructure depends on proper configuration and maintenance of these features.
TR-78	SECURITY	Distributed Trust Management	Dynamic Trust management for devices utilizing DLT technologies and MQTT protocol	ALL	ALL	Security Trust	NF	S	Distributed management of trust within aerOS	Continuous attestation of trust for all devise onboarding the system or roaming between different domains and revoking access to untrusted devices

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TR-79	SECURITY	Authentication and authorization accounting	Establishment of logs that record, based on the policies, who did what and when	ALL	ALL	Maintainability	NF	M	It is a must having an accounting system so as to register every single authentication and authorization within the aerOS continuum. This will help traceback and debug unexpected behaviors that pose conflict with the expected cybersecurity policies.	An accounting system (probably accessible via graphical frontend) that registers every authentication and authorization grant and deny, is realized.
TR-80	SECURITY	User interface for cybersecurity control	GUI to set cybersecurity policies and to check the access logs	ALL	ALL	Maintainability Accessibility	NF	M	It is a must having a graphical user interface to easily adjust security and privacy policies; and also to check whether incidents take place	Intuitive, user-friendly user interface that enables policy configuration and access log review
TR-81	SECURITY	DevSecOps coding environment	A set of plugins and guidelines for the desired programming IDE that lead to the production of safe and clean code	ALL	ALL	General	NF	S	Prior to taking any SAST/DAST testing, the coding environment should be aware of the security, privacy and efficiency constraints. Sets of plugins should guide the developer to the optimal code regarding security and efficiency.	Defined set of plugins and guidelines to adopt during development
TR-82	DEVELOPMENT	Code repository	Source Code Management tools where the different project developments will be uploaded	ALL	ALL	Maintainability	NF	M	Source Code Management tools where the different project developments will be uploaded	A code repository and Source Code Management tools are provided
TR-83	DEVELOPMENT	Continuous Integration and Continuous Delivery	Deployment of a Continuous Integration / Continuous Delivery (CI/CD) pipeline	ALL	ALL	Maintainability	NF	S	Deployment of the Continuous Integration / Continuous Delivery pipelines in the project repository	CI/CD pipelines are deployed resulting to secure and private code within the project.
TR-84	DEVELOPMENT	Static and dynamic code test	SAST/DAST pipeline	ALL	ALL	Maintainability	NF	S	Implementation of automatic code testing in the development and operation phases	Static and dynamic code testing to identify vulnerabilities and ensure quality, design safety and functional code.
TR-85	DEVELOPMENT	Security analysis in Software Development Life Cycle	Security threat modeling	ALL	ALL	Security	NF	S	Security threat modelling to detect weaknesses in the aerOS platform and define mitigation actions	Security-preserving tools in application development and infrastructure to create security-by-design solutions and a secure aerOS platform.

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TR-86	DEVELOPMENT	Privacy analysis in Software Development Life Cycle	Privacy Threat analysis	ALL	ALL	Privacy	NF	S	Privacy threat modelling to detect weaknesses in the aerOS platform and to define mitigation actions.	Privacy-preserving tools in application development and infrastructure to create privacy-by-design solutions and a secure platform.
TR-87	ANALYTICS	Embedded Analytics Tool (EAT) Platform	Development of a lightweight platform for the deployment and testing of analytical functions.	AP SP AU	App	General Performance Robustness	F	M	A flexible platform for the deployment and execution of analytical functions will allow both network operators and customers to instantanciate a variety of features such as context aware decision making for orchestration and management, or insights into existing data	The demonstration of one or more functions producing a noticeable change in network/customer operations
TR-88	ANALYTICS	EAT Interfaces	Development of interfaces for the triggering of analytical functions, data retrieval and communication with actuators	AP SP AU	App	Accessibility	F	M	The establishment of interfaces between the EAT and other project components such as Data Fabric, High Level Orchestrator or AI will increase the accessibility of EAT allowing for the component to contribute analytics to a variety of processes if needed. These interfaces enable customers to create functions specific to their needs	The demonstration of EAT functions utilising a variety of interfaces to solve a task. Full use of interfaces would include the triggering a function by an aerOS component, retreival of data through the data fabric and the communication of results to another aerOS component. reporting the result to the orginal triggering component.
TR-89	ANALYTICS	EAT Functions	Support for analytical function design through templating	AP SP AU	App	Accessibility	NF	S	As functions intend to be leveraged by both network operators and customers, supports must be provide to enable users to create their own functions. This will be addressed to detailed support documentation and the use of templating for function creation	The demonstration of functions created by project partners specific to their use cases
TR-90	ANALYTICS	EAT Visualisation	Support for visualisation of in-function metrics	AP SP AU	App	Accessibility	F	S	The visualisation of network metrics is an important feature for both network operators and customers. Analytics can involve non intuitive processes and results. However by visualising these results insights can become more obvious, especially to non	The visualisation of in-function metrics through easily accessible dashboards

ID	Refers to	Name	Description	Role	Domain	Category	Type	Pri-ority	Rationale	Acceptance Criteria
									technical users.	
TR-91	ANALYTICS	EAT aerOS Utility Function	The design and implementation of 3 analytical functions, these generalised functions will provide stratified sampling, anomaly detection and data drift	AP SP AU	App	Performance Reliability Data Quality	F	S	The visualisation of network metrics is an important feature for both network operators and customers. Analytics can involve non intuitive processes and results. However by visualising these results insights can become more obvious, especially to non technical users.	The triggering of the utility function by another project component to solve a task, for example triggering a stratified sampling feature for Frugal AI
TR-92	DATA	Data product ownership	Support for mechanisms to enable owners of data products to expose their data products in the continuum.	AU	Continuum	Accessibility Standards Security Data Quality	F	M	Based upon the definition of a data product in aerOS. Only owners of data should be allowed to onboard their data products in the data fabric. This will ensure high quality data and accountability.	Secure interface for authorized data owners to onboard data products.
TR-93	DATA	Ontology development methodology	Methodology for the development of ontologies that to enable data integration in the knowledge graph of the continuum.	AU IP AP	Continuum App	Data quality Accessibility Standards	NF	M	Following a common, standard methodology will help aerOS users to develop ontologies for their use cases.	Procedure defined and tools for their implementation identified.
TR-94	DATA	Data pipeline orchestration	Orchestration of data pipelines to enable the integration of data sources in the knowledge graph.	AU	Continuum App	Accessibility	F	M	Abstract aerOS data owners from the underlying complexities of data engineering.	The demonstration of the creation of a data pipeline based on the requirements specified by the data owner.
TR-95	NETWORK	Secure networking connectivity	Ensure cross domain private and secure communication	AU SP	Continuum App	Security Accessibility	F	M	aerOS domains expose services for resources' orchestration and sharing domain status data, and also host application workloads. Communication both among aerOS services and among workloads should be private and secured.	TLS for exposed domains endpoints and VPN for cross domain clustering
TR-96	NETWORK	3GPP NEF integration	aerOS should expose data from 3GPP APIs regarding access networks	AP	Edge Network Application IoT	Automation Development Availability	F	C	aerOS integrates IoT resources for which the access network can provide data which could enable the development of applications	aerOS service providing NEF APIs as defined by 3GPP
TR-97	AI	Explainability support on-demand	Explainability is an additional computational overload and it should be configurable when to enable it for internal aerOS use cases.		App Continuum	General	F	M	Explainability/interpretability adds computational overhead to AI which may be omitted in scenarios where explainability is not required.	There is a possibility to enable or disable explainability for internal aerOS use cases.

ID	Refers to	Name	Description	Role	Domain	Category	Typ e	Pri-ority	Rationale	Acceptance Criteria
TR-98	AI	Explainability results should be available for the aerOS administrator	Explainability is an information directed at the aerOS administrator and should be presented to him using appropriate interface.		App	General	F	M	Explainability should enable the administrator to understand aerOS decisions and monitor the operations.	There is an interface available which can be used to view explainability results.
TR-99	AI	Model reduction support	Frugality mechanisms proposed in aerOS research should include methods to reduce the AI model, e.g. by pruning.		App	General	F	M	Model reduction is one of the most popular technique to minimize AI models, therefore it should be research among aerOS approaches.	Results of evaluation of model reduction applicability to at least one aerOS scenario should be available.
TR-100	DEVELOPMENT	aerOS DevPrivSecOps guidelines	aerOS secure and privacy by design development guide	AL L	ALL	Security Privacy	NF	M	Security and privacy implementation guidelines for aerOS developers. This will allow the project developers to generate privacy and security by design code.	1 document for the implementation of the methodology
TR-101	SERVICES	Service availability and reliability	Availability and reliability metrics of domains for aerOS services	AL L	Continuu m Network	Availability Reliability Performance	NF	S	Service providers have specific availability and reliability requirements to provide the best service experience. To help with the selection of domains, the aerOS continuum should provide the metrics on the availability and reliability for a service.	Each service provider has access to the availability and reliability metrics of the provided service.
TR-102	SERVICES	Communication of distributed services in real-time	The aerOS continuum should provide real-time communication capabilities to services with underlying network technologies, such as TSN or 5G.	IP NP SP	Continuu m Network	Performance	F	S	A service provider that provides multiple services may need real-time communication between services. This includes guaranteed latency, low jitter, etc. The aerOS continuum should support low latency communication between distributed services.	Services can use underlying real-time capable networking hardware to achieve real-time communication.

B. User and System Requirements table

Table 2. Functional (F) and non-functional (NF) requirements of Pilot 1.

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P1-1	Real time data management and response	F	System	S	A real time data acquisition, processing and fast response is needed for actuators located in a manufacturing facility.	aerOS should be able to efficiently acquire and process data from a variety of devices (sensors…), in order to offer a fast response to actuators and rapidly act to avoid possible deviations.	aerOS must offer a real-time response when a parameter deviation is detected	5	NO	INNO
R-P1-2	Computing resources (cloud & edge)	NF	System	M	In order to fulfil R-P1-1 achieving real time data processing we need huge computing resources	aerOS should be able to host all the computational workload required in an industrial environment		5	NO	NASERTIC
R-P1-3	Low latency communication between edge devices and with cloud	NF	System	M	In order to fulfil R-P1-1, not only do we need high processing capabilities but also we need to access to the sources of information and to the sources of the intelligent decisions fast enough	aerOS should be able to guarantee a federated organization of devices while ensuring low latency communications among them. All on-field IoT devices must be able to intercommunicate rapidly, and they also must be able to communicate rapidly with the cloud or any other agent taking the intelligent decisions.	aerOS must guarantee that all decisions are taken applied before it is too late on the production line, even faster than what the current scenario is able to deliver	5	NO	NASERTIC
R-P1-4	Secure communications between edge devices and with the cloud	NF	System	M	Confidential information of industrial scope must remain confidential when transporting data from one device to another. Furthermore, no man in the middle should be able to intercept, alter or introduce any instructions to be taken by the industrial machinery. Any of these outcomes would lead to huge losses to the affected factory or enterprise.	aerOS should be able to guarantee secured communications, following the main cybersecurity standards in all communications between any given devices	At any given point in the communication of two devices, the information must be indecipherable and must remain integral (not modified by a third party).			
R-P1-5	Compatibility among heterogeneous devices and industrial machinery	NF	System	M	Production lines are made up of a variety of machinery which makes for a great heterogeneity of devices. This heterogeneity takes place within a given production line and accross different production lines in different factories. Making all different devices understand each other within the continuum would boost the productivity.	Production lines are made up of a variety of machinery which makes for a great heterogeneity of devices. This heterogeneity takes place within a given production line and accross different production lines in different factories. To really foster aerOS continuum, all those devices must be able to intercommunicate and understand each other in spite of its heterogeneity.	aerOS continuum and Industrial OT protocol interoperability	5	NO	NASERTIC
R-P1-6	Interoperability of the technology, which enables a various kind of data, IoT-Devices and interfaces.	NF	System	M	Same to R-P1-5	As a supplement to R-P1-5, aerOS should be built interoperability so that a wide variety of protocols, formats and interfaces are possible	Common Formats for Data echange industries are covered (OPCUA, REST-API etc.)	5	NO	SIPBB

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P1-7	Support for various types of devices, even at different levels	NF	System	M	In production lines various types of devices at different levels are present. A continuum which is able to connect these on common platform enables completely new possibilities	In production lines various types of devices such as machine tools, AGV's, 3D-printers, sensors, actuators, complete Systems etc. are present. A continuum which is able to connect these on common platform enables completely new possibilities	It must be possible to connect various types of devices on different levels. For example, AGV's, 3D-printers and an ERP-system.	4	NO	SIPBB
R-P1-8	Real time dashboarding of processed and/or collected data	F	System	M	To display collected and processed data enables understanding possibilities for workers and also customer if data is shared with them	It is able to display processed and/or collected data in some kind of dashboarding tool.	Provision of Simple charts with the time on the X-Axis and the according value one Y-Axis. In addition simple bar chart for comparisons would be great.	5	NO	SIPBB
R-P1-9	Integration with Existing Systems	NF	User	M	Production line monitoring systems differ from site to site. Seamless integration is needed to avoid disruption or conflict.	AerOS must be integrated seamlessly with existing systems, such as Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES), to streamline production workflows and data exchange.	AerOS integration should not cause disruptions or conflicts in the production line.	4	NO	SIPBB
R-P1-10	Ease of re-configuration	NF	System	S	aerOS must guarantee versatility to the end user, the end user should be able to re-configure if necessary by himself	aerOS should be easy to re-configure in the case it is needed to apply changes to the production plant	the end user should be able to make minor changes to his system and trained to re-configuration	4	NO	MADE-POLIMI
R-P1-11	Virtual Test simulation	F	System	S	The end user should be able to test the functionality of the aerOS system before going online in the real plant	The end user should be able to test the functionality of the aerOS system before going online	The end user can test the platform before integrating in the real production plant	5	NO	MADE-POLIMI
R-P1-12	AI/ML models choice	F	System	M	The AI/ML model to be used from end user perspective should be easy to be set up and it should produce trustful predictions	The system should allow to select the best AI/ML model that better produces predictions	The system allows to select among some AI/ML model that better produces predictions	5	NO	MADE-POLIMI
R-P1-13	AI/ML model setup	F	System	M	AI/ML capabilities should have an intuitive HMI to help user to easily configure the system	AI/ML capabilities should have an intuitive HMI to help user to easily configure the system	AI/ML capabilities have an intuitive HMI to help user to easily configure the system (e.g. providing interesting dataset for the purpose, provide interested output of prediction based on data model)	5	NO	MADE-POLIMI

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P1-14	Efficient Task Rescheduling and Allocation	NF	System	M	The dynamic nature of manufacturing processes, especially in scenarios involving AGVs and robotic arms, requires the ability to reschedule and reallocate tasks efficiently to adapt to changing production needs.	aerOS should be capable of real-time monitoring of production line status and AGV/robotic arm availability. Based on this data, it should efficiently reschedule and allocate tasks to available AGVs and robotic arms, ensuring optimal use of resources. The system should be able to dynamically adjust task assignments in response to real-time changes in the production environment.	aerOS must demonstrate the ability to adjust task schedules and allocations within a minimal response time, showing a marked improvement in resource utilization and operational efficiency compared to the current scenario.	4/3	NO	SIEMENS
R-P1-15	Advanced Object Recognition and Handling	F	System	M	The ability to accurately recognize and handle various objects is crucial for the successful implementation of AI-driven pick-and-place operations by robotic arms in a manufacturing setting.	AI vision software should enable the robotic arm module to recognize a wide range of objects. This involves accurately identifying object characteristics (size, shape, weight) and determining the appropriate handling strategy. The system should ensure precise and safe manipulation of objects, whether for assembly, sorting, or storage purposes.	The AI vision software and robotic arm must accurately identify and handle at least 95% of objects presented, with minimal errors in object recognition and handling. The system should also demonstrate a significant reduction in manual intervention for object handling tasks.	5/5	NO	SIEMENS
R-P1-16	Implementation of Time-Sensitive Networking (TSN) for Synchronized Operations	F	System	M	In automated manufacturing environments, particularly those involving AGVs and robotic arms, the precision and synchronization of operations are crucial. Time-Sensitive Networking (TSN) is essential for ensuring real-time communication and coordination between devices with strict timing requirements.	TSN to enable deterministic communication, ensuring that data packets are delivered with low latency and minimal jitter. This implementation is crucial for the synchronized operation of AGVs, robotic arms, sensors, and other connected devices. TSN will ensure that time-critical tasks are executed in a precisely coordinated manner, essential for maintaining the integrity and efficiency of the production process.	The system must demonstrate that it can maintain synchronized operations across various devices with a timing accuracy better than 1 millisecond. The rate of communication delays or synchronization errors should be negligible, ensuring seamless and uninterrupted production workflows.	4/2	NO	SIEMENS
R-P1-17	Support for “on-demand” real-time critical service operation and configuration	F	System	S	Services should be triggered on-demand for autonomous rather than automated process operation.	Production modular and flexible zero defect manufacturing functions require the configuration and operation of manufacturing assets (scanning sensors, IoT sensors, drives, controls) as well as timely implementation of command control protocols that could be triggered “on-demand”	Metrology equipment critical services and computing resources activated on a flexible manner	4	NO	INNOVALIA

Table 3. Functional (F) and non-functional (NF) requirements of Pilot 2.

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P2-1	Scheduling with real-time adjustments support	F	System	M	User should be able to modify task	aerOS should react to changing context and conditions and adopt application and job execution accordingly	Adjust execution parameters for the scheduled task. Check the result.	4	NO	CF
R-P2-2	Shifting computing tasks across time	F	System	M	System should be able to process urgent/specific needs task if no harm to other in the queue.	aerOS should react to changing circumstances and use predictions of heavy the workload will be and what type of energy will be available to create task queues and adapt the execution environments for specific tasks	Demonstrate scheduled task reschedule after adding new task with higher priority or specific demand.	4	NO	CF
R-P2-3	Support for execution of user applications/jobs	NF	System	M	User should be able to provide own docker images with no need pro pre-install them by an administrator.	aerOS should support execution of applications delivered by end user using the provided infrastructure	User uploads custom docker image and uses it to schedule task.	5	NO	CF
R-P2-4	Application/job conditions definable by the user	F	System	S	Enable user control of carbon footprint and schedule	User should be able to define how fast they need the results, where (topologically and geographically) processing should be performed and what should be the renewable energy usage rate for their processing.	Schedule the task with desired execution parameters. Check parameters after schedule.	5	NO	CF
R-P2-5	Support for movable workload in batches	F	System	M	Big tasks split into batches can be evicted/transferred without losing already done work.	Important characteristic of a task in this service is its limited execution time. In order to efficiently populate the system we need to have workload that is movable and in batches. It comes with an additional advantage and requirement: efficient usage of available cloud resources.	Demonstrate launching the Task split in batches	4	NO	CF
R-P2-6	Meta-operating system deployment Portability	F	System	M	Enable remote and heterogeneous devices integration	AerOS should be able to integrate and orchestrate multiple near containerized edge data centres across different networks.	Demonstrate IE integration within aerOS IE	5	NO	CF
R-P2-7	IAM	F	System	M	Enable identification and role management of users	aerOS should be able to define users and assign different roles.	IAM and role management based on existing industry-accepted standard	5	NO	CF
R-P2-8	Traceability	F	System	M	Enable recording and logging actions with regard to corresponding ID	aerOS should log actions during the scheduling and the execution of each task.	aerOS endpoint can provide information on request	5	NO	CF
R-P2-9	Tenant separation	NF	System	C	Enable deployment applications in separate environments	Multiple tenants should be able to deploy non-supervised applications in the same physical location without risk to their activities or to the system	aerOS can create secure, separate environments on a single node	3	NO	CF
R-P2-10	Security rules and policies	F	System	M	Enable different policy and rules for aerOS system.	aerOS should support security rules and policies required	Create a security policy and aerOS and a security rule.	4	NO	CF
R-P2-11	Interoperability	NF	System	M	Enable application deployment across heterogenous hardware resources	aerOS should be able to seamless run the Task on different underlying hardware.	Run the same Task on two different hardware environments.	3	NO	CF

Table 4. Functional (F) and non-functional (NF) requirements of Pilot 3.

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P3-1	(semi) Real-time data analysis	F	System	S	Depending on the situation: timely data analysis would be beneficial in improving the quality of work and automate some of the tasks that are currently handled manually (reducing manual work).	Analysing a given data in a timely manner and give a response back with the required/suggested action.	An analysis of this requirement will be addressed in the KPI evaluation task when implemented algorithms are tested on the suggested platform.	5	NO	JD
R-P3-2	Low latency communication between system components	F	System	S	Monitoring the overall system latency	The main point of interest here is the integration of TTControl's HW (non-John Deere device) with all the other John Deere devices.	Defining a tolerable overall system latency	5	NO	JD / TTT
R-P3-3	Compatibility between different types of devices in the built system	NF	System	M	Compatibility of devices is important for the system to function properly	The main point of interest here is the integration of TTControl's HW (non-John Deere device) with all the other John Deere devices.	Achieving a system with components that can fully communicate with one another	5	NO	JD / TTT
R-P3-4	Compatibility between the built system and the overall architecture of aerOS	NF	System	S	How the pilot will fit into the overall architecture of aerOS, communicate with its different components, and use its available resources	The main point of interest here is the integration of TTControl's HW (non-John Deere device) with all the other John Deere devices.	aerOS must demonstrate the ability to perform distributed computations dealing with large data in real-time. This will be analysed in the KPI evaluation task.	5	NO	JD / TTT
R-P3-5	Local processing of data flow	F	System	S	Examining the processing capabilities and health monitoring of provided HW by TTControl	The main point of interest here is the integration of TTControl's HW (non-John Deere device) with all the other John Deere devices	Able to process the provided data in time and result in actions to take accordingly	4	NO	JD / TTT

Table 5. Functional (F) and non-functional (NF) requirements of Pilot 4.

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P4-1	Develops aerOS IE that integrates data telemetry from cranes into aerOS Data continuum	F	User	M	Telemetry from cranes can be extracted using devices such as PLCs. That telemetry allows designing dashboards and execute algorithms and models to process trends in some specific parameters	In order to benefit from aerOS AI capabilities, it is necessary to feed aerOS with data from the cranes in being monitored in the port	Telemetry from cranes is stored in aerOS data stores	5	NO	PRO
R-P4-2	Integration of TOS with aerOS	F	User	M	TOS installed at ports usually provide alerts/notifications based on internal rules defined for the equipment/cranes available in the terminal. The use of such information provides added-value to aerOS since it can be used as an additional data source for algorithms	In order to exploit the data generated by the TOS, aerOS should implement the mechanisms to retrieve and storage these data	Alerts generated for configured cranes is available in aerOS data storage	4	NO	PRO

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P4-3	Integration of CMMS into aerOS	F	User	M	The CMMS is the system used by the terminals to conduct the maintenance operations of the machinery available in the terminal. The use of maintenance logs can be used in the scenario of predictive maintenance as an additional data input for the algorithms	In order to enrich the predictive maintenance scenario, it is necessary that aerOS provides connectivity with the maintenance system used by the terminal to import relevant information for the AI models.	Maintenance jobs and logs are available in aerOS data storage	4	NO	PRO
R-P4-4	Integration of IPTV camera streams in aerOS	F	User	H	The risk prevention via computer vision scenario requires the feed of at least three video cameras to detect certain patterns in the video frames, and have a clear view of containers form their 6 sides while being handled	In order to scan containers from their 6 sides, it is necessary that aerOS integrates feeds from at least 3 video cameras placed at strategic places in the terminal. These cameras should use the IPTV protocol for a better compliance.	Video streams integrated in aerOS	5	YES	PRO
R-P4-5	Monitor Trolley Wire Rope Enlargement	F	User	M	An early warning system will be put in place that monitors the discrepancy between the distance the limit switches of the trolley wire rope were positioned on the travel length of the boom with the distances that were stored in the first calibration of the machine. The warning system will predict in advance when it becomes faulty, allowing the Technical Department to plan for this issue before any undesired working condition	In order to predict when the wires in a crane must be replaced due to wear out, it is necessary to develop an AI model that, using telemetry from the crane, can provide an alert on when the wire's elongation can lead to a failure.	Model trained and in execution for IEs in STS cranes	5	NO	PRO
R-P4-6	Motor Filter Condition	F	User	M	Monitor motor speed as well as load and motor bearing housing temperature to determine if the bearings of the motor have degraded and require replacement	In order to predict when bearings in the engine need replacement, aerOS will develop an AI model that, using engine telemetry, can generate an alert before the engine fails	Model trained and in execution for IEs in STS cranes	5	NO	PRO
R-P4-7	Motor Bearings Condition	F	User	M	Measure variability between the 2 motors, master and follower hoist motor to monitor that they share the load equally. This could indicate a misalignment of one of the motors, coupling degradation, motor degradation or closed loop control issue (Speed Encoder, Parameters, Inverter etc.).	In order to avoid engine load degradation, aerOS should provide an AI model that detects and predicts motor degradation by comparing the shared load between master and follower engines in the cranes	Model trained and in execution for IEs in STS cranes	4	NO	PRO
R-P4-8	Motor load sharing from Hoist	F	User	L	This would check when the deviation between the 2 cylinders has increased greatly or avoid the disparity and notify personnel to check the wire ropes	In order to predict wear out cables in straddle carriers, aerOS should provide an AI model that uses telemetry and detects disparity between the deviation of the 2 cylinders	Model trained and in execution for IEs in STS cranes	3	NO	PRO
R-P4-9	Tensioning Aux Cylinder Pressure Monitoring	F	User	L	To calculate and monitor efficiency genset system by measuring power delivered to the engine in terms of fuel l/h and electrical energy produced. To do so, three main data inputs will be monitored: engine fuel consumption, generator output, and outdoor temperature.	In order to predict the efficiency of the generator engine, aerOS will provide an AI model that uses telemetry to detect low efficiency and predict the required maintenance	Model trained and in execution for IEs in straddle carriers	4	NO	PRO

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P4-10	Generator engine efficiency	F	User	M	Monitor motor speed as well as load and motor bearing housing temperature to determine if the bearings of the motor have degraded and require replacement	In order to predict when bearings in the engine need replacement, aerOS will develop an AI model that, using engine telemetry, can generate an alert before the engine fails	Model trained and in execution for IEs in STS cranes	4	NO	PRO
R-P4-11	Genset vibrations	F	User	L	To monitor vibration on genset and predict if this is related to genset mounting failures, or engine injector issues. The main variables to be recorded are: genset vibration, generator output frequency, and generator output load.	In order to discriminate the source of vibrations in the genset, aerOS will provide an AI model that uses telemetry from the straddle carrier and can discriminate whether the vibrations come from the genset or from the engine injectors due to wear out.	Model trained and in execution for IEs in straddle carriers	3	NO	PRO
R-P4-12	Inclination issues	F	User	M	To monitor the inclination of the straddle carrier during operation and send warnings if the system is behaving abnormally. The system should provide the main reason that could be due to e.g., suspension failing, tyres, etc. It will take into account not only machine inclination, but also load height, machine side frame speed difference, or if it is transporting a container or not	In order to prevent risky situations due to inclination of the straddle carrier, aerOS will provide an AI model that uses telemetry and detects dangerous situations, discriminating the source of the abnormal inclination	Model trained and in execution for IEs in straddle carriers	4	NO	PRO
R-P4-13	Hydraulic system	F	User	L	Hydraulic Pressure Instability can indicate issues in the system, accumulator or pressure regulators that are faulty. Several pressure transducers will be placed on the machine to measure the system and alert if there is an anomaly based on the machine operation, including also parking brakes engaged or not, spreader motion ON/OFF and outdoor temperature.	In order to prevent failures in the hydraulic system, aerOS will provide an AI model that monitors telemetry from straddle carriers and detects episodes of pressure instability that can lead to a malfunction	Model trained and in execution for IEs in straddle carriers	4	NO	PRO
R-P4-14	Container plate identification	F	User	M	Automatic identification of container plate numbers allows enhanced management of processes inside the cargo area	aerOS will provide frugal AI services based on computer vision that will identify the container plate number when the crane is handling the container in the cargo area	Plate numbers MUST be identified using computer vision independently of their location in the container	4	YES	PRO
R-P4-15	Detection of damaged containers	F	User	M	In order to ensure security on the load/unload operations, damaged containers that may lead to unsure operations (e.g., broken, split or cracked walls) should be detected and handled with special care.	In order to detect possible damaged containers while they are operated, aerOS should be able to detect different structural damages on the container's surfaces.	Algorithm trained and in execution	3	YES	PRO
R-P4-16	Detections of holes in containers	F	User	M	To ensure the security of the workers in the terminal, it is necessary to detect possible structural damages in containers that may lead to cargo being dropped through a hole into the working area	In order to ensure safety of workers and machinery, containers with severe damages and holes may be detected using video streams	Algorithm trained and in execution	3	YES	PRO

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P4-17	Detection of wrongly sealed containers	F	User	M	Containers are sealed when they are shipped. If the sealed is broken, someone may have manipulated the cargo inside. To ensure that containers being departed from the terminal are correctly sealed, it is necessary a mechanism to automatically detect the seal at specific positions in the container's outside.	In order to have traceability of sealed containers, aerOS will develop a CV module that can detect when a container carries a seal or not	Algorithm trained and in execution	4	YES	PRO
R-P4-18	Frames per second processed by CV algorithms	NF	User	M	Algorithms should be fast enough to perform inference process in almost real-time	In order to reduce bandwidth and storage size, CV algorithms should be capable of performing inference training as fast as possible	10 frames per second	4	NO	PRO
R-P4-19	Maximize evaluation metrics for AI models for PdM	NF	User	M	AI models should have a minimum quality of performance	In order to provide trustable data for final users, models will be evaluated with their corresponding metrics in order to assure trustable predictions	A quantitative analysis in terms of R2 and other evaluation metrics will be addressed in KPI evaluation task	4	NO	PRO
R-P4-20	Maximize evaluation metrics for AI models for CV	NF	User	M	CV models should have a minimum quality of performance	In order to provide trustable data for final users, models will be evaluated with their corresponding metrics in order to assure trustable predictions	A quantitative analysis in terms of accuracy and other evaluation metrics will be addressed in KPI evaluation task	4	NO	PRO

Table 6. Functional (F) and non-functional (NF) requirements of Pilot 5.

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P5-1	Cloud storage capacity	NF	System	M	2) Federated Learning: A generic model from the cloud is copied to each building, which then trains it with the local generated data. The updated models (and not the data) from each building are shared with the main model in the cloud. The central model combines the different updates and generates a new model which is then distributed again to the buildings.	Exhibit that the pipeline is working through the generation of the appropriate ML models.	Exhibit that the pipeline is working through the generation of the appropriate ML models.	5	NO	INF
R-P5-2	Support any IoT sensor type and protocol	NF	System	M	New IoT technologies should be incorporated to keep the Pilot5 service being state of the art	The pilot5 platform shall support or be able to support any sensor, any sensor platform and any access technology (WiFi, 2G/3G/4G, NB-IoT, LoRaWAN, sigfox, etc.), so as the sensors can be deployed in any environment (indoors, outdoors, fixed, mobile, wearable).	Demonstrate a multi-sensor IoT network deployments, including various sensors and access technologies.	2	NO	COS

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P5-3	Automatic service recovery upon system or network loss	NF	System	M	Service Outage is not acceptable because it can lead to idle labor hours (employees stranded with no placement recommendations)	The pilot5 platform should survive network loss, or system outage and all devices must be automatically restored in the event of failure.	Demonstrate that the sensors and smart building applications automatically reconnect and resume operation upon a network or system failure	5	NO	COS
R-P5-4	IoT Data Collection and processing fully automated, reliably transferred in a configurable manner	NF	User	M	Data completeness and promptness is vital for training the recommendation system and pilot5 intelligence algorithm	The pilot5 data collection should be automated with no human intervention and the user shall be capable of defining the interval between consecutive measurements. Moreover, data must be stored locally in case of communication disruption and be loaded in bulk mode to the backend/cloud.	Demonstrate the automated uploading and storage of measurements at the aerOS cloud infrastructure	4	NO	COS
R-P5-5	IoT system automatic configuration management	NF	User	M	Users do not want to be involved in tedious, time consuming tasks of housekeeping especially since these tasks can be automated	Updates, bug fixes, enhancements associated with sensors' capabilities shall be done without the user's intervention. The user should be notified about the "context" of those changes.	Demonstrate Over-The-Air (OTA) updates.	3	NO	COS
R-P5-6	User-friendly monitoring of system health and remote management	F	User	M	Users need to know at any time if the pilot5 platform is fully operational and offers reliable results/recommendations. Each type of user (employee, maintenance staff, building owner) will have different interest on the level and kind of information to be monitored and this needs to be flexibly supported.	Event Handling/Alarm process, Visualisation dashboards customised per user needs are necessary.	Generate various monitoring dashboards and control buttons based on the pilot5 user profiles.	5	NO	COS
R-P5-7	Scalability to Support Mass Deployments	NF	System	S	The pilot5 system must be easily setup for use in each (new) building	The pilot5 platform shall be capable of integrating mass sensor deployments (in a step-wise approach) without compromising its performance (e.g. delays in measurements storage or delays in data retrieval).	Demonstrate that adding a new smart building is efficient with no unnecessary steps.	2	NO	COS

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P5-8	Data Analytics & Decision Making at the Edge	F	User	M	Pilot 5 considers self-managed autonomous buildings, and as such intelligence must be demonstrated	By considering the metrics received by a vast range of sensors, the employee's data, historical data on energy consumption, CO2 emissions per office segments, historical data on employees' routine/preferences, the aerOS pilot 5 intelligence system (i) shall select the appropriate room and most suitable seat(s), and instantly direct the employee to pick from the alternative seats proposed through the use of a Mobile App. (ii) Shall exploit the sensors data to actuate appropriately the ventilation, heating and air-condition systems as well as control luminosity. (iii) Exhibit swarm intelligence among the AEROS capable sensors to allow them to co-operate in a decentralized manner and collectively manage each room's condition, so that the office becomes self-organised in terms of health and efficiency.	Exhibit intelligent decisions beyond the automation capabilities of the existing IoT systems	5	YES	COS
R-P5-9	APIs for 3rd Parties/Stakeholders	F	System	M	Integration with other external systems and access to raw data through well-defined APIs is an efficient and transparent process to achieve both flexibility/extensibility and security/privacy	The cloud infrastructure shall offer an API for third parties and/or stakeholders/customers enabling access to their own datasets and/or statistics.	Demonstrate the existence of such an API	2	NO	COS

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P5-10	Gateways and Base Stations Heterogeneity	NF	System	M	Gateways and base stations may be different on the set of supported capabilities, their coverage performance, their message aggregation policy, etc.	The gateways shall be able to provide a common set of services to the same type of IoT end devices, regardless of the gateway capabilities. In the same way that various protocols and sensor types will be onboarded in end devices, there will also be different types of gateways to serve either the same set of IoT devices (e.g., gateways that support the same IoT communication protocol but with different capabilities), or a different set of them (e.g., gateways that support different communication protocols). Also, the support of deployments in unlicensed-bands via the functionalities of 3GPP-based networks could be examined (i.e., N3IWF).	Demonstrate multi-gateway deployment (in the scope of the pilot, two or more gateways should suffice).	2	NO	FOG
R-P5-11	Web app for end user-system interaction	F	User	M	An interface to support the end user's interaction with the system.	The web app will have a twofold role. It will act as a virtual assistant for the user to facilitate interaction with the system. The user will be able i) to declare his working desk preferences; ii) receive, by the system, the recommend-ed desks to work; and iii) reserve the desk in which he/she is going to work each day. It will also function as an in-formation portal for the employee, presenting information about the room health index in which the recommended desks reside. The user will also have the option to rate the recommendations and this feedback will be taken into consideration for the evaluation of the system	An interface to support the end user's interaction with the system.	4	YES	FOG

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P5-12	Occupancy policy	NF	System	M	A policy to determine when a spot is truly free.	The worker may temporarily leave his/her spot, and the sensor may mistakenly indicate that this spot is free. The occupancy policy may be based in simple timer (e.g., absence greater that a threshold) or a more complex set of parameters.	False positives rate lesser than 25%	4	YES	FOG
R-P5-13	Message aggregation policy at gateway-level for lower overhead	NF	System	S	An aggregation policy for the uplink messages that arrive to the gateway, to form a packet of multiple IoT end devices' messages and send them under the same header and trailer to the server-side. This requirement will result in lower network overhead for the link between the gateway and the server-side.	The gateways shall implement a message aggregation policy. This suits to pilot 5, since it does not correspond to a time-critical mission use case. For the implementation, it would require a buffering mechanism in the gateway. The advantage is the minimization of the network overhead, since most of the sensors data sizes are of the same order of magnitude of the header/trailer sizes. The policy can be fixed or adjustable to the tradeoff of latency/overhead.	Proven benefits of the policy in terms of network overhead, while the policy does result in a latency that puts QoE below an acceptable level.	1	NO	FOG
R-P5-14	Gateway functionality for harmonizing heterogeneous data	F	System	M	A function either at a gateway-level or after the communication with the server-side but before the server-side storage that can harmonize heterogeneous data.	The function will take as input all the data from all the IoT end devices and output a predefined format for each message. This format will follow the schema of a Data Model based on NGSI-LD, following the context information management standard defined by the	Demo that receives as input heterogeneous data and produces a harmonized output.	2	NO	FOG
R-P5-15	Distributed deployment of workloads/services along the continuum	F	System	M	ETSI. The function can either be integrated in the gateway (gateway-level) or sit between the gateway and the server-side communication. The former approach requires programming of the gateway and maybe remote access in the case of a new data format is defined in the future. The latter approach can be implemented in tools such as NodeRED and is easily extensible from the administrator PC.	Demo that receives as input heterogeneous data and produces a harmonized output.	Efficient distribution of workloads (e.g., ensure that a great number of services are not deployed on the cloud, edge IEs run only the needed services, …)	5	NO	FOG
R-P5-16	Data Interoperability	F	System		Raw data created by a vast majority of different sources are hard to manipulate and be fed to more than one AI algorithms or different applications.	NGSI-LD facilitates data interoperability by creating data models and semantic technologies, enabling this way the smooth integration and exchange of of sensor data from various sources.	Creation of NGSI-LD Data models	3	NO	NCSRD

ID	NAME	CATEGORY	TYPE	PRIORITY	RATIONALE	DESCRIPTION	ACCEPTANCE CRITERIA	SATISFACTION	ETHIC	IDENTIFY BY
R-P5-17	Meta-operating system deployment Portability	F	System	M	Enable remote and heterogeneous devices integration	Smart GW enhanced with 5G connectivity should be also able to be integrated and orchestrated within aerOS IE even though is located at a completely different network	Demonstrate UE integration within aerOS IE	4	NO	NCSRD
R-P5-18	Data privacy annotation	F	System	S	Data that could disclose sensitive information should be annotated as such	Enable authorization rules based on data based on their disclosure annotation in case they provide sensitive information regarding working conditions	Sensitive data collected annotated with appropriate tags	4	NO	NCSRD
R-P5-19	Identity management	F	System	M	Enable identification of users and applications upon accessing IE services	As APIs and possible GUIs will be accessible across the IEs federation, identity management should provide enable access control point and provide tokens that can be leveraged for user/application operational capabilities	Identity system based on well-defined standards (OpenID-SSO) integrated.	5	NO	NCSRD
R-P5-20	Cybersecurity policies definition & enforcement	F	System	S	Use security policies in order to provide access to resources or data based on user/role capabilities	A multitude of services will be deployed enabling both access to IE resources and to deployed IoT services. Access to both of them should be firmly and with granularity controlled.	Integrate capabilities services while accessing resources within IE.	5	NO	NCSRD
R-P5-21	Traceability	F	System	C	Enable logging of actions regarding who did and when	As the system exposes IoT data and services manipulation that can determine working conditions and errors or malign activities can have consequences, it is critical to track decisions to recognize possible procedure errors or “bad intentions”	Service endpoint which can provide traceability information	2	NO	NCSRD

C. Legal Framework of Pilot 3

Appendix C – Legal Framework Survey

1. REGULATORY BODIES & DATA PROTECTION AUTHORITIES

1.1. Which EU-wide regulatory bodies & data protection authorities do you have or could you connect with?

https://www.tttech.com/privacy-policy

1.2. Which national and local regulatory bodies do you have or could you connect with?

TTControl as a part of TTTech Group has interactions with several regulatory bodies on national and international levels, see below for more details.

1.3. Do you have any conflict of interest with those regulatory bodies?

No.

2. EUROPEAN UNION FRAMEWORK

2.1. Have your government or local regulations incorporated the following?

(Answer YES/NO and comment if necessary)

EU DPR-2012: European Data Protection Regulation	Repealed and superseded by the GDPR.
EU Directive-2013/40: this Directive deals with "Cybercrime" (i.e., attacks against information systems).	Yes, within the Austrian Criminal Code - §§ 118a, 119, 119a, 120 Abs 2a, 126a, 126b, 126c StGB
EU NIS Directive-2016: this Network and Information Security (NIS) Directive concerns "Cybersecurity" issues.	Yes - Bundesgesetz zur Gewährleistung eines hohen Sicherheitsniveaus von Netz- und Informationssystemen (Netz- und Informationssystemsicherheitsgesetz – NISG)
EU Directive 2014/53: this directive is concerned with the standardization issue which is important for the joint and harmonized development of technology in the EU.	Yes - BGBl. I Nr. 57/2017 - Funkanlagen-Marktüberwachungs-Gesetz - FMaG 2016
EU GDPR: European General Data Protection Regulation-2016	Directly effective in every Member State, thus including Austria.
EU Connected Communities Initiative: This initiative concerns the IoT development infrastructure, and aims to collect information from the market about existing public and private connectivity projects that seek to provide high speed broadband, more than 30 Mbps.	N/a, the initiative is not a mandatory law or regulation

3. REGULATIONS

The law and ethics framework should involve the following. Please answer YES/NO if your framework does[1].

[1] Answers in this section are related to the company's framework, not necessarily needed in the use case itself.

Legislation/regulations.	YES
Ethics principles, rules and codes.	YES
Standards/guidelines.	YES
Contractual arrangements.	YES
Regulations for the devices connected.	YES
Regulations for the networks and their security.	YES
Regulations for the data associated with the devices	YES

4. GOVERNMENT REGULATIONS

Governments play a primary role in shaping the future because governments have a double role, namely

1. User role: governments plan to become major users of IoT, e.g., getting smart cities.
2. Infrastructure provider role: governments should issue regulations for devices not originally intended for connection to the IoT, as well as for devices particularly designed to be connected devices.

4.1. Which of the above is the role of your government?

Both

4.2. Do your government have in force regulations for both roles?

Yes, public procurement law and the legislation

4.3. What are these regulations?

E.g. EU regulations

4.4. Do your government ensure that IoT products and solutions are used exclusively for their specified goal?

No

4.5. Which sectors of society, industry and the economy are subject to general government legislation?

All mentioned.

4.6. Does the relevant legislation include the following fields (yes/no and define if possible):

public law	yes
business law	yes
insurance law	yes
tax law	yes
private international/human rights law	yes
security law	yes
criminal law	yes
civil liability law	yes
consumer protection law	yes
private/data protection law	yes
environmental law	yes
GDPR law	yes

Public

4.7. Do government regulations focus on the system capabilities (e.g., how data can be reused or sold) rather than on implementation (e.g., MySQL vs. Hadoop)?

5. Characteristics that May Cause Ethical Problems

The main IoT characteristics that may cause ethical problems are the following. Please try to identify the risk of having to deal with some of these (using YES/NO/maybe) in the Use Case you participate in.

Ubiquity/omnipresence: the IoT is everywhere.	No
Miniaturization/invisibility: computers and devices will be smaller and smaller, and transparent, thus avoiding any inspections, audit, quality control, and accounting procedures.	No
Ambiguity: the distinction between the natural objects, artifacts, and beings will be more and more difficult to be made, because the transformation from one category to another is easy, based on tags.	No
Difficult identification: objects/things have an identity in order to be connected to the IoT. The access to these objects and the management of their identities might cause crucial problems of security and control in the IoT ecological world.	no
Ultra-connectivity: the huge number of connections of objects and people require the transfer of large quantities of data (big data) which could be maliciously used.	Maybe
Autonomous and unpredictable behaviour: the interconnected objects might interfere autonomously and spontaneously in human activities in unexpected ways for the users or designers. People, artifacts, and devices will belong to the same IoT environment, thus creating hybrid systems with unpredictable behaviour. The incremental development of IoT will lead to emerging behaviours that the users could not fully understand.	Maybe
Incorporated intelligence: this will make the objects as substitutes of social life. The intelligent objects will be dynamic with an emergent behaviour. Being deprived of these devices will lead to problems (e.g., teenagers without the Google, smart phone or social media, might feel themselves cognitively or socially handicapped).	No
Decentralized operation: the IoT control and governance cannot be centralized, because of the large number of hubs, switches, and data. The information flows will be eased, and the data transfers will be faster and cheaper, and thus not easily controllable. There will appear emerging properties and phenomena which will require monitoring and governance in an adequate way, and this will further influence the accountancy and control activities.	No
Property right on data and information: the difficulty in specifying the identification of things and humans is reflected to the difficulty to identify who is the owner of the data retrieved by IoT sensors and devices.	Maybe

Public

Omnipresence: this makes invisible the boundaries between public and private space. People cannot know where their information ends up.	No
Accessibility of data: an attack on a PC might cause information loss. A virus or hacker attack in the IoT might have serious effects on human life (e.g., on the life of the driver of a car connected to IoT).	Maybe
Vulnerability: the list of possible vulnerabilities in IoT is scaring. It ranges from home appliances, to hospitals, traffic lights systems, food distribution networks, transportation systems, and so on.	No
Digital divide: the digital divide in the IoT is enlarged. IoT operations can be understood only by experts. Communication in IoT devices affects human lives in ways that are difficult to predict or imagine. The digital divide can only be reduced by proper coherent legal and democratic frames to delineate this process.	No

6. ETHICS QUESTIONS

6.1. Information technology ethics and Internet ethics.

What happens if the Internet connection breaks down?
Internet provide clous: machines either stop or continue autonomous operation
Who is responsible or liable for patching IoT devices, routers, and cloud connections?
Machine and service vendor
Is there an assurance that hacking on the cloud side of IoT services will not have access to a home's internal network?
No home involved in the use case
What happens if an IoT service provider experiences downtime for critical life-supporting devices?
Not relevant for the use case
What happens if an IoT device acts without the consent of its owner or acts in unintended ways (e.g., ordering the wrong products, or vacuuming at an unreasonable hour)?
Possible property damage
What happens if an IoT product vendor goes out of business and no longer supports the product?
Vertically integrated solution, not relevant
Who owns the data collected by IoT devices?
John Deere or Farmer? Tb clarified with JD
Are there cases where IoT devices should not be collecting data?
JD to answer please
What happens if the user wants to opt out?
Operation manually
What about those who do not have smart devices or the knowledge to use them? (Digital divide).
Manual operation

6.2. Ethical principles

All activities that involve the use of personal data[2] are expected to comply with the applicable data-protection legislation. Beyond legal compliance, activities should respect the ethical principles. Please, try to estimate if the use case you lead/participate complies with the following (definitely/maybe/probably not and comment if necessary):

In IoT activities, individuals should be treated as ends (not as means), and maintain their rights to property, autonomy, private life, and dignity.	Yes
Individuals should not suffer physical or mental harm from IoT activities.	Yes
Benefits from the application of IoT should be added to the common good.	Yes
The necessity and proportionality of an IoT process should be taken into account and capable of being demonstrated.	Yes
IoT applications should be performed with maximum transparency and accountability via explicit and auditable procedures.	Yes
There should be equal access to the benefits of IoT accruing to individuals (social justice).	Yes
IoT activities should have minimum negative impact to all facets of the natural environment.	Yes
IoT activities should aim to lighten the adverse consequences that data processing may have on personal privacy and other personal and social values.	Yes
Adverse effects beyond the individual (groups, communities, societies) should be avoided or minimized or mitigated.	Yes

[2] No use of personal data in the use case (Pilot3).

7. PRIVACY

The European Union General Data Protection Regulations (EU GDPR 2016, etc.) impose the principles that should underlie the processing of personal information. A new principle added to EU GDPR 2016 is the principle of "Privacy by Design".

Do your privacy framework include the following? (yes/no and if yes define)

Privacy regulations	Not relevant for TTControl in the project use case.
Data minimization	Not relevant for TTControl in the project use case.
Data portability	Not relevant for TTControl in the project use case.
Transparency	Not relevant for TTControl in the project use case.
Compliance disclosures	Not relevant for TTControl in the project use case.
IoT engagement by default	Not relevant for TTControl in the project use case.
IoT engagement by design	Not relevant for TTControl in the project use case.
Best practice	Not relevant for TTControl in the project use case.

The concepts of security and privacy have many complex interrelationships, but they are not identical. Do you have the following relations between security and privacy? (yes/no and comment if necessary)

Reductionism	Not relevant for TTControl in the project use case.
Projectionism	Not relevant for TTControl in the project use case.
Dualism	Not relevant for TTControl in the project use case.
Dialectic	Not relevant for TTControl in the project use case.

8. TRUST

In general, trust can be looked-up from different views and interpretations. Does your trust framework provide the following? (yes/no and explain)

Trustworthiness	Yes.
Dependability	Yes.
Sustainability.	Yes.

Public

Public

Reliability.	Yes.
Availability.	Yes.
Resilience.	Yes.

8.1. Personal Data Principles

Please answer if the following apply in your legal context (yes/no and explain)

People own the data (or things) they create.	- Not relevant for TTControl in the project use case.
People own the data someone creates about them.	Not relevant for TTControl in the project use case.
People have the right to access data gathered from public space.	Not relevant for TTControl in the project use case.
People have the right to their data in full resolution in real time.	Not relevant for TTControl in the project use case.
People have the right to access their data in a standard format.	Not relevant for TTControl in the project use case.
People have the right to delete or backup their data.	Not relevant for TTControl in the project use case.
People have the right to use and share their data however they want	Not relevant for TTControl in the project use case.

9. ADDITIONAL QUESTIONS

Europe 2020 "Innovation Europe" Initiative, which involves several actions towards achieving the following three goals. What is the state of these goals in your country?

Make Europe one of the world-class science performers.	Yes of course, like other partners in aerOS, we are striving to a stronger position in Europe and globally, contributing to innovation and supporting Europe in leadership, strategic autonomy, independence.
Free the innovation from obstacles such as expensive patenting, market fragmentation, and skills shortages.	Similar to other companies, we use patents as a tool to protect knowhow. Regarding the skills shortages, our company is having several talent programmes to attract young researchers.
Revolutionize the way public and private sectors cooperate (e.g., via innovation), and enhance partnerships between European institutions, authorities (national and regional), and business.	This can be done by means of an active cooperation of RTOs, companies, agencies, Member States and other stakeholders, working jointly on strategic documents like e.g. SRIA defining topics and key priorities as well as funding schemes to attract private sector.

Public

Does the existing framework regarding the protection of users is influenced by the following socio-legal-economic aspects and related issues? (yes/no and if yes define)

The trade-off between the market needs for data and correlation to support innovation, and the business success of the IoT systems and applications (public and private).	not clear
The cost of verifying and implementing privacy enhancing technologies (PET) or other solutions for ensuring appropriate care in collection, storage, and retrieval of data.	not clear
The accountability of IoT applications related to users' privacy.	not clear
Support for the context where the user operates.	not clear

Public