

D5.1 - Distributed automation & information management

ZERO-enabling Smart networked control framework for Agile cyber physical production systems of systems

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Contributors	all

Author List

Leading Author (Editor)			
Surname	Initials	Beneficiary Name	Contact email
Fritz	AF	NX-SE	artur.fritz@se.com
Co-authors (in alphabetic order)			
Surname	Initials	Beneficiary Name	Contact email
Deshmukh	SD	NX-SE	shreya.deshmukh@se.com
Contributors (in alphabetic order)			
Surname	Initials	Beneficiary Name	Contact email
Atmojo	UA	AALTO	udayanto.atmojo@aalto.fi
Bastidas-Cruz	AB	Fhg	arturo.bastidas-cruz@ipk.fraunhofer.de
Dal Maso	GD	TTS	dalmaso@ttsnetwork.com
Liakh	TL	LTU	tatiana.liakh@ltu.se
Pagliarini	GP	REPK	GianPietro.Pagliarini@promachbuilt.com
Radke	MR	FhG	marcel.radke@ipk.fraunhofer.de

Reviewers List

List of reviewers (in alphabetic order)			
Surname	Initials	Beneficiary Name	Contact email
Andolfi	MA	NXW	m.andolfi@nextworks.it
Bastidas-Cruz	AB	FhG	arturo.bastidas-cruz@ipk.fraunhofer.de
Drozдов	DD	LTU	dmitrii.drozдов@ltu.se
Khodashenas	PK	HWE	pouria.khodashenas@huawei.com
Lazaridis	GL	CERTH	glazaridis@iti.gr
Liakh	TL	LTU	tatiana.liakh@ltu.se

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Executive Summary

This deliverable D5.1 focuses on more aspects, where this first aspect describes mainly the functional and technical requirements, coming from selected trials, with focus on the automation platform architecture based on the IEC61499 standard. Further aspects are focussing on specific details of the 3-tier edge architecture and which basic software is going to be used and extended for the trials.

Coming from the D2.2 the overall automation architecture of a CPSoS will be further focussed and detailed, from both the HW and SW points of view, addressing all the aspects that enable a portable and scalable implementation of a reconfigurable network smart devices, compliant to the IEC-61499 international standard and deployed over an Edge Computing architecture. It shows the topological architecture for selected trials for safe and secure integration of the Edge Computing platform applied to Zero-SWARM.

It shows the overall CPS automation architecture and technical requirements for the development and extension of the automation platform and in coherence with the tasks T5.2 for reconfigurability and T5.3 for AI focused applications. It shows the interfaces to WP4 with the Edge-Cloud continuum framework and its interfaces in the automation platform and with its interaction with other systems through service-oriented mechanisms. It shows the integration of digital twins in the data centre tier for Virtual Commissioning and its interfaces to the Edge-Layers.

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List of Acronyms

Acronym	Description
5G	Fifth-Generation Wireless Communications
AE	Alarm And Events
AFoF	AALTO Factory of the Future
AMR	Autonomous Mobile Robot
AI	Artificial Intelligence
AIC	Automotive Intelligence Centre
AIIC	AALTO Industrial Internet Campus
AR	Augmented Reality
CAT	Composite Automation Type
CPSoS	Cyber-Physical System of Systems
CUC	Centralized User Configuration
DA	Data Access
DFA	Demonstration Factory Aachen (DFA)
DLFi	Distributed Learning Framework
DSS	Dss Dynamic Spectrum Allocation
E2E	End-To-End
eMBB	Enhanced Mobile Broadband
FB	Function Block

gPTP	Generalized Precision Time Protocol
HDA	Historical Data Access
ICT	Information Communication Technologies
IDS	International Data Spaces
IICF	Industrial Internet Connectivity Framework
IIoT	Industrial Internet Of Things
IIRA	Industrial Internet Reference Architecture
IMC	Intelligent Mechatronic Components
ITU	International Telecommunication Union
LBO	And Local Breakout
MAS	Multi-Agent Systems
MES	Manufacturing Execution Systems
mIoT	Massive Internet of Things
mMTC	Massive Machine Type Communication
MR	Mixed Reality
NASA	National Aeronautics and Space Administration NASA
NASA	Telematic Data Collector
NPN	Non-Public Networks
OLE	Object Linking and Embedding
OPC	Open Platform Communication
OPC-UA	Opc Unified Architecture
PLC	Programmable Logic Controllers
PTZ	Production Technology Center (PTZ)
ROS	Robot Operating System
SLAM	Simultaneous Localization and Mapping
SNPNs	Stand-Alone Npns
SOAP	Simple Object Access Protocol
SoS	Systems Of Systems
TSN	Time Sensitive Networking
UA	Unified Architecture
UAO	Universal Automation Organisation
UACP	Unified Architecture Connection Protocol
UES	User Equipment
UPF	User Plane Function
uRLLC	Ultra-Reliable Low Latency Communication
VR	Virtual Reality

1 Introduction

The purpose of this deliverable (D5.1 Distributed automation and information management) is to start with the basic architecture and specification which is necessary for achieving the following objectives:

- Extension of the IEC-61499 runtime with auto-discovery and self-declaration functionalities;
- Integration between IEC-61499 and Edge Computing framework (of WP4);
- Development of an AI-dedicated version of the toolchain for field practitioners;
- Development of cyber-security methodologies and solutions for the OT-IT connection.

This deliverable was delayed not more than 1 month, because of additional synchronisation needs with WP4 and WP2, latter for adjusting the reference architecture on the review results of D2.2.

1.1 Purpose of the document

This deliverable focuses on the functional requirements for providing a complete platform (i.e. build-time and run-time), based on the IEC-61499 standard for distributed automation and compatible with the most relevant and open communication protocols towards the IT (e.g. OPC-UA, MQTT, WebSocket, etc.) to manage the life-cycle of CPSoS acting at shop-floor level and their seamless integration with the IT domain through the 5G-enabled Edge.

The overall automation architecture of a CPSoS will be further detailed, from both the HW and SW points of view, addressing all the aspects that enable a portable and scalable implementation of a reconfigurable network smart devices, compliant to the IEC-61499 international standard and deployed over an Edge Computing architecture.

The specification will address the following topic', which are the basic considerations for the following tasks T5.2, T5.3, and T5.4:

- a) the structure and composition of heterogeneous CPS into an intelligent swarm, shown in a common automation platform view and in a trial specific manner, considering the hardware architecture, too;
- b) its interfaces, both for integration within an automation runtime platform and for interaction with other systems through service-oriented mechanisms;
- c) the requirements in terms of functionalities that need to be implemented by a CPS to perform its duties in an autonomous manner, while coordinating itself with the other members of the CPSoS;
- d) the topological architecture for safe and secure Edge Computing platform applied to Zero-SWARM, based on separation kernels that reduce the efforts required for safety and security assurance, with support for containers; safety-critical middleware for supporting dynamic fog applications; and deterministic networking and interoperability, using open standards, to be robust against penetration and anomalies from outside

Coming from WP4 it will addresses the development of the CPSoS' semantic information model, which describes the functionalities implemented within the smart devices and that enable the identification of the automation and predictive maintenance tasks allocated within that cognitive entity. Such an information model will be exploited to improve interoperation and flexibility of the network of CPSs and enables plug & produce functionalities with the Edge/Cloud continuum and there functionalities

for AI application integration and distributed stream computing with the most focused OT/IT communication protocols (e.g. OPC UA or MQTT).

1.2 Structure of the document

The document is structured as follows:

- **Chapter 1** is an introduction to the whole document, describes its scope and purpose, as well as its structure;
- **Chapter 2** provides an introduction to the overall CPS structure from the IEC61499 automation platform point of view;
- **Chapter 3** formulates the details from selected trials to get and specify functional requirements for WP5 tasks;
- **Chapter 4** derives from use case requirements of a selected trial the specific automation platform topology for this trial
- **Chapter 5** describes the interface to the Edge Platform and WP4
- **Chapter 7** specified the basic functionality and extensions of the IEC61499 automation platform (runtime and IDE), which are necessary for the following tasks T5.2 (reconfigurability) and T5.1 (AI integration)
- **Chapter 6** describe the digital Twin and the interfaces to the IEC61499 automation platform
- **Chapter 8** makes a conclusion and an outlook about the next steps for the deliverables of WP5

2 Overall CPS structure

2.1 From WP2 to Automation Architecture

WP2 describes the Industrial Automation Edge Entity architecture, shown in Figure 1. The further architecture development in WP5 focuses on the automation platform architecture in this deliverable D5.1, which is shown in a further development of the deployment view of D2.2.

Edge computing helps meet those timing requirements. Edge computing is characterized by networked systems ("connection") in which significant data processing ("compute") and information storage ("storage") take place on devices and entities near the edge, rather than in some centralized location. Edge computing provides the system with reduced latency bounds, beneficial to network and computation, potentially leading to efficiency gains for each [2].

In those "Edge Layers" of the deployment view, is the management and the configuration for the Shopfloor (Edge Devices Layer) - with real time behaviour, and on the Edge Gateway Layer - with near real time behaviour of the IEC61499 automation platform, which is the focus of this deliverable D5.1. This deliverable meets the technical requirements for extending the IEC61499 automation platform and its IEC61499 applications and their object design with its interfaces to the AI and Digital Twin runtime and their further development and extensions, necessary for the described trials of the Nodes. 5G mobile communication is mostly transparent for WP5 and mentioned as wireless or 5G communication. When there are further detailed requirements or extensions necessary, it will be part of other WP5 deliverables, referenced in the different sub chapters and in the conclusions chapter.

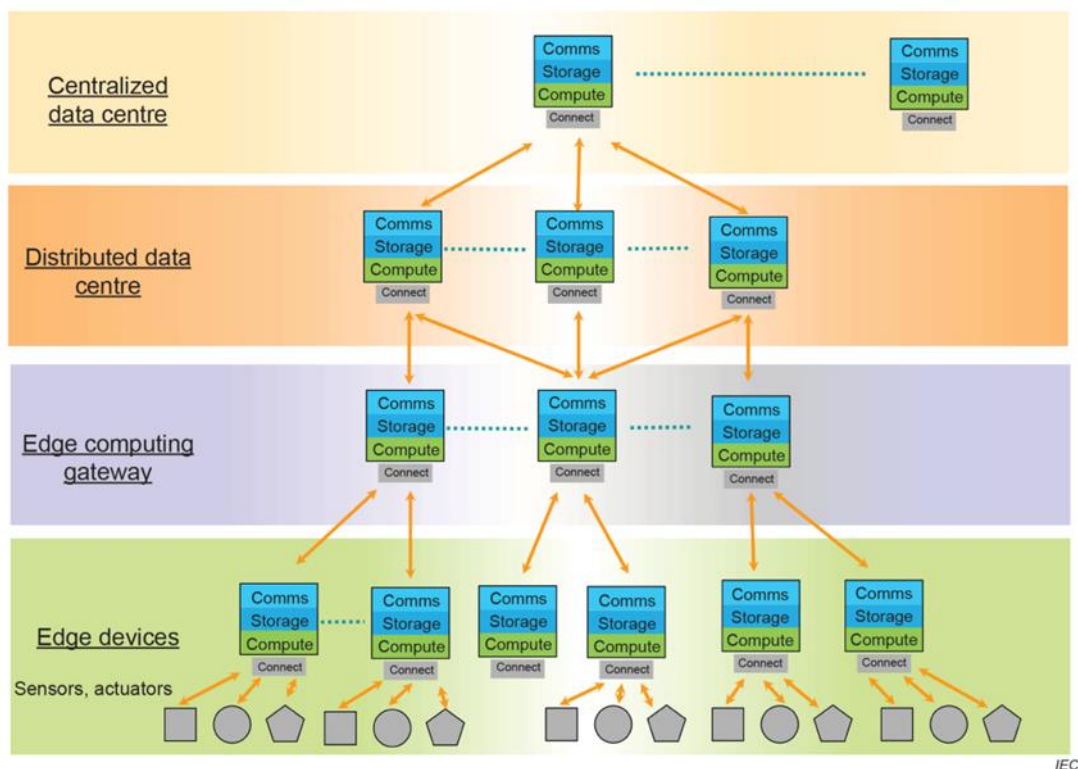


Figure 1: Zero-SWARM deployment view

Each Edge device is a representative of an IEC61499 device of the control automation platform, where an IEC61499 control application is running, consisting of an IEC61499 function block network, which is capable to **communicate** over IEC61499 protocol between the function blocks and with other different protocols with the Edge Computing Gateway Layer or with the Data Centre Layers. The IEC61499 function block can **store** data in an archive database and can **compute** control algorithm in different languages, like structured text, which is already part of the IEC61499 standard. **Connect**, shown in Figure 1, means, that each IEC61499 function block can implicitly connect to another IEC61499 function block, over IEC61499 cross communication network and to the actors and sensors of the fieldbus. In summary it turned out, that the Industrial Automation Edge Entity architecture fits very well to the IEC61499 standard and to his distributed network and application design. In the following content different software modules are identified for different tasks, and different communication protocols are going to be used in the different directions from south to north bound, where different services for AI and reconfigurability are going to be used.

2.2 Objectives for the IEC61499 automation platform topology

WP5 focuses on providing a complete automation platform (i.e. build-time and run-time), based on the IEC-61499 standard for distributed automation and compatible with the most relevant and open communication protocols towards the IT (e.g. OPC-UA, MQTT, WebSocket, etc.) to manage the life-cycle of CPSoS acting at shop-floor level and their seamless integration with the IT domain through the 5G-enabled Edge.

The Zero-SWARM ambition is to provide a methodological and technological framework, modular, open, and re-usable. The real complexity of future CPSoS (and, thus, the opportunities for new

paradigms) resides in the possibility to easily develop the multi-level orchestration intelligence needed to coordinate the behaviour of all the CPS composing a shop floor. Given the complexity of the task, it would be only possible if the CPSoS software is built with the ability of active adaptation and self-configuration. The project's adoption of IEC-61499 and the planned extension of this architecture present automatically the solution to this issue, with an industry-ready approach that already satisfies the major needs for engineering complex orchestrating applications with considering the interoperability and seamless exchange and exposure of information across the cloud-edge continuum for AI-based real-time applications to reduce the complexity of some advanced functionalities, such as perception, navigation, coordination, interaction with humans and to reduce the engineering time for an automation engineer.

Therefore, WP5 has major relations to these objectives:

Objective 1: Realize an open framework for the engineering and management of smart CPSoS, relying on advanced industrial 5G communication, to enable resilience Zero-X manufacturing:

- Orchestration and deployment of the automation platform on the edge and shopfloor layer
- Virtualisation and dockerization of the IEC61499 automation platform on dedicated hardware

Objective 3: Foster adoption of private industrial 5G as a major enabler of the AIC that provides advanced wireless connectivity integrated with distributed cloud-edge industrial computing

- Usage of 5G communication in Shopfloor and Edge and between both or between IEC61499 devices or nodes.
- Wireless and 5G communication in every direction: North/South/East/West bound communication.

Objective 4: Achieve a generic approach for distributed intelligent control applications that are aiming at portability, flexibility, reusability, interoperability, reconfiguration of distributed applications at the edge of shopfloor via a secure and trustworthy information continuum, enabling awareness in CPSoS built on top of an open, transparent and secure industrial cloud-edge continuum.

- Reconfiguration of dynamic shopfloor requirements with dedicated services and semantics, involving AMR's.
- Integration of AI functionality made easier and simpler for an Automation Engineer.

Objective 5: Develop and validate a secure, trustworthy and open toolkit to support distributed automation over the decentralised data and intelligence infrastructures. Exploiting both the IEC-61499 international standard for distributed control and its concepts as well as the OPC-UA information models, the project will develop and validate an open toolkit.

- Development of an object-oriented library set, mapping IEC61499 technology to OPC UA and other IT standards (e.g. MQTT), considering AI functionality integration.
- Development of automatic application behaviours, depending on the availability of AMR'S, influenced of the results of AI algorithm.

2.3 Developing the WP5's automation platform topology

The name swarm in Zero-SWARM's project name is an indicator of the usage of swarm technologies, like the IEC61499 distributed technology is. This IEC61499 distributed technology will be used on the Edge device tier (shopfloor) and on the Edge gateway tier (edge), latter for the integration of the different AI functionalities. Both tiers can exist of more distributed IEC61499-devices and IEC61499 edge-nodes to balance the workload of a complete company production, where finally the IEC61499 control application is independent from this hardware devices in the shopfloor and in the edge. The following Figure 2 shows the flexibility of a swarm approach with distributed devices and applications across all tiers, using IEC61499 technology. The distributed tier concept shows in the centre of the swarm the data centre, the Cloud of WP4, for monitoring and coordinating the swarm's behaviour, like a queen bee. The middle layer with the edges nodes is working like drone bees and in the outer layer the IEC61499 devices and AMRs in the shopfloor are acting as female worker bees. The interaction and communication between all the participants are automatically working over IEC61499 distributed communication, also wireless and with 5G or over a dedicated OPC UA information model, enriching the same functionality and focusing on the communication between the shopfloor and the edge with the AI-functionality:

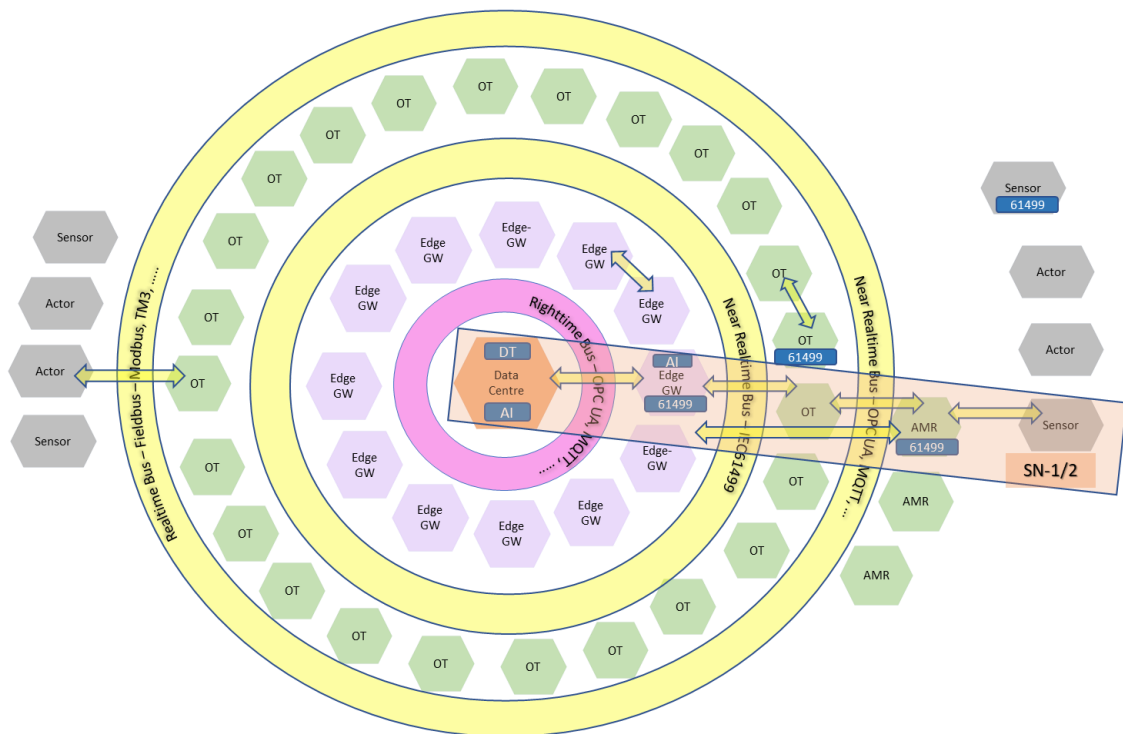
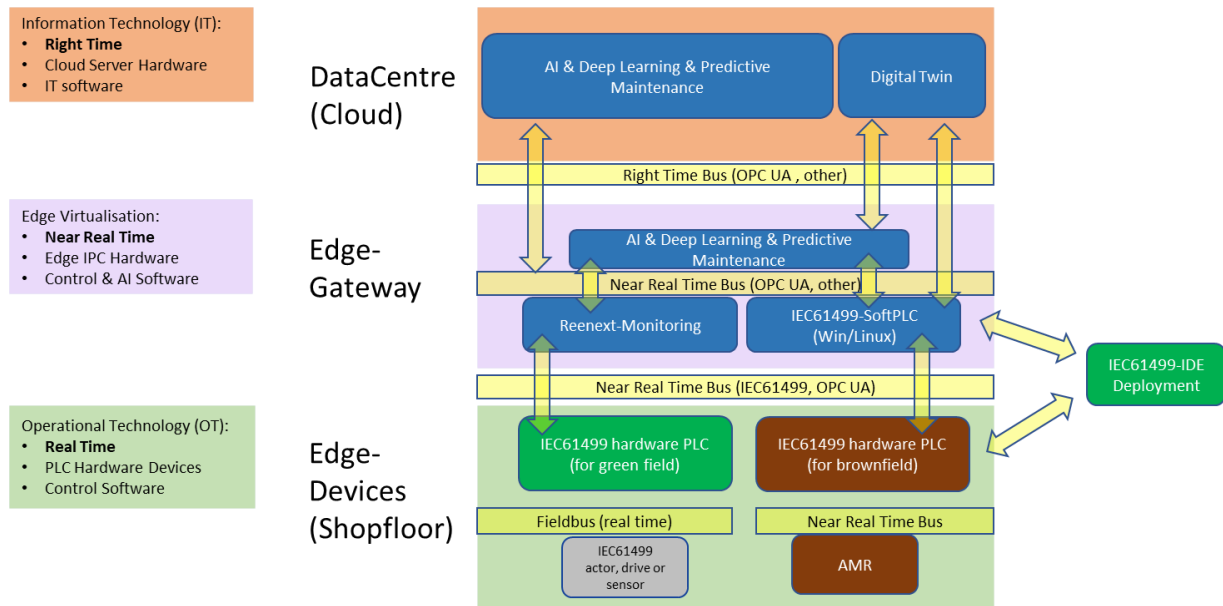


Figure 2: Zero-SWARM overall CPS structure

In the next steps a zoom into a part of the swarm (means automation platform topology) is made, showing one node of the edge and some devices (actors, sensors) and the AMR'S in the shopfloor to focus on the mains concepts and extensions of the automation platform topology:



The zoom of the overall CPS structure shows still the 3 layers as in the swarm architecture. By starting in the **OT-layer**, also named as shopfloor-layer, the integration of new devices into this IEC61499 automation layer will happen over new sensors/actors directly interacting in real time with a IEC61499 PLC, where the IEC61499 control application is running, see the left of the Figure 3, showing the green field. When there is already a legacy system existing, see the right side of the Figure 3, showing the brown field, the PLC to integrate existing AMR devices will happen over a IEC61499 CPSizer, controllers to connect with current legacy infrastructure or IEC 61499 controllers, mapping the old technology to the new one. Details will be described under Reconfigurability in this and in the following deliverable D5.2. The middle layer, the **Edge-layer** is representing a near real time layer for monitoring and AI integration near the OT-layer, which requires near real time performance for faster reactions. In the South Node Trial 1 and 2 there is an existing Edge Hardware, which will be used and integrated into this architecture over OPC UA. In parallel there is a new Edge hardware possible which virtualizes directly the IEC61499 automation layer for near real time access in the Edge to interact between IEC61499 automation system and AI system. The **Cloud-Layer** is the connection point to WP4 from Edge to Cloud, showing a right time communication between both layers for processes, which need not near real time capabilities, like a maintenance use-case for instance. In this layer the AI system and the Digital Twin for virtual commissioning use-cases is going to be integrated.

3 Functional and technical requirements

The definition of detailed requirements in terms of functionalities of a trial as well the technical requirements that need to be implemented by a CPS to perform its duties in an autonomous manner is a major goal of this chapter. This process phase needed a lot of coordinating itself and with the other members of the CPSoS and trials to enrich and improve interoperability and flexibility of the network of CPSs and plug & produce functionalities for selected trials, using the IEC61499 international standard in the automation architecture.

3.1 Functional requirements for North Node

3.1.1 Overview: Processing Station

The Main Purposes of Validation Activities of Zero-SWARM Technologies, in terms of Hardware and Software Architectures, and Algorithms are mostly related to demonstrate the real applicability in a Processing station system and especially the Reconfigurability of Devices with own Controls Systems, Monitoring and Semantic.

The processing station system is composed of several mechatronic components, including the Drill components and Table component. These mechatronic components are considered smart, i.e. they are equipped with their own control devices, implementing their basic operations. The Drill component is triggered to drill the workpiece as soon as its sensor detects the presence of the workpiece beneath it. Conversely, the Table component undergoes rotation from one fixed position to another. A complete cycle is achieved when the table rotates six times. Whenever a workpiece is positioned in the loading position, the table rotates to align it underneath the drill. It is possible to add, remove, or relocate the drill component within the existing processing station. Scenario 1 involves the normal configuration of the system. In Scenario 2, the Drill component is reconfigured to a different position. Scenario 3 explores the addition of a new Drill component to the existing system.

3.1.2 Scenario 1: Normal Configuration

1. The Drill and Table are the two mechatronic components considered for the experiment.
2. The Drill moves in an upward or downward direction. Whenever a workpiece is detected by the sensor under the drill, it moves downward and starts drilling. Once it completes drilling, it moves upwards and rests at the home position.
3. The Table rotates from one fixed position to another. The cycle is completed when it rotates six times. When a workpiece is placed in the loading positions, the table rotates to bring it under the drill.

3.1.3 Scenario 2: Reconfiguring the Drill component to another position

1. The current placement of the Drill component is relocated to a different position.
2. Upon recognizing the updated configuration, the system ensures that when a workpiece is placed in the loading positions, the Table rotates accordingly to position it beneath the Drill for further processing.

3.1.4 Scenario 3: Adding a new Drill component to the existing system

1. An additional Drill component, namely Drill A and Drill B, has been introduced to the preexisting system, alongside the presence of a Table.
2. The system recognizes a new Drill component and incorporates its unique abilities and functionalities. For instance, Drill A can drill up to a depth of 2 cm, while Drill B is capable of drilling up to 5 cm.
3. If the user chooses a workpiece measuring 5 cm, the table will rotate accordingly to position it beneath the designated Drill component, which in this case would be Drill B.

3.1.5 Validation Scenarios

Table 1: NN Validation Scenarios

Validation Scenarios	Objectives	Steps
Scenario 1: Normal Configuration Operation	Verify the correct functioning of the normal configuration	1. Place a workpiece in the loading position. 2. Ensure the Drill is in its home position. 3. Activate the system. 4. Verify that the Drill moves downward upon detecting the workpiece. 5. Confirm that the drilling operation is initiated. 6. Check that the Drill moves upward after completing the drilling process. 7. Observe that the Table rotates to bring the workpiece under the Drill. 8. Repeat the process multiple times to ensure consistency and repeatability.
Scenario 2 Validation: Reconfiguring the Drill component	Validate the proper reconfiguration of the Drill component to a different position.	1. Adjust the position of the Drill component to the new configuration. 2. Place a workpiece in the loading position. 3. Start the system. 4. Verify that the Table rotates to align the workpiece under the newly positioned Drill. 5. Ensure the Drill moves downward and begins drilling. 6. Confirm that the Drill moves upward and returns to the home position after drilling. 7. Repeat the process with multiple workpieces and configurations to ensure accuracy.
Scenario 3 Validation: Adding a new Drill component	Validate the integration and functionality of the newly added Drill component.	1. Introduce Drill A and Drill B to the existing system. 2. Configure the system to recognize and utilize the unique capabilities of each Drill. 3. Place a workpiece of 5 cm in the loading position. 4. Activate the system. 5. Observe that the Table rotates to position the workpiece under Drill B. 6. Verify that Drill B moves downward and starts drilling. 7. Confirm that Drill B moves upward and returns to the home position after drilling.

		8. Repeat the process with different workpiece depth requirements and observe the appropriate Drill being selected.
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3.1.6 Human Worker - Functional Requirements

The environment of the Human worker is shown in Figure 4:



Figure 4: Human Worker Environment in NN

Further details are explained in the following requirements tables:

Table 2: Collect Human-Related Data

Requirement ID	WP-5.1-FR1
Title	<i>Collect Human-Related Data</i>
Detailed Description	
"I want..." (what to build)	I want to detect changes in heart rate and production process cycle time of the labourer in real-time
"So that..." (why to build)	So that the human-related publishing process is established and collected data can be used further by the decision-making algorithm to identify the worker's state.
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	<i>Wearable Heart Rate Sensor; Data Fetching from the sensor over BLE GATT is implemented; Data is shared over MQTT and encrypted using TLS; Sensitive data topics require authorization (role-based access control);</i>
Owner	<i>Aalto University</i>
Priority	<i>Medium</i>
Acceptance criteria	<i>Wearable Heart Rate sensor measures at least once in 1sec;</i> <i>Product processing cycle time is reported automatically;</i> <i>Data is fetched from the sensor over Bluetooth Low Energy;</i> <i>Data is pre-processed and sent forward via MQTT;</i>

	Sensitive data is encrypted and requires access rights;
Delivery by	

Table 3: Assess Worker State Based on Human-Related Data

Requirement ID	WP-5.1-FR3
Title	<i>Assess Worker State Based on Human-Related Data</i>
Detailed Description	
"I want..." (what to build)	I want to identify worker's state (e.g. optimal, stressed or relaxed) using the human-related data stored in the database
"So that..." (why to build)	So that the MES / ERP / other production control system can either reschedule critical tasks or redistribute it with cobots to avoid injuries, decrease stress level, optimize productivity, and improve wellbeing.
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	WP-5.1-FR2 <i>Decision-Making Algorithm (DMA) written on Python ML model is supported as a core of DMA</i>
Owner	Aalto University (D5.2)
Priority	<i>Medium</i>
Acceptance criteria	<i>Decision-Making Algorithm can access human-related data either from MQTT or the database;</i> <i>Current labourer condition is determined by the mean value of a heart rate each 5sec using last 30sec data;</i> <i>Decision-making algorithm can be treated as a black-box that has human-related data on input and worker state and process recommendations as an output.</i>
Delivery by	

Table 4: Workflow Adjustment Based on Worker State

Requirement ID	WP-5.1-FR4
Title	<i>Workflow Adjustment Based on Worker State</i>
Detailed Description	
"I want..." (what to build)	I want to redistribute, re-schedule or cancel tasks from the workflow if the worker's state is not applicable for it.
"So that..." (why to build)	So that the risk of injury or defects caused by the human factor can be decreased.
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	WP-5.1-FR3 <i>Each task should have a mapping, which states are acceptable; For each state there should be a description on how to re-schedule tasks using the information about the worker's state;</i>
Owner	Aalto University (D5.2)
Priority	<i>Medium</i>

Acceptance criteria	- DMA is aware about the current state of the worker and can proactively provide commands to an ERP / MES; - If a worker is in non-applicable state for a particular task, transporting tasks can be assigned to an AGV, processing tasks – to a cobot; - If the task cannot be done by any other supportive equipment, it's being re-scheduled until the time worker is in optimal state;
Delivery by	

Table 5: Ergonomics Adjustment Based on Worker State

Requirement ID	WP-5.1-FR5
Title	<i>Ergonomics Adjustment Based on Worker State</i>
Detailed Description	
“I want...” (what to build)	I want to change ergonomic parameters to help the worker sooner get to an optimal state.
“So that...” (why to build)	So that the risk of injury or defects caused by the human factor can be decreased.
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	WP-5.1-FR3 <i>For each state there should be a description on how to help achieving optimal state via sounds, lighting, recommendations, etc.</i>
Owner	Aalto University (D5.2)
Priority	<i>Medium</i>
Delivery by	

Table 6: Acquire Feedback from the Equipment: EnAS/CPLab, MIR100, UR3/YuMi

Requirement ID	WP-5.1-FR7
Title	<i>Acquire Feedback from the Equipment: EnAS/CPLab, MIR100, UR3/YuMi</i>
Detailed Description	
“I want...” (what to build)	I want to receive feedback status of the equipment
“So that...” (why to build)	So that all the processes can be depicted in a Digital Twin (Shadow)
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	<i>EnAS/CPLab ECC recipe should regularly report to MQTT the status;</i>
Owner	Aalto University (D5.2)
Priority	<i>Medium</i>
Acceptance criteria	<i>There should be no major latency (>5sec) or incoherence in process execution statuses compared to real actions;</i>
Delivery by	

3.2 Functional requirements for Central Node

3.2.1 Overview

CN T2 aims to implement the production of a fuel cell as an IEC 61499 use case. In this use case, the bipolar plates of the fuel cell are transported by an AMR with a robotic arm mounted on top (mobile manipulator) from a storage rack to a milling station and to a robotic cell for assembly which is seen Figure 5, where this feasibility study focuses on step 4 and 5 (marked in green). The implementation of the required high-level functionalities focuses on the storage rack, the mobile manipulator and the assembly station to be able to access them from an IEC 61499 environment as a feasibility study. The high-level functionalities are going to be implemented as IEC 61499 function blocks and are used to program the process logic of the use case. This program for the demonstration of the use case is called Recipe Manager. The technical, low-level functionalities control the shop floor devices in real-time from an edge-cloud and are hidden from the user that is programming with function blocks.

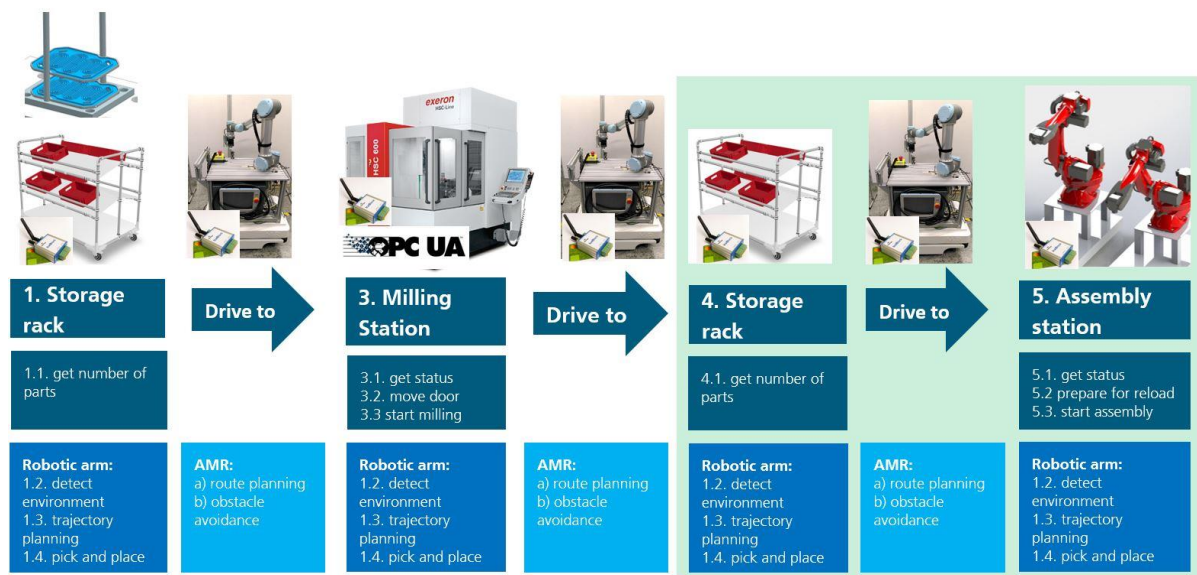


Figure 5: Central Node Trial 2 Use Case Scenario: Production of a fuel cell.

3.2.2 Validation Scenario CN Trial 2

CN Trial 2 validates the feasibility to program and control a production sequence in IEC61499 function blocks on a high abstraction level with special interfaces for robotic applications which focus on functionality rather than technical details. Instead, the technical details are handled by ROS2-services. Since ROS2 is well established in robotics to implement real-time control modules, one feature of the IEC61499 automation architecture includes the integration of ROS2 modules into the IEC61499 programming environment.

3.2.3 Validation Scenario “Mobile Manipulator”

The **Mobile Manipulator** consists of an AMR (MiR100) and a robotic arm (UR5) and is used to transport parts in the shop floor. It offers the functions `get_status()`, `move_amr_to()`, `move_arm_to()` and `pick_and_place()`.

get_status() for AMR + robotic arm:

Requests the mobile manipulator if it is currently busy or able to accept a task. The answers include the current position, the target position, battery state and mission status. The position includes labels

for predefined positions, the coordinates X and Y in the plane as well as an orientation. The status can be ready, busy, error or off:

- **ready:** The mobile manipulator can be used for a task, either for transportation of a part or for an operation using the robotic arm. The robotic arm can grasp and place an object.
- **busy:** The mobile manipulator cannot be used for a task because it is already executing a task. Either the AMR or the robotic arm are driving, moving, or waiting for control data from the edge-cloud.
- **error:** The mobile manipulator cannot fulfill its requested task but is operational and can be reset to accept new tasks.
- **off:** The mobile manipulator is not operational. Neither can it finish its current task, nor can it accept a new task. Either the way for the AGV or the robotic arm are blocked, or equipment is not working correctly.

Table 7: Function get_status

Function: get_status		
Parameter:	Type:	
IN:		
OUT:	amr_current_positon	Real [3]
	amr_target_position	Real [3]
	amr_current_position_name	String
	amr_target_position_name	String
	arm_current_position_joint	Real[6]
	arm_current_position	Real[6]
	arm_current_position_name	String
	arm_target_position_joint	Real[6]
	arm_target_position	Real[6]
	arm_target_position_name	String
	status_ID	Integer
	Battery	Real
	mission_time_spent	Real
	mission_time_remaining	Real
	error_ID	Integer
	Error	String

move_amr_to() for AMR:

Requests the AMR to drive to a given position either described as a coordinate in a map or as a name for predefined positions.

Table 8: Function move_amr_to for AMR

Function: move_amr_to		
Parameter:	Type:	
IN:	target_position	Real [3]
OUT:	status_ID	Integer

Table 9: Function move_amr_to for AMR (string)

Function: move_amr_to		
Parameter:		Type:
IN:	target_position_name	String
OUT:	status_ID	Integer

move_arm_to() for robotic arm:

Positions the end effector relative to the base of the robotic arm or to a predefined position.

Table 10: Function move_amr_to for robotic arm

Function: move_amr_to		
Parameter:		Type:
IN:	target_position	Real [6]
OUT:	status_ID	Integer

Table 11: Function move_amr_to for robotic arm (string)

Function: move_amr_to		
Parameter:		Type:
IN:	target_position_name	String
OUT:	status_ID	Integer

move_arm_joint_to() for robotic arm:

Positions the robotic arm in a unique configuration.

Table 12: Function move_arm_joint_to

Function: move_arm_joint_to		
Parameter:		Type:
IN:	target_position_joint	Real [6]
OUT:	status_ID	Integer

pick_and_place() for robotic arm:

Requests the robotic arm to grasp and move a part to a new position. The part is specified by an ID and is detected with a camera attached on the robotic arm. After grasping the new position is specified by an ID, a name, or coordinates.

Table 13: Function pick_and_place

Function: pick_and_place		
Parameter:		Type:
IN:	part_ID	Integer
	target_position_ID	Integer
OUT:	status_ID	Integer

Table 14: Function pick_and_place

Function: pick_and_place		
Parameter:		Type:

IN:	part_ID	Integer
	target_position_name	String
OUT:	status_ID	Integer

Table 15: Function pick_and_place

Function: pick_and_place		
Parameter:		Type:
IN:	part_ID	Integer
	target_position	Real[6]
OUT:	status_ID	Integer

3.2.4 Validation Scenario “Storage Rack”

The **Storage Rack** is used as part supply and intermediate storage. For a requested part-type it informs about its number and the storing position.

Table 16: Function number_of_part

Function: number_of_part		
Parameter:		Type:
IN:	part_ID	Integer
OUT:	number	Integer

Table 17: Function position_of_part

Function: position_of_part		
Parameter:		Type:
IN:	part_ID	Integer
OUT:	box_ID	Integer

3.2.5 Validation Scenario “Assembly Station”

The **Assembly Station** consists of two industrial robotic arms executing predefined programs by calling the functions `get_status()` and `start_program()`.

get_status():

Requests the assembly station if it is currently busy or able to accept a task. The answer includes the last program name and status. The status can be ready, busy, error or off.

- ready: A program can be executed on the assembly station.
- busy: The assembly station is currently executing a program.
- error: The assembly station cannot fulfill its requested task but is operational and can be reset to accept new tasks.
- off: The assembly station is not operational. Neither can it finish its current task, nor can it accept a new task. Either the way for the robotic arms is blocked or equipment is not working correctly.

Table 18: Function get_status

Function: get_status		
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Parameter:		Type:
IN:		
OUT:	program	String
	status	Integer
	error	String
	error_ID	Integer

Table 19: Function start_program

Function: start_program		
Parameter:		Type:
IN:	program	String
	parameters	Real[n]
OUT:	status	Integer

3.2.6 Validation Scenario “Recipe Manager”

The **Recipe Manager** loads a demo program and reads the required parameters (as the ingredients, e.g. position coordinates) from a file to pass them to the scheduler. The Recipe Manager also triggers the execution of the selected demo. Then, the scheduler sequences the calculations and operations. It manages the sequence of the ROS2 services controlling the devices (AMR, robotic arm, assembly station) for an exemplary production of a fuel cell. When new status events arrive, or one task is finished by a device then the scheduler calls the relevant ROS2 nodes to calculate and control the motion based on the subscribed and streamed sensor data. To implement the recipe manager and scheduler in IEC 61499, function blocks will be implemented to offer high-level services for the mobile manipulator, storage rack and assembly station. A specific demo program connects these function blocks in such a way that their functions are called at the appropriate time point in the sequence by considering the current states of the devices. The scheduler can start, stop, resume, or reset a demo program. The reset-function stops the demo and sets the devices into the initial state.

Table 20: Function start

Function: start		
Parameter:		Type:
IN:	parameter_file	String
	demo program	String
OUT:	status	Integer
	error	String

Table 21: Function stop

Function: stop		
Parameter:		Type:
IN:		
OUT:	status	Integer
	error	String

Table 22: Function resume

Function: resume		
Parameter:	Type:	
IN:		
OUT:	status	Integer
	error	String

Table 23: Function reset

Function: reset		
Parameter:	Type:	
IN:		
OUT:	status	Integer
	error	String

3.3 Functional requirements for South Node

3.3.1 Overview

Reepack South-Node Trial is based on 2 Scenarios built over the same set of Mechatronics equipment consisting of a compact automatic packaging line which targets a simplification of a typical industrial application for high production rates composed by:

Scenario 1

- De-Nester unit: device to unstack a pile of plastic trays.
- Infeed chain conveyor: to transport trays while they are loaded with food.
- CoBot automatic loading station: to automatically load products into trays – instead of/in collaboration with a manual loading.
- Tray Sealer machine: to pack, thanks to dedicated die-set, the food-product into trays in MAP (Modified Atmosphere Packaging).
- Quality Control Unit: to detect and discharge NO-Compliant Trays due to Wrinkles on Top Sealed Film or Trays Implosion for missing Gas Injection.
- AMR Device

Scenario 2

- ReeNEXT edge platform (e) which will be integrated to the packaging line and used updated with functionalities coming from Zero-Swarm developments. For the usage of mobile agents, mounted over AGVs, to support high degree of line re-configurability and to perform automatic transport of packaging materials, food products, tools and spare parts for maintenance activities. New Modules will be developed and integrated into the original ReeNEXT Platform Architecture, and AI algorithms for decision making in terms of Production and Maintenance Plannings.

3.3.2 Validation Scenarios of SN Trial 1 and Trial 2

The Main Purposes of Validation Activities of Zero-SWARM Technologies, in terms of Hardware and Software Architectures, and Algorithms are mostly related to demonstrate the real applicability in an Industrial Packaging Line and especially the Reconfigurability of Devices, with own Controls Systems,

according to Production and Maintenance Scheduling and Re-scheduling Tasks.

In particular:

- Factory Layout, Job Missions and relative Time Estimation and Priorities, Possible Failures and, especially for AMR Devices, Battery Re-Charge Necessities, Traffic Logistics, Predictive and No-Predictable Maintenances and/or Cleaning Procedures will be considered for Training and Testing of AI Algorithms
- 3 different Production Contexts will be reproduced in relation to a typical Production Line of SME, where the Production Capacity is not so high in the minimum quantities – pieces per minute (from 16 p.p.m. in 1 shift to 48 p.p.m. in 2/3 shifts) but reliability and flexibility are extremely important and required

3.3.3 Validation Context #1

The **1st Context** is related to a Normal Production Flow which starts from a Production Request coming from ERP Management System and/or filled Manually into ReeNEXT Platform thanks to Production Planning Module.

The Customer Reference, Type of Materials (Trays, Films and Gas for MAP – Modified Atmosphere Packaging), Nr. of Trays to be packed, Starting Time, Nr. of Shifts, Production Team and Machine Recipe must be defined for a proper Scheduling of Internal Orders. When the Previous Production Batch has been completed the New Tasks are accepted by Different involved Machine and Devices with acquisition of relative Settings/Recipes.

If the Devices are in Ready Status the own Tasks are executed, differently a New Decision-Making System must Re-Schedule or Re-Allocate the Tasks on Other Devices. In particular, for Testing more Complex Scenarios the Virtual Commissioning of AMR and Packaging Machine will work in parallel as additional Devices instead of Real ones.

The AMR Devices will be engaged for the Transport of Packaging Products (Food, Trays, Film) picked in the relative different Warehouses; an Interaction with Machine Operators will be necessary and consequently coordinated. At the end of Packaging Machine Process, the packed Trays will be placed by the Operator into Carton Boxes to be Transported and Stored, with e certain Cadency per Minutes, by AMR into the Finished Products Stockroom.

All Production Data will be recorded by ReeNEXT for the final Overall Equipment Effectiveness and Cost Analysis thanks to Cost Analysis Module.

Table 24: 1st Context – Validation Tasks and Timing

1 st Context	Packaging Production of Ready-Meals			Testing Time
ReeNEXT Tasks	Set New Order1	Set New Order2		n.a.
Machine Tasks	Recipe 1	Recipe2		
	Order 1 Execution	Order 2 Execution		Order 1 and 2 30min each: 12ppm - 360

				Trays
AMR Device and/or AMR Virtual Tasks	Food Product 1 Transport for Picking - Point 1	Food Product 2 Transport for Picking - Point 2	Trays and Film Transport for Picking - Point 3	5min each Task
	Packed Trays Transport for Placing - Point 4			5min each Task
ReeNEXT Tasks	Close Order1 and Cost Analysis	Close Order1 and Cost Analysis		n.a.

3.3.4 Validation Context #2

The typical consequent Situation (**2nd Context**) of a Packaging Process is the Products Re-loading, in terms of Food-Product to be Packed but also Packaging Materials to be used for the Packing.

In particular, the New Tasks, very similar to the previous ones because based on Transport, Piking and Placing in charge to AMR Devices, will be generated according to the Real Consumes, set on-demand by the Operator or Automatically by Machine Sensors.

Table 25: 2nd Context – Validation Tasks and Timing

2 nd Context	Products Re-Loading			Testing Time
Machine Tasks	Request of missing Food Products 1 and 2	Request of missing Trays	Request of missing Film	n.a.
AMR Device and/or AMR Virtual Tasks	Food Product 1 and 2 Transport for Picking - Point 1	Trays Transport for Picking - Point 3	Film Transport for Picking - Point 3	5min each Task
	Packed Trays Transport for Placing - Point 4			5min each Task

3.3.5 Validation Context #3

Finally, the **3rd Context** represents the typical Critic Situation when the Production Process is compromised by a Functioning Problem which requests Unpredictable Maintenance and Cleaning Activities.

The Packaging Products (Food, Trays, Film) must be re-stored by AMR into relative Stockrooms, the Machine must be adjusted by Maintenance Team and Cleaning Staff to avoid possible Contaminations.

The AMR will be involved for extra-ordinary Activities like the Transport of Spare Parts necessary for Maintenance and/or Chemical Solutions used for Cleaning, according to a proper Coordination with the Operators and other Priority Tasks coming from other Packaging Lines.

When the Machine Functioning has been reestablished the Machine Operator need to re-start with the Production and, consequently, the Working Conditions of 1st Context must be Re-Set and Re-Scheduled.

Table 26: 3rd Context – Validation Tasks and Timing

3 rd Context	Maintenance and Cleaning			Testing Time
ReeNEXT Tasks	Set Maintenance 1	Set Cleaning1		n.a.
AMR Device and/or AMR Virtual Tasks	Spare Parts Transport for Picking - Point 5	Cleaning Chemical Solutions Transport for Picking - Point 6		5min each Task
	Spare Parts Transport for Placing - Point 5	Cleaning Chemical Solutions Transport for Placing - Point 6		5min each Task
ReeNEXT Tasks	Re-Scheduling Order1	Re-Scheduling Order2		n.a.

3.4 Technical requirements to the automation platform for a Trial

3.4.1 Technical Requirements for IEC61499 Applications

Table 27: IEC 61499-Controllable AMR

Requirement ID	WP5.2-1
Title	IEC 61499-Controllable AMR
Detailed Description	
“I want...” (what to build)	I want to create high-level driving services for a mobile manipulator in IEC 61499 as Function Blocks.
“So that...” (why to build)	So that the actual low-level controller is running in a separate edge/cloud and hidden from the FB-Programmer.
Type	<i>Technical requirement</i>
List of dependent requirements	○ AMR with ROS2 interface ○ AMR interface allows to control wheel velocities ○ AMR interface allows to read laser scanner echo ○ AMR payload: > 30 kg to mount a robotic manipulator and its control box ○ AMR offers HRC safety function to work in an environment with humans passing in the shop floor without separate AMR lanes ○ IEC 61499 device ○ IEC 61499 interface ○ IEC 61499 runtime environment ○ IEC 61499 development environment

List of precedent requirements	
Owner	<i>FhG (D5.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	The AMR can be sent via a Function Block to a position that is either defined by coordinates in a map or by a predefined position label.
Delivery for, by	<i>CN-2, FhG</i>

Table 28: IEC 61499-Controllable Robotic Manipulator

Requirement ID	WP5.2-2
Title	<i>IEC 61499-Controllable Robotic Manipulator</i>
Detailed Description	
“I want...” (what to build)	I want to create high-level manipulation services for a robotic arm as Function Blocks in IEC 61499.
“So that...” (why to build)	So that the actual low-level controller is running in a separate edge/cloud and hidden from the Function Block Programmer.
Type	<i>Technical requirement</i>
List of dependent requirements	○ 6 DOF ○ Accuracy: 0.3 mm for placing parts for robotic cell ○ Reach: > 80 mm from AGV to assembly station ○ payload: > 5kg ○ HRC: safe for Human Robot Collaboration EN ISO 13849-1, Kat. 3, and EN ISO 10218-1 ○ wireless communication with latency < 5ms ○ IEC 61499 device ○ IEC 61499 interface ○ IEC 61499 runtime environment ○ IEC 61499 development environment
List of precedent requirements	
Owner	<i>FhG (D5.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	• <i>The end effector of the robotic manipulator can be sent to a 6-dimensional coordinate in space (position and orientation) programmed using a Function Block.</i> • <i>The end effector can pick and place a known object programmed with a Function Block.</i>
Delivery for, by	<i>CN-2, FhG</i>

Table 29: IEC 61499-Controllable Storage Rack

Requirement ID	WP5.2-3
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Title	IEC 61499-Controllable Storage Rack
Detailed Description	
“I want...” (what to build)	I want to create a storage rack service
“So that...” (why to build)	So that the mobile manipulator is informed about the availability and position of parts for production.
Type	<i>Technical requirement</i>
List of dependent requirements	○ <i>Sensors: either metal detector or photo sensor</i> ○ <i>Wireless communication via 5G</i> ○ <i>Reconfigurable and manually movable rack</i> ○ <i>IEC 61499 device</i> ○ <i>IEC 61499 interface</i> ○ <i>IEC 61499 runtime environment</i> ○ <i>IEC 61499 development environment</i>
List of precedent requirements	
Owner	<i>FhG (D5.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	○ <i>The number of parts of a type specified by an ID can be requested via a Function Block.</i> ○ <i>The box ID where a part of a specific type is placed, can be requested via a FB.</i>
Delivery for, by	<i>CN-2, FhG</i>

Table 30: IEC 61499-Controllable Assembly-Station

Requirement ID	WP5.2-4
Title	IEC 61499-Controllable Assembly-Station
Detailed Description	
“I want...” (what to build)	I want to create an interface to IEC 61499 for the assembly station specific robotic language based on the existing ROS 2 – IEC 61499 interface
“So that...” (why to build)	So that the production programs can be started from high-level IEC 61499 passing relevant parameters (like the part supply position).
Type	<i>Technical requirement</i>
List of dependent requirements	○ <i>Linux (real-time enabled)</i> ○ <i>1,5 GHz CPU, 32 GB Memory, 4 GB RAM, ethernet port, 2 USB Ports, 1 HDMI Port</i> ○ <i>ROS 2 – IEC 61499 interface</i> ○ <i>IEC 61499 device</i> ○ <i>IEC 61499 interface</i> ○ <i>IEC 61499 runtime environment</i> ○ <i>IEC 61499 development environment</i>
List of precedent requirements	

requirements	
Owner	<i>FhG (D5.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	○ A predefined, robotic specific program can be started via a Function Block given the program name. ○ The pick-up position of an object can be given to the called program in form of a parameter using a Function Block.
Delivery for/by	<i>CN-2, FhG</i>

3.4.2 Technical Requirements for the Edge Computing Platform

Table 31: Edge Node as a container for the IEC 61499 and the AI system

Requirement ID	WP5.3-1
Title	<i>Edge Node as a container for the IEC 61499 and the AI system</i>
Detailed Description	
“I want...” (what to build)	I want to create a system architecture where the Edge Node accommodates the IEC 61499 runtime and the AI runtime
“So that...” (why to build)	so that all shopfloor participants communicate with the AI system on the Edge Node
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	<i>Selection of Edge Hardware from NX-SE</i>
Owner	<i>NX-SE, RWG (D5.1, chapter 5.1.2, D5.3)</i>
Priority	<i>Medium</i>
Acceptance criteria	• <i>Edge-Node running a dockerized IEC 61499 runtime</i> • <i>Edge-Node running a dockerized AI runtime</i> • <i>Established communication between IEC61499 and AI runtime, within the Edge Node</i> • <i>All shopfloor controllers communicate via the IEC61499-gateway on the Edge Node with the AI runtime on the Edge node</i>
Test cases	• <i>Develop and distribute a IEC61499 gateway</i> • <i>Send data from different controllers via the IEC61499 edge gateway to the AI system on the Edge</i>
Delivery for, by	<i>SN-1/2, NX-SE/RWG</i>

Table 32: Communication from the IEC61499 RT system to the Cloud for AI functionality

Requirement ID	WP5.3-2
Title	<i>Communication from the IEC61499 RT system to the Cloud for AI functionality</i>
Detailed Description	
“I want...” (what to build)	I want to implement an interface (e.g. OPC UA) between the IEC61499 RT and an AI algorithm on the Cloud
“So that...” (why to build)	So that all shopfloor participants communicate over the IEC61499 gateway with the AI system on the Cloud Node, like it will be done with the AI system on the Edge Node.

Type	Technical requirement
List of dependent requirements	
List of precedent requirements	Cloud and AI partner in WP4
Owner	NX-SE, RWG (D5.1, chapter 5.2.1, 7.3, D5.3)
Priority	Medium
Acceptance criteria	AI runtime on the Cloud can send/receive data to the IEC61499 runtime on the Edge
Test cases	Get data from the shopfloor and send them over the Edge to the AI runtime on the Cloud and get results back to the shopfloor
Delivery for/by	SN-1/2, NX-SE/RWG

Table 33: AI connectivity in the IEC61499 runtime and in the engineering process

Requirement ID	WP5.3-3
Title	AI connectivity in the IEC61499 runtime and in the engineering process
Detailed Description	
“I want...” (what to build)	As an Automation Engineer I want to make a simpler and faster engineering process for the connectivity to the AI system
“So that...” (why to build)	So that the AI connection is established to a given AI function
Type	Functional requirement
List of dependent requirements	-
List of precedent requirements	See WP4: List of AI functions, AI-Library, dedicated AI runtime system usage with dedicated protocol to choose, e.g. OPC UA
Owner	NX-SE (D5.1, chapter 7.3, D5.3)
Priority	Medium
Acceptance criteria	Interface for connecting to the AI RT is implemented in form of a FB-template and can be easily used when developing an IEC61499 application
Test cases	Use interface for AI connectivity in an IEC61499 application and test if data is transferred from/to the AI runtime over the dedicated communication protocol (e.g. OPC UA)
Delivery for, by	SN-1/2, NX-SE

Table 34: IEC61499 system can trust the AI system

Requirement ID	WP5.3-4
Title	IEC61499 system can trust the AI system
Detailed Description	
“I want...” (what to build)	As an Automation Engineer I want to be sure to trust the connected AI system, mainly in the cloud
“So that...” (why to build)	So that the AI connection is established in a trusted and secure way
Type	Functional requirement
List of dependent requirements	-

List of precedent requirements	See WP4: Edge System connected to the cloud
Owner	NX-SE (D5.1, chapter 5.2.1 and 7.1.2, D5.3)
Priority	Medium
Acceptance criteria	Interface for connecting to the AI RT is established in a trusted and secure way
Test cases	Call different AI algorithm located on a different system from the cloud
Delivery for, by	SN-1/2, NX-SE

3.4.3 Technical Requirements for Reconfigurability by AMRs, AGVs

Table 35: AMR recognition in the shopfloor from production line request

Requirement ID	WP5.2-1.1
Title	AMR recognition in the shopfloor from production line request
Detailed Description	
“I want...” (what to build)	As an Automation Engineer I want to call the requested AMR, which is responsible for the dedicated task, like maintenance or production line reconfiguration or other scenario, which is described in the functional requirements
“So that...” (why to build)	So that the AMR connection is established during the runtime of the production task
Type	Functional requirement
List of dependent requirements	-
List of precedent requirements	AMR with dedicated service interface
Owner	AALTO (D5.2)
Priority	Medium
Acceptance criteria	The discovery for the right AMR is working in the right way
Test cases	The AMR offers a set of different services to interact with the production line
Delivery for, by	SN-1/2, AALTO

Table 36: IEC61499 system can trust the AMR system

Requirement ID	WP5.2-1.2
Title	IEC61499 system can trust the AMR system
Detailed Description	
“I want...” (what to build)	As an Automation Engineer I want to be sure to trust the connected AMR system
“So that...” (why to build)	So that the AMR connection is established in a trusted and secure way
Type	Functional requirement
List of dependent requirements	5.2.1
List of precedent requirements	-
Owner	LTU (D5.2)
Priority	Medium

Acceptance criteria	Interface for connecting from the AI Scheduler to the AMR is established in a trusted and secure way
Test cases	Call different services of the AMR
Delivery for, by	SN-1/2, LTU/NX-SE

Table 37: Discovery and Reconfigurability of an IEC 61499 control system

Requirement ID	WP5.2-1.3
Title	Discovery and Reconfigurability of an IEC 61499 control system with defined semantics
Detailed Description	
“I want...” (what to build)	As an Automation Engineer I want to build a smart IEC 61499 control system which should be easily reconfigurable and able to accommodate different system agents with different capabilities,
“So that...” (why to build)	So that the IEC 61499 control system to be flexible and easily reconfigurable. So, if I decide to relocate or add new agent component to a different position, the system should automatically adjust the whole system to match the new configuration, ensuring that the workpiece is always acts correctly
Type	<i>Functional requirement</i>
List of dependent requirements	-
List of precedent requirements	
Owner	<i>LTU (D5.2, chapter 4.3)</i>
Priority	<i>Medium</i>
Acceptance criteria	The discovery of relocated or added drill components is working and updates the system configuration in the right way
Test cases	The Processing station offers a set of different skill services enables flexible and reconfigurable production line.
Delivery for, by	NN, CN, LTU

Table 38: Bottom-up application building:

Requirement ID	WP5.2-1.4
Title	Bottom-up application building
Detailed Description	

"I want..." (what to build)	<i>As an Automation Engineer I want to see updates of the configuration of the system in my IEC 61499 IDE</i>
"So that..." (why to build)	<i>So that the IDE can display when a new agent connects to or disconnects from the system</i>
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	<i>FBME IDE open API</i>
Owner	<i>LTU (D5.2, chapter 4.8)</i>
Priority	<i>Medium</i>
Acceptance criteria	<i>The FBME IDE displays correctly when a new agent connects to or disconnects from the system</i>
Delivery for, by	<i>NN, CN, LTU</i>

3.4.4 Technical Requirements for the Automation Platform and Cybersecurity

Table 39: Reusable IEC61499 object design

Requirement ID	WP5.1-1
Title	Reusable IEC61499 object design
Detailed Description	
"I want..." (what to build)	<i>As an Automation Engineer I want to be sure to use the IEC61499 SW objects independently from the underlying hardware,</i>
"So that..." (why to build)	<i>so that the dedicated IEC61499 software object can be used from different machines and extend by the new AI and AMR services in an object-oriented reusable way.</i>
Type	<i>Functional requirement</i>
List of dependent requirements	<i>5.2.x, 5.3.x</i>
List of precedent requirements	<i>5.1.2, 5.1.3, 5.1.4</i>
Owner	<i>NX-SE, REPK, LTU (D5.1, chapter 7.1.1)</i>
Priority	<i>Medium</i>
Acceptance criteria	<i>Integration of encapsulated AMR interface in CAT object</i> <i>Integration of encapsulated AI interface in CAT object</i> <i>Applicable for different SW objects of the production line</i>
Test cases	<i>Take an existing CAT object from the production line and extend it by the functionality from AI and AMR</i>
Delivery for, by	<i>SN1/2, NX-SE/REPK/LTU</i>

Table 40: Wireless IEC61499 Communication from the shopfloor to the Edge/Cloud System

Requirement ID	WP5.1-2
Title	<i>Wireless IEC61499 Communication from the shopfloor to the Edge/Cloud System</i>
Detailed Description	
“I want...” (what to build)	I want to communicate wireless (Wi-Fi b/g/n and cellular 5G) over the IEC61499 distributed protocol from the shopfloor to the Edge/Cloud,
“So that...” (why to build)	so that all shopfloor participants communicate wireless and secure with the edge system over the IEC61499 standard.
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	<i>Wireless and/or 5G communication hardware and network infrastructure</i>
Owner	<i>NX-SE, LTU (D5.1, chapter 7.1.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	Application on the Edge/Cloud can send/receive data wireless (and 5G) from IEC61499 runtime on the Shopfloor over IEC61499 distributed protocol
Test cases	Get data from the shopfloor and send them wireless to the Edge/Cloud and get results back to the shopfloor
Delivery for, by	<i>NN/CN/SN, NX-SE/LTU</i>

Table 41: Wireless OPC UA Communication from the shopfloor to the Edge/Cloud System

Requirement ID	WP5.1-3
Title	<i>Wireless OPC UA Communication from the shopfloor to the Edge/Cloud System</i>
Detailed Description	
“I want...” (what to build)	I want to use OPC UA communication protocol over wireless network (Wifi and/or 5G) from the IEC61499 shopfloor to the Edge/Cloud,
“So that...” (why to build)	so that all shopfloor participants communicate wireless and secure with the edge system over the OPC UA standard.
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	<i>Wireless and/or 5G communication hardware and network infrastructure</i>
Owner	<i>NX-SE, LTU (D5.1, chapter 5.2.1 and 7.1.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	Application on the Edge/Cloud can send/receive data wireless (and 5G) from IEC61499 runtime on the Shopfloor over OPC UA
Test cases	Get data from the shopfloor and send them wireless to the Edge/Cloud and get results back to the shopfloor
Delivery for, by	<i>NN/CN/SN, NX-SE/LTU</i>

Table 42: Wireless MQTT Communication from the shopfloor to the Edge/Cloud System

Requirement ID	WP5.1-4
Title	<i>Wireless MQTT Communication from the shopfloor to the Edge/Cloud System</i>
Detailed Description	
“I want...” (what to build)	I want to use MQTT communication protocol over wireless network (Wifi and/or 5G) from the IEC61499 shopfloor to the Edge/Cloud,
“So that...” (why to build)	so that all shopfloor participants communicate wireless and secure with the edge system over the MQTT standard.
Type	<i>Functional requirement</i>
List of dependent requirements	
List of precedent requirements	<i>Wireless and/or 5G communication hardware and network infrastructure</i>
Owner	<i>NX-SE, LTU (D5.1, chapter 5.2.2 and 7.1.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	• <i>Application on the Edge/Cloud can send/receive data wireless (and 5G) from IEC61499 runtime on the Shopfloor over MQTT</i>
Test cases	• <i>Get data from the shopfloor and send them wireless to the Edge/Cloud and get results back to the shopfloor</i>
Delivery for, by	<i>NN/CN/SN, NX-SE/LTU</i>

Table 43: Store Human-Related Data in a Data Lake

Requirement ID	WP5.1-6
Title	<i>Store Human-Related Data in a Data Lake</i>
Detailed Description	
“I want...” (what to build)	I want to store the pseudo-anonymized human-related data from various sources in a single cloud database with access control which requires authorization.
“So that...” (why to build)	So that this data can be assessed in real-time by a decision-making algorithm to identify the current state of the worker. This data can also be accessed for ML model training externally.
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	
Owner	<i>Aalto University (D5.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	• <i>All the human-related data is structured in NoSQL database;</i> • <i>Database transfer should support encryption;</i> • <i>Database with heart-rate values is stored among other data types in a Data Lake manner;</i> • <i>Sensitive data is pseudo-anonymized by using masking and encrypted (according to GDPR);</i> • <i>Accessing sensitive data requires authorization;</i> • <i>Data is pseudo-anonymized (according to GDPR);</i>

	• This Data Lake can be accessed externally for ML model training (Federated Learning); • Data Lake is segmented and supports access management system;
Delivery for, by	NN, AALTO

Table 44: Execute MiR100, UR3 Missions from IEC 61499 application

Requirement ID	WP5.1-7
Title	Execute MiR100, UR3 Missions from IEC 61499 application
Detailed Description	
“I want...” (what to build)	I want the IEC 61499 automation system to automatically execute missions for MiR100 AGV and UR3 cobot based on the human state.
“So that...” (why to build)	So that MiR100 and UR3 can perform either transporting or processing tasks with a product if a worker is not in an applicable state.
Type	Technical requirement
List of dependent requirements	
List of precedent requirements	IEC61499 ROS-based communication implemented;
Owner	Aalto University (D5.2)
Priority	Medium
Acceptance criteria	• All the missions shall be executed with no major delays; • Missions can either be executed using Python-based API or IEC61499 ROS-based FB;
Delivery for, by	NN, AALTO

Table 45: Data Exchange of the Production System with a Digital Twin

Requirement ID	WP5.1-8
Title	Data Exchange of the Production System with a Digital Twin
Detailed Description	
“I want...” (what to build)	I want all the elements of the production system (EnAS/CPLab, MiR100, UR3/YuMi, Human-Machine Interface, Decision Making Module) to have communication interfaces to exchange data with the Digital Twin.
“So that...” (why to build)	So that the Digital Twin has a relevant depiction of the process and can affect the production processes.
Type	Technical requirement
List of dependent requirements	
List of precedent requirements	WP-5.1-R6 OPC UA or MQTT based communication;
Owner	Aalto University (D5.1 chapter 6.2)
Priority	Medium
Delivery for, by	NN, AALTO

3.4.5 Technical Requirements for the Automation system’s Virtual Commissioning platform

Table 46: Virtual Commissioning (VC) Platform Supporting Simulation of Human DT

Requirement ID	WP5.1-9.1
Title	<i>Virtual Commissioning (VC) Platform Supporting Simulation of Human DT</i>
Detailed Description	The VC platform should be capable of simulating the full system with 95% accuracy (95% of mechanical components of the overall system), including every element from the worker, the MiR100 and UR3 robots, to the workstations, and the data transfer and analysis procedures. It should reflect the real-world operations with a margin of error of less than 5% in all aspects, and effectively portray system response times at least within 5 seconds.
“I want...” (what to build)	I want the VC platform to support the simulation of human digital twins in at least one scenario by supporting at least one type of communication interfaces on the cloud.
“So that...” (why to build)	So that Customers could visualize the simulation in a convenient and interactive manner.
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	<i>Human DT dataflow is structured and maintained;</i>
Owner	<i>Aalto University (D5.2)</i>
Priority	<i>Medium</i>
Delivery for, by	NN, AALTO

Table 47: Data Connections between the Front Web Page and Simulation Models

Requirement ID	WP5.1-9.2
Title	<i>Data Connections between the Front Web Page and Simulation Models</i>
Detailed Description	This connection is for data transmission, e.g., simulation behaviour and results, from the server side to the web front page to be visualized later.
“I want...” (what to build)	I want to build flexible interfaces on the front web page to integrate simulation models from at least one third party tools such as Visual Components or Gazebo.
“So that...” (why to build)	So engineers could quickly visualize the behaviour and performance by integrating existing models which are available in third party tools.
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	<i>WP-5.1.1-1</i>
Owner	<i>Aalto University (D5.2)</i>
Priority	<i>Medium</i>
Delivery for, by	NN, AALTO

Table 48: Embed Data-visualizing tools in front page

Requirement ID	WP5.1-9.3
Title	<i>Embed Data-visualizing tools in front page</i>

Detailed Description	The VC platform ought to have tools for visualizing the system in use for users. This could include visual representations of data flow and processing, heart rate and condition graphs, and 3D models of the worker and the robots.
“I want...” (what to build)	I want to build at least one section on the web front page to support the selection of chart types, e.g., 2D or 3D charts.
“So that...” (why to build)	So users could be able to draw different types of charts according to their testing cases.
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	<i>WP-5.1.1-1</i>
Owner	<i>Aalto University (D5.2)</i>
Priority	<i>Medium</i>
Delivery for, by	<i>NN, AALTO</i>

Table 49: Simulation Report and Data Export

Requirement ID	<i>WP5.1-9.4</i>
Title	<i>Simulation Report and Data Export</i>
Detailed Description	From the simulation, users should be able to export data and report for each simulation result. <i>Report includes:</i> - <i>Uptime</i> - <i>Average CPU and memory consumption</i> - <i>Errors log</i> - <i>Device (PLCs/soft-PLCs) details</i> - <i>Communication Analysis</i>
“I want...” (what to build)	I want to build the section and a button which could support the feature enabling users to export simulation data after each simulation result by clicking that button.
“So that...” (why to build)	So users could analyse their simulation data in deep in the later use and share this simulation results in the team.
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	<i>WP-5.1.1-1</i>
Owner	<i>Aalto University (D5.2)</i>
Priority	<i>Medium</i>
Delivery for, by	<i>NN, AALTO</i>

Table 50: Communication from the IEC61499 RT system to the Cloud to the Digital Twin for Virtual Commissioning functionality

Requirement ID	<i>WP5.1-9.5</i>
Title	<i>Communication from the IEC61499 RT system to the Cloud to the Digital Twin for Virtual Commissioning functionality</i>
Detailed Description	

"I want..." (what to build)	I want to implement a communication interface (e.g. MQTT) between the IEC61499 RT and Virtual Commissioning in the Cloud
"So that..." (why to build)	So that the IEC61499 control application on the shopfloor can communicate over the IEC61499 gateway on the Edge Node with the Digital Twin Virtual Commissioning.
Type	<i>Technical requirement</i>
List of dependent requirements	
List of precedent requirements	<i>Digital Twin Partner</i>
Owner	<i>NX-SE, TTS (D5.1, chapter 5.2.2)</i>
Priority	<i>Medium</i>
Acceptance criteria	VC runtime on the Cloud can send/receive data to the IEC61499 runtime on the Edge
Test cases	Get data from virtual commissioning and send them over the IEC61499-Edge-Node to the control application on the shopfloor and back
Delivery for/by	<i>SN-1/2, NX-SE/TTS</i>

4 Specific Trial and Automation Platform Architecture

This chapter is based on the functional and technical requirements of selected trials where the overall CPS automation architecture will be further detailed, from both the hardware and software points of view, addressing all the aspects that enable a portable and scalable implementation of a reconfigurable network smart devices, compliant to the IEC-61499 international standard and deployed over an Edge Computing architecture. It addresses the structure and composition of a heterogenous trial into an intelligent swarm with its interfaces in the automation platform of the shopfloor and the interaction with other systems over service-oriented interfaces to the upper tiers like the edge-gateway tier (see chapter 5.1) and the data centre tier of the overall architecture (see chapter 6) , as well the semantic mapping of IEC61499 structure to the MQTT and OPC UA protocol in chapter 5.2. Further details are address in D5.2 and D5.3.

4.1 North Node

4.1.1 Overall Architecture of NN3 and NN4

4.1.1.1 Software and Dataflow Architecture

The software architecture in Figure 6 is based on the principles of component and service-oriented architectures and is aligned with the ideas of Asset Administration Shell (AAS).

The software architecture for development of control applications for the factory floor machines controlled by an IEC 61499 application will be developed using the one-line architecture. The one-line engineering pattern combined with the Service-oriented architecture (SOA) puts together a design pattern which enhances the support for plug-and-play, modularity, and reconfigurability on the software layer. The generic pattern shown in Figure 7 breaks down the application into numerous layers, in which the bottom layer, that is, the execution layer consists of various Function Blocks (FBs) representing hardware elements of the machine. Moreover, these FBs will be connected to each other in a pattern that represents the physical interaction of components of the machine.

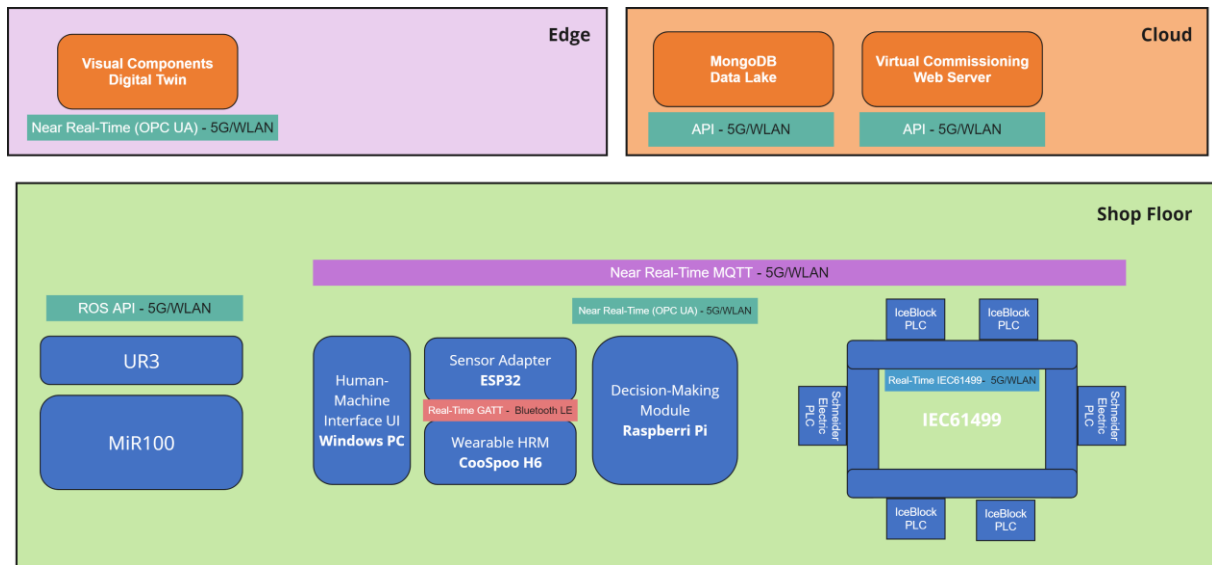


Figure 6: NN Software and Dataflow of overall Architecture

Furthermore, the services layer can consist of various number of FBs divided into various sub-layers based on the device and application. For example, organization of delivery or coordination of pneumatic operators are possible services. Finally, the production recipe or sequence of operations are contained inside a FB at the topmost layer, that is, the production layer. The various FBs across all these layers are connected by single-line adapters of the IEC 61499 standard, aimed at reducing complexity during runtime and factory floor operations. Furthermore, the pattern is supportive of the ideas of the Asset Administration Shell (AAS) and can incorporate functionalities provided by AAS.

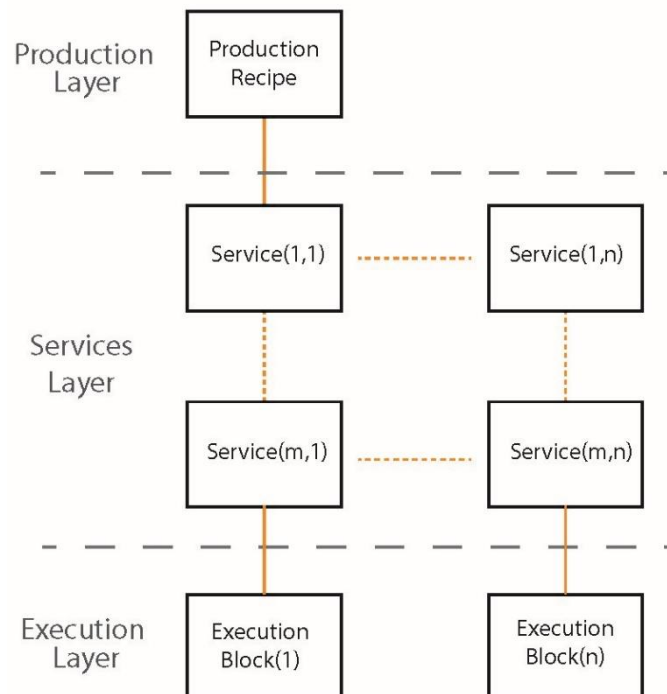


Figure 7: NN Service Architecture

4.1.1.2 3 Axis manipulation demonstrator, in AFoF & LTU testbed

In Figure 8 a web-based VC platform is used for the virtual commissioning of the 3-axis manipulator. This manipulator's digital counterparts are running on the cloud using Gazebo and Gzweb. Control applications are implemented using IEC 61499 with distributed PID controllers which are controlling axis X, Y, and Z, respectively. Those PID control commands are sent to digital models of the manipulator via OPC UA and ROS topics. After achieving the optimal performance for controlling 3-axis manipulator with optimal PID parameters and other configuration of distributed IEC 61499 control systems, physical manipulator is ready to be connected to the optimized and commissioned IEC 61499 control systems via its I/O interfaces.

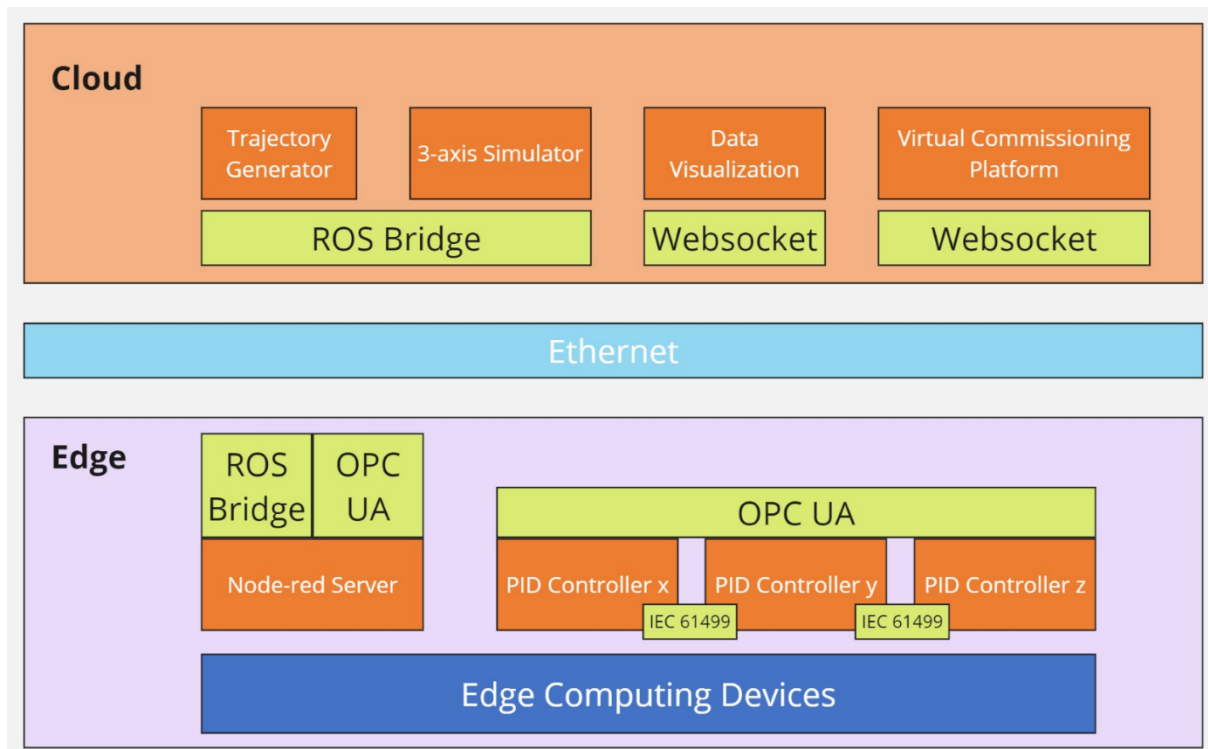


Figure 8: NN 3 and 4 - 3 Axis manipulation demonstrator – software architecture

In Figure 9 the Trajectory Generator is a Python script running on the cloud to generate the target path for the 3-axis manipulator. This target path includes discrete points in 3D coordinates in the format of discrete points in X, Y, and Z. After generating those targets, the data set is sent to IEC 61499 control applications to be further processed via OPC UA objects. This data transmission is achieved by using a ROS bridge to link ROS topics to OPC UA variables/objects. Those distributed PID controllers will process those received targets from the Trajectory Generator and control the 3-axis manipulator virtual model on the cloud.

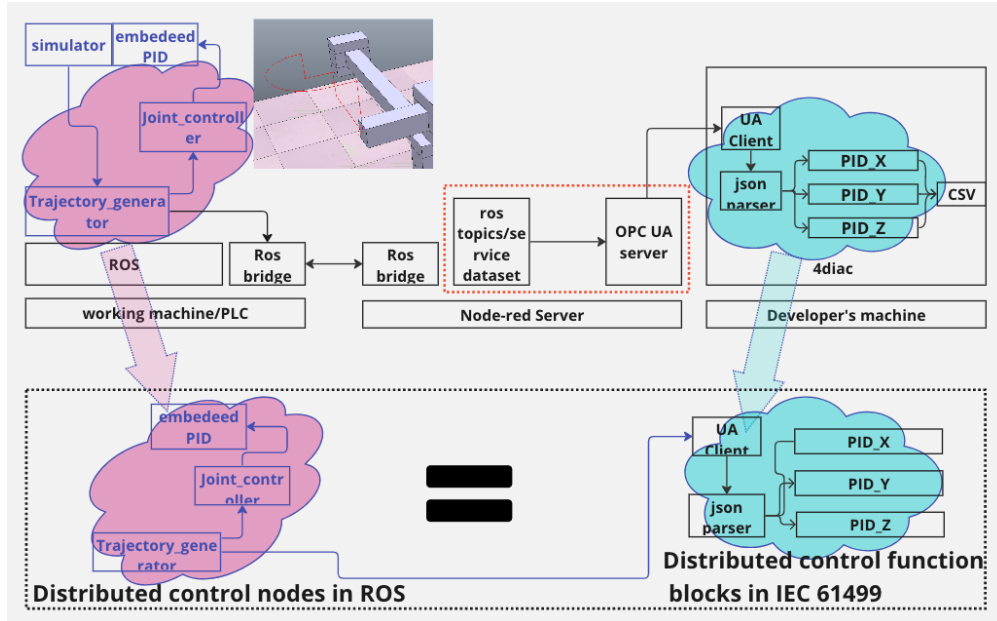


Figure 9: NN 3 and 4 - 3 Axis manipulation demonstrator – data flow architecture

4.1.2 Processing Station and Monitoring

4.1.2.1 Software and Dataflow Architecture

In Figure 10 the processing station utilizes IEC 61499 control logic software and is designed as a flexible and reconfigurable system, comprising multiple drill components and a rotary table component, each equipped with its own IEC 61499 smart control device.

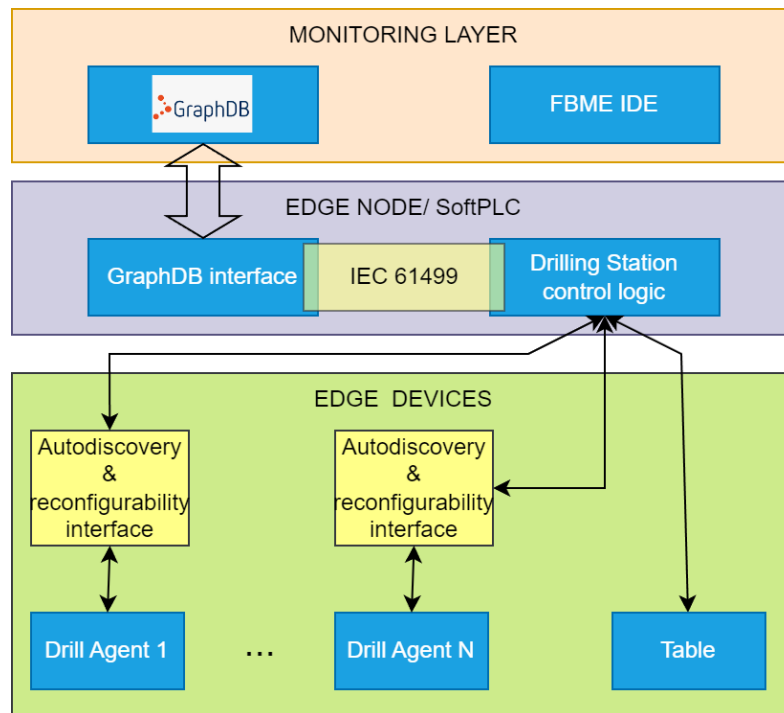


Figure 10: NN Software and Dataflow Architecture

The presence or absence of drill components is detected through an IEC 61499 autodiscovery interface

using MQTT communication protocol. Skill and capability information of each drill component is stored in the GraphDB database whenever a new drilling component appears or is repositioned within the processing station. Configuration changes are identified and displayed in FBME IDE for IEC 61499.

4.1.2.2 Physical Architecture

The Drilling station system is of several mechatronic components, including the Drill components and Table component. We plan to connect each component of the Drilling station in the shop floor with a 5G modem to the network. Each drilling agent and the Table will be equipped with an IceBlock to achieve system mobility:

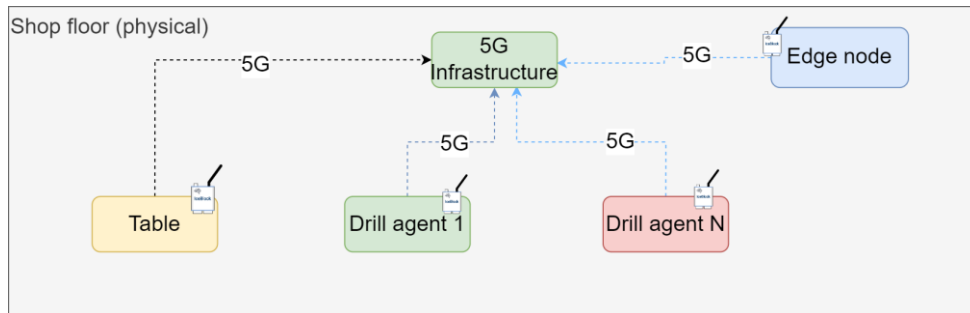


Figure 11: NN Physical Architecture

4.2 Central Node – Trial 2

4.2.1 Software and Dataflow Architecture

The production process in Figure 12 will be programmed with high-level function blocks in IEC 61499 as demo that will be loaded by the recipe manager into the scheduler.

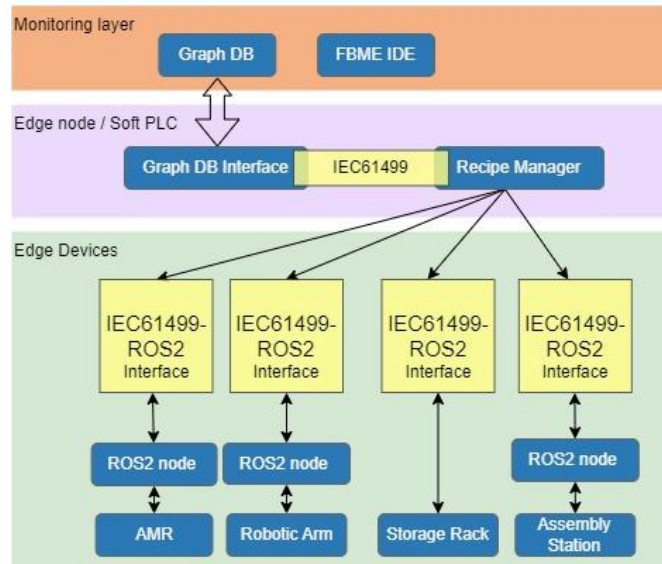


Figure 12: CN T2 Software and Dataflow Architecture

The high-level functions allow the positioning of the AMR, execute pick-and-place tasks for the robotic arm, read the status of the storage rack and start programs on the assembly station and milling station. The recipe manager and scheduler run in the edge or cloud and call the high-level functions in the required order. They access the devices in the IEC 61499 environment using the auto discovery feature

which is implemented in MQTT. The low-level control services for the shop floor devices are implemented in ROS 2 and will be hidden from the IEC 61499 programmer. We plan to use the ROS 2 - IEC 61499 interface to trigger the low-level control services.

4.2.2 Physical Architecture

The IPK test field at PTZ (shop floor) is equipped with 5G antennas. We plan that every shop floor device connects with a 5G modem to the network. These shop floor devices are an AMR, a lightweight robotic arm, an industrial assembly station and a storage rack. For a simplified and homogenous configuration of the network, we plan to use an IceBlock on every device as a modem. Using a homogenous network configuration will enable the devices to connect to the IEC 61499 environment to run the high-level functions, but they will still be able to access the ROS 2 environment for low level control:

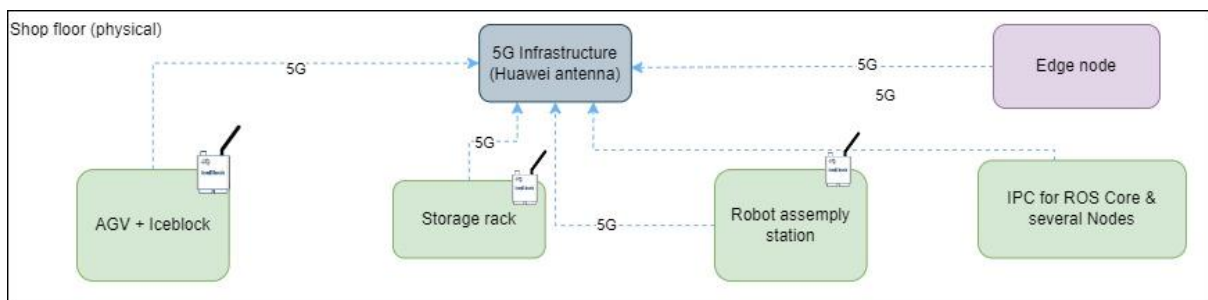


Figure 13: CN T2 Physical Architecture

4.3 South Node – Trial 1 and Trial 2

4.3.1 Software Architecture

For this specific Trial SN1 & 2 the software architecture in Figure 14 is going to be used in this manner, by having one or more AMRs in the shopfloor, which can fulfil all the validation scenarios, defined in chapter 3.3:

- Exchanging empty tray's and/or films
- Bringing a food tray with a cobot
- Exchanging the spare-parts

In the **shopfloor** (Edge Devices tier) the **production line** consists of different machines (detester, cobot, tray-sealer), which is controlled by an IEC61499 application, which is going to be extended with the reconfiguration functions in connection with the AMR and with the AI functionalities from the Edge-Node.

The Monitoring and AI functions within the **Edge-Gateway** tier are going to be adapted to fit into the IEC61499 and OPC UA object model. Furthermore, in the Edge-Layer of ReeNEXT the main configuration tasks are happening, like the Placing and Pick Location configuration, the material configuration, the spare-parts configuration and the food configuration, and the task configuration with the used components for a given recipe.

The Digital Twin (DT) and virtual commissioning is in the **cloud** (data centre tier). The later functionality of virtual commissioning is directly interacting with the IEC61499 control application, where the communication protocol will fit to the IEC61499 object model and the DT model.

Where possible the **wireless or 5G communication** will be integrated between AMR and production line and between production line and the Edge Node or Cloud.

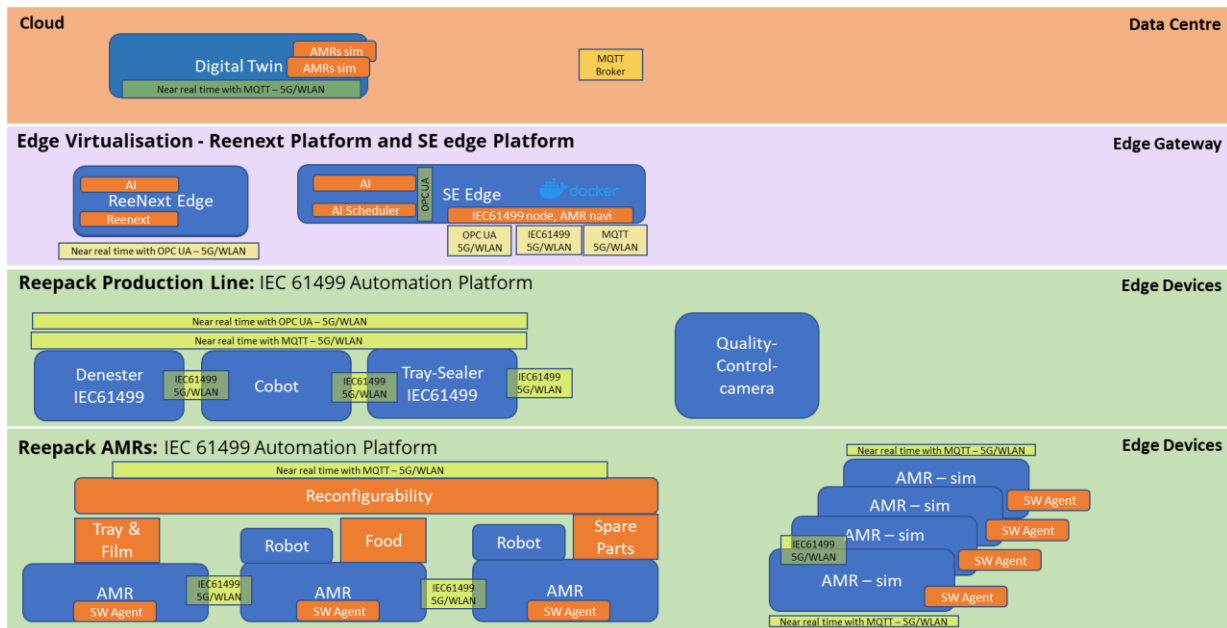


Figure 14: Software Architecture for SN 1,2

4.3.2 Physical Architecture

Figure 15 shows in the **shopfloor**, the existing demonstrator hardware of REPK, which will be updated to wireless or 5G capable IEC61499 communication devices (IceBlock from Flexbridge) and the main IEC61499 PLC (from Schneider Electric) will be updated by a new generation hardware with more memory and CPU power for supporting OPC UA communication and the extension for AI integration. An own AMR hardware with an own communication interface (MQTT preferred) or with the wireless IEC61499 interface of the IceBlock-hardware is going to be used. As fallback in case of delivery problems for the AMR, a dedicated mixture of simulation and virtual commissioning functionality for the AMR will be used instead of a real hardware.

At the **edge gateway** tier (Edge Virtualisation) 2 different edge gateway devices are used, one from REPK, which is existing their product portfolio and is going to be extended with the new software modules, and one from Schneider Electric, which is focusing on the integration of AI functionality to the extend the virtualized IEC61499 automation platform with it, more details se in chapter 5.1.

The **data centre** tier (cloud) is going to use an industrial PC for integrating the Digital Twin functionality.

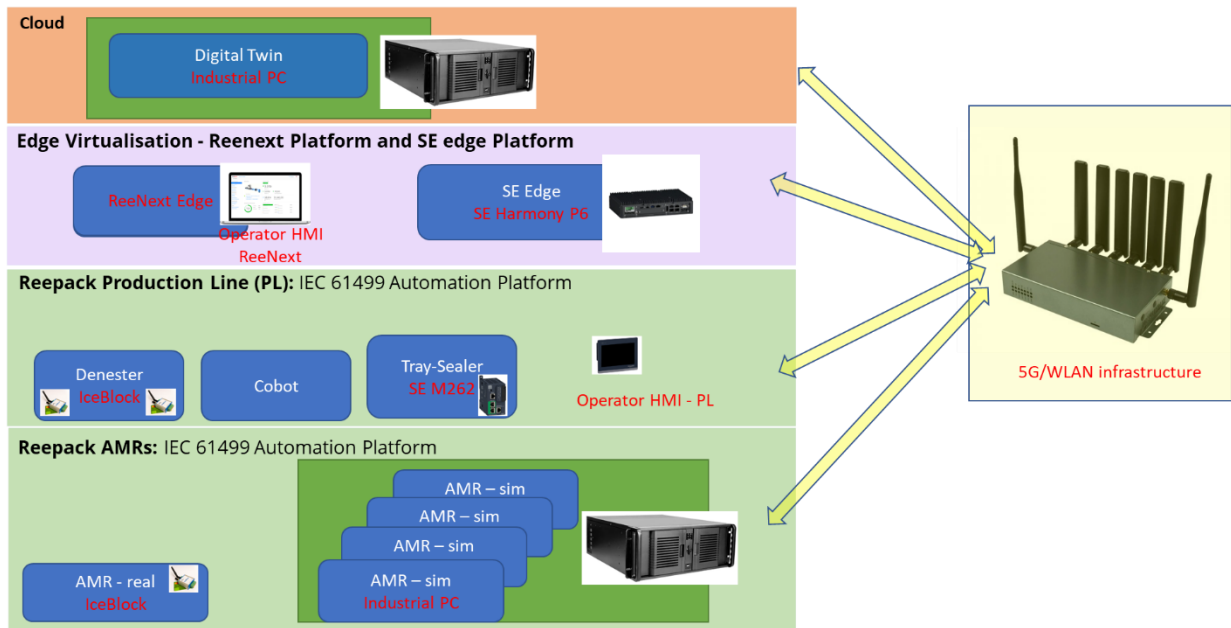


Figure 15: Hardware Architecture for SN 1,2

4.3.3 Dataflow Architecture

To easier understand the system the dataflow architecture in Figure 16 shows the movement and transformation of the data between different software modules and automation layer's, rather than the control flow of the automation system.

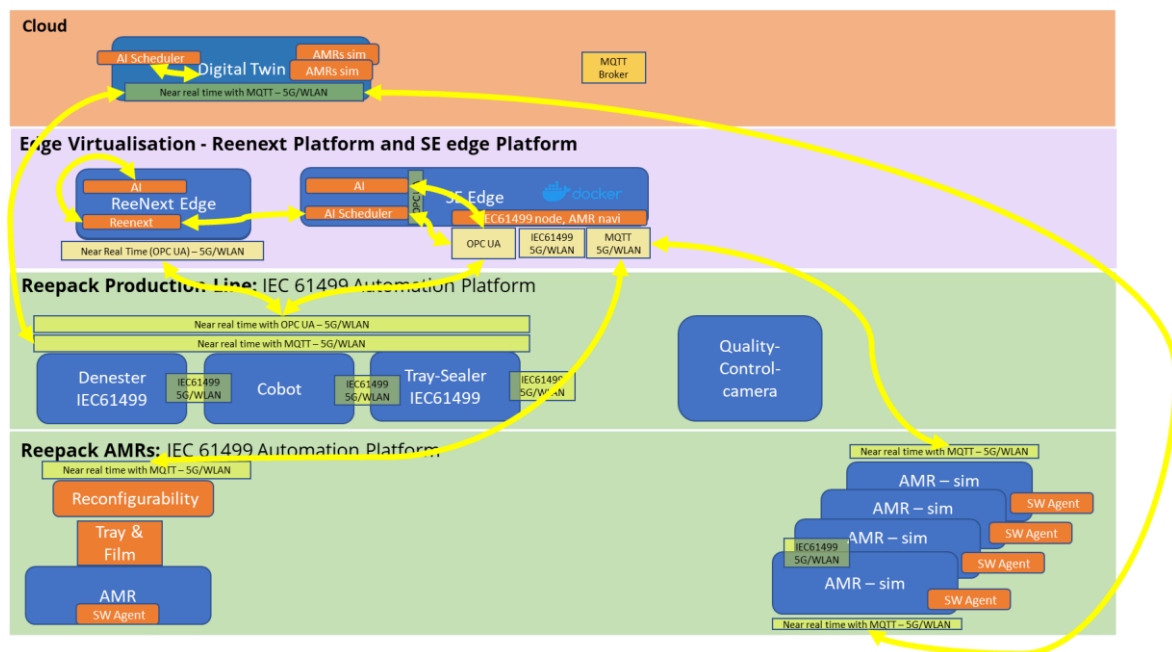


Figure 16: Dataflow Architecture for SN 1,2

The key characteristic is that data flows through the system and each component of the system is responsible for performing a specific task or specific services on the data. Data is passed between different components of the system as it is transformed, processed, and stored in different modules and tiers. The following Figure 16 shows the dataflow from the AMRs to the Edge-Gateway tier, where

MQTT standard protocol is used for this service-interfaces. The real AMR's and the simulated AMRs are going to use the same service interfaces. The Production line shows the communication to the Edge-Gateway over the OPC UA standard, which is going to build the object-oriented structure of the IEC61499 automation objects. Where the AI runtime integration into the IEC61499 automation platform and the communication to the other edge gateway device is going to happen over OPCUA.

5 Virtualized Edge Computing Platform and Interfaces

This chapter shows a powerful edge to cloud architecture from 2 different vendors, which is going to be extended with the services for specific trials to interact with the shopfloor, the AI-system, other schedulers and as well with the data centre tier in WP4 of T4.2, where wireless connectivity is a goal. Edge virtualization of the IEC61499 platform in real-time and near-real-time computational processes of AI applications is going to be integrated in this hardware.

5.1 Edge Hardware- and Software-Mapping

5.1.1 ReeNEXT-Edge-Platform for SN Trial 1 and 2

The main purpose of this chapter is to describe ReeNEXT Platform, the Hardware, and Software Architecture shown in Figure 17 like it is, and commercialized by Reepack, compliant with I4.0 requirements:

- TCP-IP Protocol at Industrial Level
- Secure Distribution of Data and Information
- Big Data Analytics
- Cloud Data Storage
- Horizontal & Vertical Data Integrations and Sharing
- Additive Manufacturing
- Simulation
- Augmented Reality

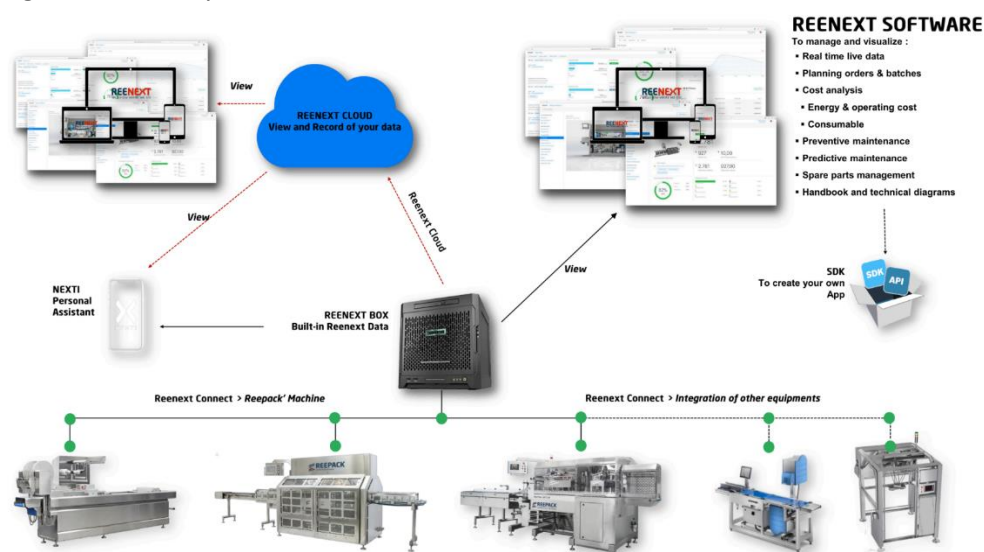


Figure 17: ReeNEXT Architecture

ReeNEXT Platform is a Stand-Alone Solution available for all Reepack Automatic Packaging Lines and

characterized by own **Hardware**:

- **Machine Predisposition:**

- Modem for Remote Control and Service
- Switch for Local Network made by PLC & HMI & Additional Units: all Control Units are directly connected to the same Local Network for Continuous Data Acquisition and Sharing
- Devices for Measuring of Commodity Consumptions, Electrical Power Supply, Compressed Air, Gas Injections for MAP; all acquired Data can be used for Real-Time Monitoring, Advance Machine Maintenance and Cost Analysis of all Production Batches.

- **ReeBOX, Plug & Play Solution based on Raspberry PI4:**

- MySQL DataBase for Data Storage: PLC Data Sharing based on SIEMENS (Dedicated Implemented by Reepack) and/or OPC-UA (Standard Communication) Protocols; Reepack SN - Trial 1/2 is

and by own **Software**, Web-Based User Interface browser and device Independent, provided with 6 Main Modules, as shown in Figure 18 below:



Figure 18: Main ReeNEXT Interface Modules

- **LiveData Module** as shown in Figure 19 with:

- Dashboard for a General Overview of Different Machines, up to 10 Devices/Lines with own PLC related to the same Customer Network, also located in Different Production Plants
- RealTime Data Monitoring per Each Machine of PLC Variables stored into ReeNEXT BOX
- Daily Data and Data Analysis for Production Statistics and Analysis

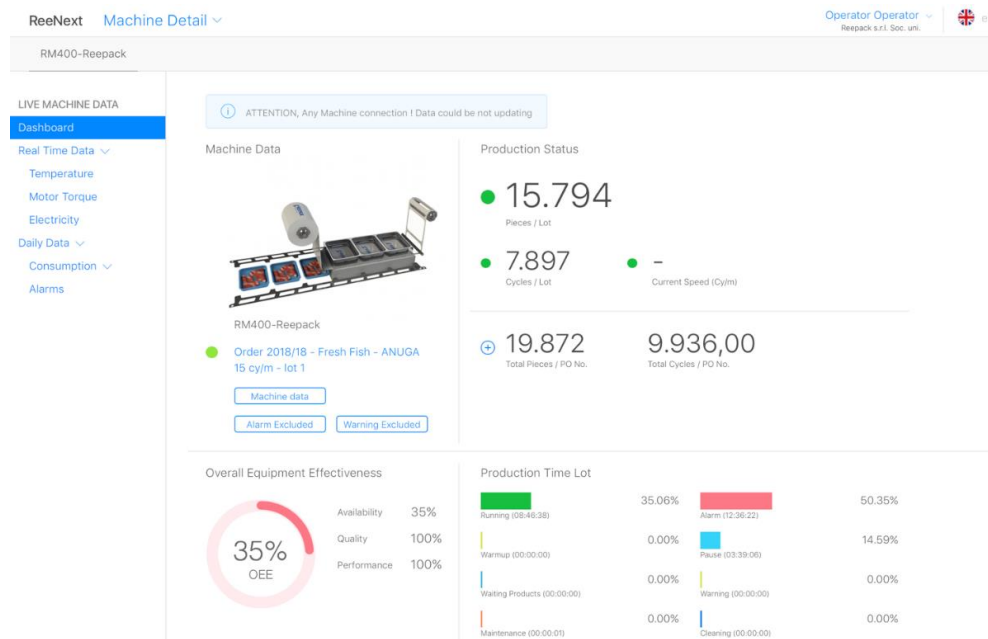


Figure 19: Main ReeNEXT Dashboard

- **Maintenance Module** as shown in Figure 20 for:
 - Predictable Maintenance based of Components DataSheet and/or Pre-Defined Scheduling
 - Predictive Maintenance based on Logic and Mathematical Algorithms merged with PLC Variables
 - Spare Parts Management
 - Historical Alarms and Configurations for Remote PLC and HMI Debug
 - Documentation: User's Handbook (Pn. And El. Diagrams, Assembling Drawings) and Machine Certifications

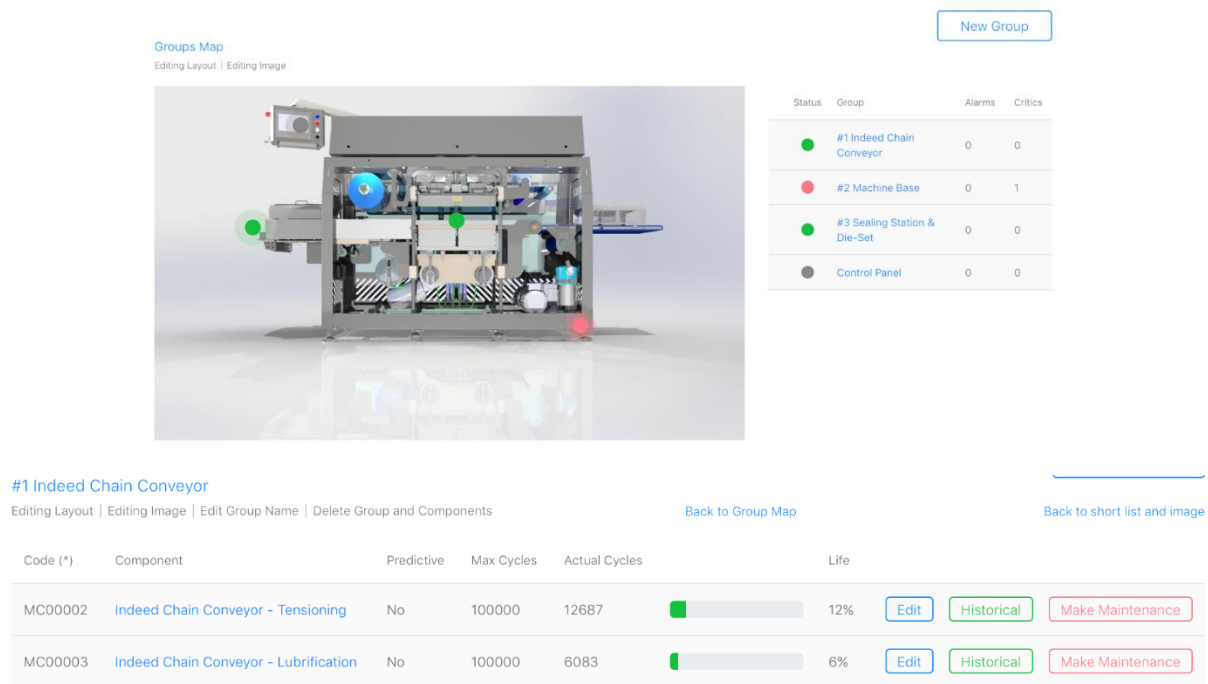


Figure 20: Main ReeNEXT Maintenance Module

- **Planning Module** as shown in Figure 21 for:
 - Creation and Management of Production Orders and/or Single Batches
 - Simulation of Different Production Scenarios according to New Production Orders

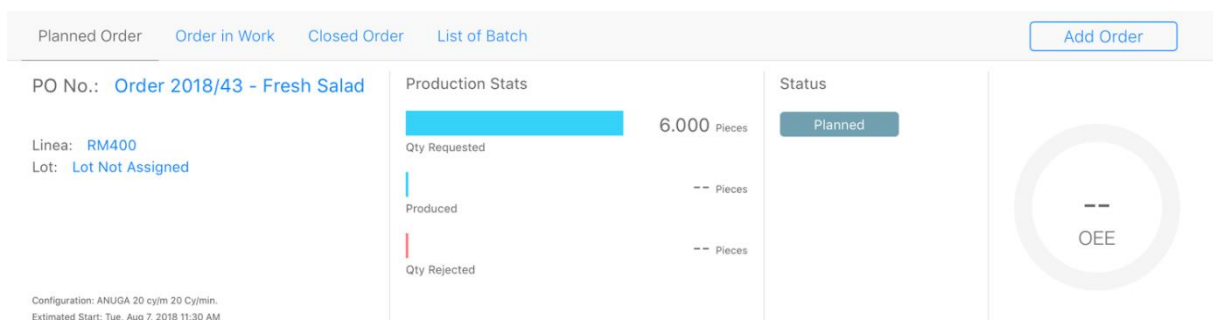


Figure 21: Main ReeNEXT Production Planning Module

- **Cost Analysis Module** as shown in Figure 22 for:
 - Creation and Management of Cost Centers

- Cost Analysis of Production Batches, based on Data Acquisitions by Machine Sensors (ReeNEXT Predisposition) and Machine Recipe (e.g. Consumed Packaging Materials – Trays/Film/Food-Product)

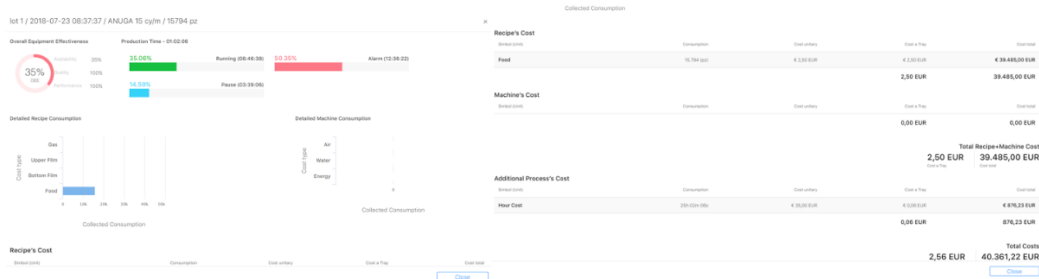


Figure 22: Main ReeNEXT Production Cost Analysis Module

- **Administration Module**
 - User's and Permissions Management in charge to Factory IT-Manager
 - License Management: Purchasing, Request and Upload of New ReeNEXT Annual License
 - Configuration of PLC Communications: Communication Set-UP and Enabling
 - Manual DataBase Back-Up (without Cloud Module)
- **Cloud Module** for:
 - Automatic Data Storage in Proprietary Cloud (in charge to Final Customer)
 - Automatic DataBase Back-Up and Disaster Recovering
- **SDK Module**
 Additional Module, shown in Figure 23, for the Integration of New Applications developed by 3rd Parties according to the Documentation (API Description) provided with ReeNEXT Platform for Reading & Writing DataBase Management.

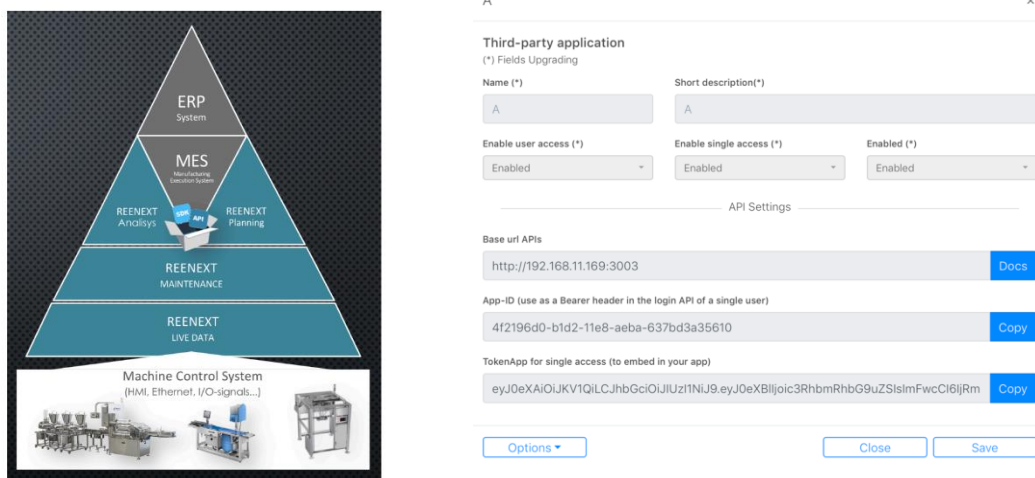


Figure 23: Example of ReeNEXT SW Integration by SDK Module and API

- **Augmented Reality Module**

Example of Integrated External Application, integrated by means SDK Module, developed by 3rd Parties for Augmented Reality Add-On.

Thanks to QR-Code Scan the Operator can link to 3D Machine Drawings and/or User's Manual Pages and/or Video for Machine Maintenance, Format Change, Set-Up, ecc.

- **Nexti Mobile App**

Example of Integrated External Application, integrated by means SDK Module, developed by 3rd Parties for Augmented Reality Add-On.

Personal Assistant for Real-Time Chat with ReeNEXT Platform for collecting Machine and Production Information, Documents and Videos.

According to Zero-SWARM KPIs, ReeNEXT Platform will be improved in Terms of New Software Modules for AI Algorithms Missions and Tasks Management and Alternative More Complex Hardware Architectures base on Industrial Edge Solutions. Machine Data Acquisition will be based on OPC-UA Protocol Communication installed as Master in Schneider Electric IEC61499 HW. The Validations Activities will be focused on Reepack South Node Trial 1/2.

5.1.2 SE-Edge-Platform for SN Trial 1/2 and CN Trial 2

A new category of PC-based control that runs dual operating systems on top of a hypervisor for a real-time soft PLC with Windows openness in a single edge device is emerging.

The need for data management and flexibility is always growing to facilitate efficient visualization, smart manufacturing, digitization, IIoT, edge computing, artificial intelligence, etc. This requires direct interaction with the control application. At the same time, the automation architecture needs to be simplified at the edge control level to improve productivity and performance.

iPC-based edge control with dual operating systems provides the next stage for digital transformation and experience. It is reliable and part of end-to end cybersecurity for more efficient operations and maintenance of capital assets.

For Zero-SWARM, we use the edge to support predictive maintenance with a real-time AI algorithm as processing takes place locally allowing for faster and more efficient decision making.

Schneider Electric's Edge Harmony P6 platform is an integrated solution for scalable industrial controls that connects field controls to high-end IOT systems. The platform is designed for digital manufacturing, industrial process control and manufacturing projects where security, access and data are at a critical level.

The Harmony P6 platform integrates the features required for controlling complex programs including local area network (LAN) and a real-time data server (RPD). Users can easily integrate and expand their MES, monitoring and control applications in one system. The platform can easily be integrated with IOT and Big Data systems and offers collection and sharing functionalities.

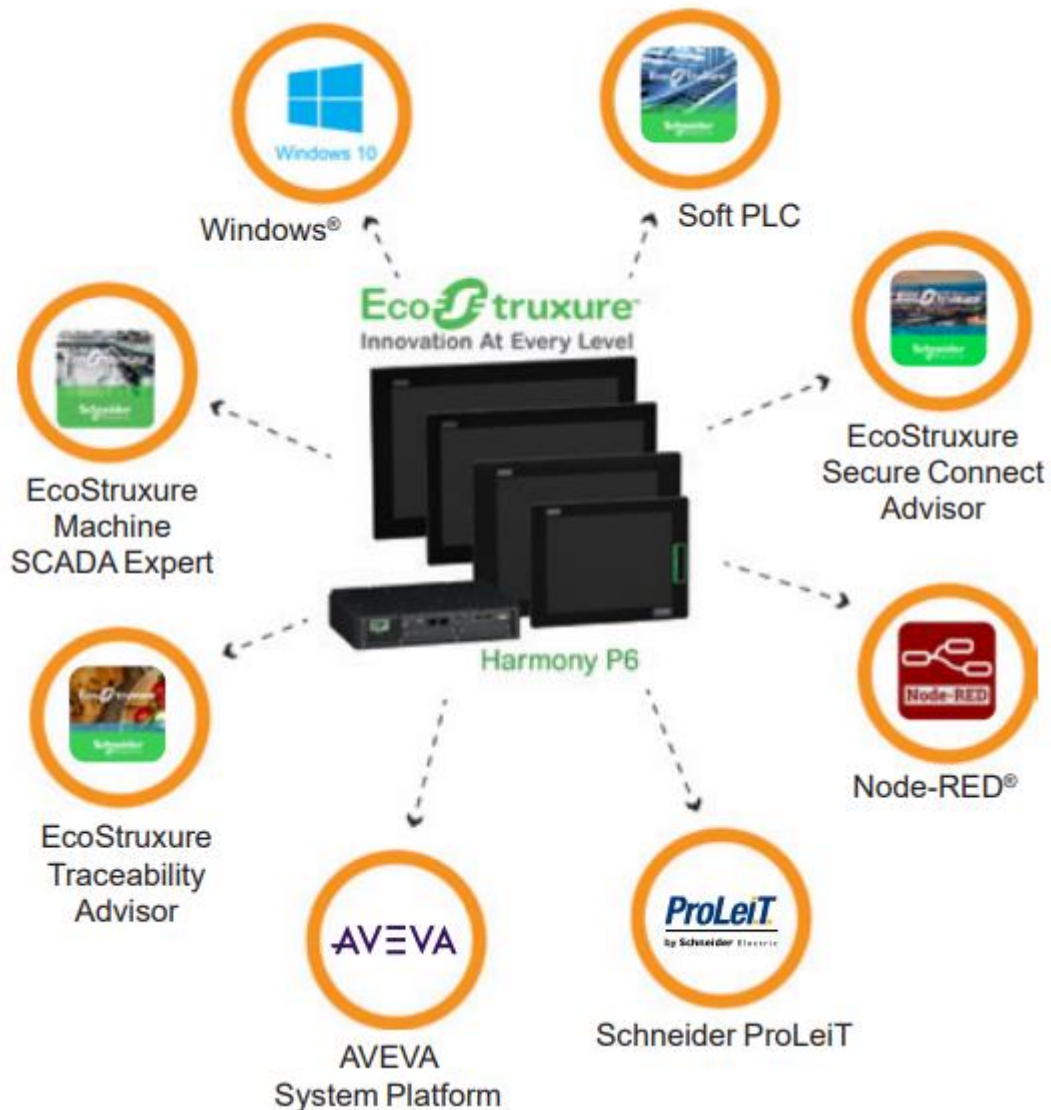


Figure 24: SE Edge Platform

As shown in Figure 24 the Harmony P6 Industrial PCs and Edge Boxes are available with preferred software associations that are tested and validated with the optimum hardware configuration. Ultimately, they can be delivered as pre-installed bundles with activation licenses. This offer is versatile and open to applications running Windows software or Linux at the Edge like HMI, SCADA, IIoT Edge, engineering and maintenance tools, thin clients and so on. In Zero-SWARM the Harmony P6 iPC with Linux OS (Ubuntu) is used with IEC61499, which aims to implement a SoftPLC, commonly called SoftdPAC from Schneider Electric. SoftdPAC is an optional module for EcoStruxure Automation Expert which is the basic IEC61499 platform from Schneider Electric. SoftdPAC is a part of the EcoStruxure Automation Expert Modicon Distributed Runtime Controllers. Unlike traditional controllers, however, SoftdPAC is a true software controller. There are numerous software applications that can run on Harmony P6 Industrial PCs and Edge Box with Windows or Linux operating systems. As a component of EcoStruxure Automation Expert, Soft dPAC offers programming and configuration within the event-driven orchestration ecosystem, but only Soft dPAC can offer extensive levels of operational flexibility. With an open hardware solution, Soft dPAC lets you distribute control throughout the plant as you see fit.

Additionally, multiple instances of Soft dPAC can be installed on a single piece of hardware using containerization technology under a Docker platform and can be maintained or operated concurrently, which is shown in Figure 25. This means tasks such as expansions to the line can be completed without interrupting an already running process, thereby limiting downtime, and increasing both productivity and profitability. A virtual internal LAN (Local Area Network), managed by the hypervisor, ensures communication between the two independent operating systems.

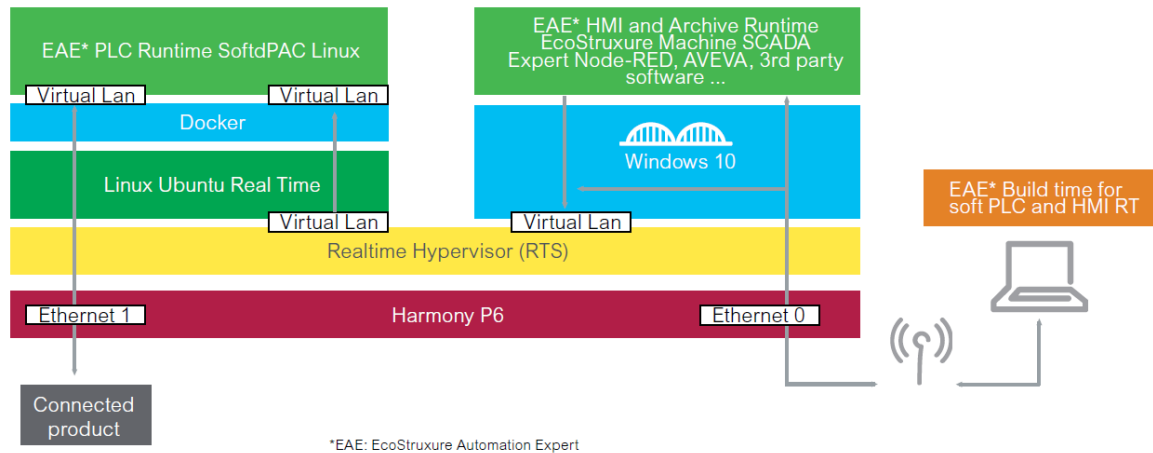


Figure 25: Harmony P6 With Realtime hypervisor dockerized

5.2 Interfaces from Edge to Data Centre

5.2.1 OPC UA for ReeNEXT- and SE- Edge Gateway

In zero-SWARM OPC UA is going to be used as interface from the Production line within the IEC61499 control application communicating to the Edge Gateway, mainly for monitoring purposes and on the other side it is used between the Edge nodes to communicate between the IEC61499 node and an AI software node. This OPC UA interface is used together with the IEC61499 automation platform in North Node Trial 3 and in South Node Trial 1 and 2.

OPC UA (Unified Architecture) is an industrial communication protocol used in automation and control systems. It offers a set of standards and specifications allowing the exchange of data between equipment and software from different vendors.

Since the IEC61499 platform derives the execution model for distributed and automated systems, it uses OPC UA for several reasons:

- **Interoperability:** OPC UA allows the exchange of data between different types of equipment, whether from Schneider Electric or other manufacturers. It facilitates the integration of products and systems from different sources, allowing users to create more flexible and scalable control architectures.
- **Security:** OPC UA integrates advanced security features, such as authentication, encryption, and access rights management. This guarantees the confidentiality and integrity of the data exchanged, which is crucial in industrial environments where the protection of sensitive information is paramount.
- **Connectivity:** OPC UA makes it possible to connect devices at different hierarchical levels, from the programmable logic controller to higher-level management systems.
- **Scalability:** OPC UA is designed to support systems of all sizes, from simple large-scale local control to distributed solutions.

- **Standardization:** OPC UA is an open and platform-independent protocol. It is supported by international organizations such as the OPC Foundation, which guarantees the interoperability and durability of solutions based on this protocol.

The IEC61499 application with its CAT in CAT structure and OPC UA in the production line:

In order to have a good understanding of OPCUA communication between the IEC61499 application in the Ecostruxure Automation Expert, and third-party equipment. The following Figure 26 shows the CAT tree structure of the encapsulation of a CAT in another CAT, a “Chain” in the “Reeco” machine in a specific “Production Line” at company “Reepack”, which is mapped in the same manner to corresponding OPC UA node ids, shown on the right side of this Figure 26. The FB-instance name is the unique identifier at the beginning of this OPC UA node id-chain.

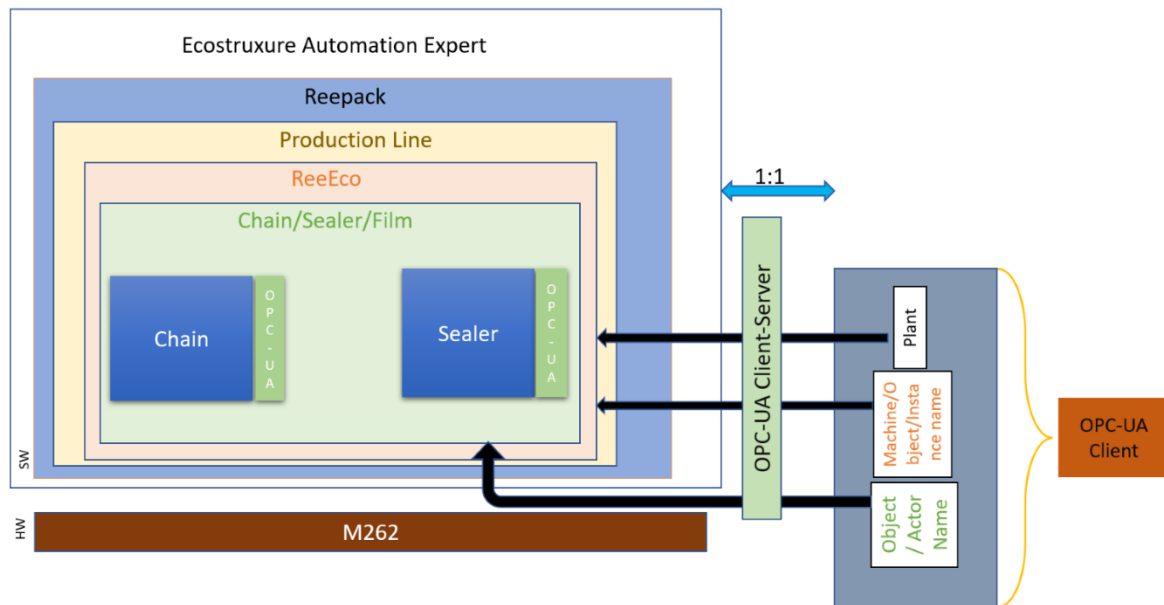


Figure 26: Mapping of IEC61499 hierarchy objects to OPC UA Node ID's

The example in Figure 27 below shows the production line, with a chain of different CATs connected to each other. Each CAT contains logic made up of other CATs and so on, like the “ReeEco” Machine consist of different CATs for the “Chain”, the “Film” and the “Sealer”. This therefore makes it possible to reduce the complexity of a complex system by representing an entire system or sub-system in a single CAT:

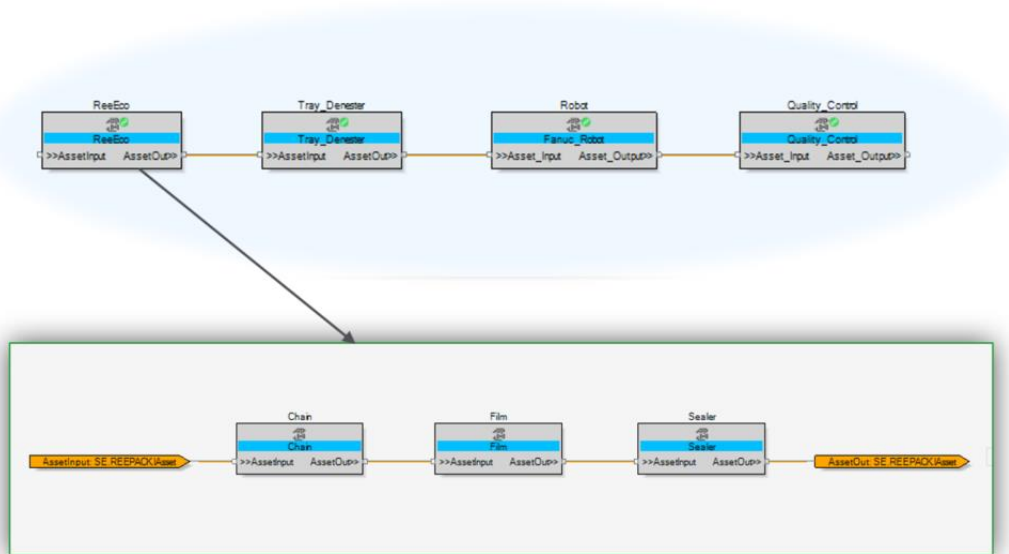


Figure 27: CAT in CAT architecture

Further details, when connecting to Kafka, see in D4.2.

5.2.2 MQTT for SE-Edge

In zero-SWARM MQTT is going to be used as interface from the Production line within the IEC61499 control application communicating to the Digital Twin in the data centre (cloud). Mainly for the use case of virtual commissioning for the IEC61499 control application, as well for the simulation of AMRs in the edge devices in the shopfloor. This MQTT interface is used together with the IEC61499 automation platform in North Node Trial 3 and 4, in Central Node Trial 2 and in South Node Trial 1 and 2. The concept of mapping a hierarchical CAT structure is nearly the same as in OPC UA, with the difference that all leaves are MQTT topics, see on the right side of Figure 28. The FB-instance name (object name) is the unique identifier in this MQTT topics, and the last leaf contains the MQTT payload, which is structured in textual JSON format or encrypted in binary format. In JSON the value serialisation of more data outputs or more data inputs within one message are easily possible.

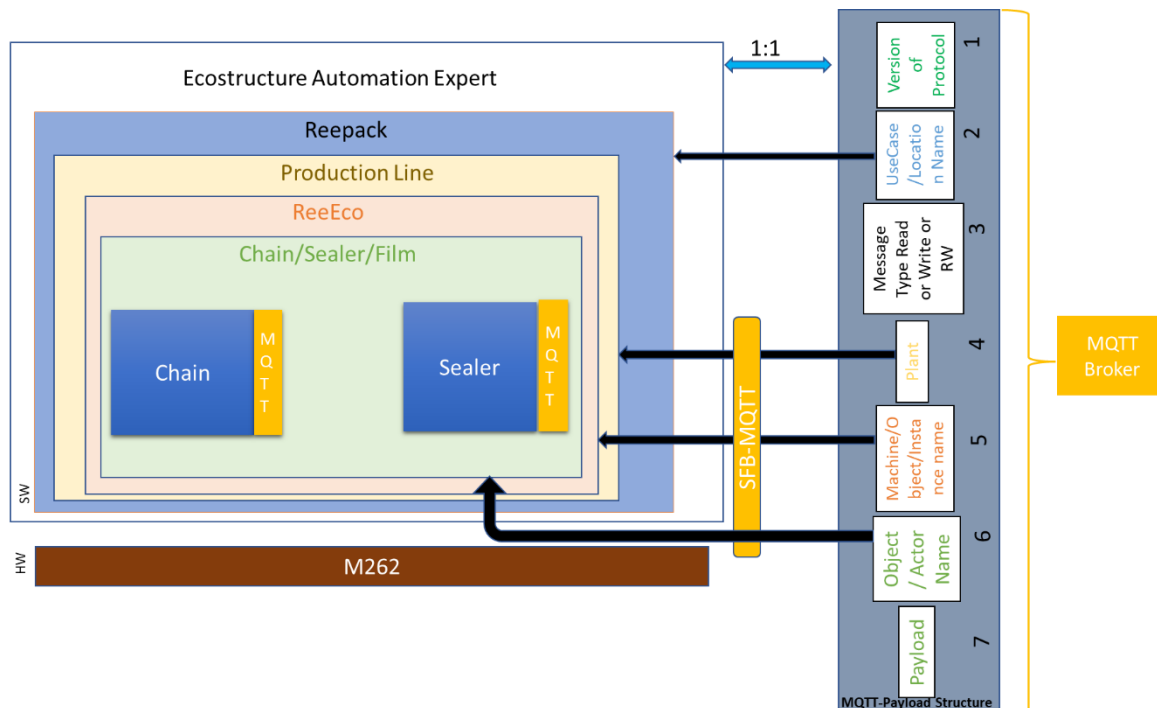


Figure 28: Mapping of IEC61499 hierarchy objects to MQTT Topic's/Payload

The physical objects of the real plant are designed in an Object-oriented way with the IEC 61499 based extension for CAT in CAT nested hierarchy. This results in a 1:1 mapping to the MQTT topic structure (on the right side of Figure 28).

The MQTT topic structure is in general terms presented as:

Topic1/	Topic2/	Topic3/	Topic4/	Topic5/	Topic6	Payload
Version of protocol/	Location Name/	Message Type/	Plant Part/	Machine/	Object Name	Message

Further details, when connecting to Kafka, see in D4.2.

6 Digital Twin for NN Trial 3 and SN Trial 1 and 2

Digital Twin is a digital representation of an existing physical asset that uses data exchange between the physical and the cyber space to forecast and optimize the behaviour of the production system at each life cycle phase. Digital Twin can enhance the system reactivity to uncertain events, support predictive and remote maintenance, enable augmented reality on the machines, and support new business models in service and after-sales. Digital Twin can also be used in the early stages of the development process to set up the concepts and to support reconfigurability.

6.1 Simulation & Virtual Commissioning by TTS

Simulation is a powerful tool that can help engineers and managers to design, test, and optimize complex systems and processes in a virtual environment. Simulation can be used to evaluate different scenarios, identify potential problems, and improve performance and efficiency. Depending on the modelling of a Digital Twin, i.e. a digital representation of a physical asset, there are different types of simulation techniques that can be executed, such as discrete event simulation (DES) and Virtual

Commissioning.

The following sections describe how the Simulation Framework developed by TTS will be integrated inside Zero-SWARM overall system architecture.

6.1.1 Deployment & connections

As stated in the IEC30164 standard, Edge and Cloud computing represent a horizontal expansion of computing and storage resources. Cloud computing is a style of computing in which scalable and elastic IT-enabled capabilities are delivered as a service and can be used to process data that is not time-driven or location-sensitive. Edge computing is a style of computing in which data processing happens where data is produced, such as on devices or sensors at the edge of a network. Edge computing has many benefits, such as lower latency, higher bandwidth, greater security, and better privacy. Edge computing is used to process time-sensitive data or data that needs to remain on premises or in a specific location due to low latency or data-residency requirements.

The deployment of the Simulation component is shown in Figure 29, in the context of the architecture presented in this document (where the other component not directly involved have been greyed out).

Inside the Simulation component there is the execution environment where the Digital Twin behavioural logic interact. Using the MQTT protocol, the Digital Twin can also interact with the IEC61499 SoftPLC entities deployed in the Edge Gateway or directly with the IEC61499 hardware PLC. The simulation model is also connected to the AI scheduler using a REST API. There is no direct connection between the Digital Twin and the physical AMR device as everything is routed through the IEC61499 PCL where the automation logic is responsible to interact directly with the low-level signals and to expose the higher lever signals using the MQTT protocol.

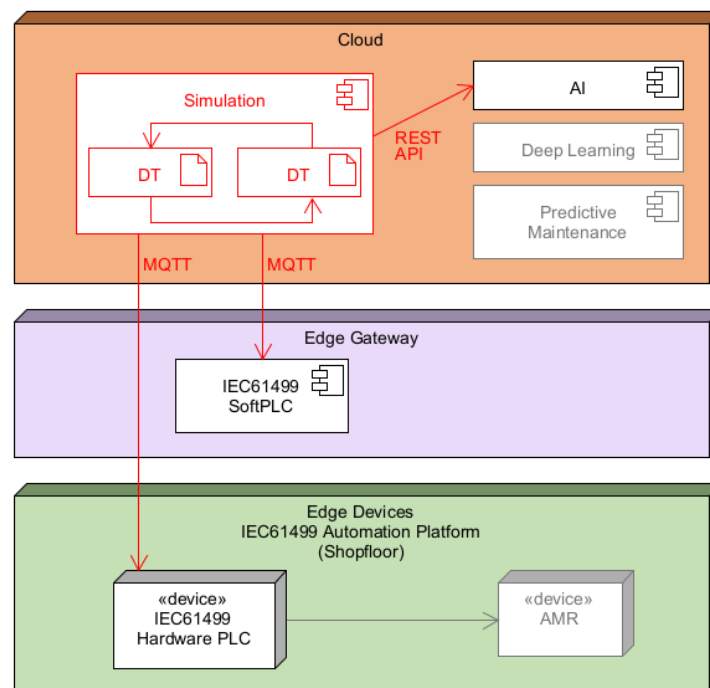


Figure 29: Simulation deployment

6.1.2 Integration of Simulation and AI for AMR jobs optimization

AMR simulation can be used to validate AI optimization algorithms of AMR jobs using an emulation layer of the AMR fleet. The envisioned tool simulates the behaviour and interaction of autonomous mobile robots (AMRs) in a warehouse environment, while testing and evaluating different AI optimization algorithms for scheduling jobs, such as order picking, inventory management, or material handling.

The use of the Simulation can provide a realistic and scalable testbed for different scenarios, such as demand fluctuations, layout changes, or resource constraints. AMR fleet emulation can also help to compare the performance and efficiency of the AI optimization algorithms when based on the features and performance of the AMR fleet management (real or emulated), such as routing, obstacle avoidance and coordination. Inside the Zero-SWARM project the objective is not to develop a fully featured AMR fleet management emulation software that behaves exactly as a real AMR in an industrial environment, but to provide an ideal model to execute the validation of the AI algorithms. The basic requirement for such ideal model is the ability to customize the virtual world, such as the warehouse layout, navigation, obstacle avoidance, right-of-way, and possibly also object detection and localization.

6.1.3 Simulation model

The simulation model is based on the Digital Twin representation of the physical devices in the shopfloor, but a fully functional production line is a composition of a more complex interacting hardware and system components. As a simulation model approximates a complex system and of the interactions, the approach to modelling depends on the final goal of the simulation and on the level of details needed. As detailed in the following sections, in Zero-SWARM the simulation is modelled with two different objectives: DES and Virtual Commissioning.

6.1.3.1 DES simulation models

DES simulation is a technique that uses computer models to represent the behaviour and performance of a system or process over time. It allows testing different scenarios and variables in a virtual environment to evaluate outcomes and optimize decisions. DES simulation can be used for early reconfiguration, scheduling optimization and performance monitoring.

The interaction between DES simulation and Digital Twin can be seen as a closed-loop feedback system: the Digital Twin provides real-time data to the DES simulation model, which can then run various simulations to test different scenarios and generate insights and recommendations. These can then be applied back to the Digital Twin or the physical devices to improve its operation and performance.

6.1.3.2 Virtual Commissioning simulation models

Virtual Commissioning is a methodology based on using 3D technology to create a simulation model of a production system so that the proposed changes and updates can be tested before they are implemented in the real system. Virtual Commissioning can reduce the time and cost of commissioning, improve the quality and performance of the system, and anticipate the engineering of the control systems. Virtual Commissioning involves three important components: a digital model (i.e. a Digital Twin), the controller code that governs the motion and responds to sensor feedback, and a development environment that allows the two to run together.

Digital Twin and Virtual Commissioning can interact and integrate with each other through a framework that defines how the data flows between the physical asset, the digital model, and the cloud or edge computing platforms. Such framework can enable a Virtual Commissioning based methodology to integrate Digital Twins into manufacturing systems. In Zero-SWARM the methodology and framework will be used to integrate AMR into the Reepack food packaging line. The DT of the AMR will be designed, integrated, and verified using a virtual environment. The methodology is validated through the integration of the DT based simulation model into a workflow for the implementation of a scheduling reactive system based on AI optimization of AMR jobs.

6.1.3.3 Simulation model overview

Considering SN-1/2, a general overview of the simulation model that works for both DES and Virtual Commissioning is presented in Figure 30. It is possible to identify the Digital Twin representation of the high-level devices composing the production line (Tray_Denester, ReeEco, Qualiti Control station, collaborative Robot) and the AMR. As the production line is wired connected in a fixed configuration, it can be considered a system.

The other components in the simulation model represent a software emulation of the line controller and of the AMR fleet management software. In both the DES and VC model they are emulated and not connected directly. There is also an adapter module that connects with the external AI Scheduler component though a REST API (HTTP/HTTPS).

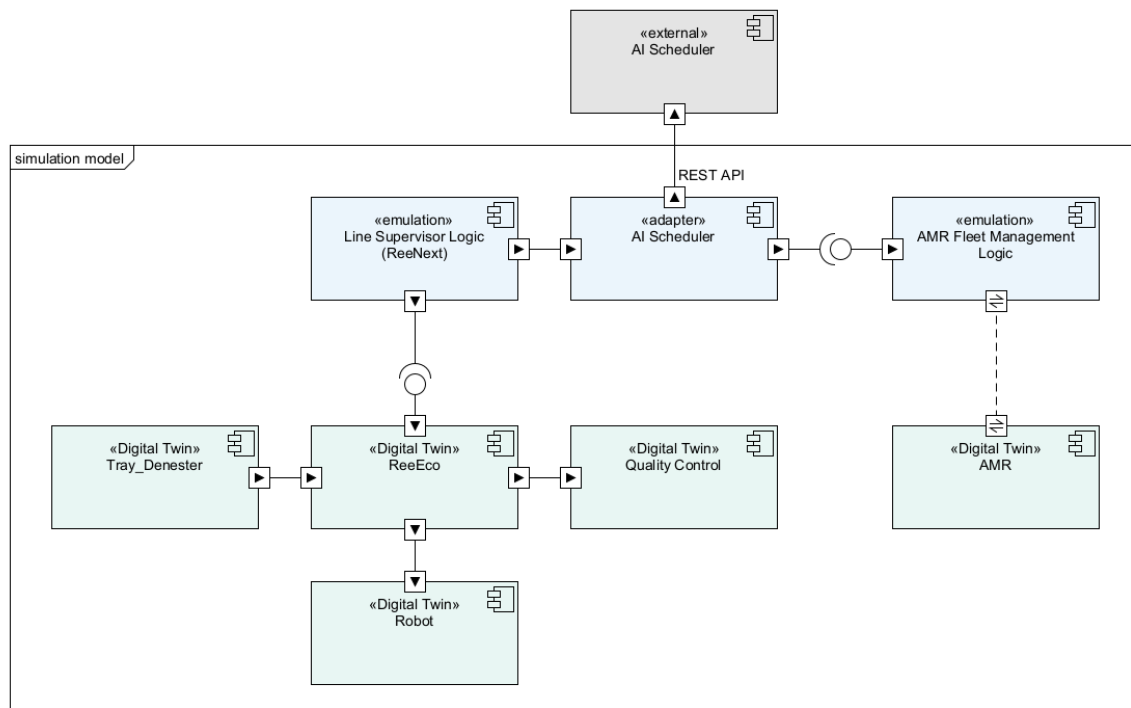


Figure 30: Overall simulation model

A Digital Twin can be a composite system: for example, the ReeEco DT is modeled, as show in Figure 31, as a composition of lower-level modules that implements a specific behavior in the same way the real system is divided into different hardware and (automation) software components.

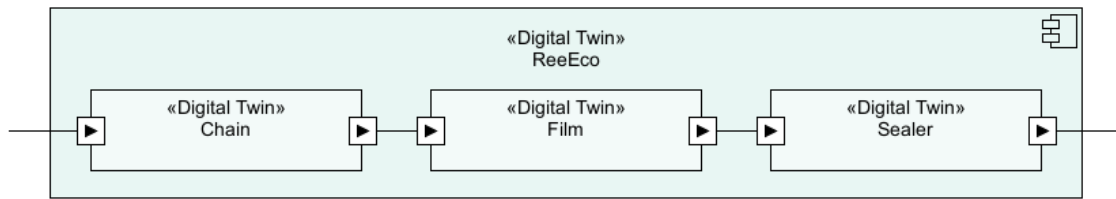


Figure 31: Digital Twin composition (System of System)

The production line system is connected to the supervisor logic as a discoverable link, meaning that a different production line can be plugged in as long as it has the same interface. The AI Scheduler adapter is also connecting to the AMR Fleet Management logic using a pluggable interface.

In the simulation, the AMR Fleet Management logic send and receive signals to/from all the AMR Digital Twins that are registered in the fleet.

The difference between a DES and a VS simulation model can be seen at the lower level, in the way the components logics is implemented. In the case of the DES model, a command usually results in a delay (i.e. a discrete advancement of time to the next event), while in the VC model a command results in the replication of the required action in the virtual 3D environment (i.e. moving a pneumatic cylinder).

6.2 IEC 61499 Cloud Virtual Commissioning by AALTO

The Virtual Commissioning (VC) platform is based on a web platform instead of a local application, where the architecture is shown in Figure 32.

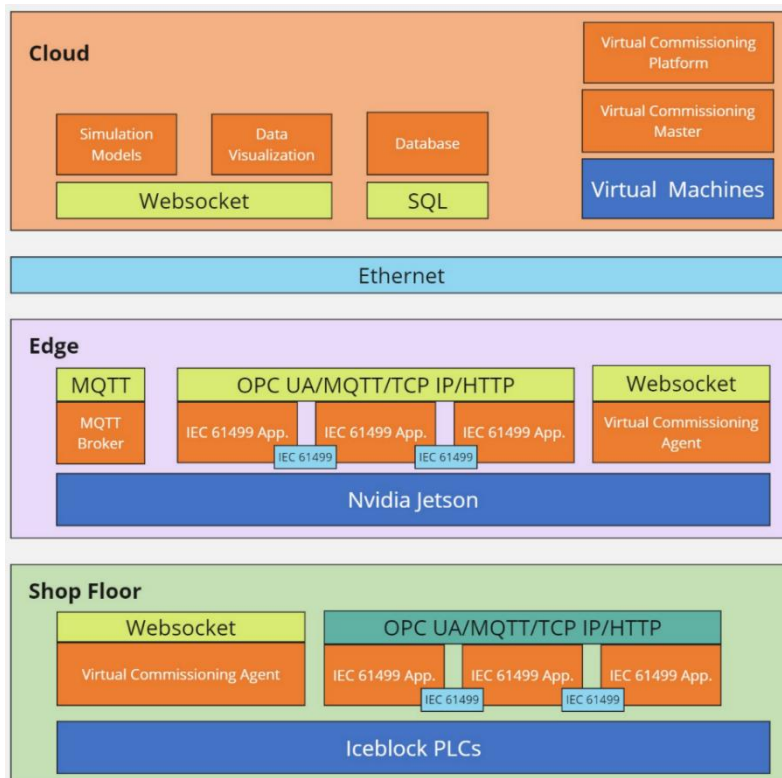


Figure 32: Virtual Commissioning Architecture by AALTO

This VC web interfaces include features of simulation models of mechatronic components of the manufacturing system, PLC/soft-PLC monitoring of liveness, CPU and memory consumption, and IEC 61499 runtime distribution in local-edge-cloud hybrid computing environment. The web server is running on cloud platform and multiple VC agents are deployed to devices (VMs or PLCs) to establish communication channels between the VC web server (master) and distributed devices (slaves). By applying this web-based VC platform, it is possible to quickly form a VC environment of distributed computing devices, which is well in the scope of IEC 61499 distributed automation systems.

This virtual commissioning environment is going to be visualized on a web platform, see Figure 33:

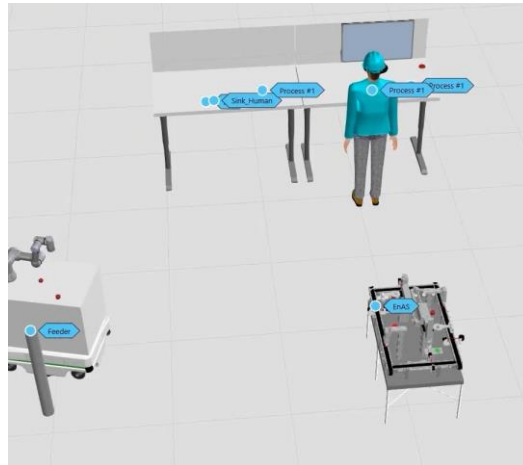


Figure 33: Virtual Human Worker Environment in NN

7 Automation Platform

7.1 Offer Overview

The EcoStruxure Automation Expert software offer in Figure 34: Eco Struxure Automation Expert, based on IEC61499 standard includes:

- The EcoStruxure Automation Expert engineering environment, with add-ons for integration of AVEVA Engineering and AVEVA System Platform software
- EcoStruxure Automation Expert HMI Runtime, a fully integrated, object-orientated industrial visualization solution
- EcoStruxure Automation Expert Archive, a centralized solution for the historization of process data, alarms, and trends
- Asset-oriented application libraries, a comprehensive set of hardware-independent libraries, ranging from basic functions to segment solutions
- Modicon Soft dPAC: the software-based distributed process automation controller, used for Edge Gateway Devices
- Distributed Programmable Automation Controller (dPAC) platform with a common, flexible, scalable IEC61499 runtime across Schneider Electric hardware:
 - ATV dPAC for Altivar
 - Modicon M251d and Modicon M262d with TM3 IO
 - Modicon M580d with X80 I/O

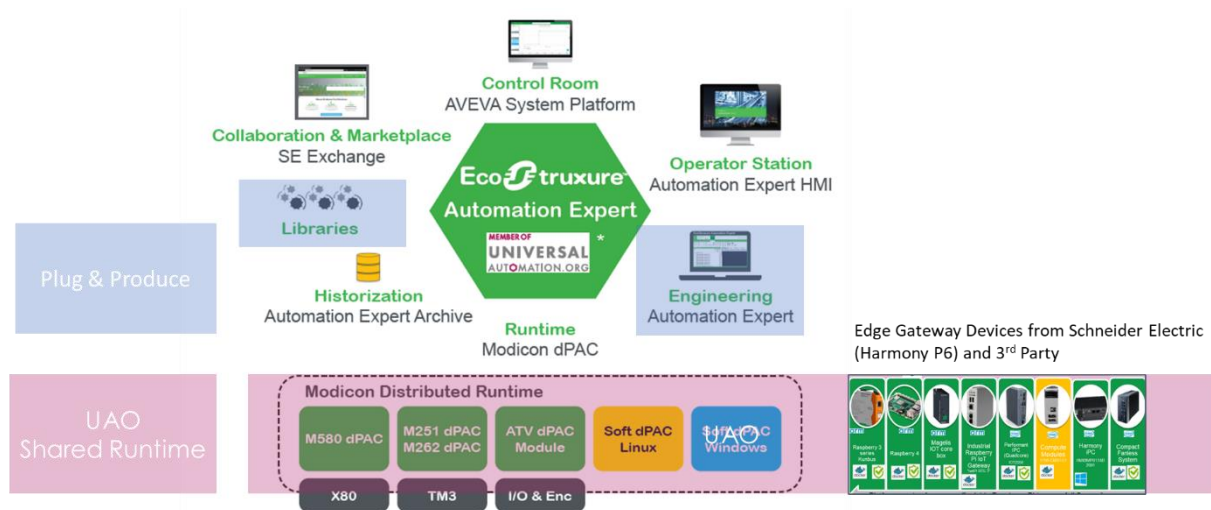


Figure 34: Eco Struxure Automation Expert, based on IEC61499 standard

7.1.1 EcoStruxure Automation Expert engineering

EcoStruxure Automation Expert is an asset-based, fully integrated engineering environment that allows portable, **IEC 61499-standard-based automation systems** to be managed within a single environment. EcoStruxure Automation Expert provides the capability to:

- Design and manage asset-based applications using object libraries based on multifaceted models (asset logic, operating modes, HMI symbols and faceplates (including alarms and trends), I/O interface, and asset documentation)
- Design the process based on asset-oriented objects with single line connections
- Create rich process displays to monitor and control the process from the control room or line terminal by dragging and dropping asset-based objects
- Manage a single solution independently of the number of controllers and HMI stations
- Design the application solution independently of the hardware configuration
- Design, configure, and manage network and device topologies
- Flexibly deploy applications to multiple hardware or software platforms based on a common runtime
- Automatically discover and diagnose compatible runtime devices
- Secure the automation system by managing authentication with encrypted communication and security certificates at solution and devices level

7.1.2 UAO shared IEC61499 runtime

The IEC61499 runtime of Schneider Electric is used in the non-profit Universal Automation Organisation [1] and these benefits are for all interested partners, as well for zero-SWARM project partners and their IEC61499 compatible hardware:

- Fundamentally object-oriented to facilitate re-use via software component libraries
- Event/data driven to make it easy to couple real-time automation with enterprise applications
- Application software must be decoupled from hardware to make it portable across different automation platforms.

- Application/Asset-centric rather than controller-centric
- Appeal to software engineers used to more modern programming languages, while maintaining certain OT characteristics.
- Plug & Produce programming using hardware-independent, proven-in-use libraries of software components

7.1.3 Extension for the zero-SWARM project

- IEC61499 runtime extension with Service Function Blocks libraries for MQTT, using cybersecurity features, offering a basic layer for the IEC61499 applications in the selected trials running on SoftPLC and on selected hardware devices (e.g. edge gateway device, Iceblock, M262), used in chapter 7.2
- In this project the EAE Engineering Tool is going to be extended with an AI plugin to simplify the plug and produce engineering for an Automation Engineer, using AI software, see chapter 7.3.
- The Schneider Electric Edge Device (Harmony P6) is going to be adapted to simplify the plug and produce engineering process with easy runtime connections between the IEC61499 and the AI runtime platform, see chapter 7.3.
- Cybersecurity Extensions, see chapter 7.4

7.2 Reconfigurability Extensions for IEC61499 IDE and runtime for T5.2

Figure 35 gives an overview about the different use cases of the reconfigurable services:

Discovery and service functionality are the basic methods to enrich a reconfigurable use case, which depends on the usage of different actors (e.g. AMRs) near a production cell, able to ask for their availability and compatibility with the production cell, and getting der possible services they offer. For the engineering system or with the engineering system the right semantic service description is necessary to have a standardized functionality description. All these services shall be compatible with wireless communication, as well with the IEC61499 control system and the engineering tool to configure these services easily from the automation engineers' point of view. For the Market an easy-to-use IEC61499 library shall be available, which shall be system integrator friendly. Possible users of this solution can be machine producers or OEMS for such AMR's. The reconfiguration services shall be able to support easy AMR connections offering different AMR services to interact with the AMR navigation system and a central scheduler. Further details are contained in D5.2.

In zero-SWARM the intent is to simplify the reconfigurability services for a production line, interacting with AMRs and integrating this functionality into a IEC61499 library to reuse such software components in every production line of a stakeholder. Furthermore, discovery services shall identify the availability of such AMRs in the production process. Such SW components shall be reused by the automation engineer for the whole plant and machines.

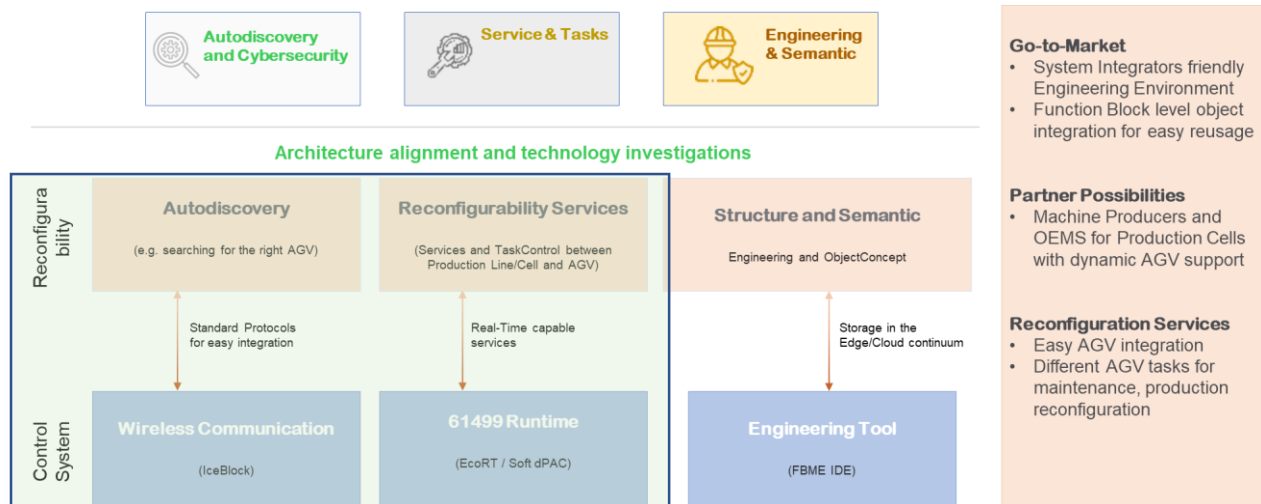


Figure 35: Zero-SWARM's reconfigurability

7.3 AI Extensions for IEC61499 IDE and runtime for T5.3

Artificial intelligence is revolutionizing the industry. From supply chains to the optimization of production chains, including preventive and predictive maintenance. The industrial applications of artificial intelligence are numerous.

Artificial intelligence makes it possible to optimize industrial performance, reduce failures and simplify simulations. Finally, it makes it possible to automate quality controls. Artificial intelligence is also a great decision-making tool. All industry sectors are being transformed into Industry 4.0. The deployment of artificial intelligence in industry used to be complex. Nowadays, it is facilitated by digital twins and dedicated solutions developed by specialized start-ups.

In industry, artificial intelligence is primarily intended to help with decision-making.

There are three levels of support:

- First, descriptive artificial intelligence makes it possible, from a mass of important data or knowledge, to simplify the information and present it in the form of dashboards and KPIs (Key Performance Indicators). A significant time saving since the analyses carried out using AI are faster, less expensive and above all much more reliable.
- Predictive AI, on the other hand, provides projections based on probabilities. We can therefore easily anticipate future situations and better predict the risks in terms of the supply chain and manufacturing defects, for example.
- Finally, prescriptive artificial intelligence is no longer limited to providing the information necessary for decision-making but also guides employees by offering them recommendations regarding the state of the system. This is called the "next best action".

In some cases, it is also used to relieve humans of certain low-risk or non-strategic tasks. More and more warehouses, for example, are entrusting portions of logistics transport to autonomous vehicles. Whatever the type of artificial intelligence used, the system will therefore make it possible to capture a large flow of data, for example via the edge platform and to analyse them, for strategic, tactical, or operational purposes.

In zero-SWARM the intent is to simplify the engineering process between AI-modeller and Automation engineer, as well to simplify the creation of IEC61499 functions blocks interaction with the AI system (algorithm), which is one optimisation step for the automation engineer, as highlighted in green in the Figure 36 for the use case of predictive maintenance. The goal is to enrich a user friendly engineering interface for system integrators and an easier integration of AI functionality in IEC61499 function

blocks. Partners could be specialist for model creation and vendors of standard modelling software. Further details are contained in D5.3.

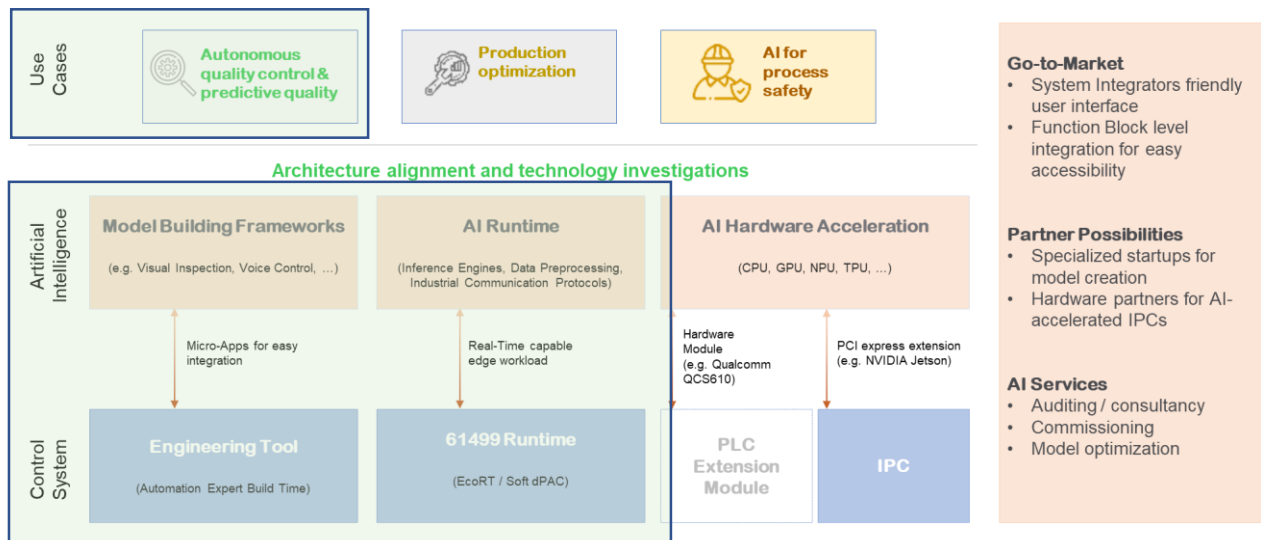


Figure 36: Zero-SWARM's AI integration into the shopfloor

7.4 Cybersecurity in the IEC61499 automation platform

The cybersecurity in the IEC61499 automation platform for the runtime, the engineering, the HMI, the archive, and different communication protocols, is a continuous development, and improvement by design. The following Figure 37 gives an overview of the actual functionalities of cybersecurity:

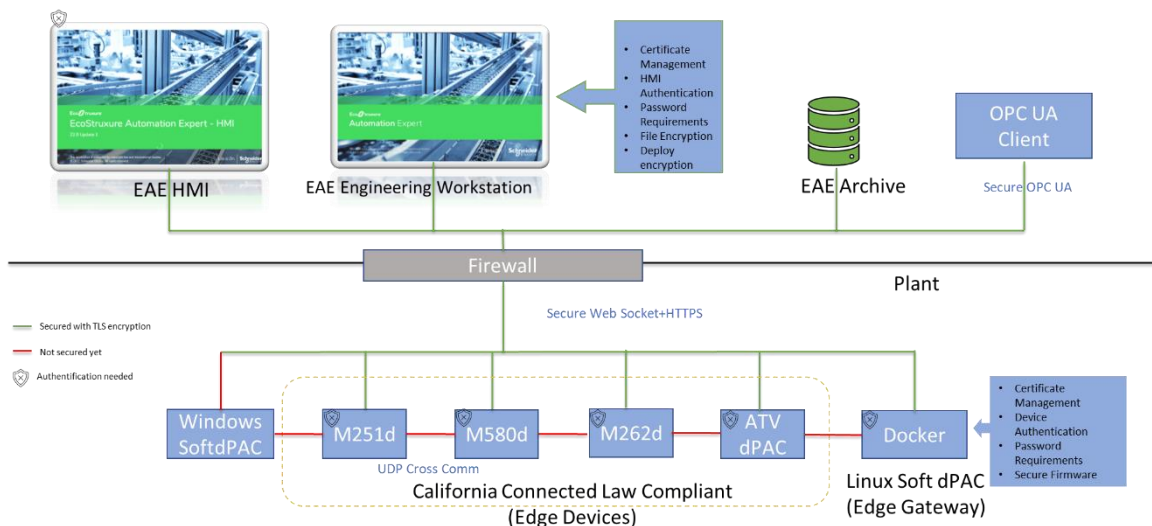


Figure 37: Cybersecure IEC61499 automation platform

The main practical cybersecure topics in the IEC61499 automation platform, considering the templates of D2.3, are:

- Strategic focus on software development, that prioritizes software security
- Continuous code qualimetry improvements (e.g. with klocwork) and others), developer trainings for cybersecurity and threat modelling of systems and subsystems, to be secure by default and by design

- Continuous code reviews, penetration testing and system verification tests
- Continuous vulnerability fixes and testing
- Further improvements/developments for IEC62443 for e.g. Role Based Access Control (RBAC)
- Digital Signed Binaries, so when a hash of a binary differs or is not strong named, the application (e.g. EAE EngineeringTool) will not start
- DoS-Protection (Denial of Service)
- Secure communication with TLS encryption between EAE HMI or EAE Engineering Tool with the Edge Devices M251d, M580d, M262d and ATV dPAC, as well with the dockerized Linux Soft dPAC and EAE archive
- California Connected Law Compliance with custom workflow (aligned inside Industry)
- Secure Web Socket, HTTPS and OPC UA communication
- Authentication/Login and Anonymous Access:
 - for EAE HMI,
 - for each edge device
 - for Linux Soft DPAC
- Certificate Management and Certificates for OPC UA and continuous development for others
- Secured IEC61499 libraries
- Security improvements for login locks and session limiting - ongoing
- Certification Management using CA server - ongoing
- Secured Function Blocks for encryption at the application level
- Security at each FB instance level on deployed devices (former FB type level only)
- MQTT will be integrated with further cybersecurity possibilities to use (e.g. encryption)

Beside this list, there are continuous checks of cybersecure coding, cybersecure design during the whole development lifecycle.

The goal of zero-SWARM is to use these cyber security features of the IEC61499 automation platform in each of the selected demonstrators, specified in this deliverable. For example, secure communication between the shopfloor and the upper layers over MQTT or OPC UA, as well as secure authentication, when deploying the SW components. Furthermore, to show the interaction of the production line with trusted and secure AMRs and AI systems.

8 Conclusions and next steps

This document presents an overview of the IEC61499 automation architecture, deflected from D2.2, and the usage within the zero-SWARM projects and selected trials, as well as detailed functional and technical requirement definitions for the trials and the necessary technology extensions.

Additionally, the usage of edge gateways, digital twins, and their basic functionalities and communication possibilities is described between Edge-Device-Layer, Edge-Gateway-Layer, and software components in the Data-Centre-Layer.

Challenges during writing this deliverable were the coordination and synchronisation with all WP5 partners and used technologies with their interfaces, and to define how these modules will be used and working together in the selected trials. This needed a detailed investigation and meetings with the trial partners, as well as the identification of the function and technical requirements, needed to extend, and how to show the innovative approaches of cybersecurity, reconfigurability and AI usage,

within selected trials, as well the placement of these functionalities in the different tiered of the reference architecture.

Further details about additional reconfiguration services, which will result in a direct IEC61499 function block design and service interface between production line/cell and the AMRs, used in selected use cases, are shown in D5.2.

Further details about the AI algorithm integration on the Edge-Gateway-Layer and in the IEC61499 Engineering tool are detailed in D5.3.

Further details about testing of cybersecurity topics and how to penetrate the whole architecture are detailed in D5.4 and D5.5, which shows a step approach with a synthetical test application and monitoring selected KPIs, similar when the automation platform is used in trials.

Further details about the integration of the software modules of the different partners in the proof of concepts and trials will be detailed in D6.1. Testcases for the software modules and the usage in the trials are defined in D6.2.

All these steps are the basis for the next deliverable versions, which will continue to implement these technologies and testing and integrating them, also in the mentioned trials.

References

- [1] Universal automation Organisation:
<https://universalautomation.org/>
- [2] Definition of the Deployment view in ISO/IEC TR 30164 Internet of things (IoT) – Edge computing
<https://www.iso.org/standard/53284.html>
- [3] IEC61499 Standard
<https://webstore.iec.ch/publication/5506>