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D7.1 Report on Application Development

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1. Executive summary

The present deliverable aims to present a report on application development of the final demonstration of the BEMO-COFRA project. This document is an update over the previous WD7.1 – Developed Software Application.

The BEMO-COFRA Architecture was the base to the Developed Software Application. The architecture was presented in deliverable D3.2 – Refined Architecture Specification. Among other aspects, the architecture guides the process of build the final application determining, which part will be encompassed by the architectural modules. This architecture is composed by five layers: i) Applications Layer, ii) Monitoring & Control Layer, iii) Virtualization Layer, iv) Gateway Layer and v) Industrial Layer. All these layers together allow the end user to access the system (generate reports, assist the production process) from a friendly user interface.

In this context, special attention should be devoted to the Control Logic. This is the fundamental part of the application because it defines the synchronization between stages of the system. To accomplish that, Control Logic uses the features of BEMO-COFRA middleware that provides an efficient way to publish and subscribe events related to the data collected in the environment.

The Developed Software Application, in an abstract view, can be seen, as a pair of modules, composed by the Monitoring & Control Application that allow the end user to interact with the whole system and the Control Logic that will guide the tasks in the industrial scenario. The chosen scenario is composed by a car body moving to a specific position in which a robot will perform welding tasks. During this process, wireless sensors, cameras, accelerometers, etc. will collect data (for example, energy consumption) to help the Control Logic and the end users guide the entire process satisfactorily.

Also, the user interface must provide adequate inputs and outputs to the end user. Therefore, the user can configure threshold values and build reports from the data collected and process in the line.

In a general view, the improvements over document WD7.1 are summarized below:

- An initial section with the agenda with the main topics to be performed until the final demonstration;
- The definition of the location where the final application will be demonstrated;
- Updates on the Wireless Sensor Networks Platform;
- Updates on the User Interfaces;

2. Introduction

2.1 Purpose, context and scope of this deliverable

The main objective of this deliverable is to present a Report on Application Development, that will be installed at COMAU, in Recife. This application depends of a series of intermediate efforts from other partners of BEMO-COFRA Project, since it is composed by distinct modules. These modules will be integrated to compose an application that reflects the BEMO-COFRA architecture already proposed [3].

First, a brief overview over the architecture presented in the deliverable D3.2 – Refined Architecture Specification [3], will be presented. As the final application should be built over the basis of the discussed architecture it will be important to know how the modules communicate with each other.

Then, the flow of the control logic will be presented and discussed. This flow shows all stages of the process, from the initial position of the car bodies to be inspect in the line, until the finalization of the welding process. Also, the devices to be employed in final demonstration will be explained and contextualized.

Finally, the main functionalities and services of the user interface will be demonstrated and explored. This document is organized in 9 chapters.

- Chapter 1 (Executive Summary) gives a brief description of deliverable's subject;
- Chapter 2 (Introduction) describes the document background, context, purpose and structure;
- Chapter 3 (Overview of the Final Demonstration) introduces the main aspects of the final demonstration: agenda, location and main idea;
- Chapter 4 (Automotive Manufacturing) gives an overview of the Automotive Manufacturing;
- Chapter 5 (Architecture Description) reviews the BEMO-COFRA Architecture that is the basis to the BEMO-COFRA project;
- Chapter 6 (Wireless Sensor Networks Platform) gives an overview of the single radio WSAN and Multi-radio WSAN architectures employed;
- Chapter 7 (User Interfaces) details the interfaces developed;
- Chapter 8 (Final Demonstration Explained) details the scenario of the final demo, how the control logic organizes and synchronizes the main stages of the process and the devices that will be used;
- Chapter 9 (Conclusion) presents the final thoughts about the proposed architecture.

2.2 Background

The BEMO-COFRA project aims to develop an innovative distributed framework which allows networked monitoring and control of large-scale complex systems by integrating heterogeneous smart objects, legacy devices and sub-systems, cooperating to support holistic management and to achieve overall system efficiency with respect to energy and raw materials.

The BEMO-COFRA features a Service oriented Architecture (SoA) and a middleware able to expose smart objects, legacy devices and sub-systems' capabilities by means of web services thus supporting syntactic and semantic interoperability among different technologies coexisting in the overall monitoring and control framework. Wireless Sensor and Actuator Network (WSAN) devices, legacy sub-systems and devices will thus be able to interact and cooperate, orchestrated by a manager in charge of enforcing a distributed logic with the overall monitoring and control network. BEMO-COFRA reuses the results of the well-reputed Hydra IP and Pobicos STREP and the recently started ebbits IP featuring a Service Oriented Architecture (SOA) and a middleware.

The integration of heterogeneous smart objects, legacy devices and sub-systems will achieve overall systems' efficiency with respect to energy and raw materials and support holistic management. The BEMO-COFRA project will address both technological aspects and user needs to promote a wider adoption of large-scale networked monitoring and control solutions.

3. Overview of the Final Demonstration

3.1 Agenda for Final demonstration

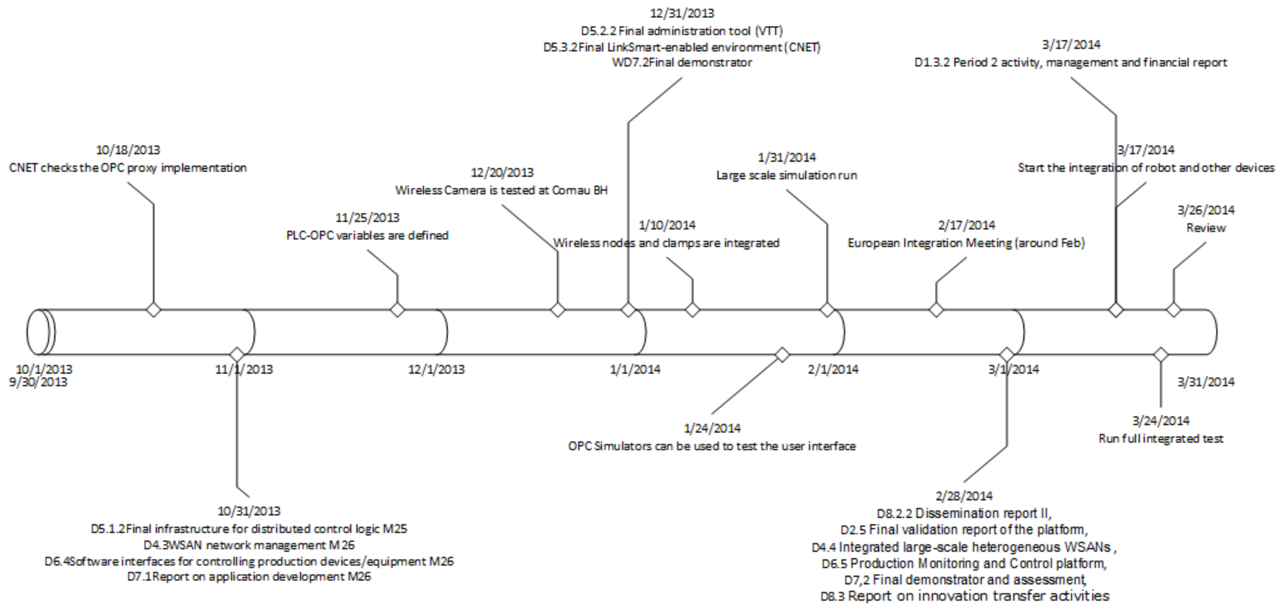

Figure 1: Agenda for the final demonstration

As this document is an update over deliverable WD7.1 – Developed Software Application, the agenda shown in Figure 1 shows a list of important events to be accomplished until the end of the project. All those events are listed below (deliverables to be submitted are not listed):

- Verification of the OPC implementation (10/18/2013);
- Definition of the PLC-OPC variables (11/25/2013);
- Test the wireless camera methods at COMAU BH (12/20/2013);
- Integration of the wireless clamps and nodes (01/10/2014);
- Simulation with large scale networks (01/31/2014);
- European Integration Meeting (02/17/2014);
- Start the integration of robots and other devices (03/17/2014)
- Run full integrated test (03/24/2014);
- Final Review (03/26/2014).

3.2 Location of the Final Demonstration

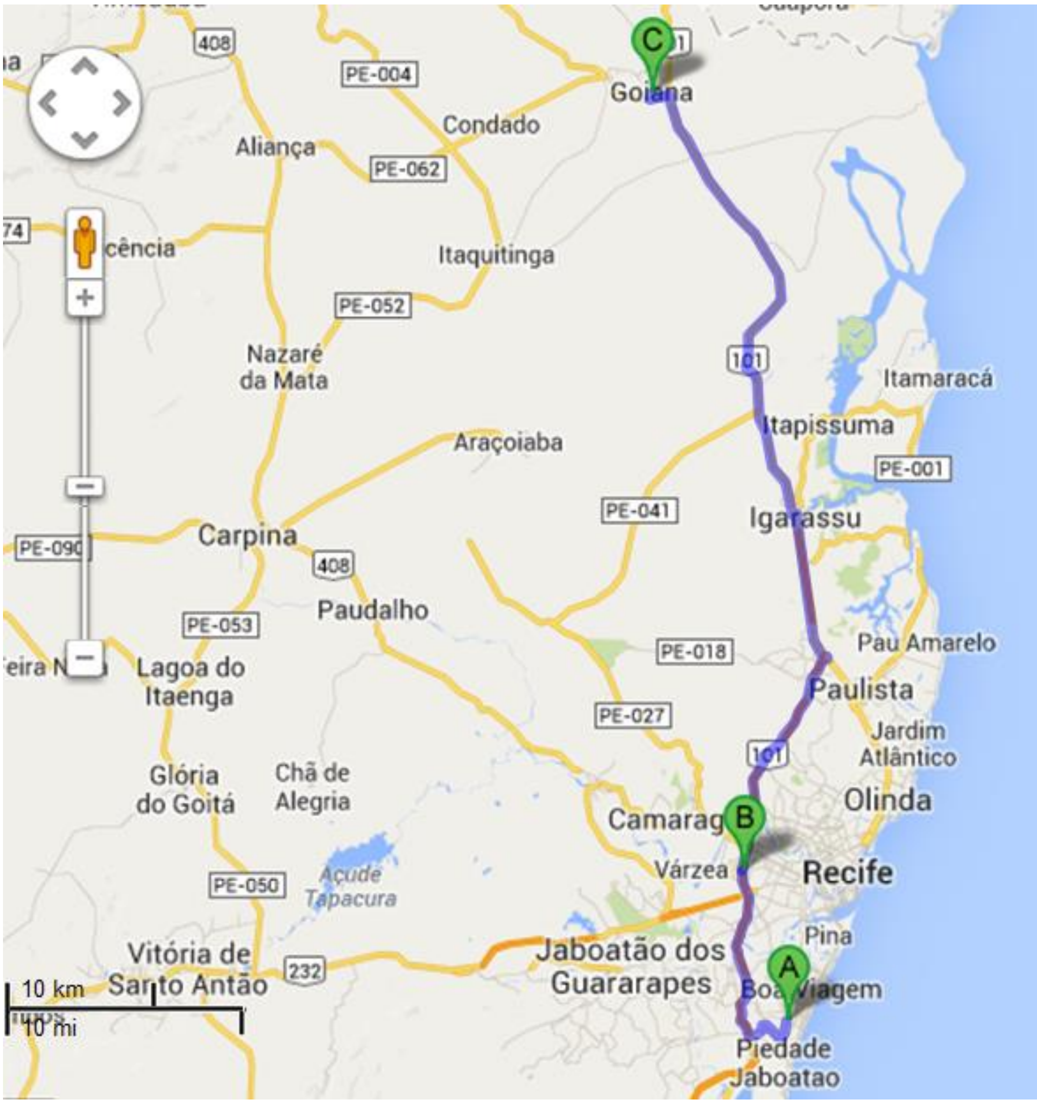

Figure 2: Location of the final demonstration

In the Figure 2 it is possible to see three markers: 1) "Location A" where is located COMAU – Pernambuco, 2) "Location B" – where is located Universidade Federal de Pernambuco and 3) "Location C" – where is located the new factory of FIAT in Pernambuco. The final application developed will run in location C. This place was chosen due to the facilities provided. In this factory will be possible use many devices, such as skids, robots, etc, since the factory will be not in production period yet.

Figure 3: Aerial view of the COMAU-PE

Figure 3 shows an aerial view of the COMAU-PE installations that will provide the necessary support in what concerns to the majority of devices used in final demonstration.

3.3 Developed Software Application Overview

This section will give a brief overview over the *Developed Software Application*, and how the main modules are interconnected. The system operation and user interface will be better explained in the next sections.

Figure 1 shows an overview focusing in the functionalities of the system. The two main modules represented are: i) *Control and Monitoring Interface*: responsible to provide a friendly interface to user monitor the data and to change configuration values in the devices they want to monitored; ii) *Control Logic*: responsible to receive the operation flow of the industrial line to be controlled, defining all stages and synchronization signals required to jump from one stage to the other.

The arrows going from the wired and wireless devices to the *Control and Monitoring Interface* represent a monitoring flow and encompass a lot of functionalities described in the architecture. For example, the module responsible to fuse the data collected from the sensor is not explicit represented, but it is present in some part that goes from the arrow that departs from the devices (wired and wireless) and arrives at the Interface. Complementary, the arrows that departs from *Control Logic* module and *Control and Monitoring Interface* represent the control flow and encompass the changes in configuration values as well as the definitions about the sequencing and synchronization between stages in the line. Finally, a database is provided to record user configurations, logs and results obtained during the operation. From this database it is possible to build reports, for example, about failures and number of products made.

The use of the BEMO-COFRA platform starts when the user logs into the system. In this moment, the car body positioned in the transportation structured (skid) can start to move to the welding position. While the car body is moving, the operator can monitor the energy consumption of the devices involved in the process (skid, robot, etc). Meanwhile, the wireless camera captures constantly images and verify if the car is present or not. These images can be visualized in real time in the interface provided by the user.

If the presence of the car body is identified at the correct position, the next step is to identify the type of the car and loads automatically the appropriated program. This task is also performed by the wireless camera located at a previously specified position. When the camera identifies (or classifies), for example, a car body of the type "with sunroof", it publishes this information, through BEMO-COFRA middleware. The *Control Logic*, represented by the PLC, can in this way change its geometric parameterization to perform the welding tasks in this type of car body. Also, after the classification, the system increments a counter indicating the total number of cars of that type already inspected.

In this stage, the welding task can be initialized and some welding spots are printed in the car body. The quality of the spots are inspected and if some of them are not ok, the system is informed and the welding process is restarted to correct that spot. All the stages of the process are informed in the user interface, in a way the operator can see if any problem or failure in the devices occurred. It is important to note, also, that the user can modify the tolerance limits of the variables to be inspected, such as orientation, velocity and direction of the skid.

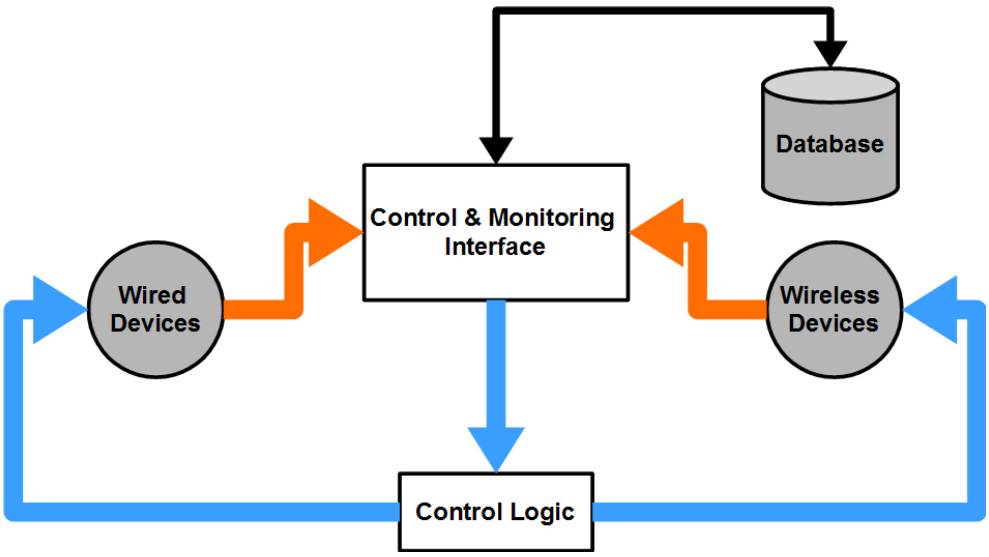

Figure 4: Developed Software Application Overview

4. Automotive Manufacturing

The body shop is structured on several levels. Starting from a general view and drilling down more in detail it is possible to say that the body shop is composed by different production lines, each of them includes several stations containing different kind of devices such as robots, PLC, rolls, elevators and so on. For each device (or unit) it is possible to monitor lots of parameters in order to understand the machine status and improve the production efficiency. The picture below briefly illustrates the layer concept previously described.

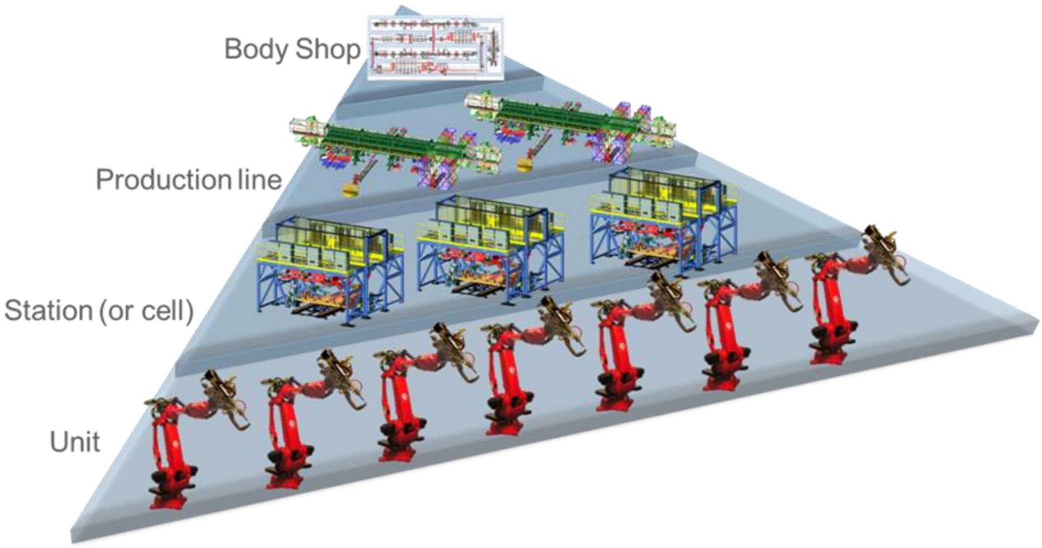

Figure 5: Body Shop layer classification

The following sections present the automotive manufacturing demonstrators that will be implemented for the final review. In particular they will consist an extension of the scenario of what has been presented during the intermediate review. Two application areas have been taken into account for this project:

- Scenario Reconfiguration

This scenario considers a significant increase of flexibility in the future car productions that allows an "on-demand" and "customized" production capabilities. This is intended to minimize the over / under production of cars with specific features.

For instance, if a factory gets an order from the dealer for a car with a sunroof. Normally this order must wait until the batch production of the cars without sunroof has finished, the engineer configure the line to produce the batch with sunroof. The batch production system tend to cause over or under production since the number of cars in the batch is roughly estimated based on the previous sales figures. We envision that in the future the production line should be able to dynamically process different car types. This will enable car types to be produced based on the current demands and therefore reduce the possibility of over and under productions.

Demonstrating this scenario, the BEMOCOFRA platform enables a welding line to process 2 different pieces of roofs type in a production batch. The stations will recognize the two different pieces of roofs type automatically. The stations take a decision to run a different path / branch of the logic based on the production order number that identifies the type of the roof. A wireless camera confirms the type of the roof and triggers the automatic reconfiguration of the devices in a welding station including the actuators and robots movements for the intended welding spots according to the roof type.

- Predictive Maintenance

In the predictive maintenance scenario we improve the current operational monitoring with the BEMOCOFRA platform. BEMOCOFRA enables continuous monitoring of what is going on in the station/line from different devices such as tablet and smart phones of the maintenance personals. In this demonstration, the operational data such as electricity and water consumption, production cycles, item id, item type are collected with the sensors installed in the station and analyzed. When the sensor reading shows that there has been an abnormal readings, the system informs the responsible personals.

The system should also be able to suggest a schedule for performing predictive maintenance based on the production schedules, to check some part e.g.: motor/axis of the robots, inform the technician for corrective maintenance (fix a broken parts)

5. Architecture Description

The architecture conceived in BEMO-COFRA project was first presented in Deliverable D3.2 – Initial Architectural Design Specification and it was designed to address challenges in industrial environments, such as process integration, flexibility, scalability and reconfigurability, manufacturing efficiency and ramp-up times.

This architecture was later refined to better assist to these requirements and it was published in deliverable WD3.2 – Refined Architecture Specification. The architecture guides the development of the every module of BEMO-COFRA Project. Thus, the final demonstration will be constructed as an instance of this methodology applied to industrial scenarios. This architecture is shown in Figure 6 and is based in a 5 Layers:

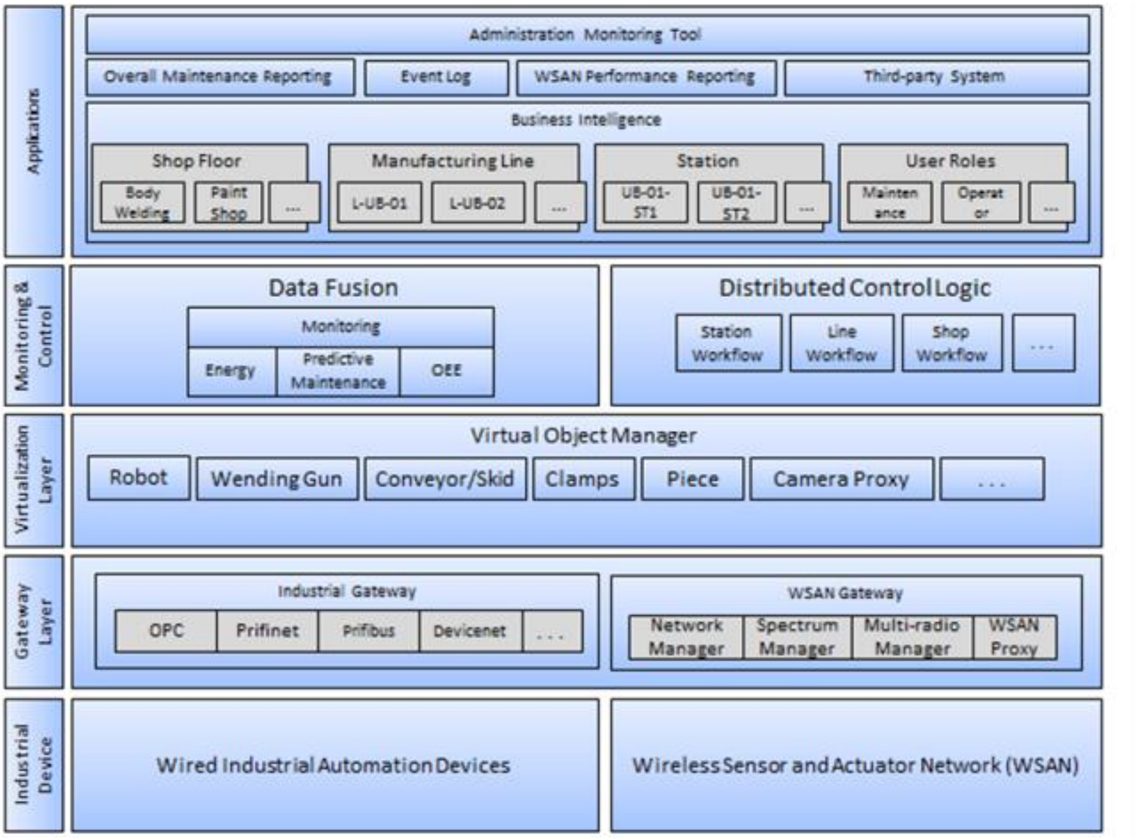

Figure 6: BEMO-COFRA Architecture.

- Applications Layer: In this layer, applications provide an interface between different users and the data extracted in a plant floor. In other words, the user can access the data collected through friendly applications and change configurations to monitor the events depending on the requisition of the production line;
- Monitoring & Control Layer: divided in two sub layers: Data Fusion and Distributed Control Logic. The two main concepts of this layer, monitoring and control are encompassed in different modules. To monitor the plant floor, data fusion module provides to Application Layer the data coming from multiple sensors. For example, if the data are redundant, this problem is resolved in the data fusion component or, if the data should be averaged over multiple samples, this module can handle that. In the other hand, the Distributed Control Logic comprises the main control that will guide the operations in the plant floor. These commands reflect the desire of the final user or administrator and are represented by the stages of a production, usually programmed in a Programmable Logic Controller (PLC);

- Virtualization Layer: provides access to the wired and wireless industrial devices using virtual proxies. In this layer, the interaction with *LinkSmart* framework is perceptible, since *LinkSmart* Proxies are a way to provide access to physical devices in the line. For example, if any sensor needs to be accessed, a proxy in *LinkSmart* middleware needs to be provided with basic functionalities, such as functionalities that allow access to the data collected or to set up some variables;
- Gateway Layer: Devices are not directly accessed through Virtualization Layer. As the industrial devices have different protocols to communicate, Gateway Layer provides access to wired and wireless devices using different protocols such as OPC, Profinet, etc.;
- Industrial Device Layer: This component is responsible for direct interaction between all components existing in a factory floor and should be controlled by the architecture. As BEMO-COFRA projects aims to control and monitor wired and wireless devices it is necessary to handle these differences in different modules. A module to handle wired devices is responsible for tracking events of devices and send information to upper layers, such as Gateway Layer. In the other hand, wireless sensor will be manipulated by other module inside the Industrial Layer. Also, this layer, storage and manage the device's drivers.

6. Wireless Sensor Networks Platform

The wireless sensor networks platform developed for the final demonstration and presented in Deliverables D4.1 and D4.2 is composed by Single-Radio and Multi-Radio nodes. This platform addresses some dependability features, amongst them we can cite:

- Availability: refers to the time during which the network end-to-end connectivity is up and running, providing sensing information, data, etc., at the receiving ends.
- Robustness: determines that the system functions correctly under - and reacts properly to harsh and abnormal conditions.
- Reliability: reflects the correctness of the received information in terms of content and timing.

In BEMO-COFRA Projects, dependable operations are supported through services that aim to obtain the following capabilities (more details can be seen in D6.2 – WSN Integrated Platform):

- Cooperative Sensing, through which it is possible to distribute the workload among the nodes and to improve the network lifetime and reliability of the collected data;
- Context Awareness, through which harsh conditions of the environment can be handled and methods can be employed to ensure the correct operation of the network. This feature was implemented using three methods:
    - Frequency agility: this service allows the network to monitor the spectrum occupancy state and reallocate the network to the best available channel during run-time when interference is detected on the current operating channel.
    - Node status monitoring: the WSAN collects and elaborates information about nodes connectivity and operational parameters, namely the end-to-end delays and packet loss rates. With this information, it is possible to detect when a certain node has been disconnected, and can indicate if certain routes are no longer valid and eventually trigger a route repair process.
    - Context-aware data transmission mechanism: ensures reliable end-to-end delivery of data packets by optimizing the node-to-Gateway route based on nodes' metrics.
- Network discovery and recovery: WSAN nodes execute a network discovery mechanism at start-up to search for the network on the available channels.

6.1 Wireless Sensor Networks Architecture

The Single-Radio WSAN in the BEMO-COFRA Project adopts the 6LoWPAN technology, and is based on the system architecture previously presented in the BEMO-COFRA deliverable 4.1 "Dependability features in single-radio WSANs". Basically, the architecture divide the network into "clusters" in order to support end-to-end connectivity in large-scale deployments, and thus to provide monitoring of the large number of machines in the plant. In each cluster, the following node roles are defined (Figure 7):

- Cluster head (CH): the node that manages the data traffic between the nodes in a cluster and the Gateway.
- Spectrum sensing node (SSN): sequentially performs energy detection on the available radio channels.
- Non-spectrum sensing node (Non-SSN): carries out the network application and do not participate in spectrum sensing.

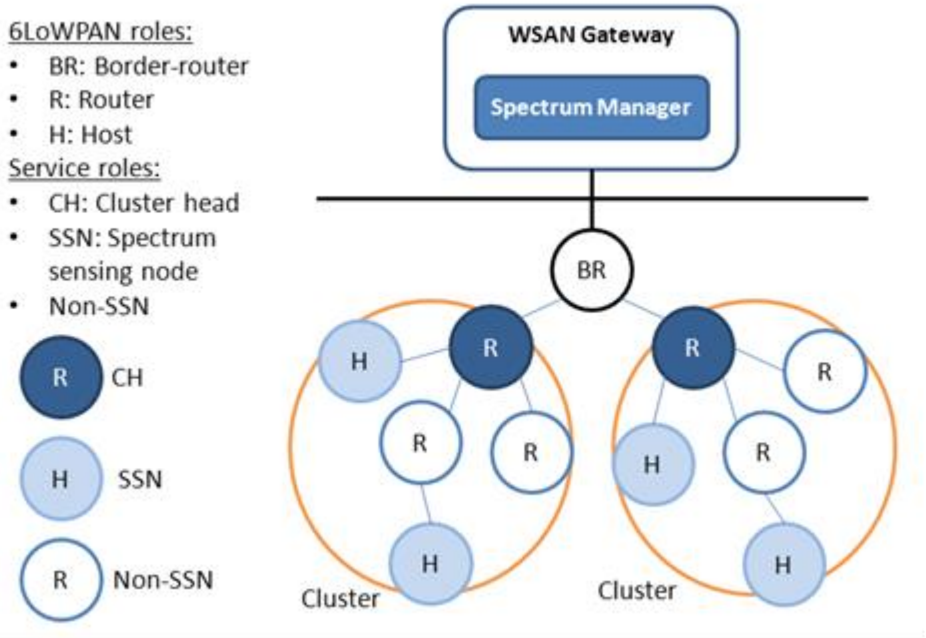

Figure 7: Single-Radio WSAN architecture.

Extending this Single-Radio architecture, the overall BEMO-COFRA WSAN network layout has been designed and is shown in Figure 8. In this Figure, it is possible to note that both Single-Radio and Multi-Radio networks coexist in the same environment and are managed by a WSAN Gateway.

In Figure 8 below it is shown a network composed by Single-Radio (which has only 6LoWPAN nodes that perform spectrum sensing and data monitoring) and Multi-Radio nodes. Multi-Radio nodes can communicate using several communication protocols, such as Wi-Fi, 6LoWPAN and Bluetooth. The nodes in this type of network communicate with the WSAN Gateway through what is known as a "Sink Multi-Radio Node", a MRN with special capabilities to packet and forward the data from all nodes in the network to the WSAN Gateway. The WSAN Gateway is responsible for collecting and processing the data arriving from the networks as well as managing and controlling network resources. Among other components, the WSAN Gateway contains the Multi-Radio Manager module, in charge of carrying out spectrum management related tasks.

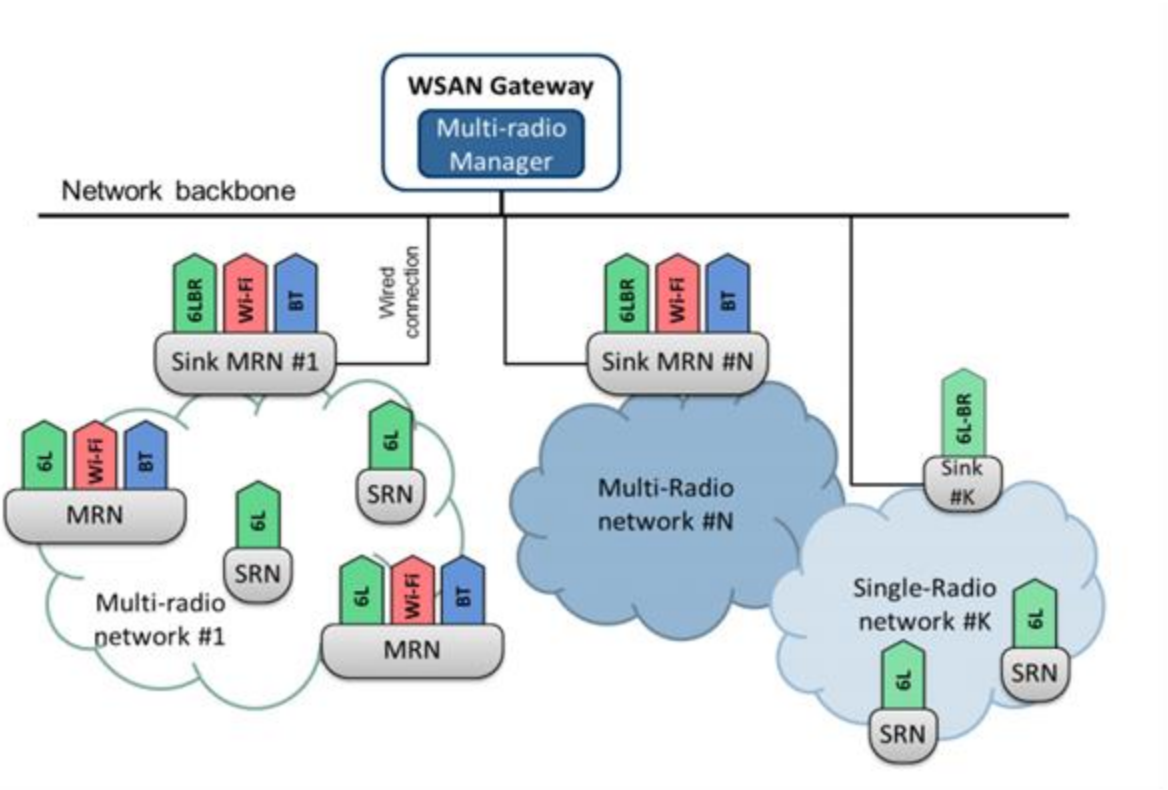

Figure 8: Multi Radio WSAN architecture.

6.2 Integration between Sink MRN and WSAN Gateway

In the application to be presented in the final review, MRNs and Sink MRNs were developed using Java and WSAN Gateway was developed using Python. The integration between these two components was successfully tested. Parameters such as "clamp state" and "skid orientation" were received by the WSAN Gateway. Another important feature tested was the frequency-agility. In tests performed, it was possible to note that:

- SSN reports from the Sink MRN are correctly processed by the WSAN Gateways;
- The WSAN Gateway correctly calculates 6LoWPAN channel occupancies;
- The WSAN Gateway correctly sends the "Interface switch" command to the Sink MRN;
- The Sink MRN successfully receives and decodes the packet;
- The Sink MRN correctly reacts: starts using the new interface while switches the channel of the previous interface (the one under bad conditions);
- All the above processes are carried out without any interruption to monitoring applications.

6.3 Support for WSAN Network Management

The network management was tested evaluating the communication between (i) a "WSAN node" programmed as an SNMP agent that sends SNMP traps, and (ii) the "SNMP Manager" through the Sink MRN. To accomplish that, an integrated SNMP agent extension was implemented into the Sink MRN. This SNMP agent is responsible for:

- Translate the multi-radio WSAN information (stored in the Sink MRN) into the SNMP trap;
- Defined a preliminary SNMP trap structure for testing;
- Correctly create and send SNMP traps from the WSAN Sink MRN to the SNMP Manager.

The Final Multi-radio WSAN management architecture should also be able to (i) generate SNMP requests from the SNMP manager to the SNMP Sink MRN in order to collect data and ii) integrate the SNMP Manager with WSAN Gateway through a WSAN proxy. Figure 9 illustrates this final architecture.

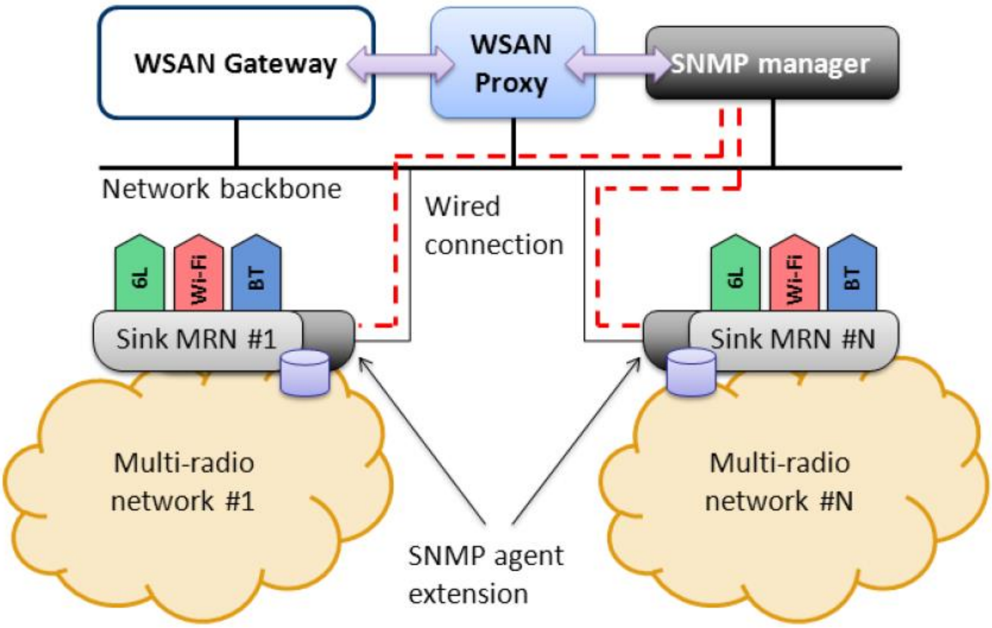

Figure 9: Final Multi-radio WSAN management architecture.

6.4 Final Large Scale Multi-radio WSAN

Other important aspect under development is the Spectrum Manager in Large Scale Multi-radio. The main point to do is to extend the Spectrum Manager to differentiate and process data arriving from different networks, as shown in Figure 10.

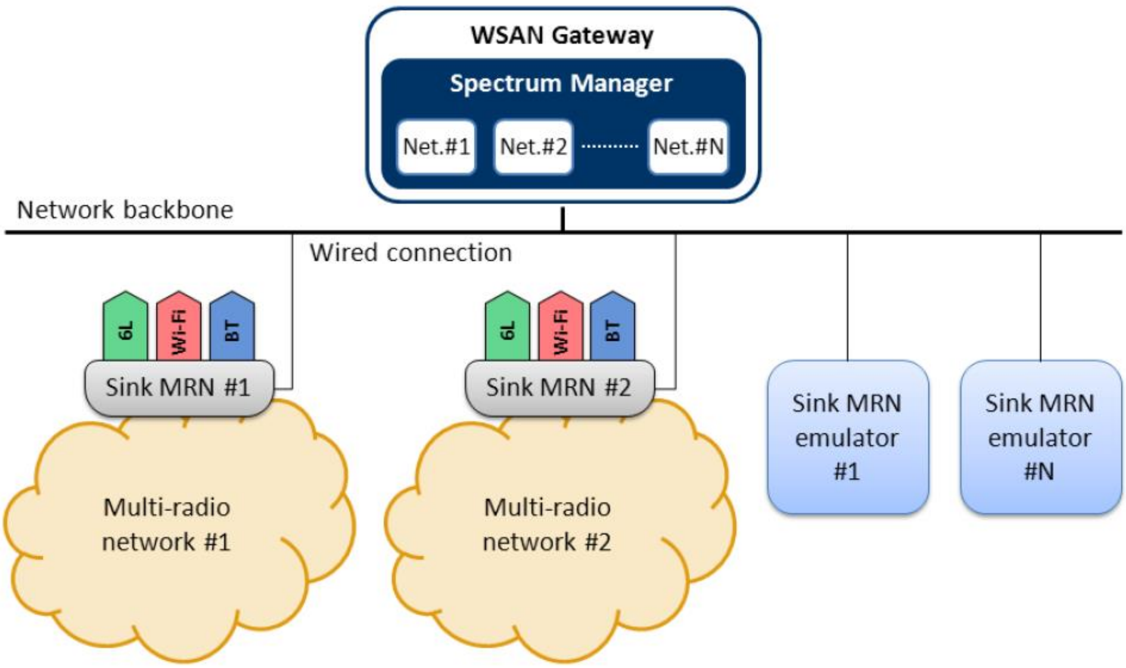

Figure 10: Final Large Scale Multi-radio WSAN deployment plan.

6.5 Hardware Specification

For the final demonstration, the sensor nodes employed in the M12 demonstration will be also used. Zolertia nodes will be used to monitor the orientation of the skid to inform the monitoring application if the operational conditions are not adequate. The Zolertia Z1 wireless sensor node is equipped with the ADXL345 3-axis accelerometer that allow these readings. The MEMSIC Telos rev. B nodes are directed connect to the sensor clamps of the robots to monitor the state of the clamp (open or closed.) In particular case of the clamp sensor, this output is connected to a general I/O pin in the MEMSIC Telos rev. B.

	MEMSIC Telos rev. B	Zolertia Z1
MCU	MSP430 16-bit, 8MHz	MSP430 (2^{nd} generation) 16-bit, 16MHz
Memory	10kB RAM, 48kB flash ROM	8kB RAM, 92kB flash ROM
Radio transceiver	CC2420 IEEE 802.15.4 compliant	CC2420 IEEE 802.15.4 compliant
On-board sensors	Visible light, temperature, and humidity	Temperature, and 3-axis accelerometer

As reported in D6.2 – WSN Integrated Platform, sensor node applications were developed using Contiki operating system v2.6 (Dunkels 2003), which is an open-source operating system for programming IoT applications. Contiki features an IPv6 stack with routing capabilities. Several modifications and additional modules have been developed by ISMB in order to enhance Contiki's default IPv6 stack connectivity and stability. Figures 11 and 12 show the two devices discussed.

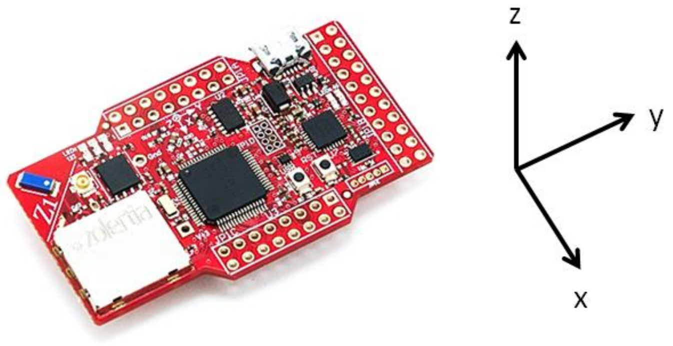

Figure 11: Layout of the accelerometer axes on the Zolertia Z1 wireless sensor node.

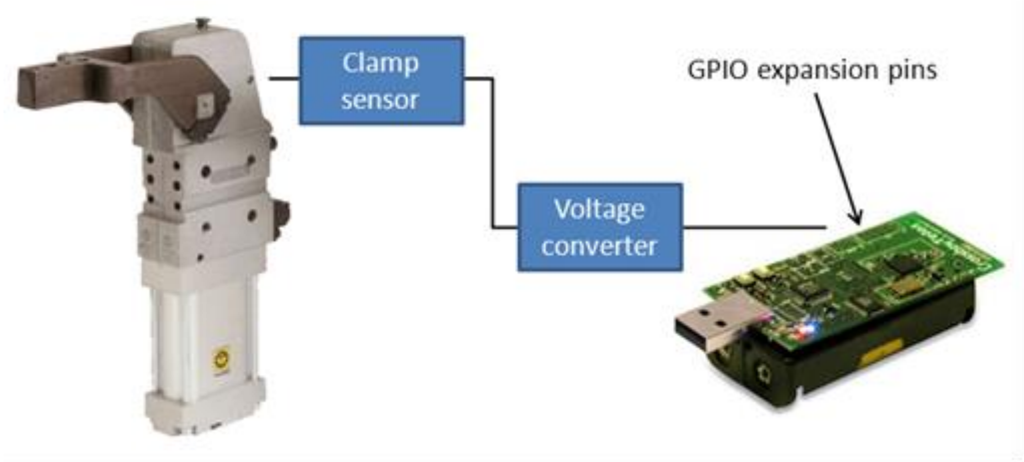

Figure 12: Interfacing the Telos rev. B sensor node platform with the Tünkers clamp.

7. User Interface

7.1 General

The user interface comprises functionalities to the end-user that handle the following situations:

- Scenario Reconfiguration: Usually, in a production line, such as the line shown in the last section, it is not easy to change the type of object to be inspect without stop the line and reconfigure the system to inspect the new type. However, in BEMO-COFRA project the type of the car will be automatically identified by wireless cameras that will inform the PLC to load the correct program. In this way, a factory line can work with n models at same time. The variables that need to be informed by the user are, for example, the minimum and maximum acceptable threshold in orientation, direction, velocity and energy consumption. If the monitored values are not inside the interval defined, the line must stop and the process is restarted.
- Operational Monitoring: in the GUI it is important to have a complete feedback about the status of the line. Thus, some outputs are required to the end user:
- The status of the process: for example, in which stage of the welding process the car is found;
- Status of the devices (turned on, turned off);
- Energy consumption of all devices;
- Number of car bodies inspected for each type;
- Failures in the devices;
- Failures in the processes: for example with the welding spot are frequently not ok, it would indicate a failure in the welding gun.
- Predictive Maintenance: in this case the sensor with some type of failure, or low battery, this information can be raised to the monitoring tools, and the devices can be replaced or repaired.

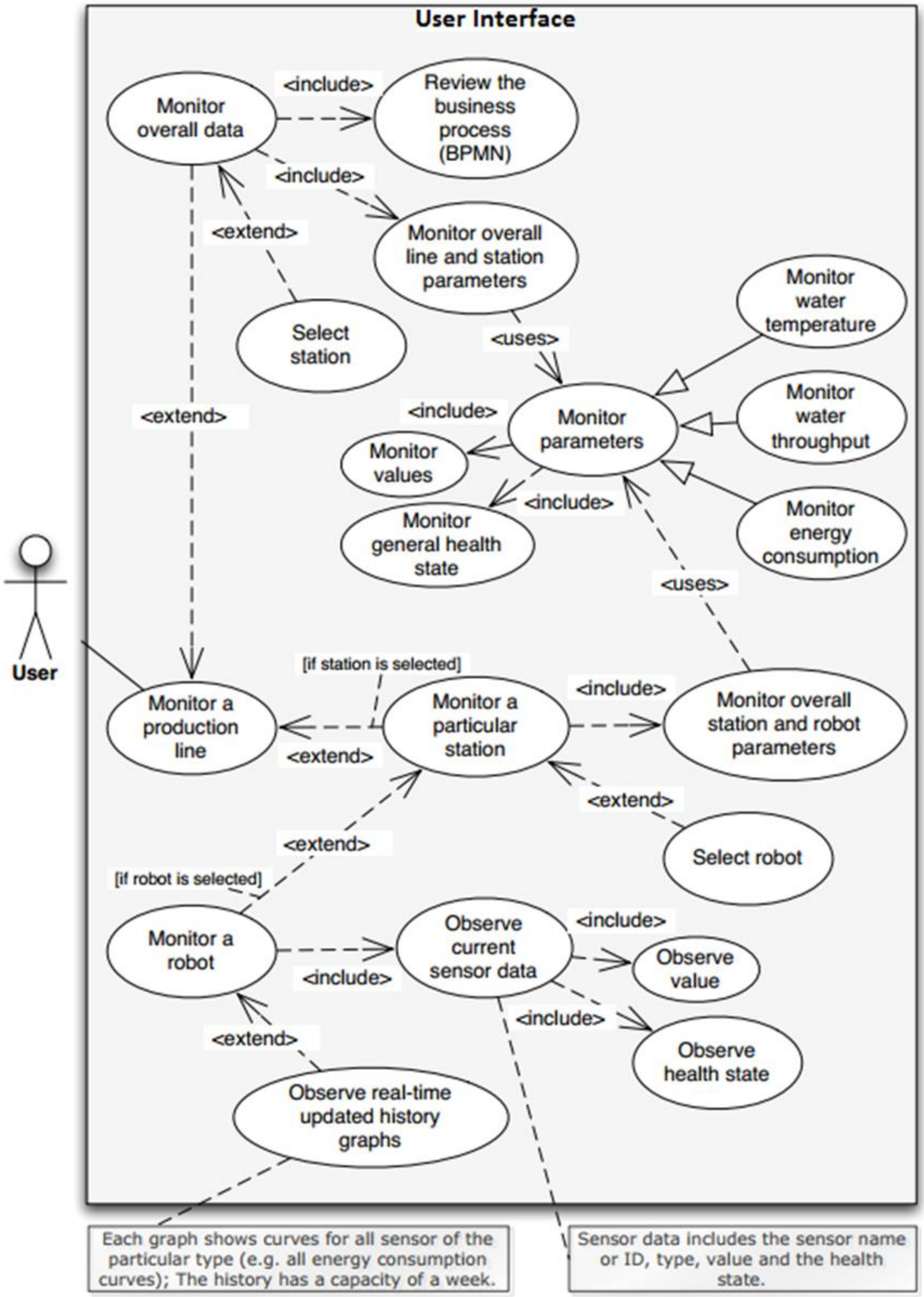

Figure 13: Use case diagram for the user interface.

The functionalities of the user interface is summarized in the use case shown in Figure 13.

7.2 Production Process & Energy Monitoring User Interface

The user interface was designed and went through several iterations. Figure 14 shows the initial design focused on the information elements and the final design also focused on the aesthetic aspect to improve the user experience.

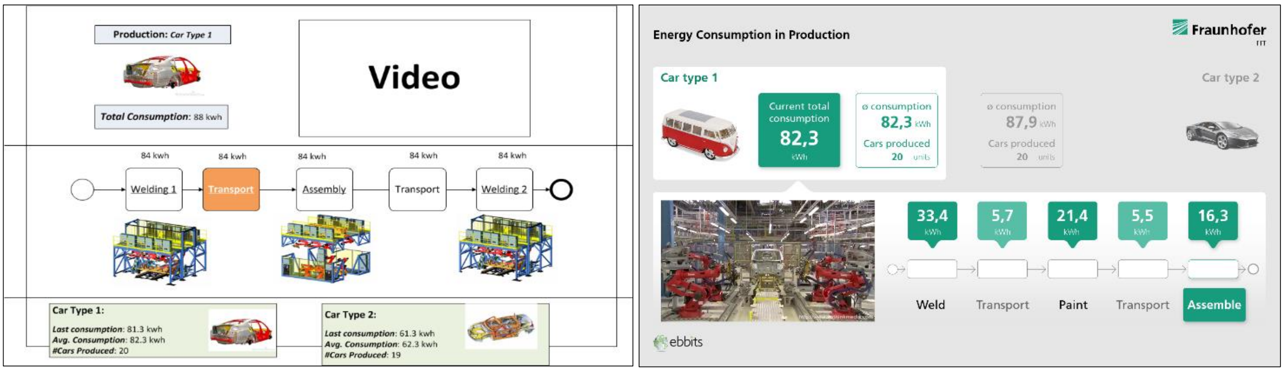

Figure 14: The initial design and the final design of the user interface.

The user interface is designed to be able to monitor as detail as each specific car being produced. For this it has to be able to show the process where a specific Skid currently is in, the energy consumptions of the processes, and the type of the car on the Skid. The energy consumption is polled from the database every second and by the end of the process the user interface components calculate the total consumption needed by the process. We added a video to show how the real process on the shop floor looks like for promotional purposes when showing the prototype on a trade fairs. When the prototype is used in the real production environment, this section could be replaced by a menu to change the information on the user interface.

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<tr><th>User Interface Design</th><th>Function</th></tr>
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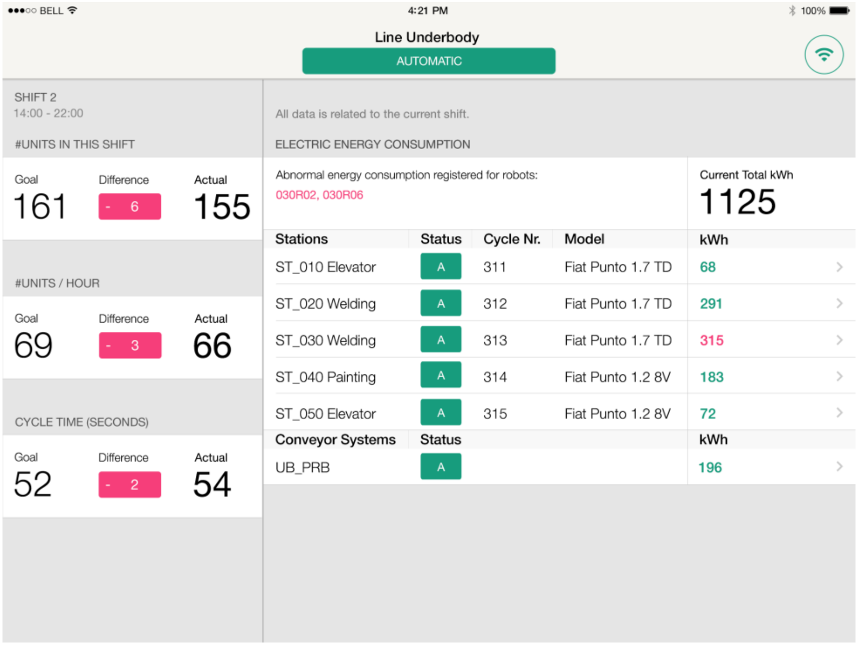

</td><td>
This page shows the average of energy consumption (electricity), on a production line detail. In the left is possible to see the total amount of units produced, the total amount of units/hour and the cycle time in seconds compared with its respective goals.

In the right it is possible to see, for each line, the amount of energy consumed.
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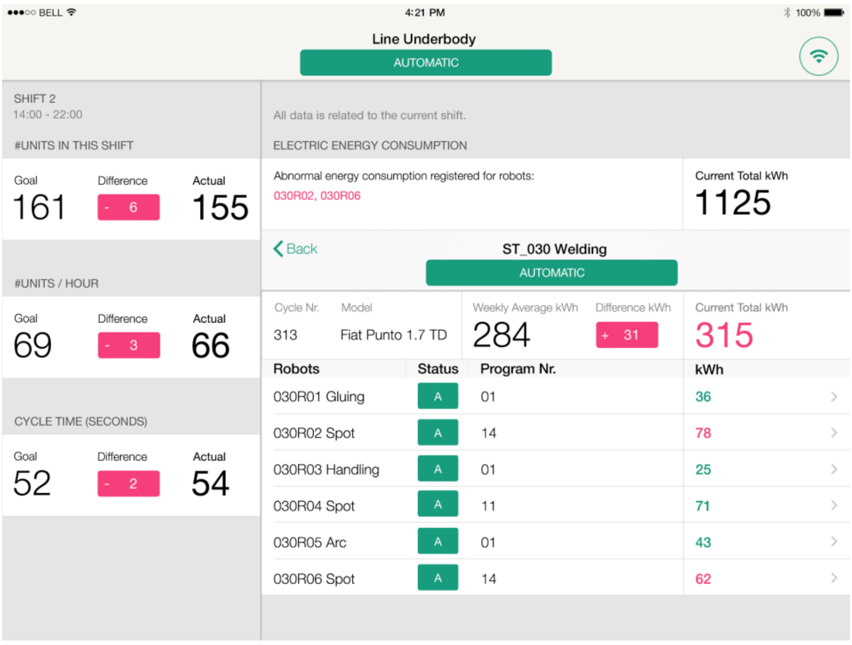
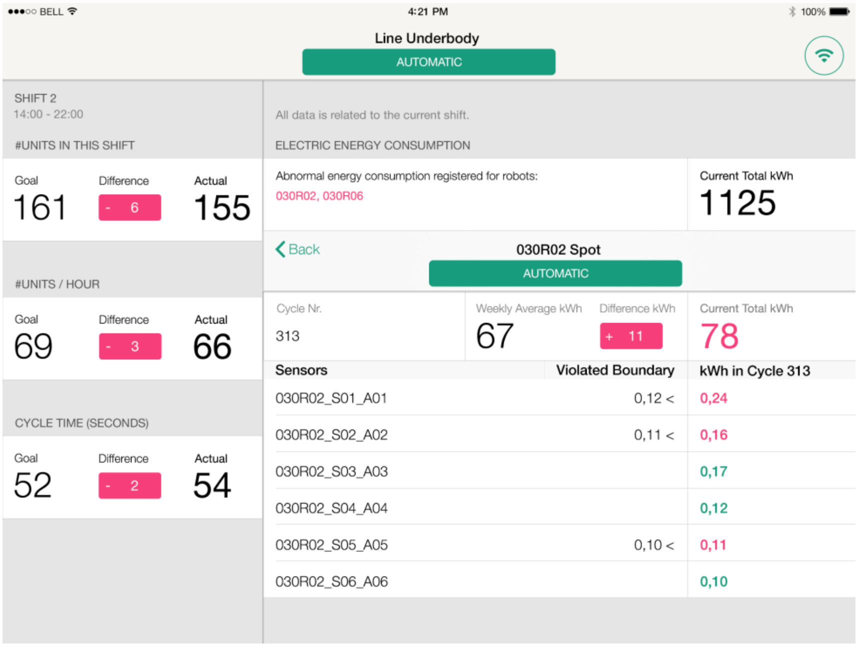


</td><td>
This page shows the average of electricity consumptions of each station. Note that, for robots 030R02 and 030R06 it was detected abnormal energy consumption.
</td></tr>
</table>



This page shows the average of energy consumption (electricity), the robots in a station.

To develop this interface and also evaluate it, a questionnaire was prepared and submitted to one of the stakeholders. It is possible to see this questionnaire (and the answers of the stakeholders) in the Appendix A.

8. Final Demonstration Explained

8.1 Scenario

The final demo has as goal validate the BEMO-COFRA project results and requirements, so it will be more complex than the demo from M12, at the middle of the project. For the final demo we will work with a station from the car manufacturing industry also, which will weld car roofs, preparing them for the whole car assembly. This station has to deal with two different models of roofs, with sunroof and without it, and be able to produce them without a previous production plan. So if at any moment the plant manager receive an order to improve the production of sunroofs, he can only add more items of this roof model at the station, and the BEMO-COFRA will be able to detect this change and set the right configuration to carry on with the production. As an improvement of flexibility, accuracy and quality at this demo the station will be able to check if the weld spots were done or not, if not the station will re-weld them, avoiding the error propagation. Also more wireless sensors will be part of the demo, increasing the wireless traffic, and a wireless actuator will be placed at this station. The consumption of energy will be measured too and showed on time for the user. The following picture shows a schema for the final demo, the devices, workflow and main characteristics will be explicated at the next sections.

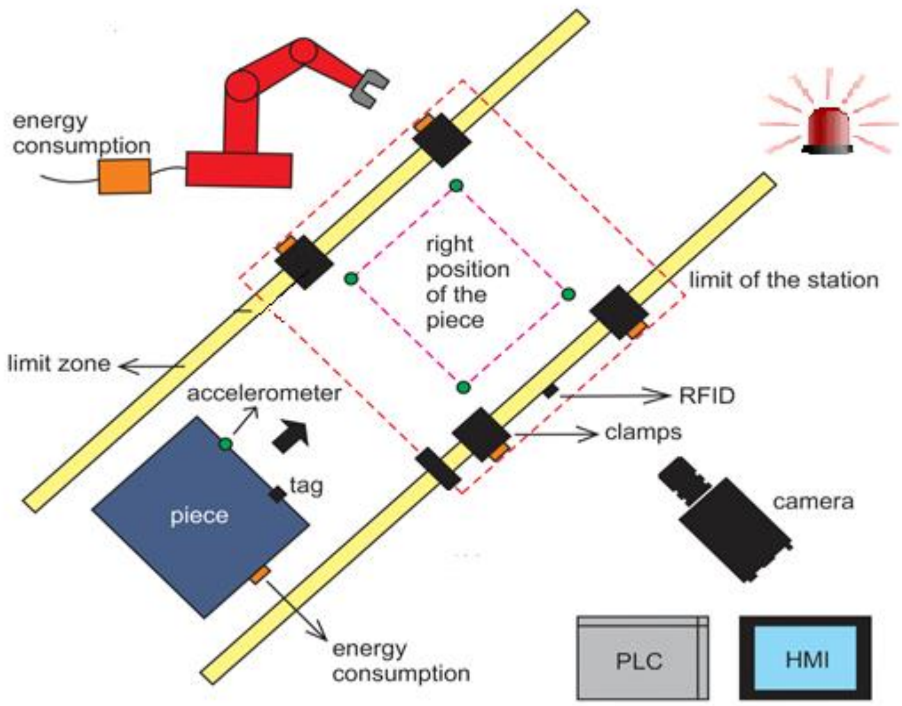


Figure 15: Final Demo Scenario.

8.2 Devices

The main devices of the final demo scenario are related and briefly introduced at next. To prepare the infrastructure of the final scenario in Recife it is important to pay attention to all details and devices that should be present there, to make available the ideal scenario to configure the BEMO-COFRA tools as fast and easy as possible. To help in this task, a tree questionnaire with the main components of the scenario was created and submitted to the partners (see Appendix B).

Robot NJ4 170 2.5 (COMAU)

The family of Smart5 NJ4 robots consists of machines with high load capacity dedicated to applications requiring the ability to program "point-to-point" or in "trajectory control". These robots have six degree of freedom, three for positioning and three for direction or attitude toward the piece.

The NJ4 170 2.5 is part of this family, with the capacity of 170 kg of payload and reach of 2501 mm. This is the most common robot used for the welding stations. The welding gun is connected at the end of the robot arm and it cables and pipes pass outside the flange.

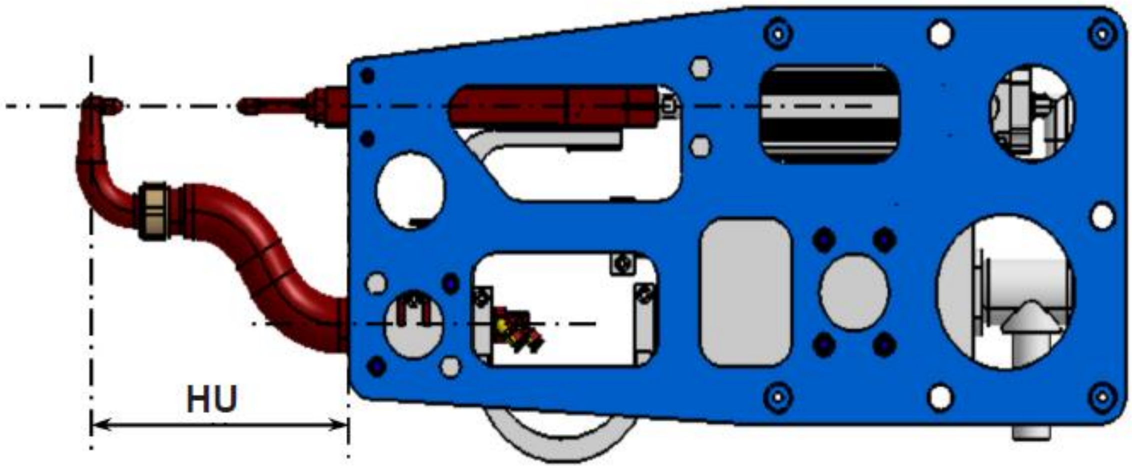
Robot Type	Payload (kg)	Reach (mm)	Robot view
SMART5 NJ4 170 - 2.5	170	2501	

VERSION		NJ4 170 – 2.5
Structure / n° axes		Parallelogram 6 axes
Load at wrist		170 kg (1) (375 lb)
Additional load on forearm		50 kg (2) (110 lb)
Torque axis 4		1010 Nm
Torque axis 5		804Nm
Torque axis 6		412 Nm
Stroke / (Speed)	Axis 1	+/- 180° (110°/s)
	Axis 2	+95° -75° (110°/s)
	Axis 3	-10°/ -230° (110°/s)
	Axis 4	+/- 200° (180°/s)
	Axis 5	+/- 200°(140°/s)
	Axis 6	+/- 200° (190°/s)
Maximum horizontal reach		2500 mm (98.5 in)
Repeatability		+/- 0,1 mm
Robot weight		1100 kg (2425 lb)
Tool coupling flange		ISO 9409 - 1 - A 125 ISO 9409 - 1 - A 160
Motors		AC brushless
Position measurement system		con encoder
Total power installed		8 kVA
Protection class		IP65
Working temperature		0 ÷ + 45 °C
Storage temperature		- 40 °C ÷ + 60 °C
Colour of robot (standard)		Red RAL 3020
Assembly position		On the floor From the ceiling

Figure 16: Robot Smart 5 NJ4 170 2.5 Specifications.

Versa Gun VC Type (COMAU)

The versa gun is the component of the weld machine that goes at the end of the robot arm. This weld gun is composed by a body, which can be of aluminium or copper, a transformer, to increase the current for the welding process, and the electrodes, which are the part that touch the area to be weld. The Versa Gun VC has as maximum welding force 450/550 daN.



Dimension	Min. - Max	Arms
HU	250mm -450mm	Copper
HU	500mm -700mm	Aluminum

Product Specifications	
Servo Force Capacity	793 daN
Weld Tip Speed	250mm-600mm/sec
Trans. AC/MFDC	65KVA – 100 KVA
Water Requirements	10 l/min. @ 2 Bar
Product Weight	100 Kg – 120 Kg
Electrical Tolerance	+/- 10% of stated Voltage
Height	500mm+
Length	700mm+
Width	170mm
MTBF	2,000,000 cycles
MTTR	15 minutes

Figure 17: Welding Gun Specifications.

Alarm

A set with red light and bell will be used as the alarm notification when something go wrong during the production. Actually, we should define the final model for this, but as a suggestion this set is quite simple, but attend the project needs.

Product Name	LED Signal Lamp
Rated Voltage	DC 24V
Light Color	Red
Material	Plastic, Electronic Parts
Size	6.5 x 10cm/ 2.6" x 3.9" (D*H)
Thread Diameter	3.9mm/0.15"
Body Color	Red, Gray
Net Weight	105g
Package Content	1 x LED Warning Light Lamp

Figure 18: Alarm Device.

Light Barrier

The light barrier will be used as an electronic fence restricting the area where the skid can be at. The light barriers are composed by transmitter and receivers, which produce an infrared light curtain, that supervise the area among these two units. If this area is exceed, the outputs will switch and our case the alarm set turned on (red light and buzzer). The lights barriers are very common today, being used in residential buildings.

Figure 19: Examples of light barriers - industrial and residential.

Electric Clamps

The electric clamp is a high-power tool designed for use in clamping tasks processing sheet metal. It consists of a three-phase hollow shaft motor, a metal housing with mounting faces, front and rear, and a clamp arm with receiver for the contour piece. When used for clamping, a recirculating ball screw driven by the motor functions on an integrated toggle lever joint and mover the clamp arm. The function control of the integrated LEDs T12 is as follows: green – operating voltage; yellow – clamp is opened; red – clamp is closed.

Product Data

Product Type	E 63
Transverse force	0.15 kN
Clamping moment	380.00 Nm
Weight	7.2 kg
Length	400.00 mm
Width	217.00 mm
Height	73.00 mm

Figure 20: Electric clamp from Tünkers.

PLC Control Logix 5572S (Rockwell)

The programmable logic controllers from Rockwell are hugely use by COMAU of Brasil in their projects. The ControlLogix ® systems use a common control engine with a common development environment to provide high performance in an easy-to-use environment. It's possible perform standard and safety control in the same chassis. This PLC is supported by the OPC that we are going use to the final Demo.

Figure 21: Programmable Logic Controler - ControlLogix 5572 S.

OPC Keepware

Kepware's Manufacturing OPC Server suite allows automatically connection to devices on the shop floor, read and write data to those devices, and fully integration of data into HMI, SCADA, MES, Historian or ERP System. The OPC has a unique architecture for suites and any additional drivers added to a suite - One Communications Server to manage, One Name Space, and One set of Diagnostics.

Power sensors

Energy control is part of the BEMO-COFRA requirements. To measure the consumption of energy by the devices, power sensors will be integrated at the station. The device with the highest consumption probably is the robot, so their characteristics will be used to specify the right sensor.

C5G: available basic versions

Robot family*1 (SMART5 series)	Matching C5G Control Unit / Comau Code	Power *2		No. of controllable robots	No. of axes avalable / max controllable *4
		Total installed / average current at 400 Vac	peak (<= 2s)		
SMART5 SiX NS	**C5G-ACC1** CR17930181	3 kVA / 4,5 A	9 kVA	1	6
		12 kVA*3 / 18,5 A	36 kVA	1	6 / 11
SMART5 NM NJ < 180	**C5G-ACC3** CR17930381	8 kVA / 14 A	24 kVA	1	6
		12 kVA*3 / 18,5 A	36 kVA	1	6 / 9
SMART5 NJ > 175 < 400 NJ 450 - 2.7		12 kVA*3 / 18,5 A	36 kVA	1	
SMART5 NJ4	**C5G-ACC3** CR17930381	12 kVA*3 / 18,5 A	36 kVA	1	6 / 9
SMART5 PAL	**C5G-ACC3P** CR17930681	12 kVA / 18,5 A	36 kVA	1	4
SMART5 NJ 420 - 3.0 NJ 500 - 2.7	**C5G-ACC5** CR17930581	12 kVA / 18,5 A	36 kVA	1	6

*1 As for the information related to the Robot features and available versions, please refer to the Robot specific "Technical Specifications" manuals
*2 The power value does not vary with the powering voltage fluctuations, as the system works at constant power.
*3 Besides the 8 kVA installed the option C5G-AFK: Auxiliary Fan Kit is required.
*4 Refer to section Additional axes.

Figure 22: General robot specifications.

We are working with two possibilities of sensors, both from Phoenix and they are:

- **Current and voltage transducers** : Detect DC and AC regardless of whether the currents are sinusoidal or distorted with MCR measuring transducers. A current protector and voltage transducer are available for alternating and direct voltages. It can measure current up to 600A and gives the true r.m.s (TRMS). Also it is possible do the retrofitting without system interruptions.

Figure 23: Current and voltage transducers.

- **Energy meters** : EMPro energy meters detect and monitor the characteristic electrical data of the machines and systems, the devices are network-capable what ensure that all measuring data will be available centrally and on-site. The EMpro MA600 is capable of performing all measurement tasks associated with power supply applications up to 700 V AC . Another good alternative is the EMpro MA400, which is capable of all standard measurements tasks in the main distribution up to 500 V AC, and the plug-in RS485 communication module allows the measuring instrument to be integrated easily into JBUS and MODBUS systems.

Figure 24: Energy meters.

Camera wireless - iVision V300

The V300 is a smart industrial camera based on Texas Instruments DaVince DM355 Soc. This family of cameras are indicated to applications such as identification and tracking, presence detection, positioning and color matching among other industrial inspection tasks. Some of this inspection tasks will be directly implemented on the final demonstration of BEMO-COFRA project.

The camera is equipped with a high sensitivity 5Mpixel resolution color CMOS sensor. The sensitivity allows the camera utilization in low light environment and the high resolution allows implementation of algorithms for precise positioning.

The embedded architecture of the camera includes the processor, the main memory, flash memory, and interfaces based on USB and Ethernet. Another functionalities available is an SDcard interface and general purpose I/O´s.

The DM355 is based on ARM9 processor and a dedicated image and video co-processor that supports MPEG-4 SP and a 50MB/s JPEG decoding. Another important feature is the iPipe that implements dedicated algorithms to operate over image sensor raw images. This algorithms allows real time pre-processing operations as: white balance and colour correction, among others. In what concerns to Linksmart core, actually, the camera supports .NET solutions that integrate with LinkSmart network through a publish-subscribe scheme. The integration of the Network Manager and Event Manager although possible it is a challenging task since it requires resources such as memory space that is not always available without a hardware upgrade.

Figure 25: V300 Camera.

8.3 Workflow and Control Logic

The workflow showed at the next figures is basically the activity sequence of the final demo. In a summarized description the final demo scenario behaves like this:

-The conveyor brings a new roof piece for the station. The parameters of the conveyor are observed to guarantee its right running. Extra sensors were added to improve the security, so if the SKID, for any reason, go out of a limited area, it is automatically stopped and an alarm is triggered with a red light and a buzzer.

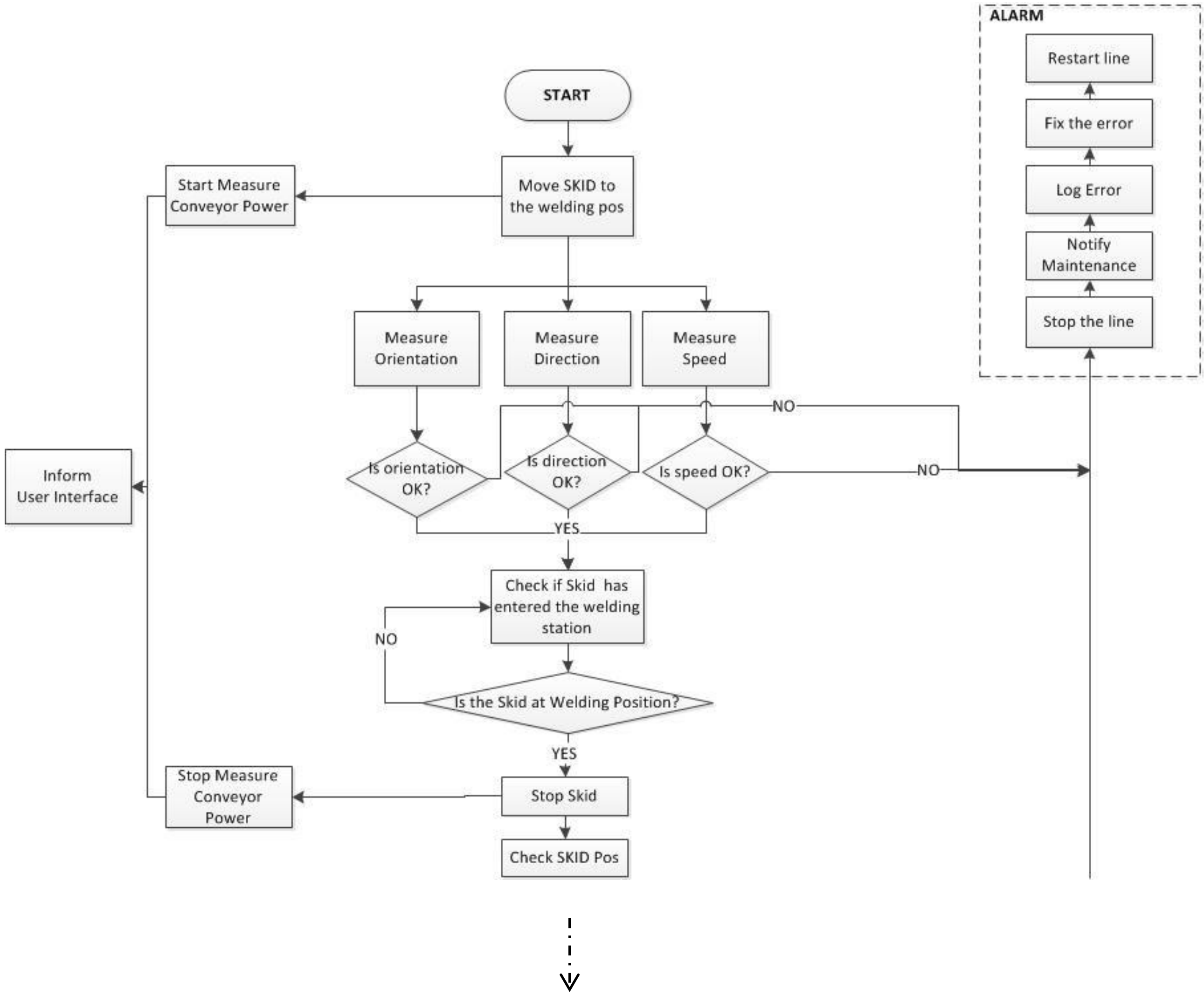
-As soon as the RFID sensor detect the SKID inside the station zone, the SKID stops and the wireless camera check the roof model and if it is at the right position.

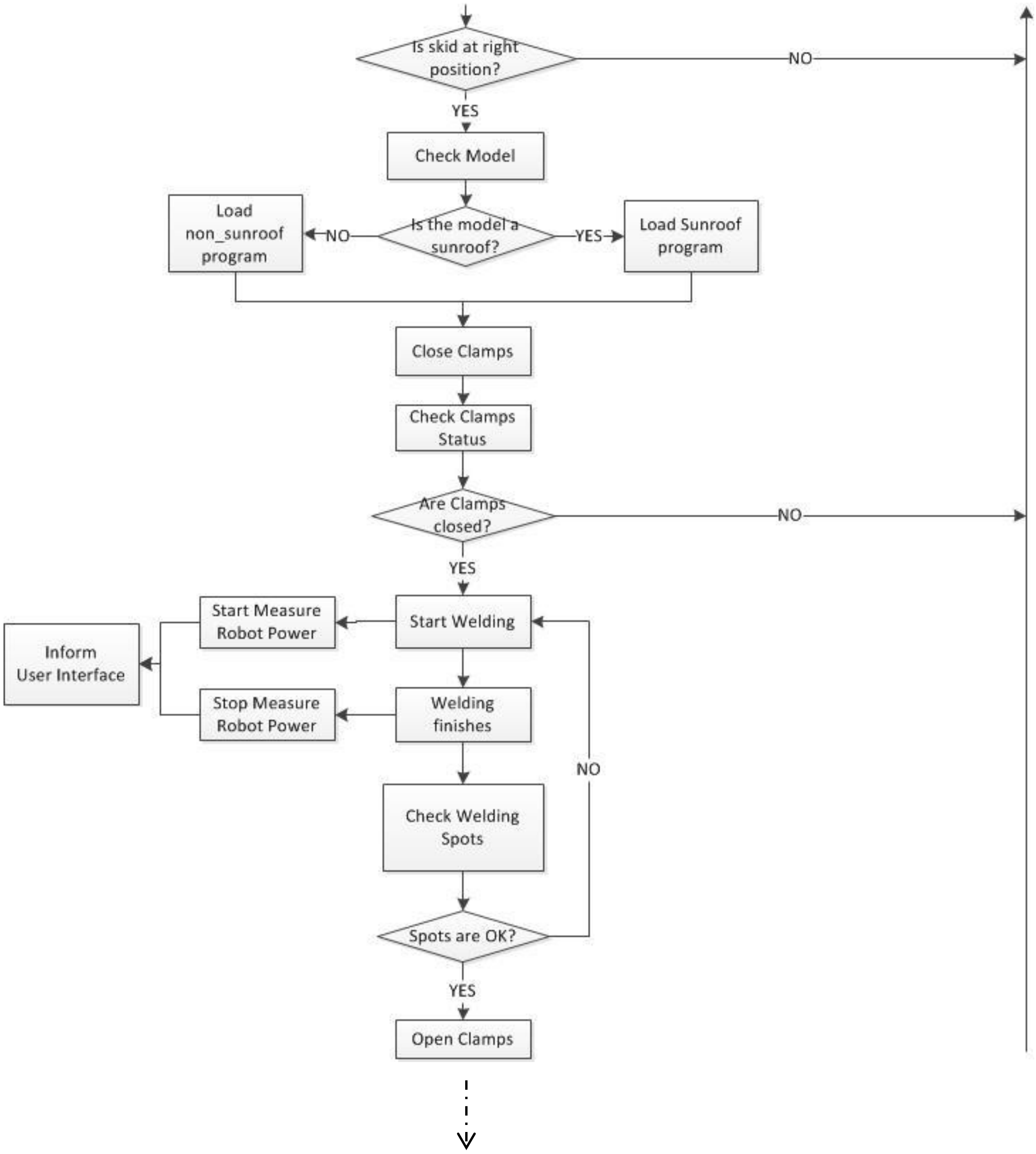
- At this moment the clamps are authorized to close according to the model, actually from this moment all the next procedures are related to the roof model. If an error occur during the clamps closure, the alarm is triggered and the station stops until the error fixture.

-With the piece blocked the robot starts the welding procedure, again if an error occur during this procedure the alarm is triggered.

-Finished the welding the camera will detect if all weld spots were done or not. If not, the robot repeat the weld procedure.

-When the camera detect all the weld spots as done, the clamps are allowed to open and then the SKID can move taking the roof piece for the next station.




Is skid at right position?
NO
YES
Check Model
Load non_sunroof program
NO
Is the model a sunroof?
YES
Load Sunroof program
Close Clamps
Check Clamps Status
Are Clamps closed?
NO
YES
Inform User Interface
Start Measure Robot Power
Start Welding
Stop Measure Robot Power
Welding finishes
NO
Check Welding Spots
Spots are OK?
YES
Open Clamps

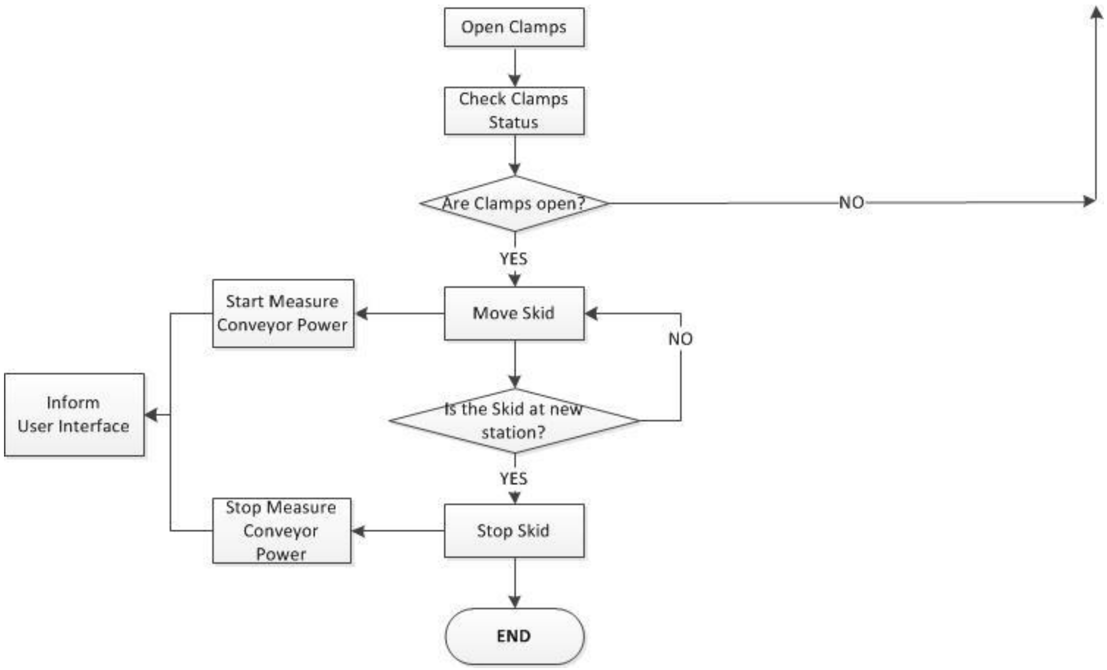


Figure 26: Final Demo Workflow.

To better understand how the events will transit at the BEMO-COFRA platform, the next sequence diagram is presented. Actually, it is not the definitive sequence diagram of the demo, but you can have a good idea of what we expect of the event sequence. Also, the most important variables from the control logic are explicated at the following table. The goal of the control logic is guarantee the station running according to the workflow established before. It is under designing and will be detailed at the deliverable D5.1.2 Final infrastructure for distributed control logic on M25.

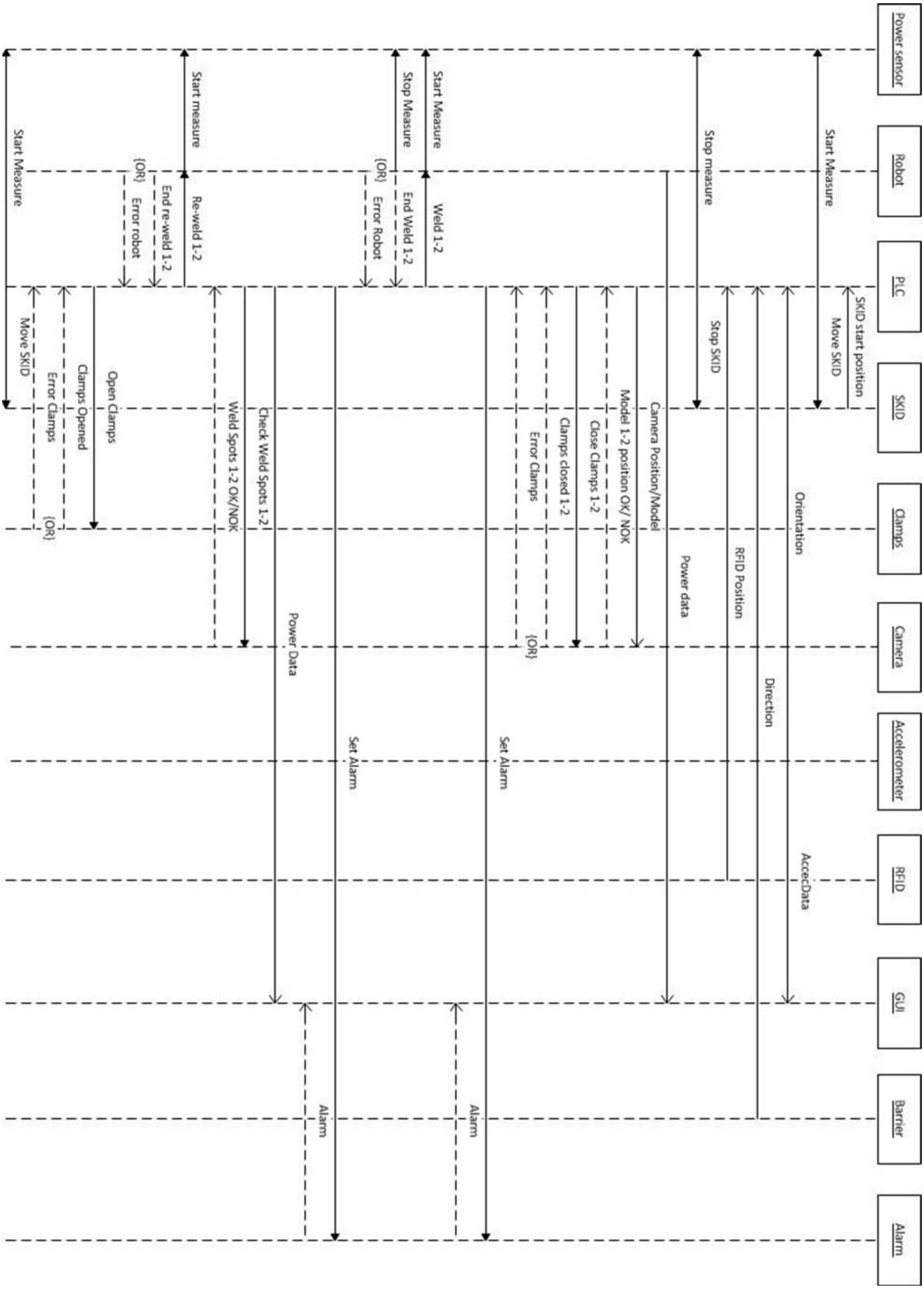


Figure 27: Sequence diagram - Final Demo.

Name	Meaning		Type
	True	False	
Orientation	Orient. Right	Orient. Wrong	Sensor
Direction	SKID inside the line	SKID outside the line	Sensor
Speed	In accordance to the limits	Over the limits or stopped	Sensor
RFID	SKID inside the station	SKID outside the station	Sensor
Move SKID	Move SKID	Stop SKID	Act
SKID position	Position OK	Position KO	Sensor
Check model	Sunroof model	Simple model	Sensor
Act Clamps 1 (without sunroof)	Close clamps	Open clamps	Act
Act Clamps 2 (with sunroof)	Close clamps	Open clamps	Act
Alarm	Set alarm	Reset alarm	Act
Status Clamps 1	Clamps closed	Clamps opened	Sensor
Status Clamps 2	Clamps closed	Clamps opened	Sensor
Weld Robot 1	Start weld	Stop weld	Act
Weld Robot 2	Start weld	Stop weld	Act
Finished Robot 1	Robot finished	Robot working	Sensor
Finished Robot 2	Robot finished	Robot working	Sensor
Check weld Spots 1	Spots OK	Spots KO	Sensor
Check weld Spots 2	Spots OK	Spots KO	Sensor
Reweld 1	Redo weld spots	Do nothing	Act
Reweld 2	Redo weld spots	Do nothing	Act
Error clamps	Error clamps	Clamps ok	Sensor
Error robot	Error robot	Robot ok	Sensor
Conveyor Energy	Start measuring	Stop measuring	Act
Robot Energy	Start measuring	Stop measuring	Act

The BEMO-COFRA includes many views of the plant or station according to the user requirements. Thus for each stakeholder, user, we can define an interface showing what is interesting for each and how deep he can go to the line, for example, he can get a device information or a whole line information. The next figure shows some of these interfaces according to the final demo scenario.

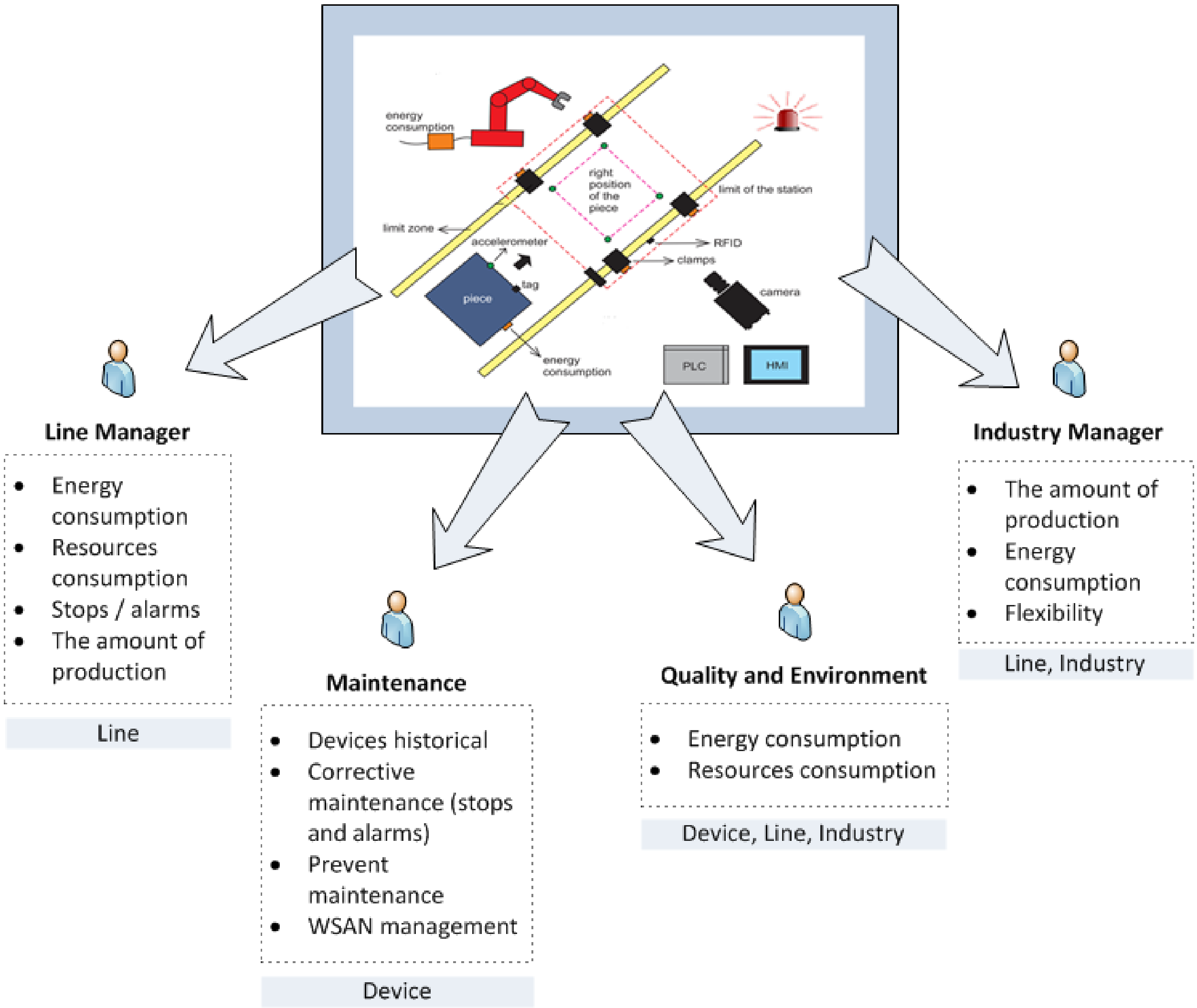


Figure 28: Users final demo view.

9. Conclusion

This deliverable presented the main aspects of Developed Software Application, revisiting the BEMO-COFRA Architecture presented in D3.2 – Refined Architecture Specification, explaining the Control Logic that will define the synchronization among the stages of the system and describing the main inputs and outputs required in the user interface. To build this deliverable, information from D2.4 – Change request and re-engineering report, D5.1.1 – Initial infrastructure for distributed control logic and DoW – Document of Work, was also important.

The application described here will be important to build D7.1 – Report on Application Development to be presented in M26.

10. References

[1] DoW – Document of Work

[2] D2.4 – Change request and re-engineering report

[3] D3.2 – Refined Architecture Specification

[4] D5.1.1 – Initial infrastructure for distributed control logic

Appendix A: Bemocofra Interface Questionnaire

0) What is your profession? And what is your role at COMAU?

Profession: Engineer

Role: Sales Manager for Comau Brazil

1) Can you describe a person who will be using this kind of an interface?

Plant managers, maintenance managers.

The plant managers are not the users of the wifi networking, but the users who takes the profit of it.

They are usually engineers. The most of them are not very familiar with technology. They need to take quick fast decisions, because every second costs a lot of money.

They are tugh people who make decisions very fast.

The system has to provide good performance and be stable.

The output of the project has to be a reliable solution.

Software interfaces the plant managers currently use: management software, usually it is a »Plant solution«, which is production management software. It is usually very simple; it provides statistics for production performance (in particular line comparison).

The interface has a number of tiers.

The high-level interface tier is focused only on plant management.

Next tier is an interface for a maintenance manager (who keeps equipment running).

2) What kind of tasks this professional would need to perform?

Observes plant parameters (important parameters should be better visible)

Depending on parameters, the manager takes decisions.

(In Bemo-Cofra) Parameters have to be controlled: A manager can be made happy with parameters or not.

E.g. a robot making two welding points here and five there. Because of the line cycle this robot cannot usually do ten welding points, so they should be made somewhere else. However, sometimes it could happen that the robot gets enough time to do this missing three welding points. Current (»pace and pull?«) systems are not able to manage to control the programs of the robots.

Sensors would say whether a robot can do the missing welding spots or not. => Flexibility.

These flexible changes can be presented in the interface in form of a report. Graphs, statistics.

If the performance is bad, the parameter is shown red.

The plant manager looks at the dashboard, gets reports and makes decisions.

S/he could see how overloaded the employees are, or change the number 8 to »on hold« position.

The user could select what kind of information should be included in the report.

E.g. Report for water consumption, for the station, for the person, etc.

Observe the status of cells, or getting an automatic email.

2.1) What data should be always visible to the user?

Nr. of parts(i.e. cars) per hour,

cycle time, error messages / or new reports available, the quality Key Performance Indicator (KPI), environmental indicators (water throughput, energy consumption, water temperature, robot part temperature)

2.2) Would it be important for the user to see the values for the line, a station, a robot and sensors at once? (E.g. for comparison)

Not at all levels. Can be done, but it is not necessary.

2.3) Would it be important to compare different stations to each other?

No, the stations cannot be compared to each other.

3) Feedback to the interface prototypes

3.1) v0

This looks like a dash board. It's not quite that, what is needed: the v1 is better suitable.

3.2) v1

No need for current car data, e.g. VIN. It would change every minute. Instead: »Production mix« (i.e. car platform) = Astra 4300 In average there are about 60 cars per hour going out. The task is to know how good it is going in this particular hour. Expected number of cars in the current shift. Comparison of the shifts. Shift / Day / Week (Year is not important) Averages should be calculated on a weekly basis. Buttons should look more like clickable objects. (Related to the Error notification buttons below the current total values.) E.g. arrows like for the station drop down buttons should be sufficient. The mental modal is mapped very well by this design.

4) What kind of historical data graphs are relevant for the user?

For the user not graph representation should be used, but a kind of a dash board. The historical graphs are related to the past, which is not important any more for the plant manager. S/he is responsible for the »now«. Graphs should be replaced by the dash boards. However, for the better visualization of the project's aims historical graph of energy consumption could be useful. for different shifts Update of the values once per cycle time. Dashboard is kind of a traffic light: very simple information. The information is related to the entire line: Line name, Station cycle time, #Units/Hour, Power consumption, Error indicators Background info: In the plant buffers are to balance the unequal working times of the different stations.

5) What other data would you advise to visualize in such interface?

Visualisation on the flore plan (»Layout«) => send the notifications (only the color codes) to the Layout.

6) What statistics are important to present?

Comparison for the shifts.

7) Would some kind of forecasting be helpful?

Forecasting is always good. But for the sakes of staying focused and keeping things easier, we shouldn't adress it in the project.

7.1) If yes, what kind?

8) Other notes

Appendix B: Demonstration Tree Questions

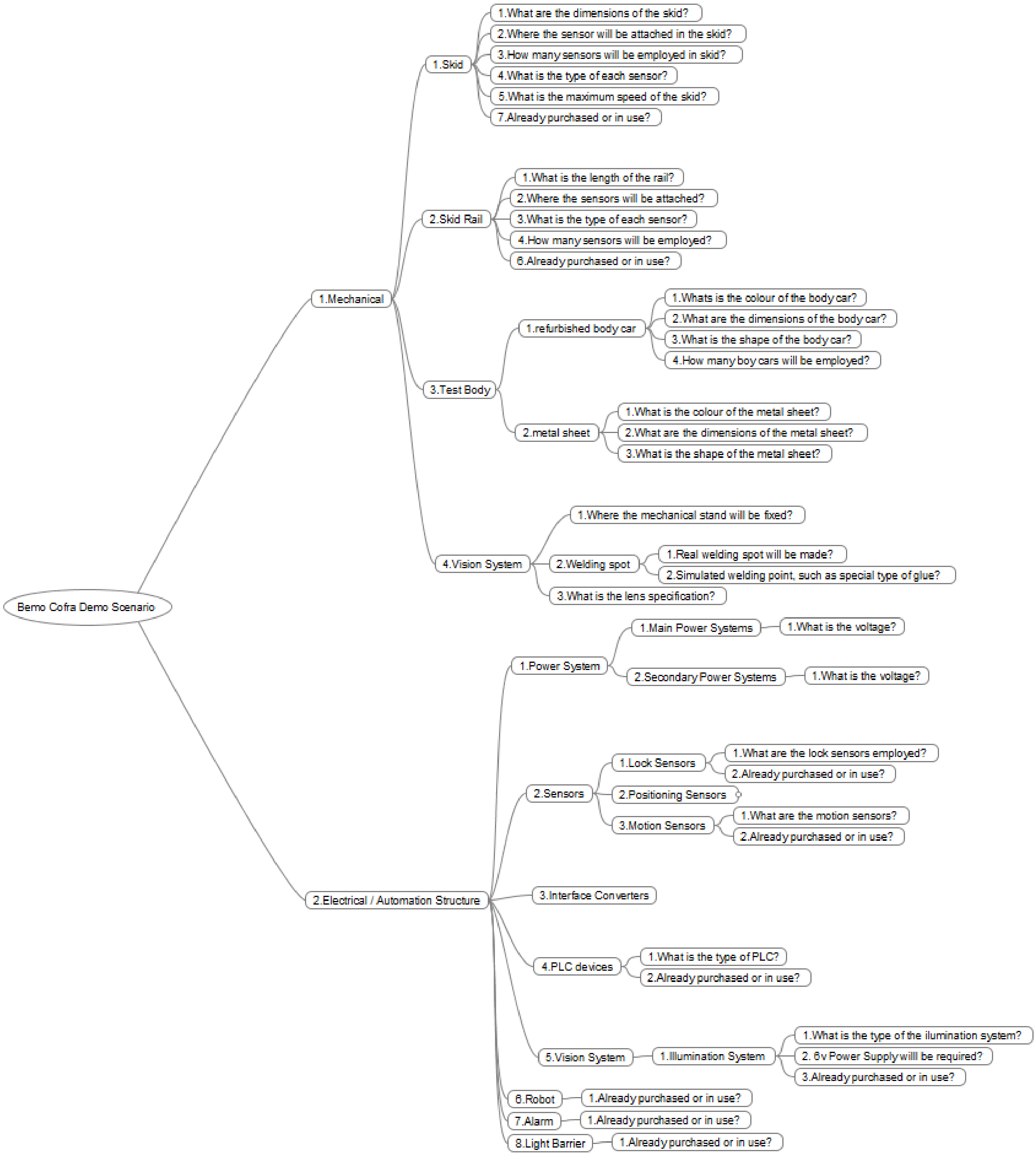


Figure 29: Demo Tree Question for Mechanical and Electrical components.

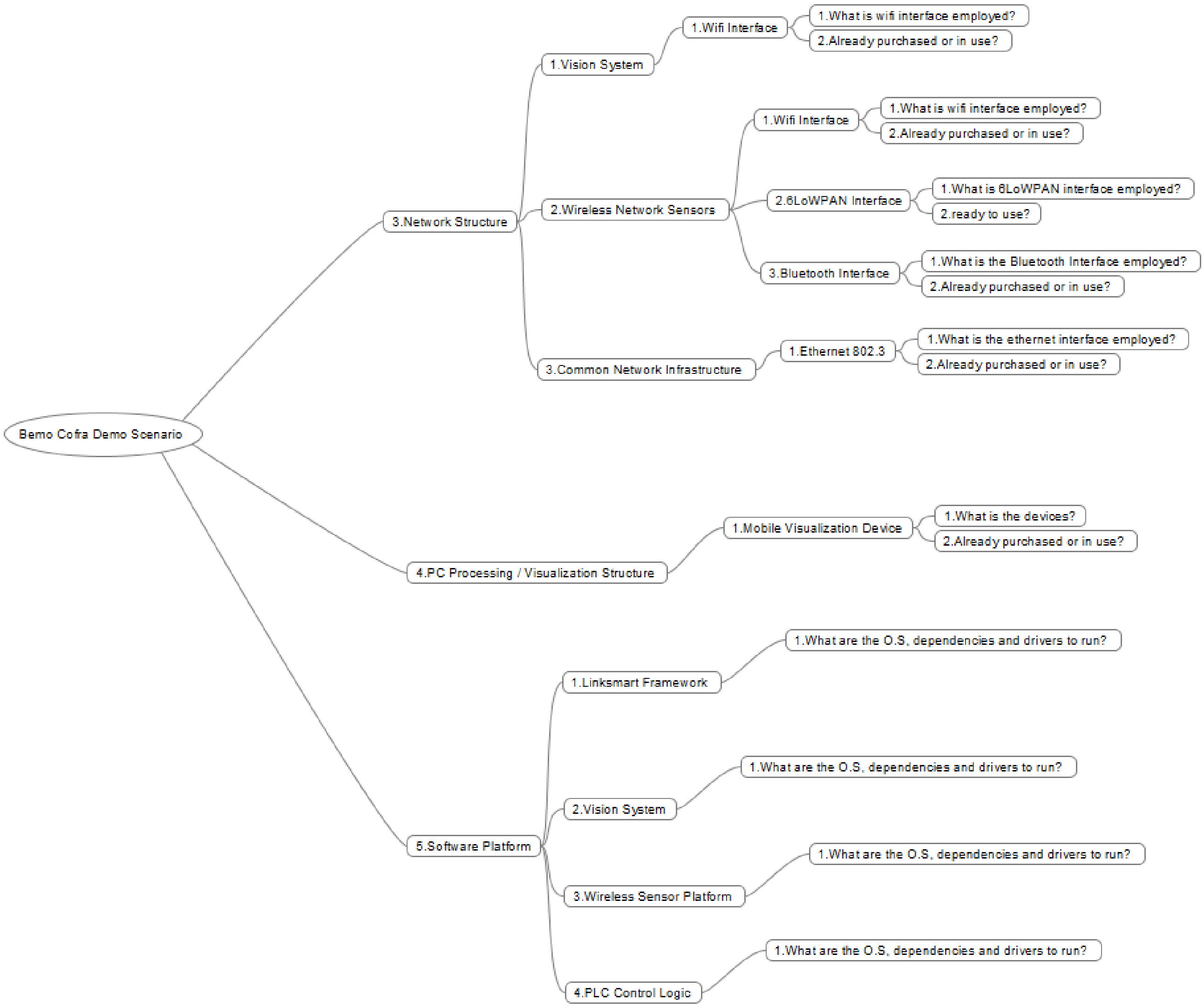


Figure 30: Demo Tree Question for Network Structure PC Processing/Visualization and Software components.