D6.7 – i4Q Solutions Demonstrator

WP6 – EVALUATE: Piloting and Demonstrating

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	• D4.5 i4Q AI Models Distribution to the Edge • D4.6 i4Q Edge Workloads Placement and Deployment • D4.7 i4Q Infrastructure Monitoring • D4.8 i4Q Digital Twin • D5.1 i4Q Data-Driven Continuous Process Qualification • D5.2 i4Q Rapid Quality Diagnosis • D5.3 i4Q Prescriptive Analysis Tools • D5.4 i4Q Manufacturing Line Reconfiguration Guidelines • D5.5 i4Q Manufacturing Line Reconfiguration Toolkit • D5.6 i4Q Manufacturing Line Data Certification Procedure **D6.7** provide inputs for **D6.9** Continuous Integration and Validation. This document has other further iteration at M36 with **D6.10** i4Q Solutions Demonstrator v2.
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ABSTRACT	This deliverable D6.7 describes from a technical point of view the experimental facilities for the implementation and use of i4Q Solutions and Pilots, consisting of a flexible smart factory system that simulates a mobile phone manufacturing process and consists of connected application modules as well as all other hardware and software systems as an integral part of the system. On the basis of these experimental installations, the i4Q Solution Providers evaluate the implementation of the solutions by improving the software. This will serve as a starting point to iteratively adapt and improve the i4Q Solutions in the i4Q Pilots in successive versions for the remainder of i4Q project.

Document History

VERSION	ISSUE DATE	STAGE	DESCRIPTION	CONTRIBUTOR
0.1	14-Oct-2022	ToC	First Draft	EXOS, UPV
0.2	17-Nov-2022	ToC	ToC Restructuring	EXOS, UPV, ITI
0.3	18-Nov-2022	Draft	Examples of the implementation in section 3 - Generic Implementation of i4Q Solutions for GENERIC Pilot Complete sections assigned in the deliverable	EXOS, UPV, ITI, All Solution Providers
0.4	23-Nov-022	Draft	Review previous version and complete sections assigned in the deliverable.	EXOS, UPV, All Solution Providers
0.5	28-Nov-2022	Draft	Full revision of the document available for internal review	EXOS
0.6	02-Dec-2022	Internal review	Internal review	BIBA, UPV
0.7	19-Dec-2022	Draft	2nd Full revision of the document addressing reviewers' comments	EXOS, UPV
1.0	30-Dec-2022	Final Document	Final quality check and issue of final document	CERTH

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS/ACRONYMS

AD	Analytics Dashboars
AI	Artificial Intelligence
API	Application Programming Interface
BC	Blockchain
BDA	Big Data Analytics
CCP	Cloud Computing Patterns
CLI	Command Line Interface
CP-AM-CAM	Camera inspection
CP-AM-iDRILL	iDrilling
CP-AM-MAGBACK-BLACK	Magazine
CP-AM-MPRESS	Muscle press
CP-AM-OUT	Output
CP-F-ASRS32-P	CP Factory High-bay storage for pallets
CP-F-FBRANCH	CP Factory Branch
CP-L-BRANCH	CP Lab Branch
CPU	Central Processing Unit
DB	Database
DIT	Data Integration and Transformation
DQG	Data Quality Guidelines
DR	Data Repository
DT	Digital Twin
EW	Edge Workload
FaaS	Function as a Service
FMS	Flexible Manufacturing System
FMU	Functional Mock up Units
FSD	Functional System Diagram
GPU	Graphics Processing Unit
gRPC	gRPC Remote Procedure Calls
GUI	Graphical User Interface
HDL	High-Definition LiDAR

HSM	Hardware Security Module
HTML	Hypertext Markup Language
IACS	Industrial Automation and Control Systems
ICT	Information and Communications Technology
ID	Identification
IIoT	Industrial Internet of Things
IM	Infrastructure Monitoring
IWSN	Industrial Wireless Sensor Network
LRT	Line Reconfiguration Toolkit
MES	Manufacturing Execution System
MQTT	Message Queuing Telemetry Transport
NA	Not applicable
NPI	New Product Introduction
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OPC	Open Platform Communications
OPE	Overall Production Effectiveness
PA	Prescriptive Analysis
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect
PKI	Public Key Infrastructure
PLC	Programmable Logic Controllers
PQ	Process Qualification
QC	Quality Control
QCM	Quality Control Manager
QD	Quality Diagnostics
QE	QualiExplore
RA	Reference Architecture
RBAC	Role-based access control
REST PI	RESTful API
RFID	Radio Frequency Identification

RIDS	Reliable Industrial Data Services
Robotino	Robotino
SDN	Software Defined Networks
SQL	Structured Query Language
SSL	Secure Sockets Layer
TCP	Fieldbus communication
TN	Trusted Networks
TPM	Trusted Platform Module
TSN	Time Sensitive Networks
UA	Unified Architecture
UI	User Interface
UR5	Universal Robots
VPN	Virtual Private Network
WP	Work package
WSN	Wireless Sensors Technologies

Executive summary

The main objective of deliverable D6.7 is to describe technically the facilities, a flexible smart factory system, proposed by UPV to provide i4Q Solution Providers and Pilots with an experimentation environment to facilitate the iterative improvement of i4Q Solutions.

The system represents a mobile phone manufacturing process and is composed of connected application modules (e.g.: including artificial vision, drilling, heating, collaborative robots, automatic warehouse). Each module is equipped with Programmable Logic Controllers (PLC) with TCP (Fieldbus communication) and OPC UA connectivity. The modules are integrated with a Manufacturing Execution System (MES) to control operations and interconnected with a conveyor belt close loop that transports carriers and pallets with products.

The availability and use of the industrial experimentation facilities of the UPV is of great importance as it will allow the demonstration of the i4Q Solutions in a system beyond the environments defined for the Pilot, although this may be more restrictive. It is important to be aware that these facilities are focused on teaching and training environments and have the complexity of being able to interact or obtain improvements similar to those of the industrial environment.

Document structure

Section 1: Introduction: Provides an introduction to deliverable D6.7 i4Q Solutions Demonstrator.

Section 2: Experimentation Facility Infrastructure Description: It describes all technical details, characteristics of the Industrial Module Stations that are part of the experimental facilities for i4Q Solutions, as well as other auxiliary hardware and software systems necessary for their operation and experimentation.

Section 3: Generic Implementation of i4Q Solutions: In this section, i4Q Solution Providers identify those Module Stations where their Solutions can be tested and give a brief description of their rationale as well as desirable future possibilities.

Section 4: Conclusions: The respective conclusions and remarks are presented in this section.

Appendix: The Appendix includes tables with information on respective data from various sources, as for example magazines, output, factory branch and other.

1. Introduction

In order to contextualize D6.7 deliverable and its contents, it is necessary to refer to a part of the process followed until today to arrive at the consideration of the need of the UPV facilities to experiment the i4Q Solutions.

So far, an analysis of the functional aspects and of the technical aspects of the solutions in the other deliverables has been made, for which specific requirements of each of the Solutions have been considered. We have also developed DEMO examples in which, taking into account the pipelines of the Pilots, the i4Q Solutions have been put into practice for some specific cases that have allowed us to see a real operation in the Pilots.

Taking into consideration all of the above, we will now use an experimentation facility for i4Q Solutions beyond the more restricted and defined environments of the Pilots, defining their physical environment in which all i4Q Solutions can be tested and experimented, offering a system that simulates the mobile phone manufacturing process. **Figure 1** shows a schematic representation of i4Q Solutions' implementation over Module Stations.

This describes the environment of the connected Module Stations including among other technical features, machine vision, drilling, heating, collaborative robots, automatic storage, which are described in the next sections of this document, following the order:

- Experimentation Facility Infrastructure Description
- Individual Module Stations – Physical (sensing)
- Network (communication)
- Middleware (computing infrastructure)
- Data from stations (storage)
- Application (analysis and optimisation)

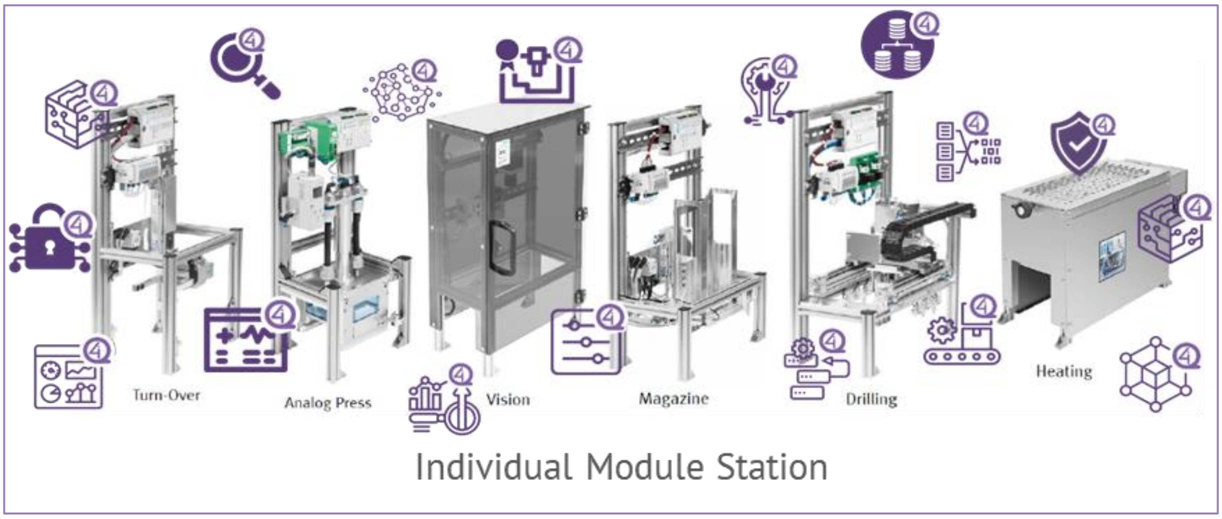


Figure 1. i4Q Solutions Implementation - Schematic representation

2. Experimentation Facility Infrastructure Description

In this section, a brief explanation will be given about the different modules that make up the FESTO line for the generic case of the i4Q project. The facility will be a physical environment in which all the i4Q Solutions can be tested and experimented. The experimentation facility will be provided by UPV is a flexible smart factory system for teaching and research purposes (**Figure 2**).

Figure 2. Smart Factory System

The system simulates a mobile phone manufacturing process and consists of a cell assembled. On one hand, a cell is responsible for assembling the different parts of the phone (front and back cover **Figure 3**). On the other hand, it has a cell palletized where the system can load and unload to pallet (**Figure 4**).

***Figure 3**. Pieces of the phone*

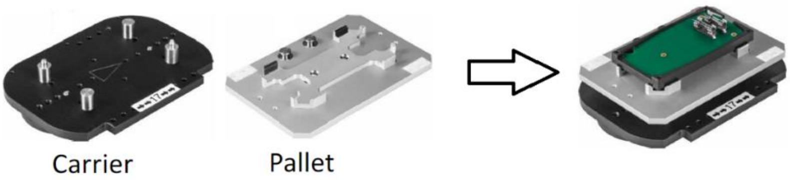


Figure 4. Cell assembled

This system is compounded by individual stations. Every station consists of a conveyor and an application module. Their modules are independent and can be easily switched. The following **Figure 5** shows the entire path a product would take from the time it leaves the warehouse until it is ready.

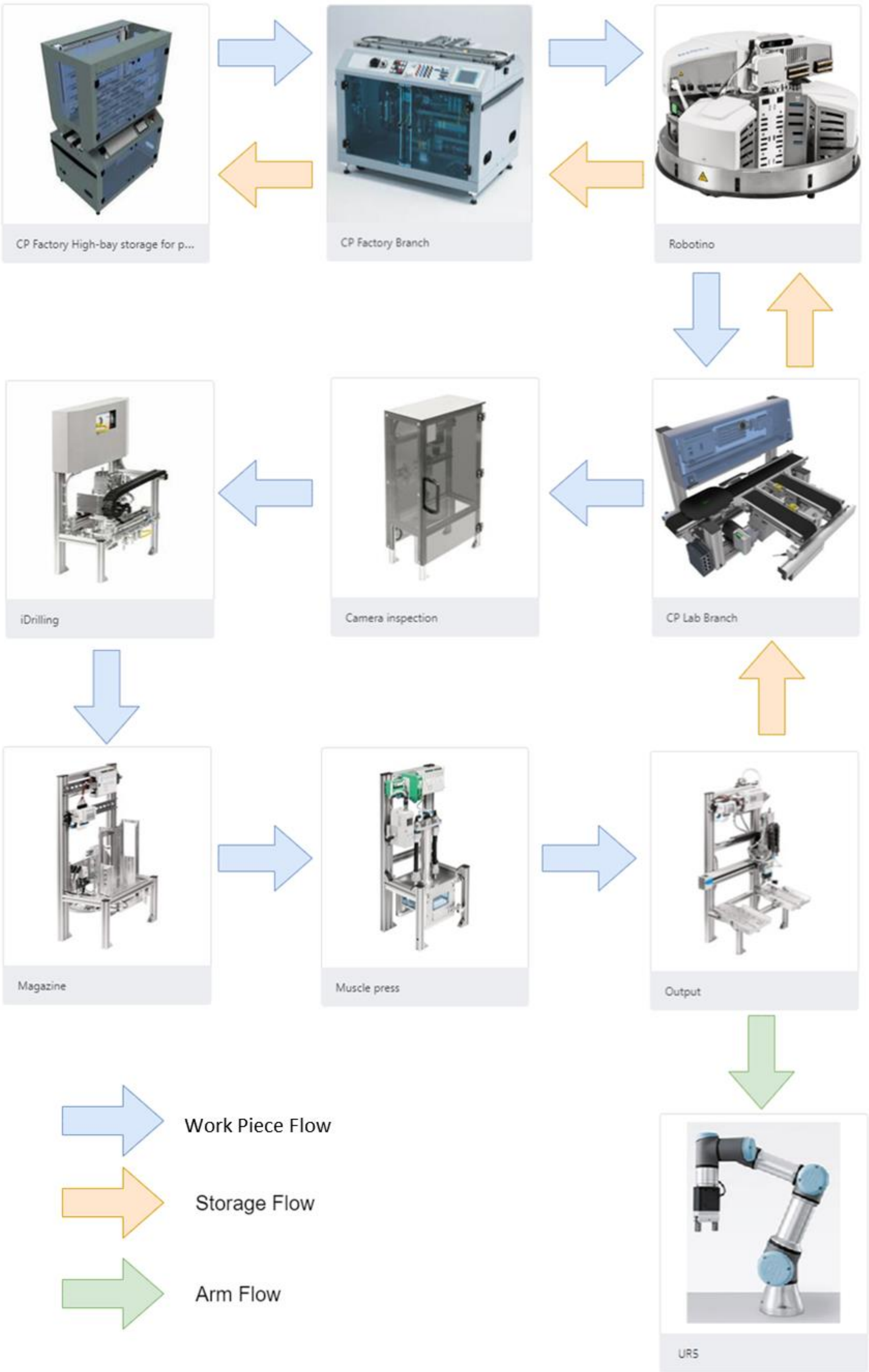


Figure 5. Modules stations

Each module station is equipped with Programmable Logic Controllers (PLC) with TCP (Fieldbus communication) and UA connectivity.

The modules are integrated with a Manufacturing Execution System (MES) to control operation and interconnected with a conveyor belt close loop that transports carriers and pallets with products.

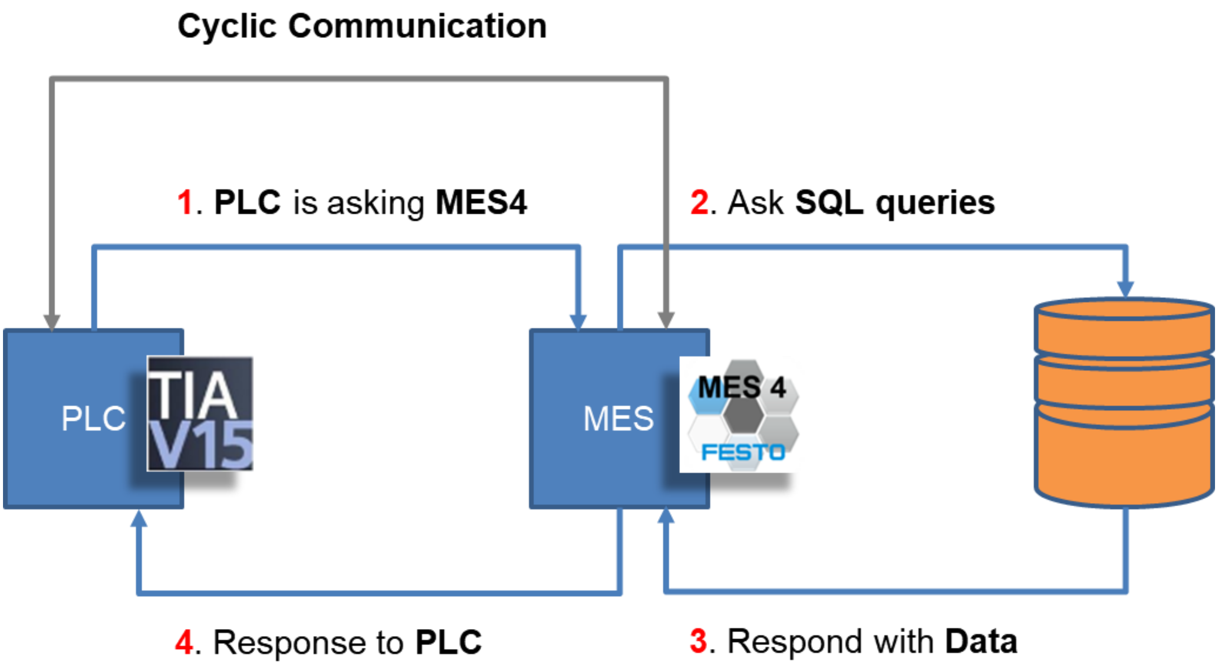


Figure 6. Modules Stations Systems

The components of the system are the following:

- PLC – TIA V15.
- MES4 FESTO: Components and communication with PLCs.
- Communications PLC-MES.
- Communication done over TCP/IP (Fieldbus communication).
- Optional OPC UA.
- Query port – 0.5Hz, sending 4 bytes of information with a state of PLC.
- Message port - ~1024 bytes where information is being exchanged with MES.

2.1 Individual Module Stations – Physical (sensing)

In this section, we will start by specifying the different workstations, we will continue with the implementation of the communication between the MES and the PLCs, and it will be continued with the determination of the production control module.

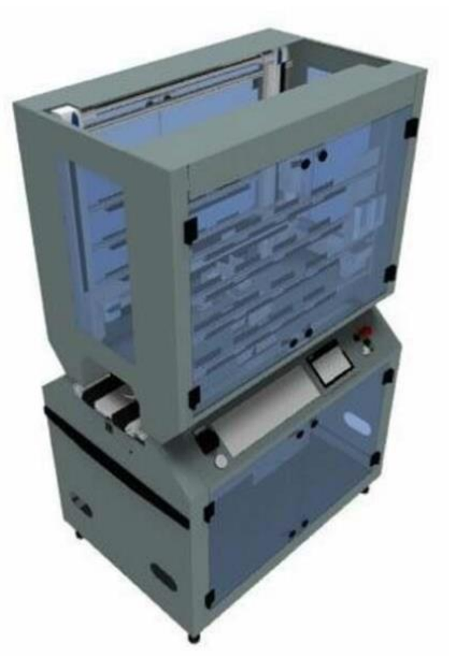
CP-F-ASRS32-P - CP Factory High-bay storage for pallets	
Station	Description
	The Automated Storage and Retrieval System (ASRS) is equipped with a Cartesian robot for the automatic storage and retrieval of pallets. Up to 32 pallets can be stored and retrieved. Two parallel conveyors move in opposite directions, each has a working position where pallets can be retrieved or placed on the conveyors [1]. Therefore, this station, as described above, allows us to keep up to 32 products in storage, whether they are finished or unfinished. This allows us to have great flexibility about and control of the products, as it allows us to know what stock we have of each product. Base module structure made of steel and aluminium profile. The station consists of the following components: - Integrated electronic cabinet: • PLC. • Emergency stop relay. - Two pneumatic stop units, with inductive sensors and RFID read/write head. - Control panel: • Several buttons, including emergency stop. • Touch screen. - Storage robot: • Two linear axis servos. • Pneumatic linear axis.

Table 1. Module Station – CP-F-ASRS32-P [1].

CP-F-FBRANCH - CP Factory Branch	
Station	Description
	This base module can automatically bypass the material flow in a CP factory system. It also provides a single workstation for the application modules. It therefore allows parts to be transported via the conveyor belts. In this case, either to introduce a new product onto the pallet leaving the previous station or to reintroduce a product into the warehouse. It also controls the flow of products, depending on the situation [2]. The Branch base module comes with a PLC and all the interfaces to work with any application module and MES4. The module consists of these components: • Base module frame. • Integrated electronics cabinet. Emergency stop relay. • 4x transport belt. • 2x pneumatic plugs, with inductive sensors and RFID read-write head. • Control panel with push buttons, touch screen and emergency stop button.

Table 2. Module Station – CP-F-FBRANCH [2].

Robotino	
Station	Description
	Robotino is a mobile robotic platform for research and education. This robot allows us to transport different parts between different points for the continuous flow of products. In the case of this project, it transports the pieces, waiting from the Branch station and taking the part to the next LBRANCH station and viceversa [3]. Equipped with an omni-directional drive and with its sensors, interfaces and modular Robotino can be used in a flexible way. The programming of individual applications is possible with various programming environments. The programs used for its control are as follows: • Robotino Factory. • Fleet Manager.

Table 3. Module Station – Robotino [3]

CP-L-BRANCH - CP Lab Branch	
Station	Description
	This station is designed to make the material flow in a CP Lab system flexible. It contains a straight belt, such as CP-L-CONV, with a junction point where it connects to a double belt. As in the previous case, it controls and conveys the different parts depending on the function to be performed. This interface between single and dual conveyor systems enables the transfer of media between CP Lab and CP Factory, CP Factory and CP Lab and Robotino or two CP Lab systems [4]. The station consists of the following components: • Base module structure made of steel and aluminium profile. • Three conveyor belts: 24 VDC motor. • Bi-directional, slow-speed DC motor controller. • Incremental position measurement by means of an optical sensor. • Capacitive sensors at both ends of the belt for conveyor detection. • PLC: Siemens S7-1500 CPU 1512SP. • 12 inputs / 8 outputs, 24 V digital. • I/O-Link master. Web interface for manual interaction. • Communication sensors to adjacent stations. • Pneumatic control bar. • Conveyor stop at branch position. • Pneumatic stop with end position sensors. • Four inductive sensors for conveyor detection (and possibly identification). • RFID read/write head for operator identification, using IO-Link. • IO-Link.

Table 4. Module Station – CP-L-BRANCH [4]

<table>
<tr><th colspan="2">CP-AM-CAM - Camera inspection</th></tr>
<tr><th>Station</th><th>Description</th></tr>
<tr><td></td><td>The camera is used as an intelligent, universal sensor with integrated controller for quality assurance through optical inspection [5].
The module consists of the following components:
• Modular frame made of aluminium profiles.
• Smart camera with integrated controller.
• Signal interface.
• Software package.</td></tr>
</table>

Table 5. Module Station – CP-AM-CAM [5]

<table>
<tr><th colspan="2">CP-AM-iDRILL - iDrilling</th></tr>
<tr><th>Station</th><th>Description</th></tr>
<tr><td></td><td>The Drilling CPS application module drills through 4 holes in the lower part of the housing. The workpieces are recognised by the first light barrier when they are moved to the application module and the conveyor stops. When the conveyor has stopped, the workpiece is checked [6].
The workpiece application checks if there is a front cover on the conveyor. The workpiece request in the middle checks if there is a back cover on the bottom. The request on the left checks if the front cover is in its correct position on the support.
When the front cover is in its correct position and there is no back cover, depending on the specifications of the work order, the first two drill holes are drilled on the left side of the work order. Drilled on the left side of the front cover. Then, the X-axis is moved to the correct position and the first two drill holes are drilled on the left side of the front cover. Position and the two drill holes on the right are drilled. After that, the conveyor leaves the iDrilling application module.
The module consists of these components:
• Modular frame made of aluminium profiles.
• Pneumatically controlled linear axis, z-direction and x-direction.
• Valve block.
• Two drilling spindles.
• Integrated web controller.</td></tr>
</table>

Table 6. Module Station – CP-AM-iDRILL [6]

CP-AM-MAGBACK-BLACK - Magazine	
Station	Description
	The Warehouse application module is feeding a conveyor with a front cover and a back cover. The conveyor is recognised by a light barrier and then stops. The sensors are checking the status of the conveyor [7]. There are three possibilities: • There is no workpiece on the conveyor. • There is a front cover on the conveyor. • There is a rear cover on the conveyor. Depending on the circumstances and the task, a workpiece is isolated from the loader to the conveyor. Subsequently, the conveyor is released. The module consists of these components: • Modular frame made of aluminium profiles. • Magazine. • Separator. • Valve block. • Signal interface.

Table 7. Module Station – CP-AM-MAGBACK-BLACK [7].

CP-AM-MPRESS - Muscle press	
Station	Description
	The Muscle press application module is designed for the pressing of cubic workpieces. The pressing process is carried out by means of a proportional pressure control. The force generated is precisely measured by a load cell [8]. The module consists of the following components: • Modular frame made of aluminium profiles. • Pneumatic muscle press. • Proportional pressure regulator. • Analogue force gauge. • Signal interface.

Table 8. Module Station – CP-AM-MPRESS [8]

<table>
<tr><th colspan="2">CP-AM-OUT - Output</th></tr>
<tr><th>Station</th><th>Description</th></tr>
<tr><td></td><td>The workpiece output application module is equipped with a two-axis handling system and is used to produce cubic workpieces on two roller guides. The workpiece output of the application module can be used as a manual work place to retrieve workpieces [9].
The module consists of these components:
Modular frame made of aluminium profiles.
Handling module.
Pneumatic parallel gripper.
Two sliding rollers.
Valve block.
Signal interface.</td></tr>
</table>

Table 9. Module Station – CP-AM-OUT [9].

UR5 - Universal Robots	
Station	Description
	The robot arm, together with the previous station, forms a possible end product. If the product is not returned to the warehouse, it is stored in different boxes. The organisation of the products is part of the programming of this robot arm [10]. The versatility of the factory design is one of the main features of Industry 4.0. CP Lab modules can be combined and expanded in a variety of ways. The front unit of a robotic arm is crucial for automating part gripping. Whether you opt for compression grippers, circumferential gripping or vacuum suction – for all applications, a modular robot gripper assembly is available for every application, specially adapted for robot arms from Universal Robots. Compression grippers, circumferential grippers or vacuum suction grippers are available for all applications. Vacuum suction: there is a modular set of robot grippers for every application, specially adapted for Universal Robots robot arms.

Table 10. Module Station – UR5 [10]

2.2 Network (communication)

In this section we are going to see the methods we must communicate use with the communication elements of the Festo pilot plant. For this, we have two possibilities, remotely or locally. To facilitate the use by the different members of the project, it will be prepared to be used remotely. This will be accessed via VPN (Virtual Private Network). The Universitat Politècnica de València (UPV) already has a VPN; therefore, it would only be necessary to have a user and follow the steps indicated in its web page. VPN stands for Virtual Private Network.

This technology allows us to create a local network and allows us to connect to different elements of different networks, allowing us to send and receive data without the need for them to be physically connected, since the connection is made through the Internet connection. This can be used by many devices as it works in all applications since it uses all Internet traffic.

Along with this, this extension of the technology offers better security. This is because it uses a point-to-point connection of the packets that are transmitted between them, using dedicated connections, encrypted connections, or a combination of them.

Once connection is established on the same local network required, it is necessary to communicate with each PLC of each station in the plant. Communication is based on TCP/IP so the response is sent to correct module. Packets routing is processed on this layer and there in no control in MES protocol. The generic plant is interconnected with its own network. Therefore, to connect to the different modules externally, port forwarding will be used.

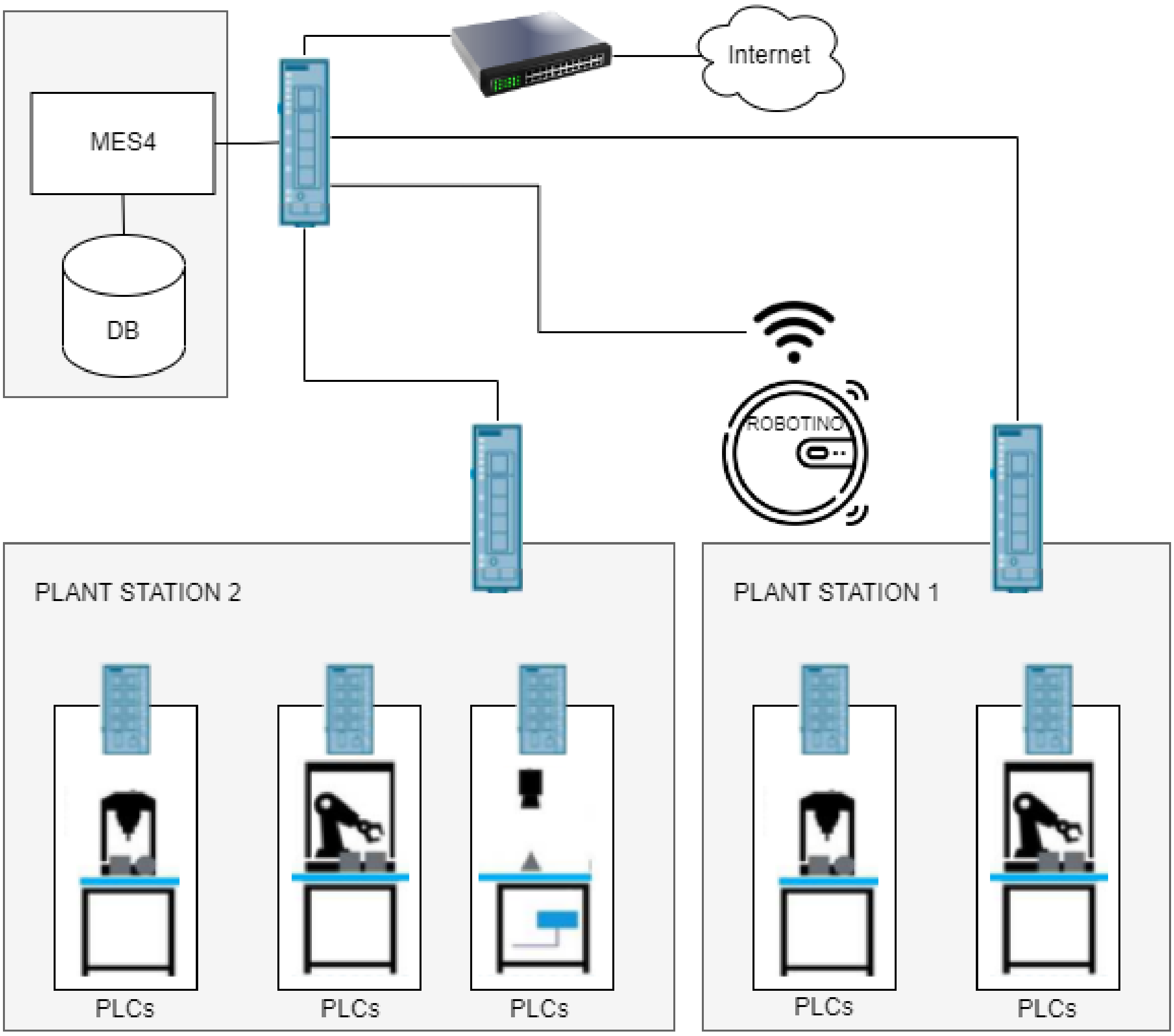


Figure 7. Connection Systems

Port forwarding is a feature that allows access to a certain device from another device, i.e., traffic is redirected through the incoming router to specific IP addresses and ports. On this occasion, in the laboratory, the laboratory switch is used as the gateway, and it is there where the different connections will be redirected. To do this, it is necessary to know the private IP address, or gateway, of the switch and by accessing that address, using a web browser, this technique can be enabled. The list of the different connections made by port forwarding can be seen in the following table:

Communication				
Name	External Port	Internal Port	Internal Server IP	External server IP
CP-F-ASRS32-P	5011	4840	172.21.1.1	158.42.126.44
FBRANCH	5081	4840	172.21.8.1	158.42.126.44
CP LBRANCH	5021	4840	172.21.2.1	158.42.126.44
CP-AM-CAM	5031	4840	172.21.3.1	158.42.126.44
CP-AM-iDRILL	5041	4840	172.21.4.1	158.42.126.44
CP-AM-MAGBACK-BLACK	5051	4840	172.21.5.1	158.42.126.44
CP-AM-MPRESS	5061	4840	172.21.6.1	158.42.126.44
CP-AM-OUT	5071	4840	172.21.7.1	158.42.126.44

Table 11. Communication

Each station has its PLC where the corresponding program is executed. All variables that are used by each PLC are stored in an OPC UA server. OPC UA is a vendor-independent communication protocol that enables the exchange of information and data on devices within machines, between machines and from machines to systems. It is based on the client-server principle (**Figure 8**).

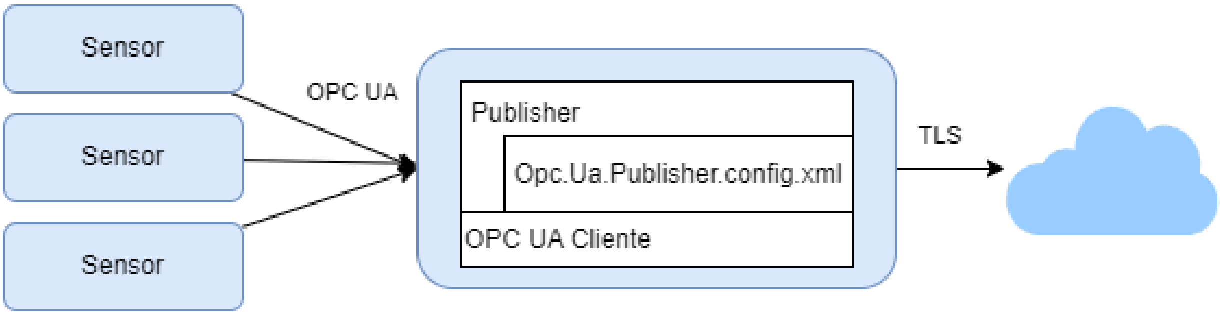


Figure 8. Sensors Systems

To test the connection, we can use a UaExpert client. The UaExpert is designed as a general-purpose test client supporting OPC UA features like DataAccess, Alarms & Conditions, Historical Access and calling of UA Methods. After connecting via UA Expert to the different modules, we can obtain information from different sensors in the FESTO line. This information is divided into inputs and outputs (**Table 12** and **Table 13**).

#	Server	Node Id	Display Name	Value	Datatype	Source Timestamp	Server Timestamp	Statuscode
1	iDRILL	NS0|Numeric|2259	State	0 (Running)	Int32	13:24:11.742	13:24:11.742	Good
2	iDRILL	NS3|String|"QB0"	QB0	0	Byte	13:32:57.444	13:32:57.444	Good
3	iDRILL	NS3|String|"Rfid1_OUT"	Rfid1_OUT	Double click to ...	ExtensionObject	13:32:57.444	13:32:57.444	Good
4	iDRILL	NS3|String|"byLedOutputs"	byLedOutputs	Double click to ...	ExtensionObject	13:32:57.445	13:32:57.445	Good
5	iDRILL	NS3|String|"wAnalogOut0"	wAnalogOut0	0	UInt16	13:32:57.445	13:32:57.445	Good
6	iDRILL	NS3|String|"wAnalogOutOpPan...	wAnalogOutOp...	0	UInt16	13:32:57.445	13:32:57.445	Good
7	iDRILL	NS3|String|"xGF1"	xGF1	false	Boolean	13:32:57.445	13:32:57.445	Good
8	iDRILL	NS3|String|"xGF2"	xGF2	false	Boolean	13:32:57.445	13:32:57.445	Good
9	iDRILL	NS3|String|"xMB1"	xMB1	false	Boolean	13:32:57.445	13:32:57.445	Good
10	iDRILL	NS3|String|"xMB2"	xMB2	false	Boolean	13:32:57.445	13:32:57.445	Good
11	iDRILL	NS3|String|"xMB3"	xMB3	false	Boolean	13:32:57.446	13:32:57.446	Good
12	iDRILL	NS3|String|"xPF1"	xPF1	true	Boolean	13:32:57.446	13:32:57.446	Good
13	iDRILL	NS3|String|"xPF2"	xPF2	false	Boolean	13:32:57.446	13:32:57.446	Good
14	iDRILL	NS3|String|"xPF3"	xPF3	true	Boolean	13:32:57.446	13:32:57.446	Good
15	iDRILL	NS3|String|"xPF4"	xPF4	false	Boolean	13:32:57.446	13:32:57.446	Good
16	iDRILL	NS3|String|"xPH2_A"	xPH2_A	false	Boolean	13:32:57.446	13:32:57.446	Good
17	iDRILL	NS3|String|"xPH2_B"	xPH2_B	false	Boolean	13:32:57.447	13:32:57.447	Good
18	iDRILL	NS3|String|"xPH2_C"	xPH2_C	false	Boolean	13:32:57.447	13:32:57.447	Good
19	iDRILL	NS3|String|"xPH2_D"	xPH2_D	false	Boolean	13:32:57.447	13:32:57.447	Good
20	iDRILL	NS3|String|"xQA1_A1"	xQA1_A1	false	Boolean	13:32:57.447	13:32:57.447	Good
21	iDRILL	NS3|String|"xQA1_A2"	xQA1_A2	false	Boolean	13:32:57.447	13:32:57.447	Good
22	iDRILL	NS3|String|"xQA1_A3"	xQA1_A3	false	Boolean	13:32:57.448	13:32:57.448	Good

Table 12. OPCUA Input

#	Server	Node Id	Display Name	Value	Datatype	Source Timestamp	Server Timestamp	Statuscode
1	iDRILL	NS0|Numeric|2259	State	0 (Running)	Int32	13:24:11.742	13:24:11.742	Good
2	iDRILL	NS3|String|"IB0"	IB0	0	Byte	13:30:55.453	13:30:55.453	Good
3	iDRILL	NS3|Numeric|5204	Icon	89504e470d0a1...	ByteString	13:30:55.693	13:30:55.693	Good
4	iDRILL	NS3|String|"Rfid1_IN"	Rfid1_IN	Double click to ...	ExtensionObject	13:30:55.693	13:30:55.693	Good
5	iDRILL	NS3|String|"byAnalogIn0"	byAnalogIn0	114	Byte	13:30:55.694	13:30:55.694	Good
6	iDRILL	NS3|String|"byAnalogIn1"	byAnalogIn1	0	Byte	13:30:55.694	13:30:55.694	Good
7	iDRILL	NS3|String|"wAnalogIn0"	wAnalogIn0	0	UInt16	13:30:55.694	13:30:55.694	Good
8	iDRILL	NS3|String|"wAnalogIn1"	wAnalogIn1	0	UInt16	13:30:55.694	13:30:55.694	Good
9	iDRILL	NS3|String|"xBG1"	xBG1	false	Boolean	13:30:55.694	13:30:55.694	Good
10	iDRILL	NS3|String|"xBG1_BCD0"	xBG1_BCD0	false	Boolean	13:30:55.695	13:30:55.695	Good
11	iDRILL	NS3|String|"xBG2_BCD1"	xBG2_BCD1	false	Boolean	13:30:55.695	13:30:55.695	Good
12	iDRILL	NS3|String|"xBG3_BCD2"	xBG3_BCD2	false	Boolean	13:30:55.696	13:30:55.696	Good
13	iDRILL	NS3|String|"xBG4_BCD3"	xBG4_BCD3	false	Boolean	13:30:55.696	13:30:55.696	Good
14	iDRILL	NS3|String|"xBG5"	xBG5	false	Boolean	13:30:55.698	13:30:55.698	Good
15	iDRILL	NS3|String|"xBG6"	xBG6	false	Boolean	13:30:55.698	13:30:55.698	Good
16	iDRILL	NS3|String|"xG1_BG7_KG1"	xG1_BG7_KG1	false	Boolean	13:30:55.698	13:30:55.698	Good
17	iDRILL	NS3|String|"xG1_BG8_KG2"	xG1_BG8_KG2	false	Boolean	13:30:55.698	13:30:55.698	Good
18	iDRILL	NS3|String|"xG1_BG9"	xG1_BG9	false	Boolean	13:30:55.698	13:30:55.698	Good
19	iDRILL	NS3|String|"xKF21_IN6"	xKF21_IN6	false	Boolean	13:30:55.699	13:30:55.699	Good
20	iDRILL	NS3|String|"xSF1"	xSF1	false	Boolean	13:30:55.699	13:30:55.699	Good
21	iDRILL	NS3|String|"xSF2"	xSF2	true	Boolean	13:30:55.699	13:30:55.699	Good
22	iDRILL	NS3|String|"xSF3"	xSF3	true	Boolean	13:30:55.699	13:30:55.699	Good
23	iDRILL	NS3|String|"xSF4"	xSF4	false	Boolean	13:30:55.699	13:30:55.699	Good
24	iDRILL	NS3|String|"xSF5"	xSF5	true	Boolean	13:30:55.699	13:30:55.699	Good

Table 13. OPCUA Output

Each of these inputs or outputs has a specific nomenclature that refers to a sensor within the production line. As it can be seen in **Figure 9**, each of these sensors are marked on the production line. In case an empty carrier arrives at the application module, the sensors read an RFID chip and execute the *GetFirstOperationForResource* request command which connects to MES and sends the *ResourceID* parameter of this module. At this point the MES will send valid data of the target order in its response, especially *OrderNumber*, *OrderPosition*, *PartNumber* and *OperationNumber*. In case any carrier arrives with any material, valid data will be read from the RFID chip and the module sends a request command. In the query sent there are only these parameters *ResourceID* of the module *OrderNumber* read from the RFID chip *OrderPosition*. After these interactions, the MES sends valid data describing an operation (*ResourceID*, *OperationNumber* and *PartNumber*). The MES data is compared with the parameters of a transporter and, if they are the same, the operation will be processed. If not, the application module will release the conveyor lock, and the conveyor will be released [12].

Figure 9. Sensors PLCS in the FESTO line

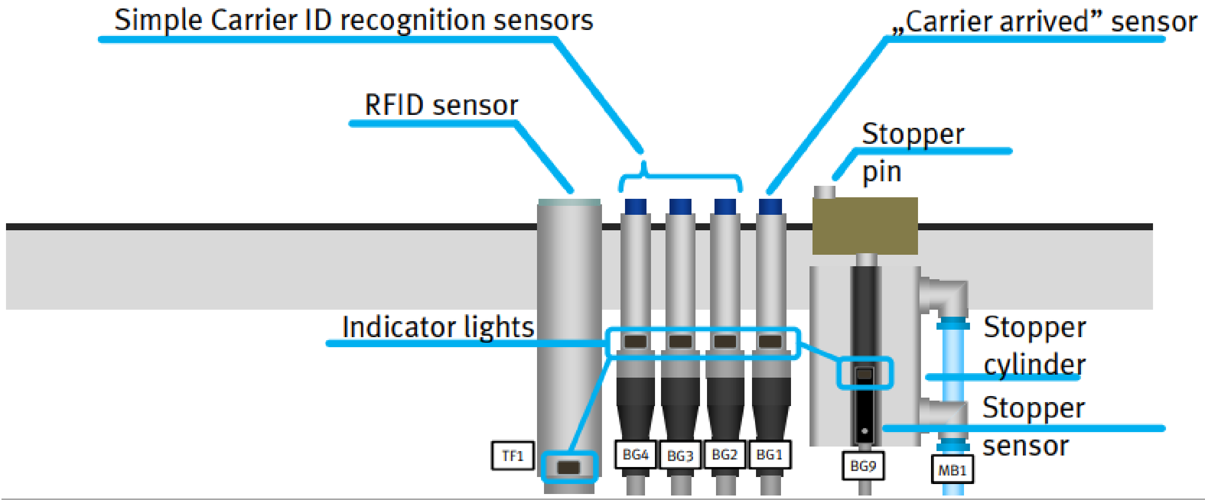
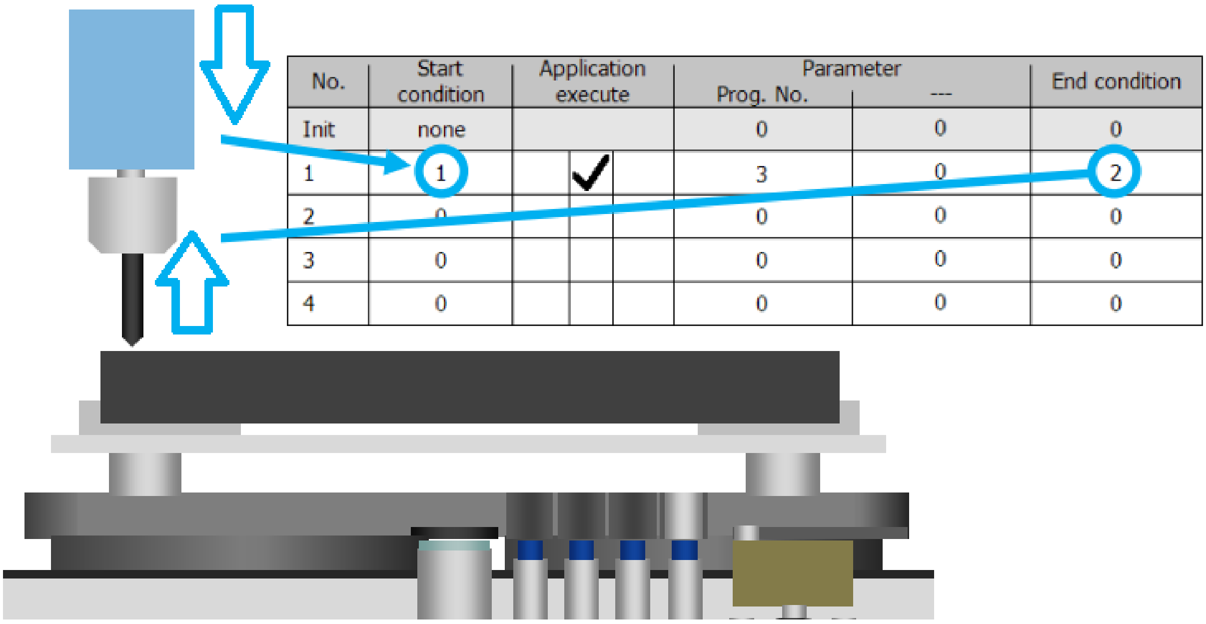


Figure 10. Parts of the stopper

As we can see in the **Figure 10** the first inductive sensor [BG1] will show if the carrier reaches the stopper. Once at this point, the RFID sensor reads the tag information. It checks in the transition table, to know the task to be executed and the performed (in this example, with the Idrill machine, it punches).



No.	Start condition	Application execute	Parameter Prog. No.	---	End condition
Init	none		0	0	0
1	1	✓	3	0	2
2	0		0	0	0
3	0		0	0	0
4	0		0	0	0

Figure 11. Drill Performance

Once finished, it checks the final state of the part and adds that information to the RFID tag. Finally, the Stopper is released and allows the carrier to leave (**Figure 12**).

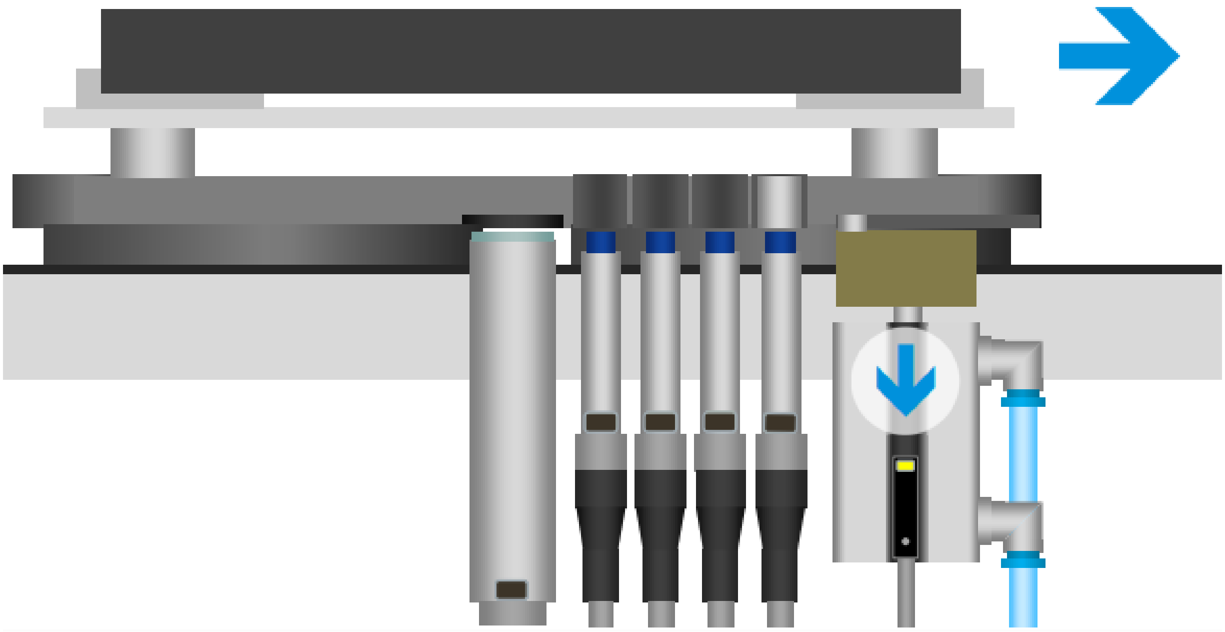
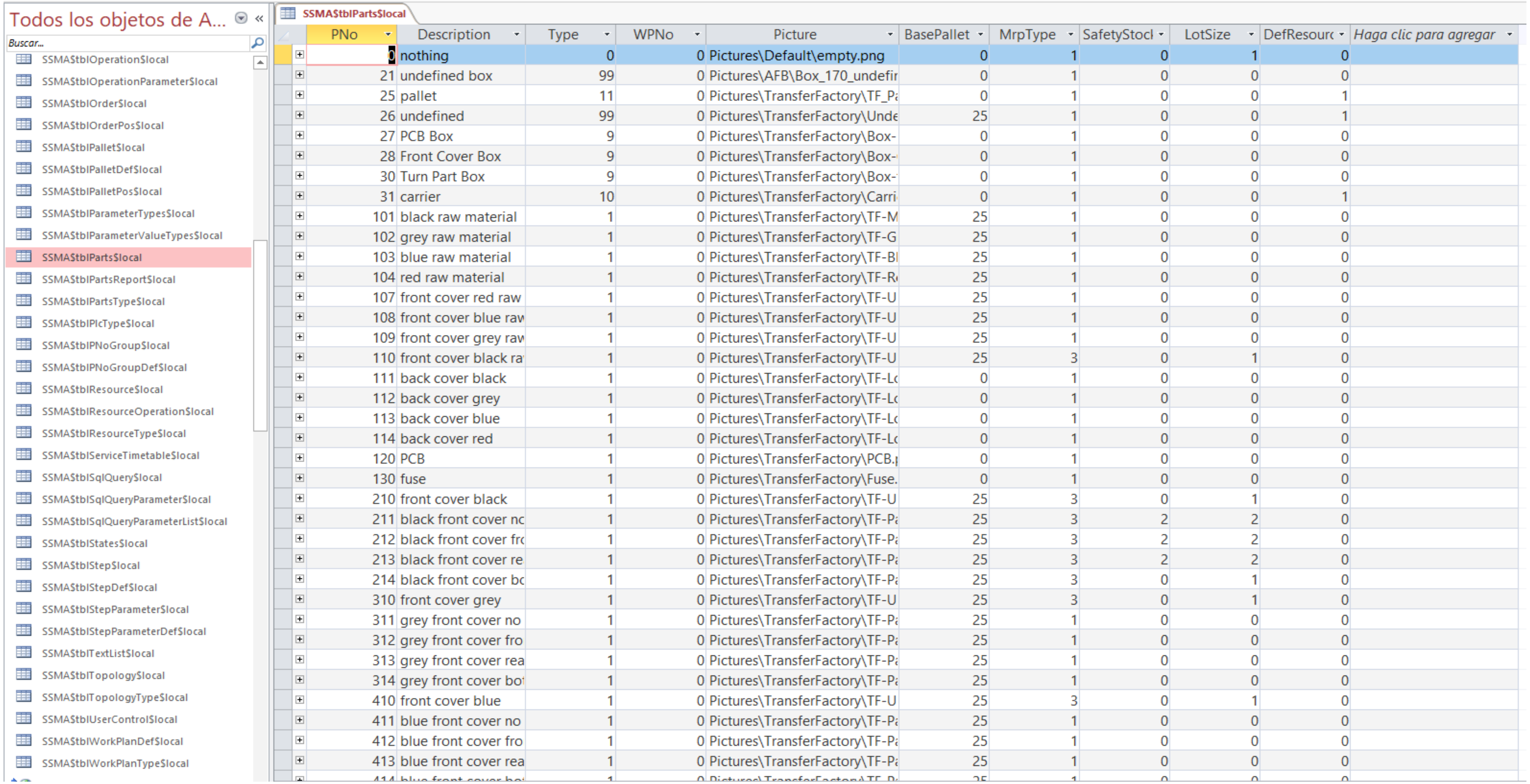


Figure 12. The stopper to let the carrier go

These PLC sensors identify the passage of the carriers with the product (telephone) (**Figure 12**) and send the data via OPCUA to the MES, which stores it in its database. To access all variables used by the Festo MES application it is necessary to communicate with the Access database of the MES application. In order to have the historical data of the variables, it is necessary to have access to a database that allows to store the information obtained periodically with a frequency configured for each variable. On the other hand, it is necessary to configure the access to the Access database where all the information of the Festo MES application is stored in order to be able to manage both the output boxes and the part of the orders and the status of the different stations over time. It must be taken into account that the access to this database is very limited and only allows to integrate data in the project and not to store new data. This is a limitation of the database itself; there are other types of databases that would allow the addition of data. There are other types of databases that would allow the addition of data, but in this case, the database is in Access (**Table 14**).



PNo	Description	Type	WPNo	Picture	BasePallet	MrpType	SafetyStocl	LotSize	DefResourc	Haga clic para agregar
0	nothing	0	0	Pictures\Default\empty.png	0	1	0	1	0	
21	undefined box	99	0	Pictures\AFB\Box_170_undefir	0	1	0	0	0	
25	pallet	11	0	Pictures\TransferFactory\TF_Pa	0	1	0	0	1	
26	undefined	99	0	Pictures\TransferFactory\Unde	25	1	0	0	1	
27	PCB Box	9	0	Pictures\TransferFactory\Box-	0	1	0	0	0	
28	Front Cover Box	9	0	Pictures\TransferFactory\Box-	0	1	0	0	0	
30	Turn Part Box	9	0	Pictures\TransferFactory\Box-	0	1	0	0	0	
31	carrier	10	0	Pictures\TransferFactory\Carri	0	1	0	0	1	
101	black raw material	1	0	Pictures\TransferFactory\TF-M	25	1	0	0	0	
102	grey raw material	1	0	Pictures\TransferFactory\TF-G	25	1	0	0	0	
103	blue raw material	1	0	Pictures\TransferFactory\TF-Bl	25	1	0	0	0	
104	red raw material	1	0	Pictures\TransferFactory\TF-Re	25	1	0	0	0	
107	front cover red raw	1	0	Pictures\TransferFactory\TF-U	25	1	0	0	0	
108	front cover blue raw	1	0	Pictures\TransferFactory\TF-U	25	1	0	0	0	
109	front cover grey raw	1	0	Pictures\TransferFactory\TF-U	25	1	0	0	0	
110	front cover black ra	1	0	Pictures\TransferFactory\TF-U	25	3	0	1	0	
111	back cover black	1	0	Pictures\TransferFactory\TF-Lo	0	1	0	0	0	
112	back cover grey	1	0	Pictures\TransferFactory\TF-Lo	0	1	0	0	0	
113	back cover blue	1	0	Pictures\TransferFactory\TF-Lo	0	1	0	0	0	
114	back cover red	1	0	Pictures\TransferFactory\TF-Lo	0	1	0	0	0	
120	PCB	1	0	Pictures\TransferFactory\PCB.p	0	1	0	0	0	
130	fuse	1	0	Pictures\TransferFactory\Fuse.	0	1	0	0	0	
210	front cover black	1	0	Pictures\TransferFactory\TF-U	25	3	0	1	0	
211	black front cover nc	1	0	Pictures\TransferFactory\TF-Pa	25	3	2	2	0	
212	black front cover frc	1	0	Pictures\TransferFactory\TF-Pa	25	3	2	2	0	
213	black front cover re	1	0	Pictures\TransferFactory\TF-Pa	25	3	2	2	0	
214	black front cover bc	1	0	Pictures\TransferFactory\TF-Pa	25	3	0	1	0	
310	front cover grey	1	0	Pictures\TransferFactory\TF-U	25	3	0	1	0	
311	grey front cover no	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	
312	grey front cover fro	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	
313	grey front cover rea	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	
314	grey front cover bot	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	
410	front cover blue	1	0	Pictures\TransferFactory\TF-U	25	3	0	1	0	
411	blue front cover no	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	
412	blue front cover fro	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	
413	blue front cover rea	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	
414	blue front cover bo	1	0	Pictures\TransferFactory\TF-Pa	25	1	0	0	0	

Table 14. Table “Part” from Access DB

2.3 Data from Stations

Throughout this section we will look in depth at the data we choose from each of the modules shown in **Figure 13**. Each of these modules provides data with a different nomenclature, which can be seen in depth in the **Appendix I** of this deliverable. The data obtained are mostly of a Boolean nature. For the most part, these data provide information about the point at which the carriage is located, as well as its status and the task performed on it. On the other hand, we can also find more module-specific data, such as the pressure in the "Muscle press" module or the status of the operation in the "iDrill" module.

Figure 13. FESTO Modules Stations Middleware (computing infrastructure)

To make the connection with the OPCUA client and dump the data from the different sensors in the Kafka server and PostgreSQL, a server has been prepared from the UPV in Ubuntu 20.04 **(Figure 14)**. This server will be prepared to deploy all i4Q solutions in Docker and install the necessary tools for its proper functioning.

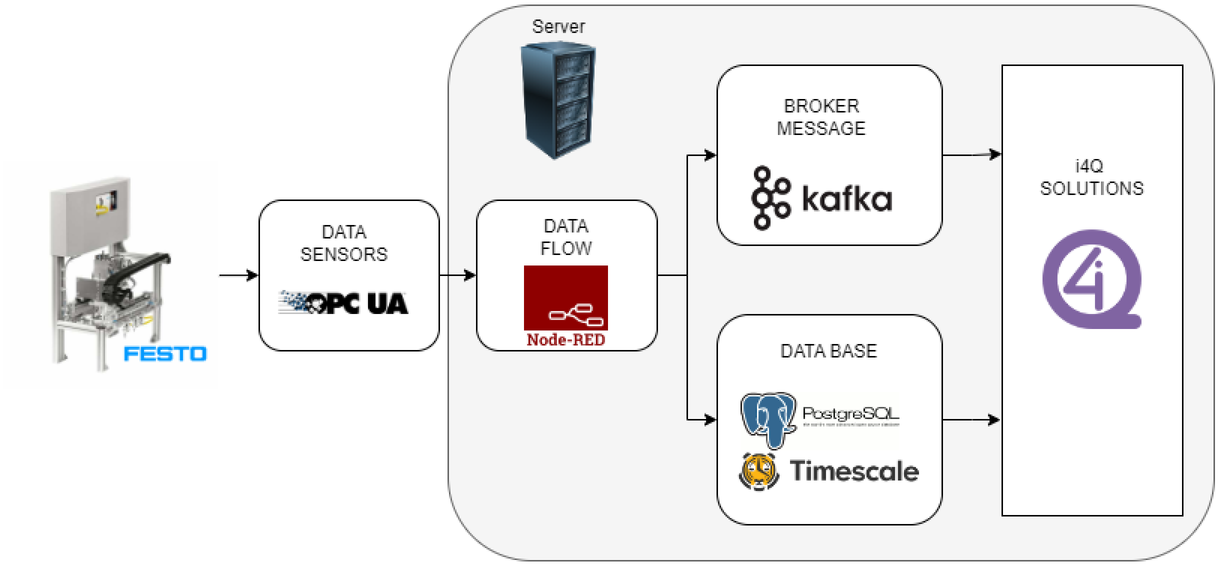


Figure 14. Data Flow Festo Machine

Once the necessary tools have been installed, the flow of data obtained by OPCUA directly from the FESTO machine will be programmed by means of the Node-Red solution, to dump them in two data storage tools. On the one hand, the message broker that we use, with Kafka, and on the other hand, a database to keep a history with PostgreSQL and Timescale. From this point, the different i4Q solutions will be connected to implement your use case. It should be noted that FESTO machines are prepared for education and that their functionalities may be limited.

2.4 Application (analysis and optimization)

FESTO works with MES4, which is a manufacturing execution system (MES) prepared for Industry 4.0 learning platforms. In this MES we can initiate or finalize orders at each station. This communication is based on the FESTO protocol that uses the standard TCP/IP protocol. In the core of this PLC, everything is prepared for communication via OPC UA.

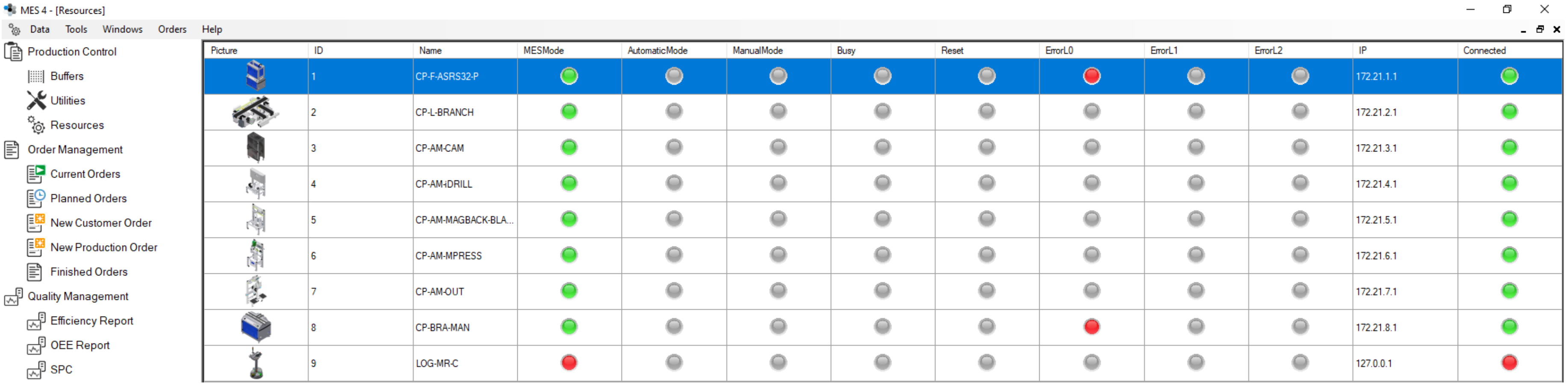


Figure 15. MES4 Configuration Panel – 1

For a user, MES4 offers a graphical interface **(Figure 15)** for work plans creation, the definition of resources, operations, material, and data collection and evaluation (for example some of OEE parameters). All these user actions are realized as read or write operations into a database [12].

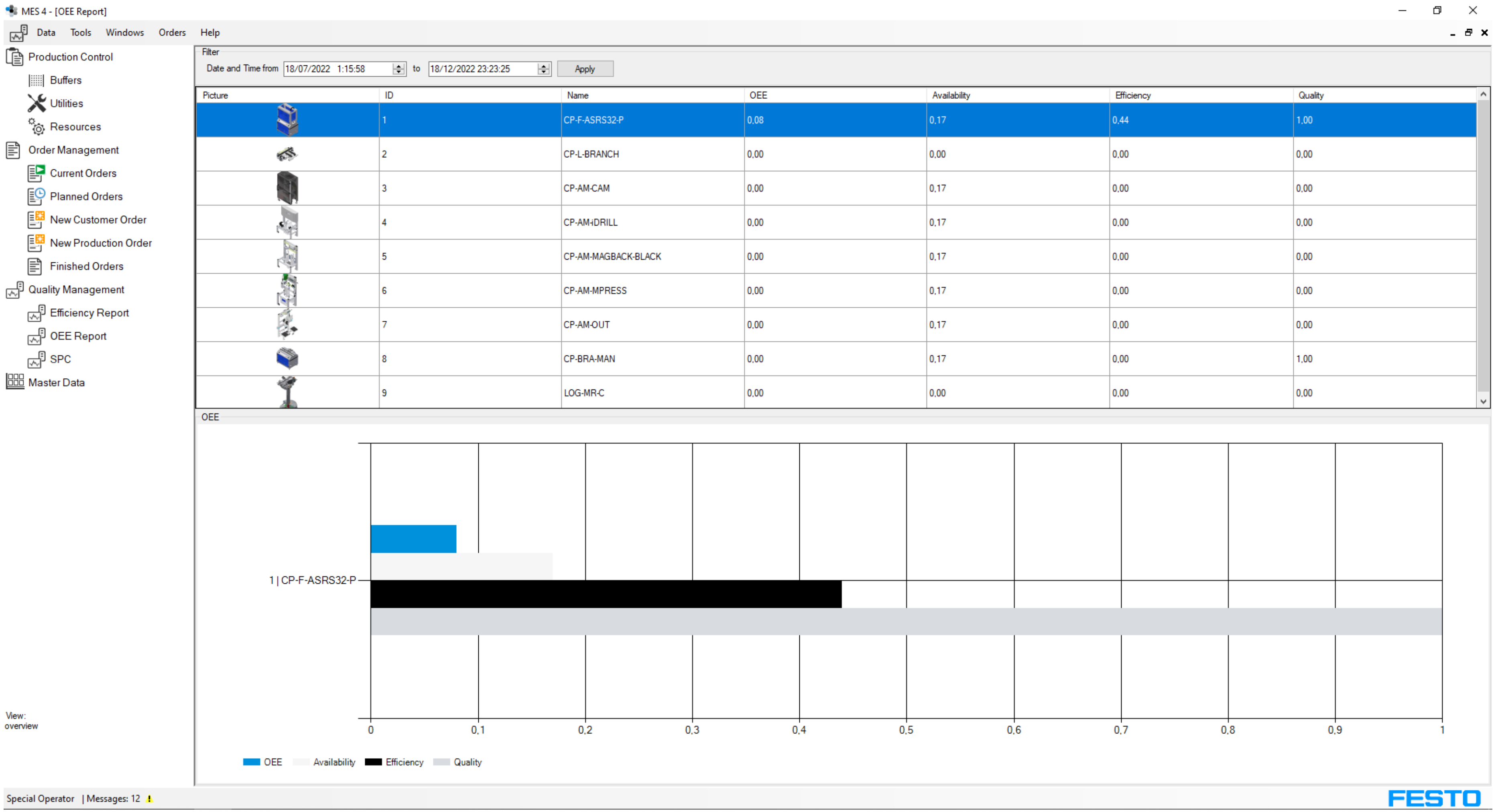


Figure 16. MES4 Configuration Panels – 2

Thanks to the use of OEE **(Figure 16)** that comes by default in MES4, we can see firsthand the quality impact that i4Q solutions have on the FESTO production line.

3. Generic Implementation of i4Q Solutions

3.1 Identification of i4Q solutions implementation in stations

The following **Table** ***15*** identifies, by i4Q Solutions Providers, those Module Stations that can be used for solution testing. It should be noted that an "X" is used to identify the Module Stations that are certain to implement the tests, and "(X)" is used to note that it is not absolutely certain that the Module Station is valid to implement the tests of the solution, the grey columns are the guidelines, which will not be deployed in the generic pilot. The solutions that have not been selected, is because until the technical elements are more advanced and the Module Stations of the generic pilot are better known, it is not certain that a use case can be realized. However, any necessary modifications will be included in the second version of D6.7.

	i4Q **Solutions**																					
Modules Stations	WP**3** - Manufacturing Data Quality								WP**4** - Manufacturing Data Analytics for Manufacturing Quality Assurance								WP**5** - Rapid Manufacturing Line Qualification and Reconfiguration					
Stations	i4Q^{DQG}	i4Q^{QE}	i4Q^{BC}	i4Q^{TN}	i4Q^{CSG}	i4Q^{SH}	i4Q^{DRG}	i4Q^{DR}	i4Q^{DIT}	i4Q^{DA}	i4Q^{BDA}	i4Q^{AD}	i4Q^{AI}	i4Q^{EW}	i4Q^{IM}	i4Q^{DT}	i4Q^{PQ}	i4Q^{QD}	i4Q^{PA}	i4Q^{LRG}	i4Q^{LRT}	i4Q^{LCP}
APPLICATION MODULES																						
Output (CP-AM-OUT)			(X)	X				X		X	X	X			X	(X)	(X)		(X)			
iDrilling (CP-AM-iDRILL)			(X)	X				X		X	X	X			X	(X)	(X)	X	(X)			
Camera inspection (CP-AM-CAM)			(X)	X				X	(X)	X	X	X			X	(X)	(X)	X	(X)			
Magazine (CP-AM-MAG)			(X)	X				X	X	X	X	X			X	(X)	(X)		(X)			
CP Muscle press application module (CP-AM-MPRESS)			(X)	X				X		X	X	X			X	(X)	(X)	X	(X)		X	
BASE MODULES																						
CP Factory Branch (CP-F-BRANCH)			(X)	X								X			X	(X)	(X)		(X)			
INTEGRATED STATIONS																						
CP Factory High-bay storage for pallets (CP-F-ASR32-P)			(X)	X				X				X			X	(X)	(X)		(X)			
CP Lab Branch (CP-L-BRANCH)			(X)	X				X	X			X			X	(X)	(X)		(X)			
Robotino			(X)	X								X			X	(X)	(X)		(X)			
UR5			(X)	X								X			X	(X)	(X)		(X)			

Table 15. Module Stations - i4Q Solutions

3.2 i4Q^QE - QualiExplore for Data Quality Factor Knowledge

QualiExplore (i4Q^QE, D3.10) is a tool to support data quality management. It is not specific to one single machine in the general pilot but the entire process including human activities. The tool (D3.10) and the guideline (4Q^DQG, D3.9) will be evaluated using the entire process.

3.3 i4Q^BC - Blockchain Traceability of Data

The Blockchain Traceability of Data (i4Q^BC) solution aims to enhance the level of trust that different solutions and components can place on data. It provides services of immobility and finality of data, serving as the source of truth, enabling trust in data by providing the possibility for full provenance and audit trail of data stored [11]. The development of this solution included developing Hyperledger Labs Orion (D3.3), the blockchain database selected for the implementation of the i4Q Blockchain Infrastructure, and associated client SDKs. This solution provides the Hyperledger Labs Orion client SDK in Golang (D3.3) and in Java (D3.11) which enable various applications to use the Orin blockchain database cluster. Based on the Orion client SDK in Java, i4Q^BC developed a machine configuration infrastructure (D3.11) to track the changes made to the configuration of manufacturing machines, while using the advanced features of the blockchain database. The machine configuration infrastructure has a frontend service and integration with Kafka server to facilitate the interaction of human and IT components.

In the context of the generic pilot, the i4Q^BC solution can be used to track the historical input/output data of variables of machines (e.g., configuration, performance), and serve as the source of truth for machine data. The partners of i4Q^BC solution will work together with the pilot partner to identify one machine, for which the traceability and veracity of machine data is important. The i4Q^BC solution will then be adapted and evaluated with this machine. For example, the input data of the machine can be handled as machine configurations, and be managed with the machine configuration infrastructure and the blockchain database (i.e., Hyperledger Labs Orion). This allows users to control and audit the inputs and machine configurations. The i4Q^BC solution would connect the Kafka server to consume the data published by the OPCUA client and sensors and produce data to serve other components. Upon the success of the first round of evaluation with one machine, the i4Q^BC solution will be scaled up to support other machines in the production process or other i4Q components for which the blockchain traceability of data is critical.

3.4 i4Q^TN - Trusted Networks with Wireless & Wired Industrial Interfaces

The i4Q Trusted Networks with Wireless and Wired Industrial Interfaces (i4Q^TN) is a software defined industrial interface for data communication, characterized by predictability and determinism, high reliability, trustability and low consumption while reducing the cost of new communication infrastructures. i4Q^TN ensures high-quality data collection and low latency information exchange, providing connectivity to industrial data sources through Trusted Networks able to assess and ensure precision, accuracy and reliability [11].

i4Q^TN is based on two main differentiated components, an Industrial Wireless Sensor Network (IWSN) orchestrated by a centralized SDN controller, allowing the integration of new data sources in addition to existing sources of each Festo station in the generic pilot. The other main component in i4Q^TN is a complete ecosystem of TSN enabled equipment, allowing wired system to ensure a high deterministic and latency bounded communication between different compliant devices. Each component of the i4Q^TN solution in the generic pilot will be integrated in isolation, since each part of the solution cover a specific requirement or use case, either wired or wireless networks.

Therefore, focusing in the IWSN part of the solution, a small set of devices can be used to deploy an IWSN to acquire additional information from a specific workstation, such as the CP-AM-iDRILL or even mobile nodes installed over the AGV Robotino. The small set of nodes could acquire environmental parameters information, using industrial probes or specific IoT sensors, and also measure energy information at low system level, to determine the carbon footprint of a certain process such as drilling. The selection of the final workstation and the specific sensors will depend on the final use case or the pipeline that includes other solutions.

For TSN, the overall system could be of interesting for deploying a TSN network. TSN enables a converged network, meaning that different kind of messages can be converged on a single network. This kind of messages could be messages coming the MES to the individual machines, machine to machine communication, camera data or data required for offline evaluation of the machine performance. Additionally, the (re-)configuration of the overall network of the total facility infrastructure can be performed online, if there is a change in the infrastructure (meaning e.g., machines that are removed or additionally connected during runtime) to the overall infrastructure. The selection of the actual workstations or the overall infrastructure will depend on the final use case that will be selected and how the machines will be deployed within the use case and what kind of (re-)configuration of the infrastructure will take place. In general, it can be mentioned that TSN can be deployed on all machines.

3.5 i4Q^SH - IIoT Security Handler

i4Q Security handler (i4Q^SH) is a system that uses Public Key Infrastructure (PKI) to provide trust to industrial control systems (ICS). These systems are those that collaborate to achieve a common industrial aim. Cryptography is a key strategy that companies use to protect the systems that house their most valuable asset or information, whether in transit or at rest. Cryptography has become a critical infrastructure, as cryptographic solutions increasingly rely on securing sensitive data.

The most important concepts in information security are confidentiality, integrity, and availability. Confidentiality is roughly equivalent to privacy. Confidentiality measures are designed to prevent sensitive information from unauthorized access attempts. Integrity involves maintaining the consistency, accuracy and reliability of data throughout its life cycle. Availability signifies that information must be consistently and easily accessible to authorized parties.

The public key infrastructure (PKI) is a chain of trust that enables to authorize a person, a service, a machine or an application, to establish a secure connection or to validate the origin of a software or a document. This involves certificates, which are created, managed and distributed by a PKI, as well as the ability to revoke them. The public key of a certificate must be kept secure and secret, and the private key must be kept secure and hidden. It can be stored in a hardware security module (HSM).

OPC Unified Architecture (OPC-UA) is a machine-to-machine communication protocol for industrial automation developed by the OPC Foundation. It is a protocol to transfer data.

Open62541, an open source OPC-UA, has been configured to allow the use of certificates in its operations. To work with it, it is possible to use certificates created with OpenSSL or use other methods. In this work we have used Lamassu, a PKI designed for IoT environments. Certificates have been generated with Lamassu and used to perform certified operations.

Trusted Platform Module (TPM) is an international standard to maintain keys secure. It will be the one that stores the keys that have been generated and used with the OPC-UA. The WISE-710 device has been used to store the keys and perform the secure operations.

In the context of the generic pilot, the i4Q^{SH} **Security handler** is useful to protect the communication of the system. The operations performed by the OPC-UA can be certified using keys. A certificate must be generated to ensure that the data encryption is done correctly and that no outsider can access the data. Moreover, these keys will be securely stored in the WISE-710 and this element adds security to the system.

3.6 i4Q^{DR} - Data Repository

The i4Q Data Repository (i4Q^{DR}) is a distributed storage system that will oversee receiving, storing, and serving the data in an appropriate way to other solutions [11]. Note that these operations will be performed according to standard data storage system's mechanisms so that no specific data transformations will be applied.

Therefore, in the context of the generic pilot, the i4Q^{DR} can be used to store any data that can be obtained from the workstations described in Section 3. Raw data could be directly stored in the DR, after being retrieved from the stations. However, in some other cases it might be more interesting, or even necessary, to pre-process the raw data before storing it into the DR. For this purpose, the i4Q^{DiT} solution can be used. Indeed, this is the flow followed in the pipelines of BIESSE and WHIRPOOL pilots (see deliverables D6.2 and D6.3, respectively).

The i4Q^{DR} provides a wide range of storage technologies to support different types of data. The exact storage technologies to be deployed by the i4Q^{DR} will depend on the data structure, the amount of data to be stored/retrieved, the frequency of the interaction with the solution, etc.

Workstations generate data regarding several aspects of the process they perform. Therefore, it might be the case that only certain parts of that data are actually relevant for the pilot's use case or for the rest of solutions involved in the pilot's pipeline. Thus, the most appropriate approach is to store in the i4Q^{DR} only the most relevant parameters or fields of the data produced by the workstations. Performing such a filtering of the information requires a deep analysis of the information provided by i4Q Pilots, which is out of the scope of this deliverable, but that will be performed in the following version of this deliverable. In any case, the rest of this section provides some suggestions on which type of parameters of the data generated by the workstations could be of more interest.

In the case of the CP-F-ASRS32-P workstation, the most relevant information seems to be the fact that a pallet is being stored or retrieved, and the time when this action happens. This could be used to keep track of the pieces produced so far.

Regarding the workstations FBRANCH and CP-LBRANCH, the i4Q^DR could be used to store whether they are transporting a piece and the exact time when this information is retrieved. Depending on the exact parameters recorded by the station, it might be possible to store also some information regarding the origin and the destination of the piece being transformed. For instance, in case of possible branches in the transportation flow, to infer whether the piece is going one way or another.

For the Robotino, some interesting parameters could be the origin and the destination of the transportation. This information could be used to check that a piece has actually reached its expected destination. Other relevant information is the time taken for the trip of the station, which can be used to detect whether the Robotino has found some obstacle on its way from the one station to another.

With respect to the CP-AM-CAM the i4Q^DR can be used to store the pictures taken by the station, besides other data extracted by the station from the picture.

The CP-AM-iDRILL considers several digital inputs. Depending on the value of those inputs and the work order the station will perform one action or another. Thus, storing the value of the digital inputs and information on the action that is being performed can be interesting to check that the production process is being performed in the appropriate way. Furthermore, if information on the specific values of the axis when the station is functioning can be retrieved and stored in the i4Q^DR, other solutions can be used to check whether those values are satisfactory or may result in a defective piece.

In the case of the CP-AM-MAGBACK-BLACK station, an example of interesting information that can be stored in the i4Q is the time at which a piece is put on the conveyor. This information can be used to start keeping track of the path followed by the piece in the production line.

CP-AM-MPRESS contains a load cell that measures the force generated. Recording this parameter can be interesting to check with other solutions whether that value has some effect on the quality of the piece (such as breaking or weakening it), or to monitor that the applied force is among a valid interval.

With respect to the CP-AM-OUT, the i4Q^DR could be used to store the time when a piece is being collected by the station. This information can be used, for instance, to gather the number of pieces that have been finished, and, in combination with the data provided by other stations, to compute the total time of the process.

Finally, the data generated by the UR5 can be used for purposes similar to the ones of the CP-AM-OUT. Furthermore, if the UR5 can deposit the piece in different places (e.g., different trays), it might be interesting to store the parameters of the specific place where the piece is put, as well as the time when this action happens.

3.7 i4Q^DIT - Data Integration and Transformation Services

Data integration and transformation services is a solution suitable for preparing the data for further analysis. It is implemented in the beginning of an analytical pipeline and can pre-process sensor signals, apply data cleaning, combine different datasets and extract features.

In the generic pilot, i4Q^{DIT} can be used with CP-LBRANCH, to draw data from the sensors used for conveyor detection. The solution can also work with all stations that have a signal interface, in order to draw data or send pre-processed data and plots to be visualized in the interface. Furthermore, DIT can connect to the data repository, where the data from the stations might be stored, instead of drawing data directly from a station. DIT can also deliver harmonized and combined datasets on demand, that can be analyzed by other solutions.

3.8 i4Q^{DA} - Services for Data Analytics

The i4Q Services for Data Analytics (i4Q^{DA}) is an experimentation environment that allows the creation of data analytics workflows. These services allow the creation of AI workflows without the complexity of machine/deep learning knowledge, and also provides a user friendly, code free, interface that makes data analysis accessible not only to data scientists.

Regarding the generic pilot, this tool can be used to make analysis on the data which can be streaming data, coming to the workstations, from the Kafka message broker, that were described in Section 3, or batch data, that can be obtained from a database, like the i4Q^{DR}. Since this solution uses data to execute some type of analysis, and it can be any kind of data as long as it is relevant for the analysis being performed and the desired outcome, the i4Q^{DA} can be used with any workstation that generates data from their production process. An example of this would be an analysis with data from the CP-AM-MPRESS station, to evaluate whether the force generated from this station would influence the quality of the end product. The same can be applied to the CP-AM-iDRILL station, the CP-AM-OUT station, the CP-AM-MAG station and the CP-AM-CAM station. For this last workstation, the data of the quality analysis can be put into perspective with data from any of the other 4 stations mentioned above, to train some type of prediction model, in order to have a model that can be used by the tool to make real time predictions of the production process regarding the expected quality of the end product.

3.9 i4Q^{BDA} - Big Data Analytics Suite

Please refer to the section above, since the i4Q^{BDA} is a bundled version of the i4Q^{DA} mentioned above, where this solution allows the deployment in the premises of the generic pilot.

3.10 i4Q^{AD} - Analytics Dashboard

The i4Q Analytics Dashboard (i4Q^{AD}) is a reporting interface with flexible visualization drill-down charts and dashboards that allows the monitoring of industrial data in real time using incremental algorithms. The aim of this solution is to provide a graphical interface to explore and visualise the data provided by the other solutions (refer to Deliverable 4.4 for further information).

In the context of the generic pilot, the i4Q^{AD} can be used to visualise any of the data provided by the other solutions, or directly from the workstations described in Section 3, through the Apache Kafka message broker, using Apache Druid as an intermediate data warehouse. This means that if there is any solution that collects data from a workstation, then the i4Q^{AD} can present the data that was collected from that workstation by the aforementioned solution. Therefore, the AD can be used to display data collected directly from the workstations, via the i4Q^{DR}, or through any of the solutions that collects data from the workstation and performs operations on the collected data.

For example, the i4Q[DR] can be used to show the historical records of part collection from the CP-AM-OUT workstation, collected by the i4Q[DR] solution as exemplified in the Subsection 1.11.

3.11 i4Q[AI] - AI Models Distribution to the Edge

i4Q [AI] addresses a multi-tier infrastructure designed for the management of AI-based models in a hybrid cloud-edge manufacturing environment. Models distribution are designed to be scalable and automated as much as possible by employing techniques such as policies, rules and labels-based placement, distribution and deployment. The main supported feature is the distribution of AI models to the edge where they are expected to be used by locally running workloads. Support the management of lifecycle of AI models, from creation at the cloud, initial deployment at the edge, and re-deployment when revised models are available. Finally, when not needed anymore he deletion of the model is supported as well [11].

This solution shall be exercised as a part of the FACTOR us case, specifically interacting with the LRT solution. The interaction between components was exercised within the FACTOR use case demonstrated in the FACTOR server and environment.

In the context of the generic pilot this solution will contribute to the deployment of corresponding AI models at edge nodes available in the generic pilot, such that data emitted by sensors on the simulated production floor shall be processed locally rather than via a round trip to a cloud or data center.

3.12 i4Q[EW] - Edge Workloads Placement and Deployment

i4Q[EW] is a toolkit for deploying and running AI workloads on edge computing environments, using a Cloud/Edge architecture. i4Q[EW] provides interfaces and capabilities for running different workloads on different industrial devices, efficiently on the edge, including placement and deployment services. The design and implementation of this solution tackles the challenges of scalability and heterogeneity into account right from the beginning. Main feature is to take placement decisions and deploy AI workloads from the cloud (or a data centre) to the edge, where they are expected to use locally available models. To enable that, a policy-based deployment pattern can be used via associating policies and labels with the potentially different target nodes [11].

Workload placement and distribution components designed for edge computing providing scalable, automated, flexible, and easy to use workload management. Automatic dynamic placement decisions based on availability of resources. Focus on i4Q use cases with Kubernetes (one of the flavors) as target edge infrastructure.

In the context of the generic pilot this solution shall be used to efficiently deploy and run AI based workloads at the simulated factory floor, to be able to use the local deployed models, thus being able to efficiently run complete AI workloads at the edge

3.13 i4Q^{IM} - Infrastructure Monitoring

The i4Q Infrastructure Monitoring (i4Q^{IM}) is comprised of a collection of monitoring tools and proactive alerting systems, to track the integrity of workloads and trigger alerts when imminent problems are estimated to occur. It utilizes machine learning algorithms to analyze the data deriving from industrial sensors and effectively detect possible failures in the manufacturing lines. The goal of the solution is to provide timely warnings to the machine operators, in order to take action and prevent irreparable machine damages.

In the context of the generic pilot, the i4Q^{IM} can be integrated in any module station that requires condition monitoring of its components. For example, in the iDrilling (CP-AM-iDRILL) module the solution can provides alerts in the event of detecting severe degradation of the drilling spindles. If any form of component wear or breakage is possible to occur to a module, then the i4Q^{IM} can be applicable.

3.14 i4Q^{DT} - Digital Twin Simulation Services

The i4Q Digital Twin (i4Q^{DT}) is a software that allows industrial companies to achieve a connected production simulation, with a digital twin for manufacturing enabling virtual validation/visualisation and productivity optimisation using data from different factory levels (small cell to entire factory) [11]. The i4Q^{DT} is capable of handling both physics-based models and data-driven models, all in a user-friendly environment that does not require for the user to have programming knowledge.

The physics-based workflow of the i4Q^{DT} uses Functional Mock-up Units (FMU) that represent the behaviour of a certain asset and has been modelled with tools like Simulink or Modelica. The i4Q^{DT} allows the user to build a more complex model and to simulate it, starting from simpler and individual FMU models, thus making the framework independent from the modelling source.

The data-driven workflow of the i4Q^{DT} is based on the implementation of different machine-learning algorithms for predicting the quality of a process or a product, such as the ones provided by libraries like TensorFlow, Keras or Sklearn. The i4Q^{DT} allows the user to parameterize, train and store these models, as well as to carry out the predictions and show the results.

In this generic pilot, the physics-based workflow of the i4Q^{DT} can be demonstrated by building the model of the entire workpiece flow, allowing the user to obtain results of the behaviour of the workstation in terms of working times and transport delays. For achieving the most accurate digital representation of the real system, real temporal data will need to be obtained for the behaviour of the workpiece flow, from the initial storage unit (ASRS) to the robotic arm that stores the final product (UR5), passing from the different conveyors.

3.15 i4Q^{PQ} - Data-driven Continuous Process Qualification

The i4Q Data-Driven Process Qualification (i4Q^{PQ}) is a user-friendly forecasting and real-time monitoring tool to describe the current behavior of single quality measurements of manufactured products.

Since the variable of interest is not dependent on the type of machinery equipment, any continuous variable can be inserted into i4Q^PQ. However, it is recommended for higher interpretation of the output to insert inherent product features.

3.16 i4Q^QD - Rapid Quality Diagnosis

The i4Q Rapid Quality Diagnosis (i4Q^QD) is a micro-service designed to offer an efficient rapid diagnosis on potential manufactured product defects and on possible failures occurring during the manufacturing process. It performs extensive statistical analysis on machine parameters and production conditions and applies machine learning techniques on industrial sensors to ensure higher quality final products.

With regard to the generic pilot, the i4Q^QD can be utilized on any module station that involves the production of parts, since it can provide the capability of product defect detection as well as offer insights on the factors (machine parameters) that contribute more towards the quality conformity of the manufactured product. Based on that assumption the i4Q^QD can be integrated in most of the application modules.

Therefore, in the Camera inspection (CP-AM-CAM) module which is directly connected with the quality assurance aspect of the product, the i4Q^QD can allow the detection of quality defects using the visual data provided by the module. Additionally, it can be applied to the iDrilling (CP-AM-iDRILL) and Muscle Press (CP-AM-MPRESS) module, since they are closely involved in the machining of the product. Here the solution can alert the operators upon the detection of anomalies in the manufacturing process (e.g., machine chatter) or in the part being produced.

3.17 i4Q^PA - Prescriptive Analysis Tools

The Prescriptive Analysis Tool i4Q^PA is a micro-service consisting of simulation models as a service, taking as input the manufacturing resources, current production planning and process condition, and proposing process configuration parameters, ensuring that non-simulation experts may also exploit the prescriptive analyses.

The i4Q^PA uses different data analytics platforms, thus allowing the evaluation and comparison of the results that come from the simulation of different industrial scenarios. The i4Q^PA provides an extensive set of optimisation techniques that help in the development of the mathematical methods that will make the prescriptive analysis. These optimisation techniques have as objective the selection of the best of the digital twin instances that have been simulated, or even the selection of those simulation scenarios that need to be selected or avoided in order to reach faster the optimal solution, based on a scenarios map [11].

Therefore, the i4Q^PA will prescribe the optimum configuration of the system so that the working time and transport delays can be reduced. For that, the i4Q^PA will require the model generated by the i4Q^DT.

3.18 i4Q^LRT - Manufacturing Line Reconfiguration Toolkit

The Manufacturing Line Reconfiguration Toolkit i4Q^LRT is a set of tools for optimizing manufacturing processes. These tools can be easily used to address known optimization use cases in the area of manufacturing line reconfiguration problems. Fine-tuning machine setup parameters along the line to improve quality standards, or improving manufacturing line setup time are some examples of problems that i4Q^{LRT} solves for manufacturing companies. With this in mind, in this generic pilot, i4Q^{LRT} will be used with the objective of monitoring the status of some of the FESTO plant modules and providing an output with a possible optimization configuration to avoid failures.

It is likely that, in the first instance, we will not be able to act directly on the line due to the limitations of the FESTO plant. So, this generic pilot will be used to demonstrate how the solution is configured to fetch data from a database client, subscribing to a message broker or waiting for a trigger from another solution. Once the configuration and usage has been demonstrated, we will also focus on demonstrating how to configure the user interface integration so that it can be easily used by the plant operator. Taking into account the limitations of the plant, we will try to generate a simple use case that demonstrates the correct operation of i4Q^{LRT}.

This solution can be applied on all those modules that can implement an improvement in product quality and all those whose functioning parameters can be modified to decrease the number of machine breakdowns. In a first attempt, we will act on those modules oriented to production and not to transport or storage. This limits us to Camera inspection, iDrilling, Magazine or Muscle Press. After a first investigation of these modules, we have decided to focus on trying to apply some optimization model for the Muscle Press (CP-AM-MPRESS), so that we act on the amount of pressure to be applied at the time of putting "the phone cover". After analyzing the variables that we can visualize, we see that we have variables of regulation of the behaviour of the machine that we could modify.

4. Conclusions

Deliverable D6.7 describes the GENERIC Pilot experimental facilities, for use in the i4Q project as a test bed for the i4Q Solutions before they are used by the i4Q Pilots. This first version of the " i4Q Solutions Demonstrator" identifies and technically describes all the Module Stations, plus all the hardware and software systems and communications for their operation, as well as a diagram of the communications between elements of the system.

i4Q Solutions Providers have made a first identification of those Module Stations likely to be used for the testing of their solutions, as well as the limitations they may have, but the second version of D6.7 will make a more precise and in-depth analysis of the capabilities of the i4Q solutions to achieve the full potential in all Module Stations.

These industrial experimentation facilities of the UPV have a relevant importance since they will demonstrate the i4Q Solutions operation in a system beyond the more restricted and defined environments of the pilots. These facilities are focused on teaching and training environments and do not have the complexity of the real industrial environments of the pilots.

References

[1] FESTO (2022a). CP Factory High-bay storage for pallets CP-F-ASRS32-P. Available: https://ip.festo-didactic.com/InfoPortal/CPFactoryLab/hardware/station/details.php?model=CP-F-ASRS32-P

[2] FESTO, (2022b). CP Factory Branch (CP-F-BRACH). Available: https://ip.festo-didactic.com/InfoPortal/CPFactoryLab/hardware/base/details.php?lang=en&model=CP-F-BRANCH

[3] FESTO. (2022C). Robotino. Available: https://www.festo-didactic.com/es-es/servicio-y-asistencia/robotino/?fbid=ZXMuZXMuNTQ3LjE0LjM0LjExNjg

[4] FESTO, (2022d). CP Lab Branch (CP-L-BRANCH). Available: https://ip.festo-didactic.com/InfoPortal/CPFactoryLab/hardware/station/details.php?model=CP-L-BRANCH&lang=en

[5] FESTO, (2022e). Camera inspection (CP-AM-CAM). Available: https://ip.festo-didactic.com/infoportal/CPFactoryLab/hardware/application/details.php?model=CP-AM-CAM&lang=en

[6] FESTO, (2022f). iDrilling (CP-AM- iDRILL). Available: https://ip.festo-didactic.com/InfoPortal/CPFactoryLab/hardware/application/details.php?model=CP-AM-iDRILL&lang=en

[7] FESTO, (2022g). Magazine (CP-AM-MAG). Available: https://ip.festo-didactic.com/InfoPortal/CPFactoryLab/hardware/application/details.php?model=CP-AM-MAG&lang=en

[8] FESTO, (2022h). Muscle press (CP-AM-MPRESS). Available: https://ip.festo-didactic.com/InfoPortal/CPFactoryLab/hardware/application/details.php?model=CP-AM-MPRESS&lang=en

[9] FESTO, (2022i). Output (CP-AM-OUT). Available: https://ip.festo-didactic.com/InfoPortal/CPFactoryLab/hardware/application/details.php?model=CP-AM-OUT&lang=en

[10] FESTO, (2022j). Universal Robots (UR5). Available: https://www.festo.com/es/es/e/productos/landing-pages-id_326973/

[11] i4Q. (2022). I4Q Solutions. Available: https://i4q.upv.es/

[12] Marcon, P., Jirsa, J., Venkrbec, L., Zezulka, F., Benesl, T., Kaczmarczyk, V., & Arm, J. (2022). An Experimental Training Production Line to Demonstrate the Basics of Industry 4.0. IFAC-PapersOnLine, 55(4), 139-144.

Appendix I

Magazine (CP-AM-MAG)				
Description	**Reference Tag**	**CP Lab address**	**Data**	**Type**
Lift cylinder in upper end position	+CL-BG1	%I0.0	Boolean	Digital Input
Lift cylinder in lower end position	+CL-BG2	%I0.1	Boolean	Digital Input
Separator closed	+CL-BG3	%I0.2	Boolean	Digital Input
Separator open	+CL-BG4	%I0.3	Boolean	Digital Input
Work piece present in magazine	+CL-BG5	%I0.4	Boolean	Digital Input
Magazine front cover	+CL-BG7	%I0.6	X = pallet present X = front cover present	Digital Input
Magazine front cover	+CL-BG8	%I0.7	X = front cover already present X = back cover already present	Digital Input
Move lift cylinder up	+CL-MB1	%Q0.0	Boolean	Digital Output
Move lift cylinder down	+CL-MB2	%Q0.1	Boolean	Digital Output
Close separator	+CL-MB3	%Q0.2	Boolean	Digital Output
Open separator	+CL-MB4	%Q0.3	Boolean	Digital Output
Open lift cylinder end position lock	+CL-MB5	%Q0.4	Boolean	Digital Output

Table 16. Magazine Data

Output (CP-AM-OUT)				
Description	Reference Tag	CP Lab address	Data	Type
Z-axis in upper end position	+GM-BG1	%I0.0	Boolean	Digital Input
Z-axis in lower end position	+GM-BG2	%I0.1	Boolean	Digital Input
Gripper open	+GM-BG3	%I0.2	Boolean	Digital Input
Left drop-off position occupied	+GM-BG4	%I0.3	Boolean	Digital Input
Right drop-off position occupied	+GM-BG5	%I0.4	Boolean	Digital Input
X-axis referenced	+GM-KF1-X1:20	%I0.5	Boolean	Digital Input
X-axis target position reached	+GM-KF1-X1:12	%I0.7	Boolean	Digital Input
X-axis controller ready	+GM-KF1-X1:21	%IX1.5	Boolean	Digital Input
Move Z-axis up	+GM-MB1	%Q0.0	Boolean	Digital Output
Move Z-axis down	+GM-MB2	%Q0.1	Boolean	Digital Output
Open Z-axis end position lock	+GM-MB3	%Q0.2	Boolean	Digital Output
Open gripper	+GM-MB4	%Q0.3	Boolean	Digital Output
Enable X-axis controller	+GM-KF1-X1:10	%Q0.4	Boolean	Digital Output
X-axis motion record selection bit 0	+GM-KF1-X1:1	%Q0.5	0 = reference 1 = left drop-off position 2 = right drop-off position 3 = pick-up position	Digital Output
X-axis motion record selection bit 1	+GM-KF1-X1:2	%Q0.6	0 = reference 1 = left drop-off position 2 = right drop-off position 3 = pick-up position	Digital Output
Start X-axis motion	+GM-KF1-X1:6	%Q0.7	Boolean	Digital Output

Table 17. Output Data

Factory Branch (CP-F-BRANCH)				
Description	Reference Tag	CP Lab address	Data	Type
Emergency stop not acknowledged	+K1-F2-KF1	%I0.0	Boolean	Digital Input
Emergency stop button pushed	+S1-F2-FQ1	%I0.3	Boolean	Digital Input
Stopper cylinder (branch) in lower end position	+G1-BG20	%I1.0	Boolean	Digital Input
Carrier detected at stopper (branch) / Stopper (branch) carrier ident code bit 0 detected	+G1-BG21	%I1.1	Boolean	Digital Input
Stopper (branch) carrier ident code bit 1 detected	+G1-BG22	%I1.2	Boolean	Digital Input
Stopper (branch) carrier ident code bit 2 detected	+G1-BG23	%I1.3	Boolean	Digital Input
Stopper (branch) carrier ident code bit 3 detected	+G1-BG24	%I1.4	Boolean	Digital Input
Carrier detected at conveyor entry (belt 2)	+G1-BG26	%I1.6	Boolean	Digital Input
Carrier detected at conveyor exit (belt 2)	+G1-BG27	%I1.7	Boolean	Digital Output
Deflector arm closed (carrier continues straight on belt 2)	+G1-BG30	%I3.0	Boolean	Digital Input
Deflector arm opened (carrier gets diverted to belt 3)	+G1-BG31	%I3.1	Boolean	Digital Input
Coupling signal from Robotino received	+G1-KG35	%I3.5	Boolean	Digital Input
Stopper cylinder (belt 4) in lower end position	+G1-BG40	%I4.0	Boolean	Digital Input
Carrier detected at stopper (belt 4)	+G1-BG41	%I4.1	Boolean	Digital Input
Carrier has left critical section via belt 3	+G1-BG42	%I4.2	Boolean	Digital Input
Carrier has left critical section via belt 2	+G1-BG45	%I4.5	Boolean	Digital Input
Stopper cylinder (belt 1) in lower end position	+G1-BG50	%I5.0	Boolean	Digital Input
Carrier detected at stopper (belt 1) / Stopper (belt 1) carrier ident code bit 0 detected	+G1-BG51	%I5.1	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 1 detected	+G1-BG52	%I5.2	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 2 detected	+G1-BG53	%I5.3	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 3 detected	+G1-BG54	%I5.4	Boolean	Digital Input
Carrier detected at conveyor entry (belt 1)	+G1-BG56	%I5.6	Boolean	Digital Input
Carrier detected at conveyor exit (belt 1)	+G1-BG57	%I5.7	Boolean	Digital Input
Drive belt 1 in forward direction	+K1-QA1:A1	%Q0.0	Boolean	Digital Output
Drive belt 1 in reverse direction	+K1-QA1:A2	%Q0.1	Boolean	Digital Output
Select belt 1 speed	+K1-QA1:A3	%Q0.2	F = normal T = slow	Digital Output
Drive belt 2 in forward direction	+K1-QA2:A1	%Q0.3	Boolean	Digital Output
Drive belt 2 in reverse direction	+K1-QA2:A2	%Q0.4	Boolean	Digital Output

Select belt 2 speed	+K1-QA2:A3	%Q0.5	F = normal T = slow	Digital Output
Drive belt 3 in forward direction	+K1-QA3:A1	%Q0.6	Boolean	Digital Output
Drive belt 3 in reverse direction	+K1-QA3:A2	%Q0.7	Boolean	Digital Output
Move stopper cylinder (branch) down	+G1-MB20	%Q1.0	Boolean	Digital Output
Select belt 3 speed	+K1-QA3:A3	%Q1.3	F = normal T = slow	Digital Output
Drive belt 4 in forward direction	+K1-QA4:A1	%Q1.5	Boolean	Digital Output
Drive belt 4 in reverse direction	+K1-QA4:A2	%Q1.6	Boolean	Digital Output
Select belt 4 speed	+K1-QA4:A3	%Q1.7	F = normal T = slow	Digital Output
Close deflector arm	+G1-MB30	%Q3.0	Boolean	Digital Output
Open deflector arm	+G1-MB31	%Q3.1	Boolean	Digital Output
Switch on coupling signal to Robotino	+G1-GF35	%Q3.5	Boolean	Digital Output
Move stopper cylinder (belt 4) down	+G1-MB40	%Q4.0	Boolean	Digital Output
Move stopper cylinder (belt 1) down	+G1-MB50	%Q5.0	Boolean	Digital Output

Table 18. Factory Branch Data

Muscle Press (CP-AM-MPRESS)				
Description	**Reference Tag**	**CP Lab address**	**Data**	**Type**
Back cover present	+HL-BG1	%I0.0	Boolean	Digital Input
Pressure setpoint reached	+HL-KF11:D3	%I0.4	Boolean	Digital Input
Open emergency stop valve	+HL-MB1	%Q0.0	Boolean	Digital Output
Regulator behaviour bit 0	+HL-KF11:D1	%Q0.4	0 = selection via display 1 = fast 2 = standard 3 = precise	Digital Output
Regulator behaviour bit 1	+HL-KF11:D2	%Q0.5	0 = selection via display 1 = fast 2 = standard 3 = precise	Digital Output
Current force	+HL-KF10:12	%IW19	0 V = 0 N 10 V = 200 N	Analog Input
Current pressure	+HL-KF11:X	%IW22	0 V = 0 bar 10 V = 6 bar	Analog Input
Set pressure setpoint	+HL-KF11:W+	%QW21	0 V = 0 bar 10 V = 6 bar	Analog Output

Table 19. Muscle PRess Data

Factory High-bay storage for pallets (CP-F-ASRS32-P)				
Description	**Reference Tag**	**CP Lab address**	**Data**	**Type**
Emergency stop not acknowledged	+K1-F2-KF1	%I0.0	Boolean	Digital Input
Emergency stop button pushed	+S1-F2-FQ1	%I0.3	Boolean	Digital Input
Stopper cylinder (branch) in lower end position	+G1-BG20	%I1.0	Boolean	Digital Input
Carrier detected at stopper (branch) / Stopper (branch) carrier ident code bit 0 detected	+G1-BG21	%I1.1	Boolean	Digital Input
Stopper (branch) carrier ident code bit 1 detected	+G1-BG22	%I1.2	Boolean	Digital Input
Stopper (branch) carrier ident code bit 2 detected	+G1-BG23	%I1.3	Boolean	Digital Input
Stopper (branch) carrier ident code bit 3 detected	+G1-BG24	%I1.4	Boolean	Digital Input
Carrier detected at conveyor entry (belt 2)	+G1-BG26	%I1.6	Boolean	Digital Input
Carrier detected at conveyor exit (belt 2)	+G1-BG27	%I1.7	Boolean	Digital Output
Deflector arm closed (carrier continues straight on belt 2)	+G1-BG30	%I3.0	Boolean	Digital Input
Deflector arm opened (carrier gets diverted to belt 3)	+G1-BG31	%I3.1	Boolean	Digital Input
Coupling signal from Robotino received	+G1-KG35	%I3.5	Boolean	Digital Input
Stopper cylinder (belt 4) in lower end position	+G1-BG40	%I4.0	Boolean	Digital Input
Carrier detected at stopper (belt 4)	+G1-BG41	%I4.1	Boolean	Digital Input
Carrier has left critical section via belt 3	+G1-BG42	%I4.2	Boolean	Digital Input
Carrier has left critical section via belt 2	+G1-BG45	%I4.5	Boolean	Digital Input
Stopper cylinder (belt 1) in lower end position	+G1-BG50	%I5.0	Boolean	Digital Input
Carrier detected at stopper (belt 1) / Stopper (belt 1) carrier ident code bit 0 detected	+G1-BG51	%I5.1	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 1 detected	+G1-BG52	%I5.2	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 2 detected	+G1-BG53	%I5.3	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 3 detected	+G1-BG54	%I5.4	Boolean	Digital Input
Carrier detected at conveyor entry (belt 1)	+G1-BG56	%I5.6	Boolean	Digital Input
Carrier detected at conveyor exit (belt 1)	+G1-BG57	%I5.7	Boolean	Digital Input
Drive belt 1 in forward direction	+K1-QA1:A1	%Q0.0	Boolean	Digital Output
Drive belt 1 in reverse direction	+K1-QA1:A2	%Q0.1	Boolean	Digital Output
Select belt 1 speed	+K1-QA1:A3	%Q0.2	F = normal T = slow	Digital Output
Drive belt 2 in forward direction	+K1-QA2:A1	%Q0.3	Boolean	Digital Output
Drive belt 2 in reverse direction	+K1-QA2:A2	%Q0.4	Boolean	Digital Output

Select belt 2 speed	+K1-QA2:A3	%Q0.5	F = normal T = slow	Digital Output
Drive belt 3 in forward direction	+K1-QA3:A1	%Q0.6	Boolean	Digital Output
Drive belt 3 in reverse direction	+K1-QA3:A2	%Q0.7	Boolean	Digital Output
Move stopper cylinder (branch) down	+G1-MB20	%Q1.0	Boolean	Digital Output
Select belt 3 speed	+K1-QA3:A3	%Q1.3	F = normal T = slow	Digital Output
Drive belt 4 in forward direction	+K1-QA4:A1	%Q1.5	Boolean	Digital Output
Drive belt 4 in reverse direction	+K1-QA4:A2	%Q1.6	Boolean	Digital Output
Select belt 4 speed	+K1-QA4:A3	%Q1.7	F = normal T = slow	Digital Output
Close deflector arm	+G1-MB30	%Q3.0	Boolean	Digital Output
Open deflector arm	+G1-MB31	%Q3.1	Boolean	Digital Output
Switch on coupling signal to Robotino	+G1-GF35	%Q3.5	Boolean	Digital Output
Move stopper cylinder (belt 4) down	+G1-MB40	%Q4.0	Boolean	Digital Output
Move stopper cylinder (belt 1) down	+G1-MB50	%Q5.0	Boolean	Digital Output

Table 20. Factory High-bay storage for pallets Data

iDrilling (CP-AM-iDRILL)				
Description	**Reference Tag**	**CP Lab address**	**Data**	**Type**
X-Axis in left end position	+VN-BG1	%IX0.0	Boolean	Digital Input
X-Axis in right end position	+VN-BG2	%IX0.1	Boolean	Digital Input
Front cover orientation corrects	+VN-BG3	%IX0.2	Boolean	Digital Input
Front cover present	+VN-BG4	%IX0.3	Boolean	Digital Input
Z-Axis in upper end position	+VN-BG5	%IX0.4	Boolean	Digital Input
Z-Axis in lower end position	+VN-BG6	%IX0.5	Boolean	Digital Input
Back cover already present	+VN-BG8	%IX0.7	Boolean	Digital Input
Emergency stop switch pushed	+K1-24VNA	%IX1.5	Boolean	Digital Input
Move X-axis left	+VN-MB1	%QX0.0	Boolean	Digital Output
Move X-axis right	+VN-MB2	%QX0.1	Boolean	Digital Output
Switch on drill 1	+VN-MB3	%QX0.2	Boolean	Digital Output
Switch on drill 2	+VN-MB4	%QX0.3	Boolean	Digital Output
Move z-axis up	+VN-MB5	%QX0.4	Boolean	Digital Output
Move z-axis down	+VN-MB6	%QX0.5	Boolean	Digital Output
Open z-axis end position lock	+VN-MB7	%QX0.6	Boolean	Digital Output

Table 21. iDrilling Data

CP Lab Branch (CP-L-BRANCH)				
Description	Reference Tag	CP Lab address	Data	Type
Deflector arm closed (carrier continues straight on belt 1)	+W1-BG1	%I0.0	Boolean	Digital Input
Deflector arm opened (carrier gets diverted to belt 2)	+W1-BG2	%I0.1	Boolean	Digital Input
Stopper cylinder (belt 1) in lower end position	+W1-BG3	%I0.2	Boolean	Digital Input
Stopper cylinder (belt 3) in lower end position	+W1-BG4	%I0.3	Boolean	Digital Input
Stopper cylinder (belt 2) in lower end position	+W1-BG5	%I0.4	Boolean	Digital Input
Carrier detected at stopper (belt 2) / Carrier has left critical section via belt 2	+W1-BG6	%I0.5	Boolean	Digital Input
Carrier detected at stopper (belt 3)	+W1-BG7	%I0.6	Boolean	Digital Input
Coupling signal from Robotino received	+W1-KF8	%I0.7	Boolean	Digital Input
Carrier detected at stopper (belt 1) / Stopper (belt 1) carrier ident code bit 0 detected	+W1-BG9	%I1.0	Boolean	Digital Output
Stopper (belt 1) carrier ident code bit 1 detected	+W1-BG10	%I1.1	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 2 detected	+W1-BG11	%I1.2	Boolean	Digital Input
Stopper (belt 1) carrier ident code bit 3 detected	+W1-BG12	%I1.3	Boolean	Digital Input
Carrier detected at conveyor entry	+W1-BG13	%I1.4	Boolean	Digital Input
Carrier detected at conveyor exit	+W1-BG14	%I1.5	Boolean	Digital Input
Turn deflector arm	+W1-MB1	%Q0.0	F = continue T = divert	Digital Output
Move stopper cylinder (belt 2) down	+W1-MB2	%Q0.1	Boolean	Digital Output
Move stopper cylinder (belt 1) down	+W1-MB3	%Q0.2	Boolean	Digital Output
Move stopper cylinder (belt 3) down	+W1-MB4	%Q0.3	Boolean	Digital Output
Drive belt 1 in forward direction	+W1-QA1:A1	%Q0.4	Boolean	Digital Output
Drive belt 2 in forward direction	+W1-QA2:A1	%Q0.5	Boolean	Digital Output
Drive belt 3 in forward direction	+W1-QA3:A1	%Q0.6	Boolean	Digital Output
Switch on coupling signal to Robotino	+W1-GF8	%Q0.7	Boolean	Digital Output

Table 22. CP Lab Branch Data

Camera Inspection (CP-AM-CAM)				
Description	Reference Tag	CP Lab address	Data	Type
Camera Ready	+BX-BX1:O3	%I0.3	Boolean	Digital Input
Inspection passed	+BX-BX1:O1	%I0.4	Boolean	Digital Input
Inspection failed	+BX-BX1:O2	%I0.5	Boolean	Digital Input
Trigger camera	+BX-BX1:I0	%Q0.3	Boolean	Digital Output

Table 23. Camera Inspection Data