BEinCPPS

Innovation Action Project

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D7.5 – Norte Regional Ecosystem Business Assessment and Recommendations

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1.0	05/06/2017	Produced final version

Deliverable Peer review summary

Id.	Addressed	Comments

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Executive summary

D7.5 report includes the first sessions of business assessment (M15) complemented by a further analysis for lessons learned and recommendations. In particular, the experimentations performed in KYAIA are reported and the final achieved results are assessed and measured according to specific Key Performance Indicators (KPIs). Finally, key lessons learnt and useful recommendations for CPS adoption in SMEs are reported.

Three experiments were prepared and put in operation at KYAIA, the biggest Portuguese footwear manufacturer and unquestionable leader in the Portuguese footwear production and retailing: Access sensors on footwear production lines (Exp#1), Diagnostic and predictive maintenance (Exp#2) and Production monitoring (Exp#3).

The application experiments targeted the two manufacturing plants of KYAIA and the respective internal logistic systems, one in Guimarães (Exp#1 and Exp#2) and the other on Paredes de Coura (Exp#1 and Exp#3). The experiments included 40 working posts in the first plant and 200 working posts on the second one, both on the stitching area. Each of the manufacturing lines is supported by an internal logistic system that carries boxes containing the material to be processed, from working post to working post. This is achieved by three robotic manipulators in the first manufacturing plant (HSSF, High Speed Shoe Factory) and by running conveyor belts in the second manufacturing plant. PLC devices and a significant number of sensors and actuators located on the physical elements comprising the logistic system control the actions within the logistic systems.

The aim of the application experiments is the following:

- Exp#1 - to allow sensor-based and actuator-based data to be accessed on KYAIA manufacturing plants.
- Exp#2 – to analyse real-time sensor-based and actuator-based data related to the critical physical elements on the High Speed Shoe Factory in order to detect the actual occurrence of physical problems (1st phase) and to estimate their possible occurrence in the near/medium term (2nd phase).
- Exp#3 – to monitor the running of footwear logistic systems in real time by means of a single and effective dashboard.

Key collaborators of KYAIA participated in the experiments: ICT staff on all the three experiments, maintenance operator on the Exp#2 and one of the production managers on Exp#3. They were trained and supported by the members in the Work Package. The three application experiments were successfully accomplished and they are running in production mode.

The degree of achievement of the business indicators is good. A decrease of the down time of working posts has been reached (Guimarães), subcontracting costs for maintenance activities has decreased (Guimarães), as well as production costs (Paredes de Coura). An increase on the number of produced pairs of shoes was measured. Details are provided in the remaining of the report.

1 Introduction

1.1 Introduction

This documents provides the assessment of the results achieved in the Champion experimentation (KYAIA), including a description of the defined key performance indicators measured. The lessons learned during the process, the results achieved and recommendations for the implementation of CPPS are also documented.

In particular, after a description of the followed methodology in section 1, the Norte Champion (KYAIA) is briefly described in section 2. The experimentation plan is deeply described in section 3, while sections 4 and 5 are dedicated to the results of the experiments and the lessons learnt and recommendations.

1.2 Contributions to other WPs

Information reported in this deliverable should be used as input to work packages 2 and 3, in terms of supplying feedback about the usage of the BEinCPPS components.

1.3 Contributions to other deliverables

In general, information reported in this deliverable should be used as input to some of the deliverables of work packages 2 and 3. Additionally, the second version of this deliverable, D7.6, must use this one as major input.

1.4 Methodology

To gather BEinCPPS champions' business requirements, the project follows the well-known spiral development approach, described in Figure 1. This approach essentially parallelizes the development activities of the classical 'waterfall' approach, from requirements to system design to verification and validation. Indeed, the spiral approach allows a continuous review of the development results and user requirements in order to better deliver added value to the users and the stakeholders of the system.

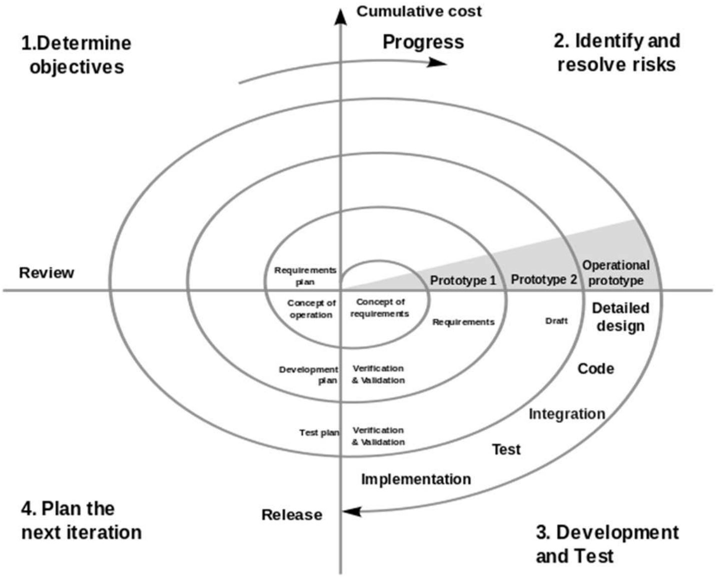


Figure 1 - Boehm, B. (2000) Spiral Development: Experience, Principles, and Refinements, SPECIAL REPORT CMU/SEI-2000-SR-008

In particular, BEinCPPS business requirements, refer to the scenarios involved in the area of intervention of each champion, which have been studied and specified by the analysis of the correspondent business processes and sub processes.

The main phases of BEinCPPS requirement engineering cycle are presented in Figure 2.

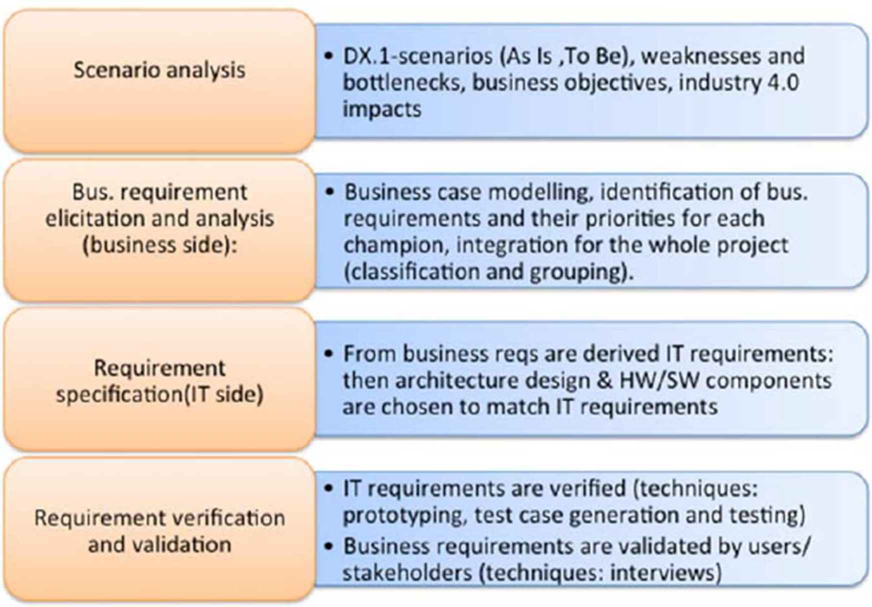


Figure 2 - BEinCPPS business engineering (adapted from Sommerville, 2007)

The first phase is related to the "Scenario analysis", where each champion identifies the relevant CPS-ization scenarios, by building up the weakness and bottlenecks of the "As is" situations, taking into account their business objectives and impacts.

The second phase concerns the "Business requirements elicitation and analysis". During this phase the business processes that support the identified scenarios are analysed by means of state of the art methods (use case models, BPMN, extended actigrams, UML, etc.) with the BEinCPPS available design tools. Business requirements are organized in a database, for further processing, integration and classification.

In the third phase, "Requirements specification", IT requirements are devised by the technical partners on the basis of the business requirements. Architecture design occurs in a way that IT requirements are matched by the IT artefacts (software and hardware) that build up the BEinCPPS architecture, with the support of proper customized activities for the non-standard components and interfaces with legacy systems.

The last phase is the "Requirements Verification and Validation".

Verification and Validation (V&V) is the process of providing evidence that the software and its associated products satisfy system requirements allocated to software at the end of each life cycle activity, solve the right problem and satisfy intended use and user needs. This methodology aims at verifying, validating and evaluating a software product from its conception to final release and implementation in real-life, trial settings. In general, Verification ensures that the product is being built according to the requirements and design specifications, while Validation makes certain that the product actually meets the user's needs, the specifications were correct in the first place and the product fulfils its intended use when placed in its intended environment. In this specific case verification is enacted with test case development and testing (matching system functionalities to IT requirements) where validation covers how and how much the system functionalities match the user/stakeholders needs identified in the first phases of the project.

General understanding of V&V process:

- Verification: do the IT artefacts deployed match the technical specification and expectations?
- Validation: do (and to what extent) the solution deployed matches the user/business requirements and expectations?

Figure 3 shows how the BEinCPPS approach is specifically enacted in the aforementioned spiral approach. The figure presents the first half of the project, with the final requirements documentation being one of the inputs of the project second half that will begin with a second scenario analysis, built on the previous outcomes (the requirement database and requirement document which contains the verification and validation results).

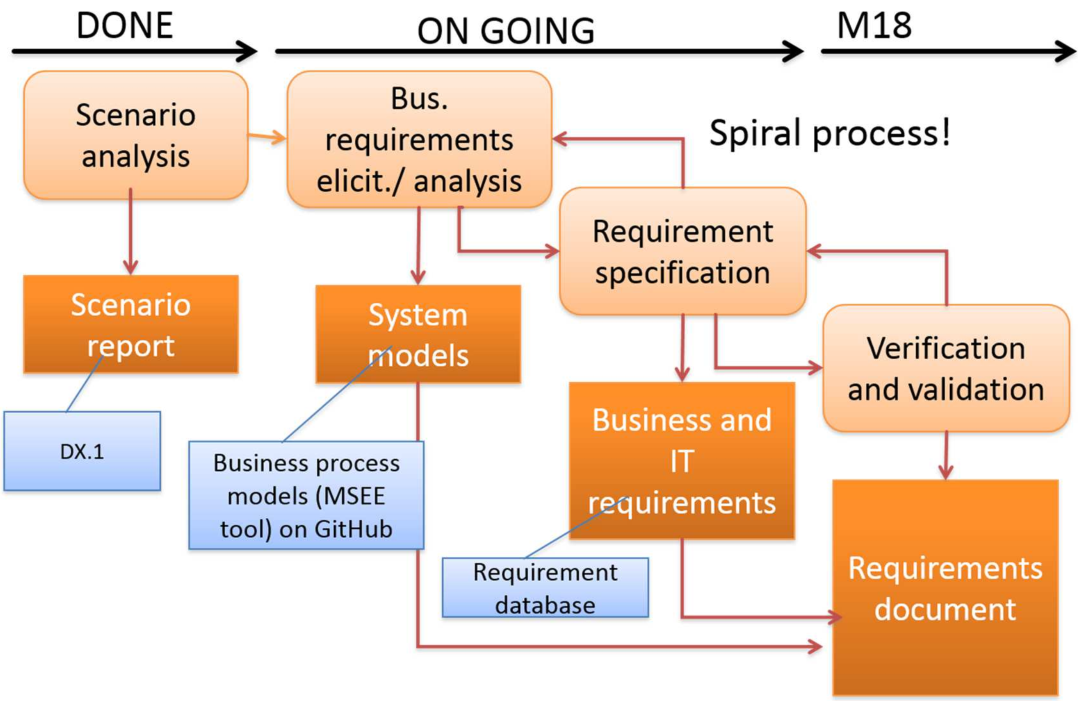


Figure 3 - Spiral approach of BEinCPPS reqs. engineering method

Figure 4 shows the data structure supporting the project, especially the scenario analysis, requirements elicitation and requirement specification. The model includes as well the repositories, such as Github, which are used in the project to share the related information.

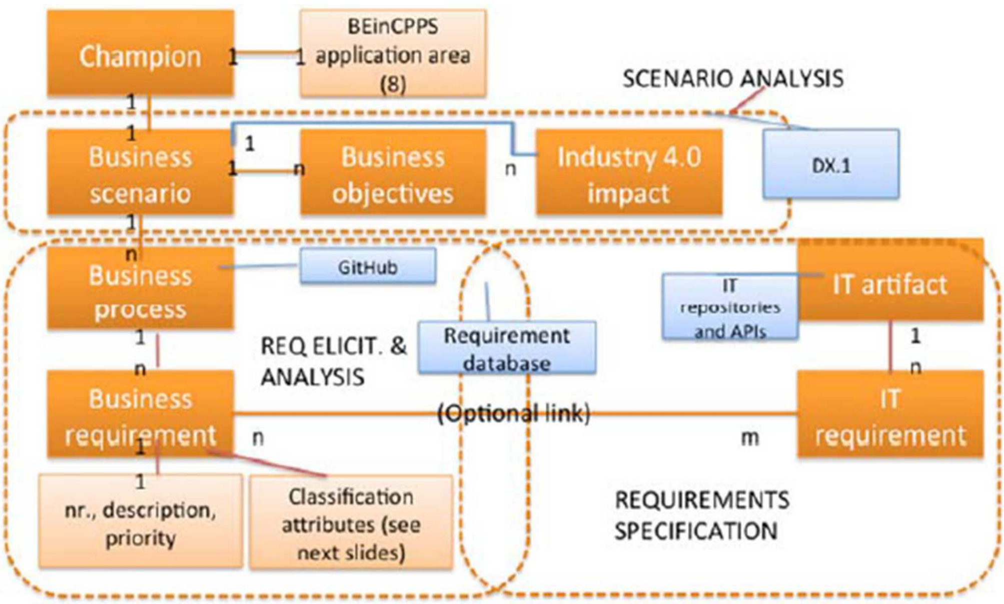


Figure 4 - BEinCPPS requirement eng. data structure

Each champion has identified one business scenario or area of intervention, with its specific business objectives and KPIs, and industry 4.0 impacts. Recount of these activities, building up the 'Scenario analysis' has been included in the five champions Deliverables Dx.1 due M3.

After this phase, the scenarios, studied as a chain of business processes that make up the whole business process of the intervention area, have been linked with specific objectives and indicators: the most effective way for this is also to assign specific business objectives and indicators for each business process. Then, for each business process a list of business requirements has been identified, in order to identify precisely how the system/solution deployed will support the transformation of the old "As Is" processes to the new "To Be" situation. This is essentially the 'business requirement elicitation and analysis' phase. A requirement database has been shared among the champion partners.

In the third phase, the 'requirement specification' phase, the business requirements are matched with IT requirements devised to enable technical partners to design the specific architecture and the set of interfaces and IT artefacts to be deployed in each champion. A core set of IT artefacts has been identified as a common ground as well (see Deliverable D2.1). This allows consortium partners to identify, by backtracking the logical links of the data structure, what is the added value of each specific IT artefact and to what common needs it may contribute to satisfy.

2 Norte Champion description

2.1 Company description

KYAIA, Fortunato O. Frederico & Ca Lda, was created in May 1984, and currently is the leader of a business group composed by sixteen companies, with more than 600 workers, spread by different areas such as footwear production, sole injection, distribution and retail, real estate and rural tourism. KYAIA is the biggest Portuguese footwear manufacturer. KYAIA has its head office in Guimarães, in the North region of Portugal, with 8000m², and owns two manufacturing plants (Guimarães and Paredes de Coura) that include advanced production lines equipped with new technologies, like CAD/CAM, cutting systems (water jet and knife), last manufacturing machines, automatic warehouses, automatic stitching and assembly conveyor systems, and ICT support systems. KYAIA has also its own retail chains and online stores.

Since 1995, KYAIA has been involved in national and European RTD projects. In the CEC-made-shoe European project, the goal was the development of a new concept for the shoe production characterized by production in flow with high flexibility, supported by a new highly flexible logistic system that integrates the different traditional manufacturing sections of assembly and final finishing in just only one section. Subsequently, the company conceived and implemented a new radically new factory, the High Speed Shoe Factory (HSSF), integrating all the shoe production phases (cutting, stitching, assembly and final finishing) and allowing the simultaneous production of shoe models of different constructive systems.

2.2 Use case description/intervention performed

2.2.1 Manufacturing plants at KYAIA

KYAIA was one of the earlier adopters of internal logistic systems in their two manufacturing plants (Guimarães and Paredes de Coura). At Paredes de Coura manufacturing plant (see Figure 5), the stitching phase is organized in two separate production systems, each comprising two production lines (see Figure 6) and two warehouses, with approximately 200 working posts. The assembly phase is implemented on a single manufacturing line. Each of the manufacturing lines is supported by an internal logistic system that carries boxes containing the material to be processed from working post to working post and between working posts and the warehouses, through running conveyor belts. PLC devices are in control of the internal logistic systems.

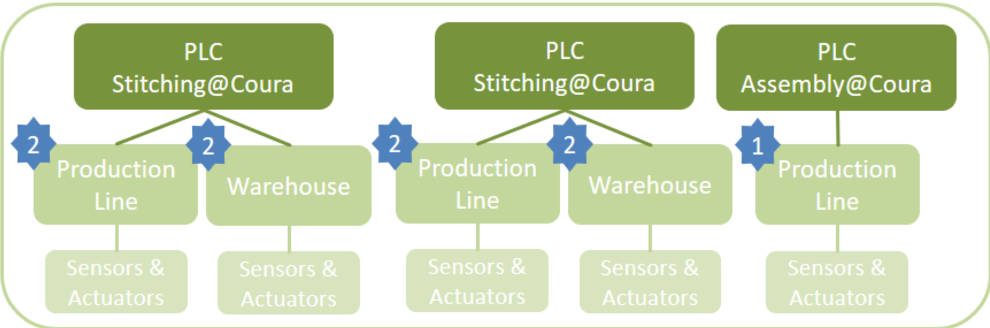


Figure 5 – Architecture of the manufacturing plant at Paredes de Coura

Figure 6 – Manufacturing plant at Paredes de Coura: stitching manufacturing lines at the front and warehouses at the back

At Guimarães plant, an innovative production system, named High Speed Shoe Factory (HSSF, see Figure 7) constitutes the most recent generation of production system being adopted in the footwear sector by KYAIA. It is the result of a Portuguese research and innovation project and is a prototype not yet fully exploited.

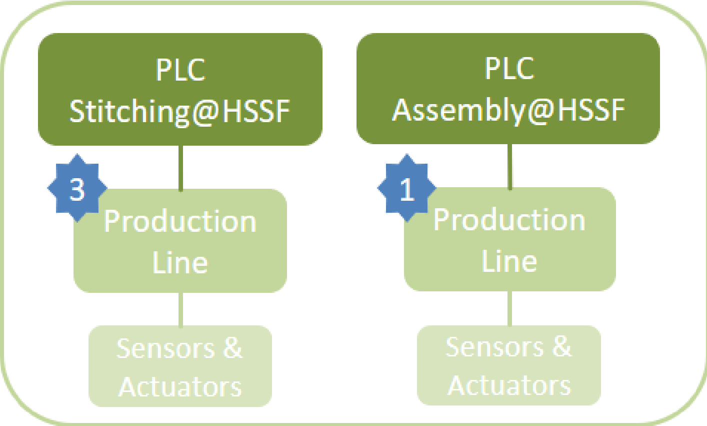


Figure 7 - Architecture of the manufacturing plant at Guimarães (HSSF)

The HighSpeedShoeFactory comprises two major systems:

- the Stitching Logistic System (see Figure 9 and Figure 10), implementing the activities of pre-stitching, stitching and pre-assembly along approximately 40 working posts, distributed on three production lines (each with its own robotic manipulator);
- the Assembly Logistic System (see Figure 8), implementing the final assembly and finishing activities of the final product.

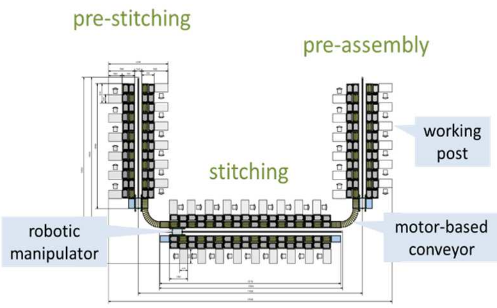


Figure 9 - Stitching Logistic System (HSSF)

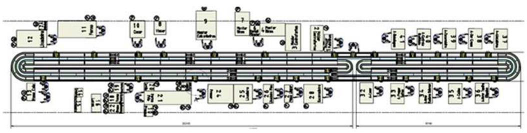


Figure 8 - Assembly Logistic System (HSSF)

Figure 10 – The High Speed Shoe Factory: stitching production lines

2.2.2 BEinCPPS applications experiments

Three experiments were prepared and put in operation at Kyaia:

- Access sensors on footwear production lines;
- Diagnostic and predictive maintenance;
- Production monitoring.

These application experiments are described in the following sections. Figure 11 presents the abstract architecture envisioned for the interventions at KYAIA.

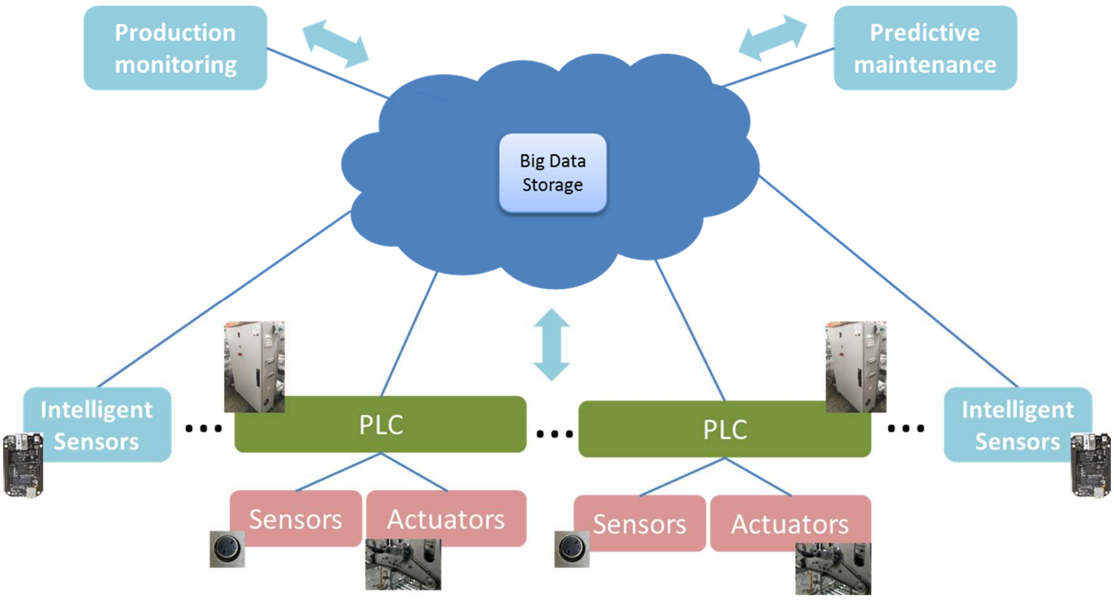


Figure 11 – Abstract architecture of the system envisioned for KYAIA and footwear manufacturing companies

2.2.2.1 Access Sensors on footwear production lines

The aim of this application experiment is to allow sensor-based and actuator-based data to be accessed on KYAIA manufacturing plants, to store the correspondent data streams on a persistent NoSQL data repository and to propagate them on near real time to factory and enterprise level applications.

The application experiment was carried on all the stitching manufacturing lines in the two manufacturing plants (Guimarães and Paredes de Coura). This corresponds, respectively, to a total of three stitching lines with 42 working posts and three robotic manipulators in the High Speed Shoe Factory and four stitching lines with 200 working posts in the Paredes de Coura plant. These manufacturing plants comprise different generations of internal logistics systems, with different PLC devices. The ICT components supporting the experiment are in operation since September 2016 and have been managed by INESC TEC and KYAIA, in this last case with the involvement of two collaborators from the ICT department. The role of KYAIA has been to validate the time series of data that are being gathered from the shop floor, and by doing this, to ensure that they are correct and do correspond to the actions realized in the shop floor (for example, transporting a box from one working post to another working posts, placing a box on a working post, etc.). The system is autonomous and generates daily emails to KYAIA indicating its current status.

Figure 12 identifies the targeted manufacturing plants (in the bottom of the diagram) and on top of the PLC devices the major software components.

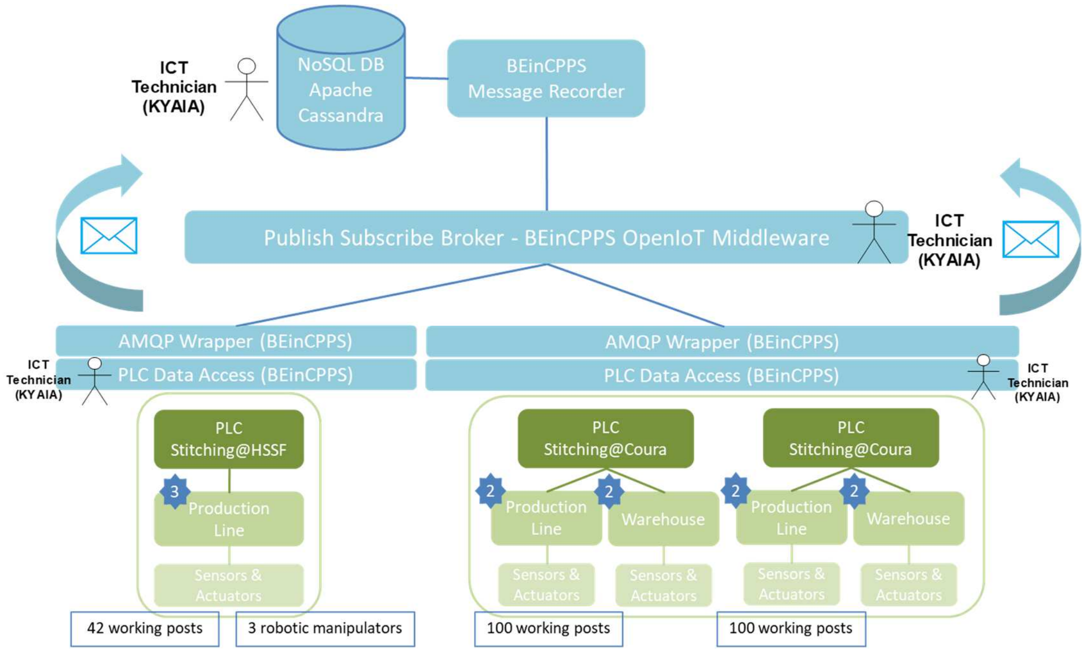


Figure 12 - Major elements on the "Access sensors on the shop floor" application experiment

The PLC Data Access externalizes sensor/actuator data out of the PLC devices, by publishing these sensor/actuator data streams on a message broker through a publish subscribe communication model, allowing ICT services and applications to subscribe these data streams. The application was developed by INESC TEC and reads segments of memory within PLC devices in order to know the current state of sensors and actuators.

For each sensor/actuator and other controlling variables the PLC Data Access component:

- Keeps the last retrieved value;
- Compares current value with last value;
- Generates a message to the publish subscribe message broker indicating a state transition:
  - channel - identifies the sensor/actuator or controlling variable;
  - value – sensor/actuator value (bit) or controlling variable.

Messages are published on the OpenIoT Middleware through the AMQP Wrapper (Advanced Message Queuing Protocol). Concurrently, the Message Recorder component (developed by INESC TEC) receives all the published messages and stores them on a NoSQL data base (Apache Cassandra) as time series of data. This way, data gathered from the stitching manufacturing lines are persistently saved.

2.2.2.2 Diagnostic and predictive maintenance

The aim of this application experiment is to analyse historical and near real-time sensor-based and actuator-based data related to the critical physical elements on the High Speed Shoe Factory (working posts, robotic manipulators, integration conveyors) in order to detect the actual occurrence of physical problems and to estimate their possible occurrence in the near/medium term future.

The application experiment was carried on the stitching manufacturing lines at the manufacturing plant in Guimarães (i.e. the High Speed Shoe Factory). This corresponds, respectively, to a total of three stitching lines with 42 working posts and three robotic manipulators. Initial versions of the ICT components supporting the experiment were installed on September 2016. Major adaptations and incremental validations were achieved until the end of 2016 and the experiment was carried out by KYAIA on January/February 2017. Two collaborators participated: one from the ICT department and one from the Maintenance department. The role of KYAIA has been to explore the human machine interface in order to use the alarms generated by the system to plan and to do maintenance actions on the correspondent physical elements in the logistic system.

The architecture of the implemented solution is presented in Figure 13. A brief description of these software components follows.

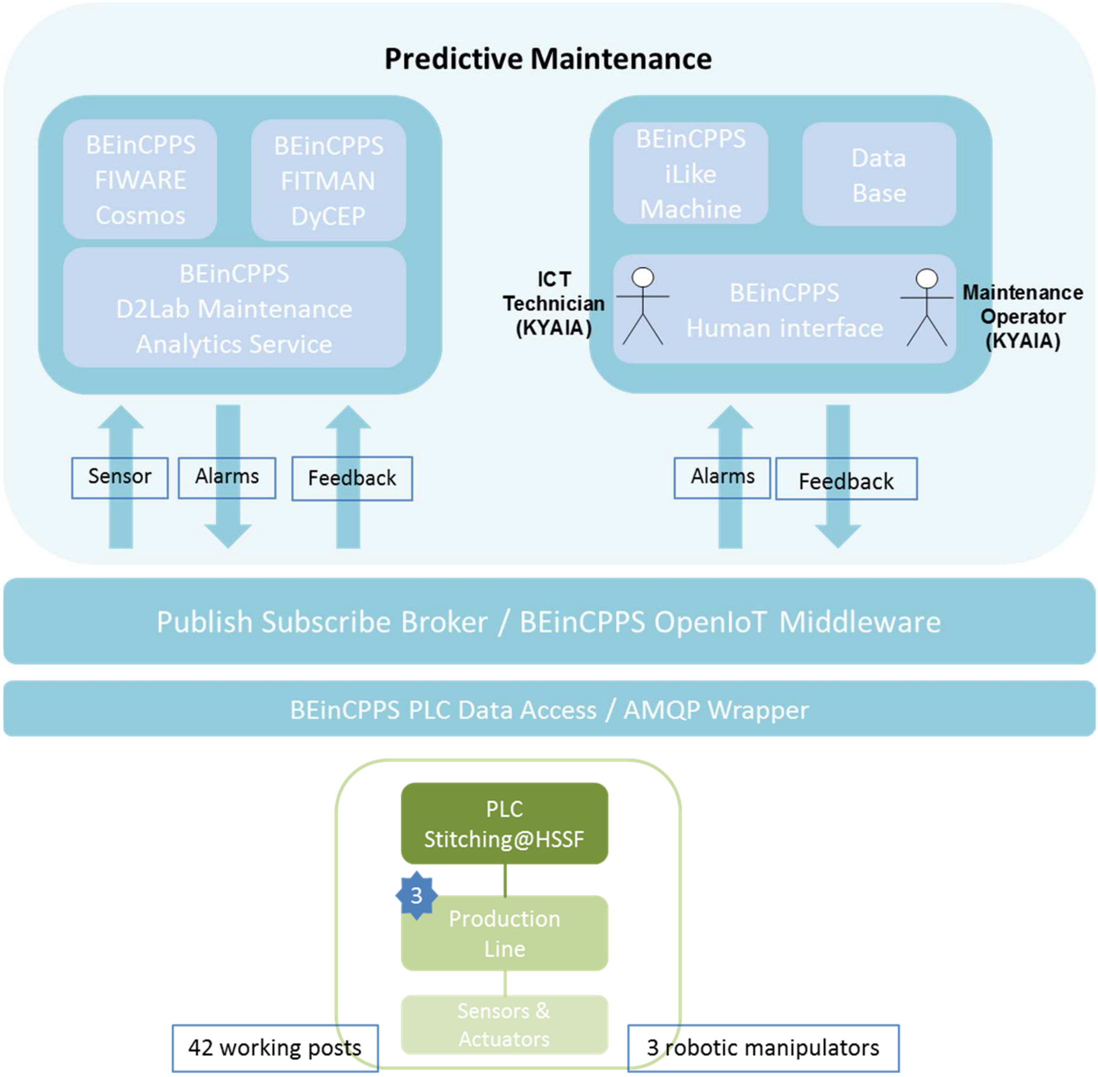


Figure 13 - Major elements on the "Advanced data analytics for diagnostic and predictive maintenance" application experiment

Advanced data analytics for diagnostic and predictive maintenance

As described in the previous section, the events gathered at the stitching manufacturing lines and that identify the actions made by the logistic system are published in the OpenIoT Middleware by the PLC Data Access. As depicted in the upper left corner of Figure 13, the D2Lab component (developed by the partner NISSATECH) acts as a subscriber and receives all the events. The approach taken to process these events (i.e. the ones generated by the sensors at the working posts) is illustrated on Figure 14, representing the simpler transformations between events.

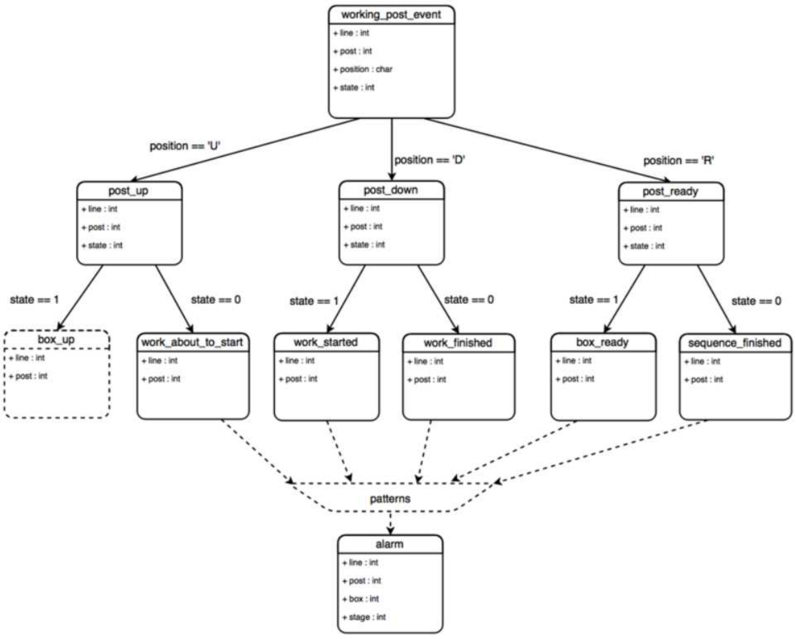


Figure 14 – Data analytics service: stream definitions

Based on these events, data patterns are defined representing the normal flow of operations performed on the manufacturing line. The data patterns are relatively simple, and can be easily expressed with *(not) followed by* logic and a timeout and, most importantly, matching by manufacturing line and working post. Figure 15 shows the events that feed the data patterns and the business rule that trigger an alarm once they are broken.

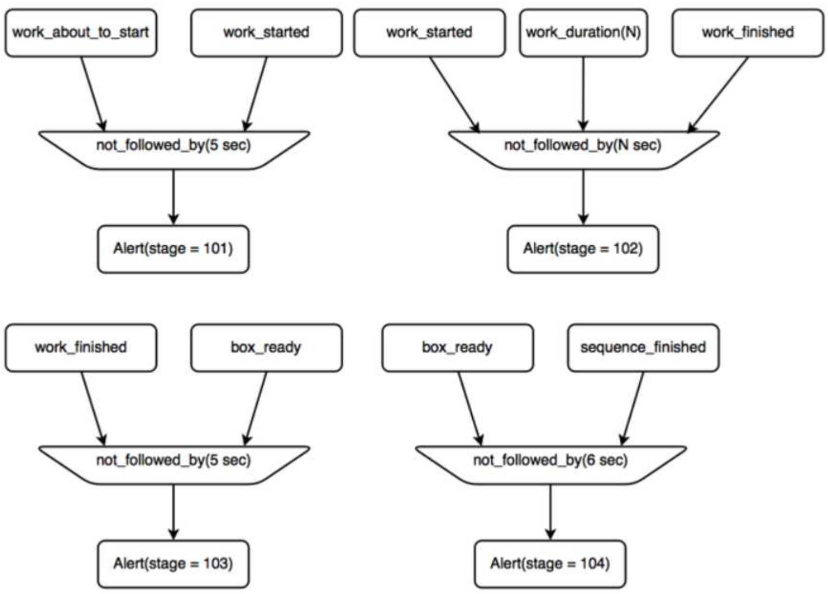


Figure 15 – Data analytics service: alarm patterns

Table 2 identifies the scenarios that led to the generation of alarms. The alarms are automatically published in the BEinCPPS OpenIoT Middleware.

Table 1 – Data analytics service – generated alarms

Alarm	Description
101	Box picked up from the up location, but did not show up on bottom in an appropriate time and work has not started.
102	Work has started, but takes more than work_duration seconds. Work duration is specified for each operation.
103	Box is removed from bottom position/working area, but is not placed on place for the manipulator to pick it up.
104	Box not picked up by the manipulator for an extended period of time.
201	Gripper error status value went from 0 to 1.
301	Emergency button status value went from 1 to 0.

The above description seems simple but it should be noted that the initial point was the identification of data patters, on the manufacturing line, by the domain specialists (KYAIA and INESC TEC).

Mobile interfaces for diagnostic and predictive maintenance

The Mobile Interfaces for diagnostic and predictive maintenance is represented in the right top corner of Figure 13 (development was done by the partner HOLONIX). It aims to complement the previous application (i.e., Advanced Data Analytics) with ICT mobile interfaces targeting maintenance teams in the shop floor and production responsible (of the production line and manufacturing plant), allowing them to react to detected alarms and potential problems (see Figure 16). Its main objective is thus to make the maintenance operator aware of the malfunctions on the production lines and to receive from him the feedback of the operations performed to solve the problems (see Figure 17).

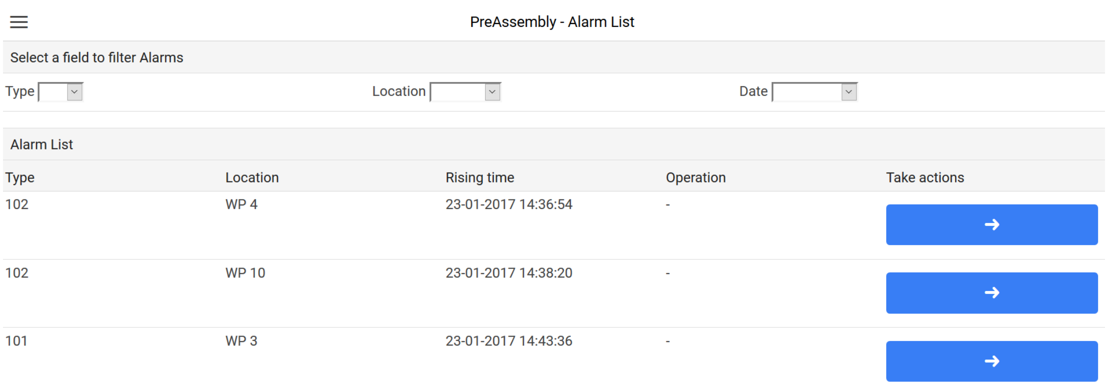


Figure 16 - Mobile Interfaces: alarms generated on a specific line

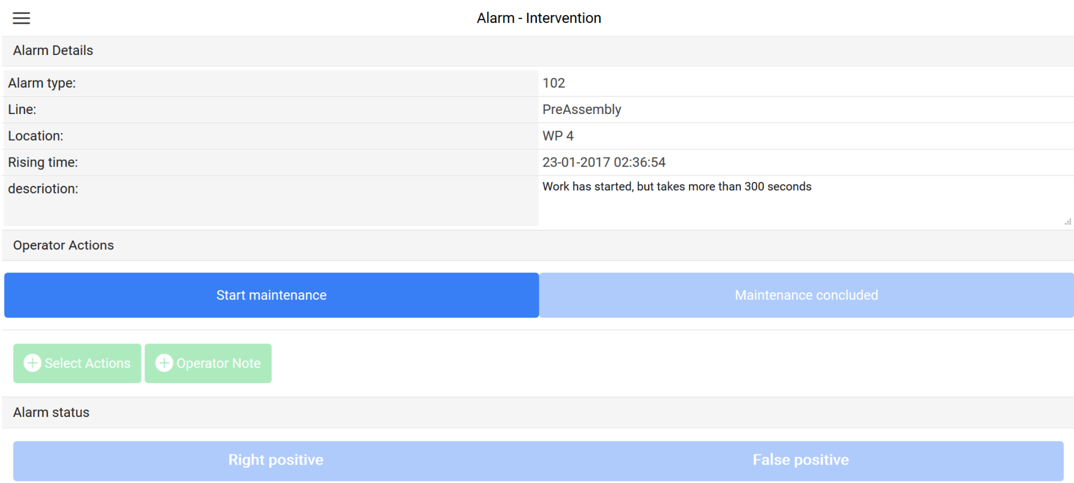
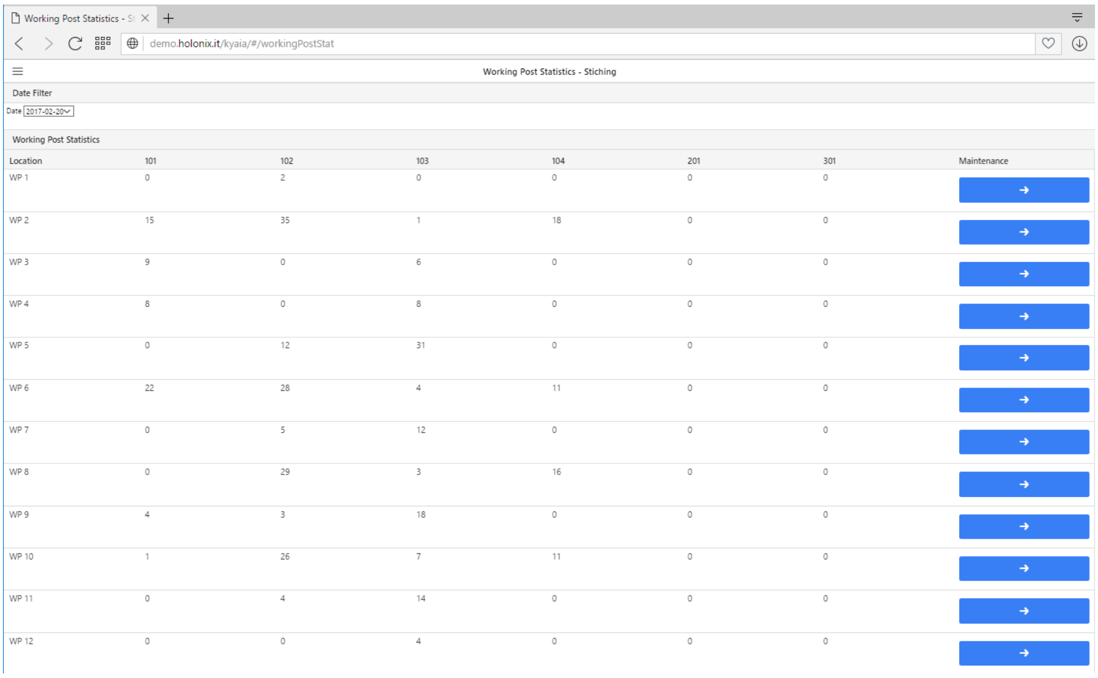


Figure 17 - Mobile Interfaces: registration of the maintenance operations done by the operator

Figure 18 shows the daily alarm statistics that is useful to expedite the processing of alarms when are generated a huge amount of alarms.



Location	101	102	103	104	201	301	Maintenance
WP 1	0	2	0	0	0	0	
WP 2	15	35	1	18	0	0	
WP 3	9	0	6	0	0	0	
WP 4	8	0	8	0	0	0	
WP 5	0	12	31	0	0	0	
WP 6	22	28	4	11	0	0	
WP 7	0	5	12	0	0	0	
WP 8	0	29	3	16	0	0	
WP 9	4	3	18	0	0	0	
WP 10	1	26	7	11	0	0	
WP 11	0	4	14	0	0	0	
WP 12	0	0	4	0	0	0	

Figure 18 - Mobile Interfaces: accumulated number of alarms on a single day in a working post

2.2.2.3 Production monitoring

The aim of this application experiment is to monitor the running of footwear logistic systems in real time (stitching manufacturing lines). The application delivers a dashboard graphical user interface accessible on any Internet browser and provides real time information about the work accomplished in each working post in a production line: which container box is assigned to each working post, what is the estimated time for the manufacturing operation, how much time did the operator consumed, etc. It is useful to inform the production manager about work assignment and alert him/her about possible delays and possible work disarrangement in a given working post.

The application experiment was carried on all the stitching manufacturing lines at Paredes de Coura manufacturing plant. This corresponds to a total of four stitching lines with 200 working posts. The ICT components supporting the experiment are in operation since September 2016 and have been managed by KYAIA. The role of KYAIA has been to exploit the information provided in by application in two physical places: on the manufacturing line, by the manager of the production line, and on the ICT department by the manager of the ICT infrastructure.

The architecture of the developed solution is presented in Figure 19.

The Working Posts Monitor (left top corner of Figure 19) is a simple application (see the middle of Figure 20), displaying in just one screen the current status of the logistic system. The application acts as a subscriber of the OpenIoT Middleware and, as such, it receives all the events generated by the sensors in the field level identifying what is going on in terms of flow of production (by knowing the flow of the correspondent container boxes). By looking at the application screen, the production manager is aware of how work is being assigned to the working posts and how it is being carried out by the correspondent operators (in terms of estimated and consumed time). When necessary, changes are made in the actual work assignment, by acting on the SmartSL component. Development of the Working Post Monitor was done by KYAIA itself.

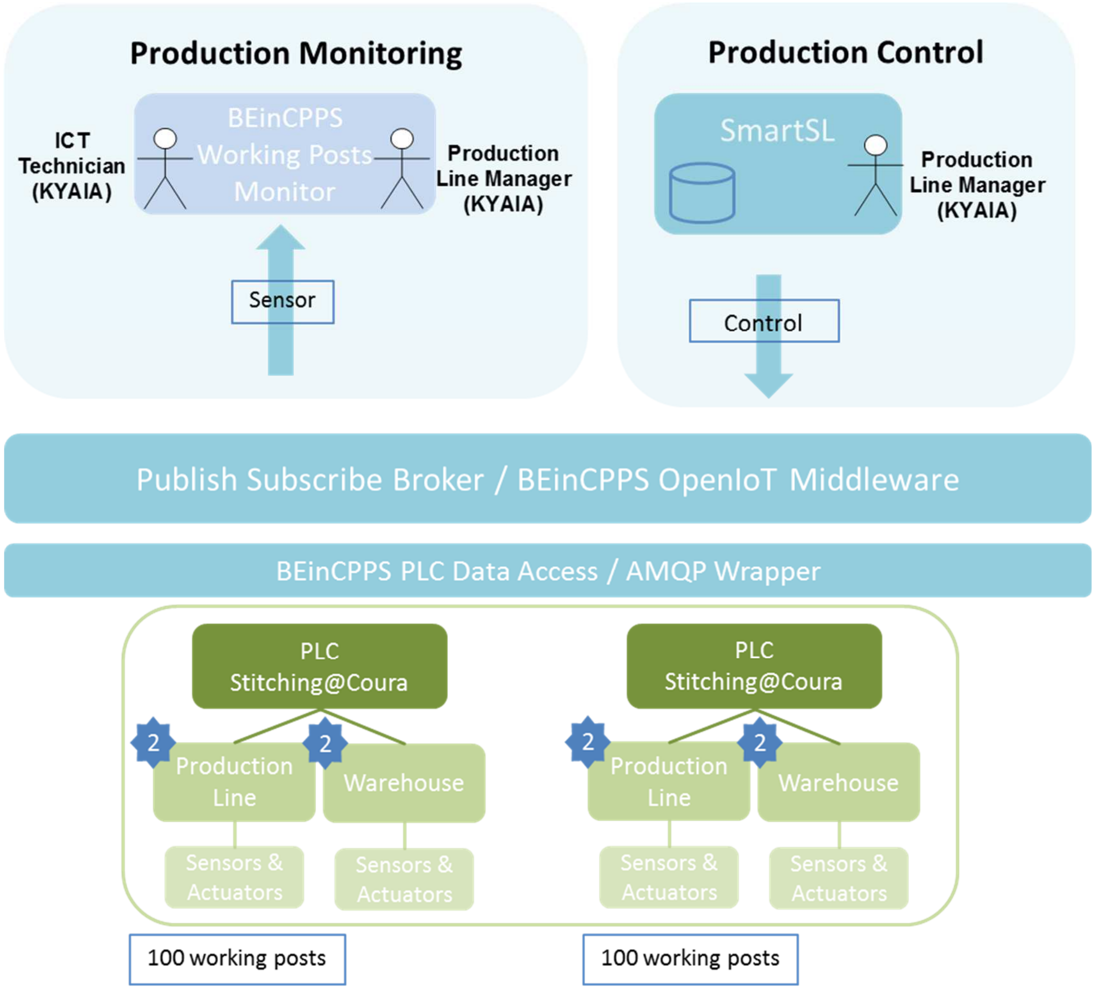


Figure 19- Major elements on the "Working Posts Monitor" application experiment

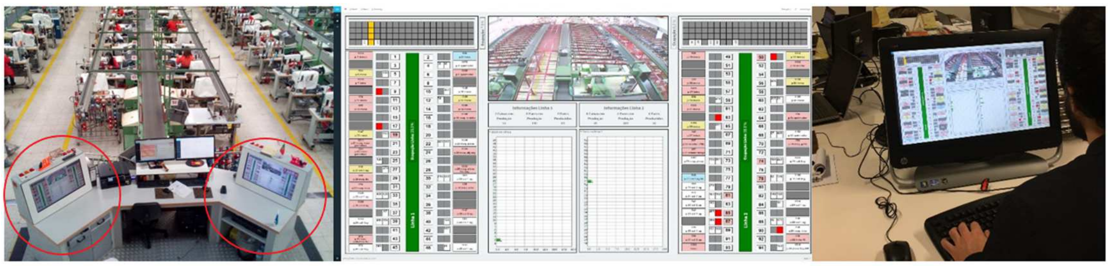


Figure 20 - Working Posts Monitor: on the manufacturing line (left fotograph), its display screen (screen shot on the middle) and on the ICT department (right photograph)

3 Experiment plan

3.1 List of Experiments

Next tables provide the following information:

- Table 2 – brief description of the each experiment;

- Table 3 – identification of the business processes and requirements to be addressed;
- Table 4 – identification of the business objectives and KPIs (AS-IS and TO-BE).

Table 2 - Experiment plan

Exp. Number	Experiment Name	Experiment Description				
		Objective	**Time**	**Location**	**Involved stakeholders**	**Involved resources**
Ex01	Access Sensors on footwear production lines	Gathering and propagation of field-level data to factory and cloud (enterprise) levels and storage on a NoSQL	From 09/2016 To 02/2017 (running now on production)	-Guimarães (HSSF); -Paredes de Coura;	-Carlos Teixeira (KYAIA, ICT management); -Amadeu Mendes (KYAIA, ICT management); -César Toscano (INESC TEC, project manager); -Rui Dias (INESC TEC, software architect and developer); -Nenad Stojanovic (NISSATECH, project manager); -Milan Jovic (NISSATECH, software architect and developer)	-At Guimarães, HighSpeedShoeFactory (three production lines, 42 working posts, three robotic manipulators); -At Paredes de Coura Factory (4 production lines, 200 working posts); ICT components (see section 2.2.2.1)
Ex02	Diagnostic and predictive maintenance	Real time detection of physical problems on working posts and robotic manipulators and estimation of their possible occurrence in the near/medium term future.	From 01/2017 To 02/2017	-Guimarães (HSSF)	-Carlos Teixeira (KYAIA, ICT management); -Miguel Ribeiro (KYAIA, Maintenance technician); -César Toscano (INESC TEC, project manager); -Rui Dias (INESC TEC, software architect and developer); -Nenad Stojanovic (NISSATECH, project manager); -Milan Jovic (NISSATECH, software architect and developer);	HighSpeedShoeFactory (three production lines, 42 working posts, three robotic manipulators)

					-Ida Critelli (HOLONIX, project manager); -Weian Xu (HOLONIX, software developer)	
Ex03	Production monitoring	Real time view on the current status of the production system through elaborate user interfaces fulfilling the needs both of the production manager and of the responsibles in the production lines.	From 09/2016 To 02/2017	-Paredes de Coura	-Amadeu Mendes (KYAIA, ICT management); -Sandra Correia (KYAIA, Production line manager); -César Toscano (INESC TEC, project manager); -Rui Dias (INESC TEC, software architect and developer);	Paredes de Coura Factory (4 production lines, 200 working posts)

Table 3 - Business Process and Business Requirements

Exp. Number	**Experiment Name**	**Business Process**	**Business Requirements (BR)**
Ex01	Access Sensors on footwear production lines (HSSF + Paredes de Coura)	Maintenance Process and Production Process	BR31 - Gathering, publishing and storing all shop floor events
Ex02	Diagnostic and predictive maintenance (HSSF)	Maintenance Process and Production Process	BR20 - Decreasing down time of a working post BR21 - Decreasing down time of a robotic manipulator BR22 - Near real time malfunction detection within a working post

			BR23[1] - Near real time malfunction detection within a working post (response time) BR24 - Near real time malfunction detection within a robotic manipulator BR25[2] - Near real time malfunction detection within a robotic manipulator (response time) BR26 - Prediction of future malfunction occurrences in a robotic manipulator BR27 - Maintenance knowledge base
Ex03	Production monitoring (Paredes de Coura)	Production Process	BR28 - Logistics system monitoring BR29[3] - Logistics system monitoring (response time) BR30 - Production lots monitoring

[1] BR22 Near real time malfunction detection within a working post - The system should trigger the alarm in a mobile device in a 15 secs time window.

[2] BR25 Near real time malfunction detection within a robotic manipulator (response time) - The system should trigger the alarm in a mobile device in a 15 secs time window.

[3] BR29 Logistics system monitoring (response time) - Status changes (e.g. location of a box, location of a robotic manipulator) in the logistic system should appear in the computer screen in a 5 secs time window.

Table 4 - Business Objectives and KPIs

Exp. Number	Experiment Name					
		Business Process	**Business Objective**	**BPI**	**BPI "AS IS" value**	**BPI Target "TO BE" value**
Ex01	Access Sensors on footwear production lines (HSSF + Paredes de Coura)	Maintenance Process Production Process	*To decrease production lead time*	*1- Downtime[4] of WPs* *2- Downtime[5] of Manipulator* *3- Nr. produced shoe pairs* *4- Production costs / shoe pair* *5- Data from WPs* *6- Data from Manipulators*	*1- 15 min/day[6]* *2- 60 min/week[7]* *3- 272000* *4- X[8]* *5- no* *6- no*	*1- 5 min/day* *2- for next phase* *3- +2.5%* *4- -5%* *5- yes* *6- yes*
Ex02	Diagnostic and predictive maintenance (HSSF)	Maintenance Process Production Process	*To improve the efficiency of production*	*1- Downtime of WPs* *2- Downtime of Manipulator* *3- Real time anomaly detection (WP)* *4- Real time anomaly detection (Manipulator)* *5- Predictive anomaly occurrence (Manipulator)* *6- Maintenance knowledgebase* *7- Subcontracted maintenance costs*	*1- 15 min/day[9]* *2- 60 min/week[10]* *3- No* *4- No* *5- No* *6- No* *7- X[11]*	*1- 5 min/day* *2- for next phase* *3- Yes* *4- for next phase* *5- for next phase* *6- Yes* *7- -25%*
Ex03	Production monitoring (Paredes de Coura)	Production Process	*To increase production flexibility*	*1- Reassign work to WP* *2- Redistribute work to WPs* *3- Real-time visibility on logistics*	*1- No* *2- No* *3- No*	*1- Yes* *2- Yes* *3- Yes*

[4] Down time of a WP (working post) - period of time when the working post is unavailable due to a failure.
[5] Down time of a robotic manipulator - period of time when the robotic manipulator is unavailable due to a failure.
[6] Downtime of WP – On average, a single WP is down 15 min a day (estimated value).
[7] Downtime of manipulator – On average, a single manipulator is down 60 min one week (estimated value).
[8] X – Production costs, KYAIA policy prevents the disclosure of this information.
[9] Downtime of WP – On average, one WP is down 15 min a day (estimated value).
[10] Downtime of manipulator – On average, one manipulator is down 60 min one week (estimated value).
[11] X – Subcontracted maintenance costs, KYAIA policy prevents the disclosure of this information.

4 Experiment Results and Business Assessment

4.1 Business requirements

The following table shows the state of fulfilment of business requirements.

Table 5 - Business Requirements Assessment

Exp. Number	Experiment Name	Business Requirements (BR)	BR Fulfilled (Yes/No)	Comments
Ex01	Access Sensors on footwear production lines (HSSF + Paredes de Coura)	BR31 - Gathering, publishing and storing all shop floor events	Yes	
Ex02	Diagnostic and predictive maintenance (HSSF)	BR20 - Decreasing down time of a working post	Yes	
		BR21 - Decreasing down time of a robotic manipulator	not applicable	*To address in the next implementation phase as planned.*
		BR22 - Near real time malfunction detection within a working post	Yes	
		BR23 - Near real time malfunction detection within a working post (response time)	Yes	
		BR24 - Near real time malfunction detection within a robotic manipulator	not applicable	*To address in the next implementation phase as planned.*
		BR25 - Near real time malfunction detection within a robotic manipulator (response time)	not applicable	*To address in the next implementation phase as planned.*
		BR26 - Prediction of future malfunction occurrences in a robotic manipulator	not applicable	*To address in the next implementation phase as planned.*
		BR27 – Maintenance knowledge base	Yes	
Ex03	Production monitoring	BR28 - Logistics system monitoring	Yes	

	(Paredes de Coura)	BR29 - Logistics system monitoring (response time)	Yes	
		BR30 - Production lots monitoring	not applicable	*To address in the next implementation phase as planned.*

4.2 Business KPIs

The following table shows the business objectives assessment.

Table 6 - Business Objectives Assessment

			Business Assessment				
Exp. Number	**Experiment Name**	**Business Objectives**	**BPI.**	**BPIs "As is" value**	**BPIs Target "To be" value**	**BPIs Actual value**	
Ex01	Access Sensors on footwear production lines (HSSF + Paredes de Coura)	*To decrease production lead time*	*1- Downtime of WPs* *2- Downtime of Manipulator* *3- Nr. produced shoe pairs* *4- Production costs / shoe pair* *5- Data from WPs* *6- Data from Manipulators*	*1- 15 min/day* *2- 60 min/week* *3- 272000* *4- X* *5- no* *6- no*	*1- 5 min/day* *2- for next phase* *3- +2.5%* *4- -5%* *5- yes* *6- yes*	*1- 10 min/day* *2- for next phase* *3- +5.5%* *4- -10%* *5- yes* *6- yes*	
Ex02	Diagnostic and predictive maintenance (HSSF)	*To improve the efficiency of production*	*1- Downtime of WPs* *2- Downtime of Manipulator* *3- Real time anomaly detection (WP)* *4- Real time anomaly detection (Manipulator)* *5- Predictive anomaly occurrence (Manipulator)* *6- Maintenance knowledgebase*	*1- 15 min/day* *2- 60 min/week* *3- No* *4- No* *5- No* *6- No*	*1- 5 min/day* *2- for next phase* *3- Yes* *4- for next phase* *5- for next phase* *6- Yes*	*1- 10 min/day*[12] *2- for next phase* *3- Yes* *4- for next phase* *5- for next phase* *6- Yes*	

[12] Target value of downtime of WPs not achieved due to difficulties on detecting physical anomalies in a working post.

			7- Subcontracted maintenance costs (stitching line)	*7- X*	*7- -25%*	*7- -50%*	
Ex03	Production monitoring (Paredes de Coura)	*To increase production flexibility*	*1- Reassign work to WP* *2- Redistribute work to WPs* *3- Real-time visibility on logistics*	*1- No* *2- No* *3- No*	*1- Yes* *2- Yes* *3- Yes*	*1- Yes* *2- Yes* *4- Yes*	

4.3 Questionnaire results

(See Annex 1)

5 Overall lessons learned & recommendations

Discussion on key lesson learnt during the Champion experimentations and recommendations for the implementation of CPPS ("especially targeting SMEs")

Access Sensors on footwear production lines

In all the logistic systems developed up to date in the Portuguese footwear sector (also in KYAIA), the PLC completely hides the readings/writings that it performs in the sensors/actuators. The main difficulty in the application experiment was to retrieve this data (sensor/actuator signals) from the controlling PLC. Concretely, one had to identify the memory segments in the PLC device that relate to the readings/writings performed on each sensor/actuator on the logistic system. This was achieved with the help of the company that developed the automation software running on the PLC.

This experiment allowed KYAIA and INESC TEC to acquire knowledge about the internal working of the PLC and the way the physical elements in the logistic system are controlled by the PLC. This allowed to know exactly the type of data one can extract from the manufacturing lines in order to enable the development of software applications (e.g. production management, maintenance management, performance management) intimately related with the physical manufacturing process, thus starting building a cyber-physical production system (CPPS).

The application experiment was successful, having been fulfilled all the planned objectives. In fact, the application experiment in running in production mode.

Main recommendations for implementing CPPS in the scope of footwear manufacturing lines automated by internal logistic systems are:

- To model the physical manufacturing process in terms of physical elements, their relationship, and their structure in terms of sensors and actuators.

- To model the flow of material, components and product in the manufacturing line.
- To map the relationship between the sensors and actuators and the memory segments in the controlling PLC. To model the corresponding data types.
- To acquire as much as possible information on the automation software running on the PLC device.
- To install, configure and use the following BEinCPPS components:
  - PLC Data Access – this component, developed within BEinCPPS, allows one to access data available on the internal memory of PLC devices and to publish the gathered data in an information bus.
  - OpenIoT Middleware – this component acts as a message broker, allowing any external applications to access data published by the PLC Data access component.
- When configuring the PLC Data Access component, one may specify the sequence for reading data elements. However, this is not related to any specific order of getting the sensor values by the PLC itself. Thus, one should not design an application based on specific sequences of sensors readings.

Diagnostic and predictive maintenance

Up to date, maintenance of the physical elements that comprise the logistic systems developed in the Portuguese footwear sector (also in KYAIA) has been done in a very informal way. An electrician is usually in charge of doing maintenance actions and the scope of the intervention is very limited, as he/she does not have the skills and training to do many interventions. When this arises the company that developed the logistic system is called to act on the field.

Among the three application experiments, the diagnostic and predictive maintenance experiment was the most challenging, in terms of both manufacturing context and technology to involve. Many obstacles were faced but the most relevant was the high number of alarms raised by the data analytics service. On the first trials of the software we verified that many of the alarms are simply generated because some workers don't follow the usual working procedures and this has impact on the events that are being generated by the sensors and later on analytically processed. Thus, instead of detecting bad behaviour on the physical elements, one is detecting those situations, which are not the ones targeted by the application. A partial solution to the problem was implemented by not displaying to the maintenance operator single instances of the alarms (he/she was not able to process hundreds of alarms on a day) but simply an accumulated sum of the daily alarms per working post.

A second major obstacle in the development of the data analytics service was the specification of the expected data patterns (expected values taken by the sensors/actuators along time) and their anti-patterns. The first specification is straightforward but it is the second specification that if implemented in software would allow us to identify the real problems in the logistic system. However, this wasn’t achievable in terms of software implementation. The compromise was to partition the expected data patterns in several parts and do the anti-pattern implementation for each such part.

The third difficulty inherent to the development of the application and its practical experimentation derived from the fact that the selected BEinCPPS technology (FIWARE COSMOS, FITMAN DyCEP and iLike Machine) needed additional development in order to exploit it in a manufacturing context. The first two components were hidden inside the D2Lab Maintenance Analytics Service, developed by NISSATECH in the project. For supporting the interaction with the maintenance operator, a mobile user interface was implemented on top of the iLike Machine component. All this implied a significant effort in software development, concurrently tested and validated by INESC TEC and KYAIA on several iterations.

The application experiment implemented most of the planned objectives. All the software artefacts are running in production mode.

Main recommendations for implementing CPPS in the scope of footwear manufacturing lines automated by internal logistic systems are:

- To model the physical manufacturing process in terms of physical elements, their relationship, and their structure in terms of sensors and actuators (UML as basic notation, SysML for complex cases where UML is insufficient).
- To model the flow of material, components and product in the manufacturing line (UML as basic notation, SysML for complex cases where UML is insufficient). Specifically, one should model the normal/standard behaviour of the manufacturing operators when doing manufacturing operations and the exceptions to that.
- To model (UML) all possible sequences of actions done by the logistic system (e.g. robotic manipulator places box on the UP location of a working post, operator moves the box to the DOWN location, operator does the planned operation on the material contained inside the box, operator concludes the operation and moves the box to the READY location, robotic manipulator peeks the box and transports it to another working post). These sequences should be mapped into an expected sequence of data values retrieved from sensors/actuators available on the logistic system. Finally, one should partition a complex sequence of data values into several parts and configure the Data Analytics Service to detect them.
- To install, configure and use the following BEinCPPS components:
    - D2Lab Maintenance Analytics Service – this component is the critical software component in the application experiment and generates alarms from each detected data pattern coming on the sensor/actuator values through the Publish Subscribe Broker (OpenIoT Middleware).
    - Human Interface – this component interacts with the maintenance operator in order to identify all the generated alarms and to subsequently support him/her on registering all the maintenance actions done on the logistic system. This interface should target the visualization of daily accumulated number of

alarms of a given type and for each major physical element (e.g. working post, robotic manipulator).

- Exploitation of data learning technologies like FIWARE COSMOS, and FITMAN DyCEP requires special expertise not currently available in the industry and by most software engineers. Main recommendation when pursuing a solution supported by the analysis of "big data" is to involve specialists in this domain.

Production monitoring

The control of the logistic systems developed in the Portuguese footwear sector (also in KYAIA) has been done by two major elements: a set of PLC devices and an ICT system known as SmartSL. The SmartSL system allows the production manager to specify which working posts are available, what type of manufacturing operations they can perform, which operators are assigned to each working post, etc. Basically, it is a Manufacturing Execution System specifically focused on the needs of footwear manufacturing lines, being responsible for configuring the PLCs that are connected to it. However, no real time information is propagated from the PLC to the SmartSL system, i.e. from field level to factory level. This application experiment targeted this need of providing real time information about the current status of production, by gathering information from the PLC, allowing subsequently the manager of the manufacturing line to reconfigure the SmartSL system and change the assignment of footwear material and components to the working posts (alerts are raised about possible delays in each working post).

The key characteristic of the application experiment is that of providing real time visibility on the assignment of manufacturing tasks to each working posts in a single, but mostly effective, computer screen, without any interaction. Because of this no major obstacles were detected on its practical application.

This application experience allowed KYAIA to acquire knowledge about the data events generated on the shop floor and to use those that are suited to feed a graphical dashboard available on any internet browser.

The application experiment was successful, having been fulfilled all the planned objectives. The application experiment in running in production mode (Paredes de Coura manufacturing plant). KYAIA aims to implement the same type of instrument in the manufacturing plant at Guimarães.

Main recommendations for implementing CPPS in the scope of footwear manufacturing lines automated by internal logistic systems are:

- To design the Working Posts Monitor as an application with one computer screen displaying the physical layout of the manufacturing line and their working posts in a graphical way, and providing information on work assignment and visual alarms indicating possible delays on its fulfilment.
- To complement the running of the SmartSL system with the Working Posts Monitor, on the manufacturing line itself (to be used by the manager of the line), and on other departments of the company (for example, when available, the ICT department).

6 Conclusion

Three application experiments were successfully done at KYAIA: “Access sensors on footwear production lines”, “Diagnostic and predictive maintenance” and “Production monitoring”. They have involved the two manufacturing plants of KYAIA, one in Guimarães (HSSF) and the other in Paredes de Coura, with the participation of several departments, namely, the ICT, the maintenance and production.

The application experiments employed software components selected from the initial BEinCPPS Platform (background components) that were complemented by new developments (foreground components) made by the team comprising the work package (WP7).

Experiment nr. 1 “Access Sensors on footwear production lines” worked very well. All the planned requirements were fulfilled and the system is in full production mode. Experiment nr. 2 “Diagnostic and predictive maintenance” worked well. The planned requirements were fulfilled. The system is in full production mode, running at Guimarães, the manufacturing plant of KYAIA, but requires additional changes in the technique used to detect data patterns and generate the corresponding alarms. Experiment nr. 3 “Production monitoring” worked very well. All the planned requirements were fulfilled and the system is in full production mode, running at Paredes de Coura manufacturing plant.

7 ANNEX 1

Lessons Learnt Questionnaire

1. What worked well during the experimentations? Why?

Experiment nr 1 “Access Sensors on footwear production lines” worked very well, all the planned requirements were fulfilled and the system is in full production mode, running at the two manufacturing plants of KYAIA. A critical factor in this success was the help of the manufacturer of the software running in the targeted PLCs, which allowed us to get into the details of the internal structuring of the PLC devices. Also, the effort needed to build the PLC Data Access was delimited and allowed INESC TEC and KYAIA to have it running in a very short period of time. The results of this application experiment were then exploited in experiments nr 2 and 3.

Experiment nr 2 “Diagnostic and predictive maintenance” worked well, all the planned requirements were fulfilled but some issues were faced. The system is in full production mode, running at Guimarães, in the manufacturing plant of KYAIA. All the components of the planned architecture were put into operation, real time alarms of possible abnormal conditions in the operation of working posts are being generated and displayed in a computer screen (desktop and mobile) which is used by the maintenance operator. However, the data analytics service requires more changes in the technique used to detect data patterns and generate the correspondent alarms.

Experiment nr 3 “Production monitoring” worked very well, all the planned requirements were fulfilled and the system is in full production mode, running at Paredes de Coura manufacturing plant. The developed application is a single computer screen providing valuable real time information to the manager of the manufacturing lines and allowing him/her to introduce changes in the current assignment of work. This fact that the application has no human interaction and fulfils human needs was decisive in its usage. Also, the effort spent in software adaptation, customization and development was reasonable, with low risks of un-success. This was mainly done by KYAIA with the supervision of INESC TEC.

2. What did not work well during the experimentations? Why?

As stated before, experiment nr 2 “Diagnostic and predictive maintenance” worked well, but faced some issues which must be explained. This application experiment is the most challenging one, making use of cutting-edge technology (e.g. data analytics), not known by some of the partners in the team (only NISSATECH has the skills and know-how to address the data analytics domain). Also, the application experiment required significant customization of the foreground BEinCPPS components (FIWARE COSMOS, FITMAN DyCEP and iLike Machine). Thus, time was needed to do this development and to test and validate it on several iterations. Additionally, the large number of alarms that started to be generated (most of them not associated with physical error conditions) turned the management of the information processed by the maintenance operator to be a very difficult task.

3. What unexpected issues occurred and how did you fix them? Did you develop any useful solutions?

In experiment nr 2 “Diagnostic and predictive maintenance”, we were confronted with an unexpected situation: the initial modelling of the manufacturing line and the way the work is transported and assigned in the logistic system is not consistent with the reality, as some workers in the manufacturing line do not follow the usual working procedures defined by KYAIA. This was only detected when looking at the generated alarms and validating its correspondence with the situations the data analytics service was detecting. Many alarms started to be generated and consequently appearing on the mobile human interface. For the maintenance operator, this amount of data was impossible to treat. In a second phase, changes were made on the human interface application so that the maintenance operator could see an accumulated number of alarms of a given type for each working posts and for each day. This turned the information more valuable and easily processed by the human operator. Also, the generation of the alarms by the data analytics services was the object of improvements in order to generate more positive alarms and less false positives.

4. Did any opportunity emerge during the experimentation? Which kind?

Yes, experiment nr 3 “Production monitoring” has been put into operation at Paredes de Coura. KYAIA wants to have it running in the other manufacturing plant (Guimarães) as the results achieved were very good.

The PLC Data Access turned to be an important asset as it allows data to be retrieved from PLC devices which up to know were considered closed black boxes. Future exploitation of the application experiments in other footwear manufacturers will need its usage.

5. Were the project goals attained? If not, what changes would help to meet goals in the future?

Yes, all the planned business requirements were fulfilled.

6. What are the three most important lessons learned on the experiments?

-Gathering data from manufacturing lines and publishing it in an information bus (by the publish subscribe model) enables the development of ICT applications with different purposes. Production monitoring and diagnostic predictive maintenance are two examples.

-To be used at the shop floor, user interfaces should be as simple and effective as possible (few screens with valuable and aggregate information).

-When developing a project supported by data analytic techniques perhaps the best strategy is to first computationally process all the available data, proceeded by its analysis by the ICT experts and by the domain experts and then one should try to identify useful patterns that could enable further developments.

7. What recommendations would you make to others doing similar projects?

Please follow the lessons learned identified above and take into consideration the issues identified above.

Strengths	**Weaknesses**
What worked well during the experimentation? All three experiments (very well Exp1/Exp3, well Exp2). *Why?* Participation of the manufacturer of software on PLCs. Simple and effective user interface.	*What did not work well during the experimentations? Why?* Experiment nr 2 worked well but faced some issues. Very challenging use case. Cutting-edge technology. Required significant customization. Time.

Lessons Learnt

Were the project goals attained?

Yes.

What are the three most important lessons learned on the experiments?

Gathering and publishing field level data on information bus.

Simple and effective user interfaces on the shop floor.

New data analytics approach: first analyze data streams, then identify data patterns

Did any opportunity emerge during the experimentation? Which kind? Yes, experiment nr 1 and 3 are easily migrated to other manufacturing contexts.	*What unexpected issues occurred and how did you fix them? Did you develop any useful solutions?* Manufacturing workers not following normal working procedures. Large amount of data. Data aggregations were built.
Opportunities	**Threats**