VerSatilE plug-and-play platform enabling remote pREdictive mainteNAnce

Grant Agreement No	:	767561
Project Acronym	:	SERENA
Project Start Date	:	1st October 2017

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Title	:	Test-beds design and adaptation
Reference	:	D6.1
Dissemination Level	:	PU (public)
Date	:	2018-09-29
Author/s	:	COMAU
Circulation	:	EU/Consortium

Summary:

Description of the SERENA test beds design and adaptation. This deliverable is the main outcome of T6.1 including the preliminary setup and scenarios of each demonstrator as part of their corresponding tasks in WP6, namely T6.2-T6.5.

Contents

List of Abbreviations

CMM	Coordinate Measuring Machines
HMI	Human Machine Interface
HTTP	Hypertext Transfer Protocol
JSON	JavaScript Object Notation
LD	Linked Data
M	Month
PLC	Programmable Logic Controller
PoC	Proof of Concept
REST	Representational State Transfer
RUL	Remaining Useful Life
SW	Software
VPN	Virtual Private Network

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Executive Summary

The purpose of this document is to describe the outcome of T6.1 along with the contribution of T6.2-T6.5 describing the preliminary setup and scenarios for each industrial use case, namely:

- Robotics industry [COMAU]
- White goods case [WHEMEA]
- Elevators use case [KONE]
- Metrological equipment [TRIMEK]
- Steel production [VDLWEW]

Towards that end, first a generic reference architecture of the SERENA system is briefly presented, capturing the main requirements of the project. Next and through the sections 2 to 6, the adaptation of the common architecture to each testbed's requirements is presented along with the testbed description itself. In particular, each testbed includes the following subsections:

- Concept description
- Identification of the problem that each testbed is related to.
- Design of the testbed to address the identified problem, including the key failure causes identified, how they can be artificially induced, the corresponding maintenance activities, its validation approach, related reliability metrics identified so far as well as a preliminary risk assessment with the corresponding mitigation actions.
- Predictive analytics within the context of each testbed.
- How the SERENA solutions fit to the testbed and if external solutions are expected to be used instead.
- Software and hardware requirements for setting the testbed.
- Also, the deployment of each testbed in a real-world environment is discussed.

Finally, Section 7 is dedicated on the re-usability of potential equipment and/or software across the demonstrators, as identified upon the time of compiling this document.

For completeness, a brief description of the maintenance service enabling predictive analytics in the context of the COMAU and WHEMEA testbeds is presented in the Appendix A.

1 Introduction

1.1 Objectives

Aim of this deliverable is to report on the design and integration of the testbeds within the different industrial areas, towards testing and validating the solutions of the SERENA project. In particular the objectives of the testbed design and adaptation are the following:

- Design and finalise the demonstrator's physical layout
- Define the evaluation scenario/story
- Assess on the hardware and software requirements
- Decide on the validation approach and evaluated metrics (qualitative/quantitative)

1.2 Common cloud testbed implementation

In order to effectively assess the SERENA system and its solutions as an integrated set, a preliminary generic PoC was implemented by M14, including the key functionalities of the system in an integrated pipeline. For that initial PoC, the SERENA cloud has been and remains hosted on Dell's Infinite testbed, in a dedicated tenant environment. All use cases are hosted on the same tenant environment. The SERENA cloud is implemented as a micro services architecture based on Docker containers. Each SERENA cloud service, such as the visualisation service, is implemented as one or more Docker containers. The implementation and lifecycle of the SERENA services are managed by Docker Swarm, a container orchestrator. The underlying hosting environment consists of a number of virtual machines, which host the service containers on run time Docker engines.

To replicate the eventual SERENA cloud architecture, the underlying environment is implemented in three parts a) a development environment; b) a runtime environment; and c) a service state storage facility. The development environment is a separate set of servers used to download and build images for deployment to the runtime environment. Because it is isolated from the runtime environment, images can be tested and validated before they are pushed to the local Docker image registry, which is shared with the runtime environment. The runtime environment hosts the various services that make up the SERENA cloud. The services intercommunication is primarily using HTTP REST interfaces, but other protocols are supported for specific requirements, such as real-time data feeds. The SERENA services can move between hosts, and additional service instances started, to balance the workload on the cloud. As services are not fixed to a given host, the application state in each container, is externalised and maintained on a separate common storage facility. The common storage facility ensures that containers can access their state regardless of where they are on the SERENA cloud, and can be maintained independently of the containers. Therefore, the Docker image registry and the common state storage facility, form two of the SERENA data repositories supported in the cloud.

In the eventual SERENA cloud architecture, it is envisaged that the SERENA gateways and SERENA cloud would coexist in the same local area network. However, to allow each use case partner to locate their gateways close to the factory machinery they are collecting data from, Dell have provided a VPN client to connect to the initial SERENA PoC running on their testbed in Cork, Ireland. The VPN tunnel provides a secure connection from the use case partner's site, over the Internet, to the SERENA tenant cloud in Dell, and facilitates the direct transmission of raw, smart and context data from the gateways to the cloud. Additionally, the VPN client allows technical partners to access the cloud environment to develop their SERENA services, and where applicable modify the environment. Data is exchanged between the edge gateways and the cloud in JSON-LD format. JSON-LD is an extension to standard data that supports LD and provides a mechanism to exchange context data (machinery metadata) between the edge gateways and the SERENA cloud. The contextual data augments the raw and smart data with the semantics of who the data was collected and detail of the machinery it was collected from. The contextual data provides a more complete richer understanding of the data, its meaning, and how it can be analysed.

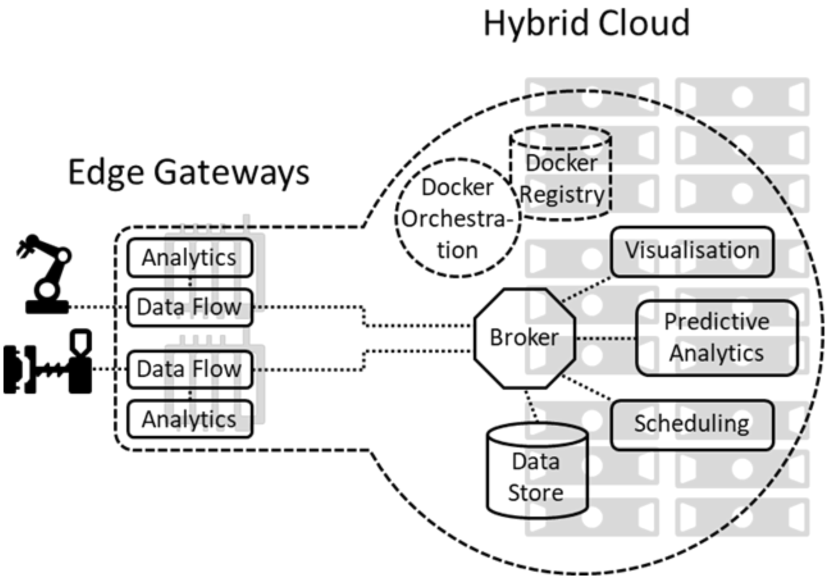

Figure 1. Core SERENA cloud service

The SERENA cloud architecture is made up of a number of interconnected services, which collectively form the SERENA system, as illustrated in Figure 1. For the initial PoC the services include a) the ingest broker, which receives data from the distributed gateways and syndicates the data to the cloud-based services; b) the data store(s), which act as the storage repositories for the raw, smart and metadata, as well as the results of the predictive analytics; c) the predictive analytics, user to analyse and model the factory machinery behaviour; d) the scheduling services, which reschedules maintenance activities based on the results of the predictive analytics; e) the visualisation service, which provides 3D interactive models of the factory machinery HMI; and e) the docker runtime environment, orchestrator and registry.

2 Robotics Industry Testbed

2.1 Concept description

COMAU deploys industrial robots around the world and the need to collect data to monitor health status of all its machines, in order to avoid sudden failures, is increasing. For this reason, COMAU is interested in studying connection to conditions causing failures and this is the aim of this testbed. COMAU has designed and developed a test-bed which consists of a real robot axis. The reason is that it is easier and less expensive to manipulate than an entire robot and it allows to better isolate the effect of environment phenomena. The aim is to simulate an industrial equipment sending information about its health status in almost real time in order to implement algorithms for predictive maintenance. The test-bed includes a motor, a gearbox, a belt and an encoder that measures the position (in round motors) of the motor. At the end of the mechanical chain there is a 5 kilos weight.

Figure 2. RobotBox mechanical structure

2.2 Problem identification investigated within the testbed

Cause	***Effect***	***Related parameters***	***Measurement method***	***Comments***
Backlash	Less precision in robot trajectories.	Current raw data, current features, position raw data.	Robot controller and related .log file.	Historical data collected from 5000 hours of work.
Belt tensioning	If the belt is too tensioned, the current consumption exceeds from its normal level. Otherwise if the belt is not enough tensioned, it could happen some shifts in the mechanical chain that provoke malfunctioning.	Current raw data, current features.	Robot controller and related .log file.	Labelled data are provided, by using a system to discretize belt tensioning and make the experiment repeatable: from 0 to 5 washers had been used to regulate the distance between the motor and the gearbox, i.e. the tensioning of the belt.

2.3 Testbed design

The test-bed, named RobotBox, sends the measured raw data to the locally connected gateway. At the gateway smart data or else features are calculated creating a JSON file (with all the information, including the analytics results) that is pushed afterwards to the cloud. All these communications pass through http protocol.

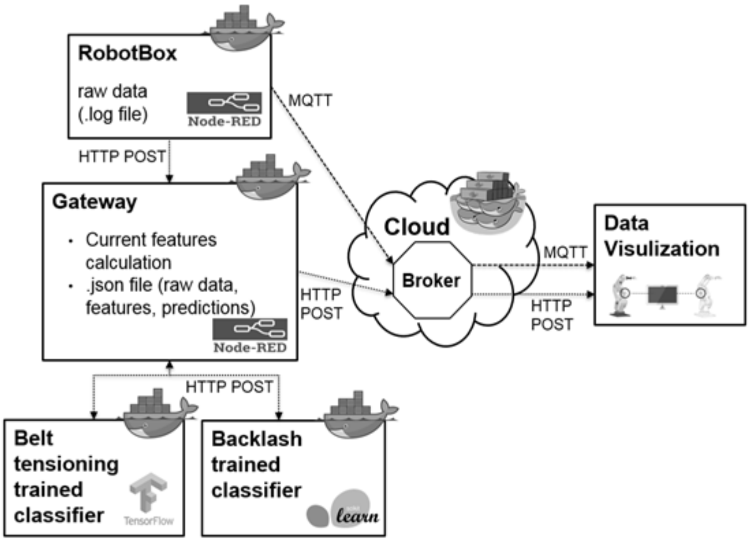

Figure 3. Use case implementation

In this use case, there is another data flow related to the real-time RobotBox position (sampled every 2ms) in order to create a real time visualisation of the activity performed.

The pictures below represent the RobotBox 3D model, where the motor, the gearbox, the belt, the encoder, and the weight are clearly visible. A Unity 3D WebGL application shows in a web browser many information coming from the SERENA platform in "near real-time":

- warnings, errors and RUL with different colours highlighting the involved part to immediately capture the operator's attention;
- preventive and predictive information to be displayed by selecting the involved part of the RobotBox;
- 3D virtual procedure to guide the operator while performing the maintenance activities;
- visualize the real-time position on the RobotBox 3D model to enable a remote monitoring of the physical behaviour observed.

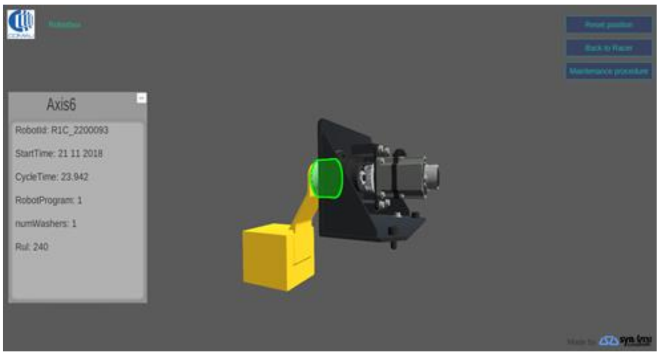

Figure 4. Example of 3D visualization

In the first image, it is possible to see the status of the gearbox in term of internal backlash; the status was discretized with three different colours (green, yellow and red) to immediately capture the operator's attention and provide an intuitive indication of the main information to check. The information box displays some important prognostic or predictive values, such as washer number and the RUL (Remaining Useful Life).

In the second one the information is about the belt tensioning maintenance procedure.

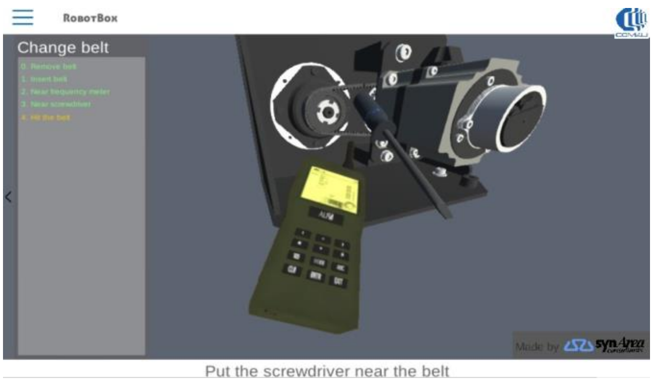

Figure 5. Example of 3D maintenance procedure

2.4 SERENA solutions

	Technology	**External technologies**	**Justification**
Gateway / Data acquisition	Data acquisition is delegated to a REST service on NiFi listening on a specified port for POST requests.	-	
Maintenance planning and predictive analytics	The Predictive Analytics service performs two tasks: 1. model building triggered by either a specific user input or an output of the self-assessment service. It produces as output the prediction model. 2. Prediction task triggered by a new robot cycle and generating a prediction label along with a RUL value. Scheduling Service for assigning maintenance tasks to on site personnel, based on the RUL value.	-	
AR-based operator support	Unity3D engine platform. 3D computer graphics software for animation, modelling, texturing, rigging, lighting and rendering.	Web Browser, mobile devices.	The VR/AR- based Unity 3D app can be developed and deployed for multiple platforms and operating systems.
Cloud based platform	In the COMAU experiment, the SERENA Cloud Platform will be deployed in the Infinite testbed provided by DELL.		

2.5 Hardware/Software requirements

Hardware

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	Motor of 6th axis of COMAU Racer Robot.	-	1	-
2	5 kilos Mass	-	1	It is used to simulate the end effector weight and momentum.
3	Gearbox	-	1	It is used to reduce the velocity and increase the torque.
4	Belt	-	1	It is used to transmit the motion from the motor to the adaptor.
5	Controller	-	1	Used to lead motor movements.

6	Test-bed	-	1	-
7	The SERENA cloud environment, see section 1.3		1	The SERENA cloud environment, see section 1.3

Software

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	Node-Red	-		A flux is used to collect raw data from the RobotBox and to calculate some
2	Node-Red	-		A flux is used to send a .json file to the Cloud platform.
3	TensorFlow and Python	-		Libraries used to implement a machine learning algorithm to predict the washer's number, with a view to understand if the belt status is acceptable or not.
4	Docker container			Each component is developed in a container, so that the platform could be scalable and flexible.
5	Web Server (Apache/Tomcat)			The Unity 3D WebGL HTML5 Applications needs a web server to be deployed and accessible in a web page of the SERENA cloud platform.
6	Javascript, REST API			To interface the Unity 3D WebGL HTML5 App with the SERENA system.
7	MQTT Broker protocol			Used for the data stream, to visualize the real-time position on the RobotBox 3D model, to enable a remote monitoring of the physical behaviour observed.

8	Python, Qlik and Chart.js			Libraries used to develop dashboard with the analytics results.
9	Docker (https://www.docker.com/) an opensource application containerization facility	-	8	Each component is developed in a container, so that the platform could be scalable and flexible.
10	Docker Swarm (https://docs.docker.com/engine/swarm/) an open source container orchestration manager	-	1	The orchestration manager manages the deployment and lifecycle of the Docker containers. Several alternate orchestration managers, such as Kubernetes, were considered, and any one of them been suitable candidates, but Docker Swarm was selected by IPT as it had a small platform footprint.
11	Portainer (https://www.portainer.io/) a HMI for Docker and Docker Swarm	-	1	Portainer provides a full set of visualisations of Docker containers and Docker Swarm services and grow out of the Docker community.
12	Apache HTTPD (https://httpd.apache.org/) a web server used to host the visualisation service	-	1	Is one of the most common open source web servers in use today.

2.6 Deployment

Plan	The plan to include the SERENA architecture in COMAU is composed by: - Install in the gateway the node-red flow to collect the features and get the analytics results. - Integrate all the service as Docker container in the current ICT infrastructure. - Decide if connect to an external cloud or install all the SERENA system on premise.
Demonstration scenario	If the belt is insufficiently tensioned, the maintenance has to tension it moving away the gearbox and the motor. If instead the belt is too frayed, it has to be changed with a new one. If the backlash is too accentuated, the only possibility is the adaption replacement. The objective is to have a resilient and scalable architecture service-based which is able to manage all the process chain, starting to the data acquisition, some local smart computations to the cloud communication and the analytics prediction. All the information about the process, the machineries status and the prediction has to be simply showed in a dashboard as well as the actual status (e.g. the robot position).

	The other two services requested are the maintenance scheduled based on the analytics results and the use of augmented reality. The COMAU use case will be hosted on Dell's SERENA cloud environment.
Replicability of defects	As regards the belt tensioning, a different number of washers is used to simulate the loss of tensioning which normally takes place over time. With respect to backlash, the failure is provoked "naturally", by requiring a stressing cycle to the RobotBox and accelerate the wear over time. We are installing a slide on the RobotBox in order to reach a more accurate and finer belt tensioning and developing a way to align the initial position for all the (by now) two test-beds.
Validation approach	The validation consists in evaluate the entire system internally in COMAU, specifically on the two versions of the RobotBox. The second step consists in generalize both the architecture and the analytics component in other machineries which use belts and anthropomorphic robots.
Reliability Metrics	Both the belt tensioning and the backlash are quite tricky to treat and model, that is why there are not some standard metrics.
Risk assessment/ mitigation actions	Thus far, collecting data regarding belt tensioning and backlash requires to stop the production or to complicate too much the mechanics; thus, we do not have any historical data. This lack of data is really limiting for the analytics purposes; in order to overcome this problem, we have created a test-bed where we can dynamically change the belt tensioning simulating the degradation of the belt in actual environments. Regarding the backlash, there have been retrieved data from a COMAU internal PoC where some motors were tested for around 5000 hours and backlash data was sampled over a year.
Current state	Creation of the new dataset changing from just a belt tensioning classification status to the remaining useful life.

3 White Goods Testbed

3.1 Concept description

As explained in D1.1 the equipment under test in WHR use case is the Foaming Machine and, in particular its mixing head. The scope of the experimentation is to monitor the condition of the Mixing Head in terms of 1) General Health Status; 2) Early Warning. These two conditions, or alarms, should be driven from a behavioral model generated through a Machine Learning approach using set of data gathered in different part of the equipment and able to correlate weak signal with future head failures modes.

At the current status of the knowledge the predictability of Mixing Head failure is extremely low: the main failure mode is the deformation of the self-cleaning piston that, once occurring, is causing the equipment to be in breakdown and requiring its substitution and lack of dedicated sensors and means for real time health status indicator of the component are causing the impossibility to prompting timely maintenance intervention.

For the experimentation, WHR is considering a two steps approach: 1) the equipment involved in the use case has already a set of data gathered from functional subsystem partially related with mixing head; 2) introduction of new sensors driven by FMECA approach.

The first step is challenging as is oriented in verifying existence of correlation between components status and head status: if verified we could enable a failure prediction using low cost sensors usually available in the standard configuration of the equipment (i.e. pressure, temperature, flow)

The second step is also challenging as involving a completely new family of sensors that requires the installation of a modified mixing head.

3.2 Problem identification investigated within the testbed

Cause	***Effect***	***Related parameters***	***Measurement method***	***Comments***
Self-cleaning piston blocked	Pouring system unavailable	Polyol T	Thermocouple	
		Polyol P	Pressure gauge	
		Isocyan T	Thermocouple	
		Isocyan P	Pressure gauge	
		Polyol quantity	Flow*time	
		Isocyan quantity	Flow*time	
		Mechanical Stress	Extensometers	

3.3 Testbed design

The testbed WHR has been designed to exploit existing datasets without compromising the production continuity. Two main datasets have been identified, shot data and maintenance data. Another dataset, less structured but useful to improve diagnostic and prognostic algorithm, will be supplied as well upon request.

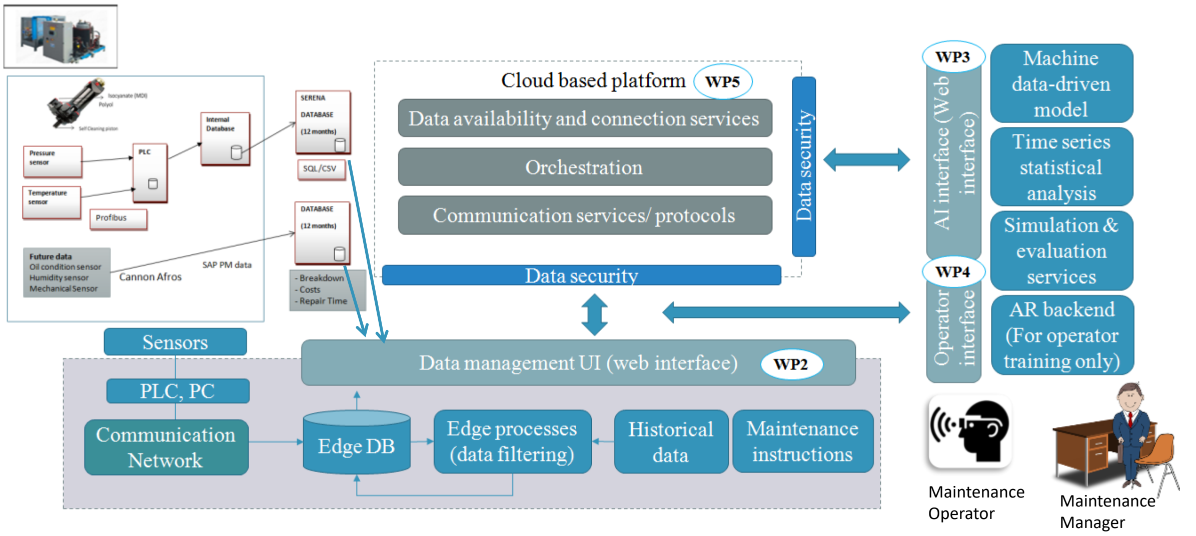

Figure 6: White goods testbed architecture

The first dataset is composed of data gathered in real-time from production equipment through an application provided by the vendor (and as such not adaptable by WHR) and made available to SERENA platform in a SQL database accessible through VPN. The data gathering has started in April 2018 and is ongoing. The dataset provided at first phase is comprising, Static Shot data and Dynamic Shot data. For each shot (usually occurring every 60-80 sec) we are recording data which are characterizing the shot itself: the datetime, the recipe code (associated 1:1 to model type) and the scalar describing number of components delivered by the system. Also, for each shot timeseries representing components temperature, pressure and real quantity measured during the pouring time (ca. 16 sec.). The second dataset is composed by logs of maintenance activities as recorded in SAP/PM database. Since the integration of Sap/PM into SERENA is not in the scope of the testbed, this set will be provided manually in .csv format to partners. The correlation can be made on timestamp.

3.4 SERENA solutions

	Technology	External technologies	Justification
Gateway / Data acquisition	Required Hardware not specified yet	-	Detailed use case planning still ongoing
Maintenance planning and predictive analytics	• The data analytics service will be used including the following: - model building triggered by a specific user input, it provides in output the prediction model - prediction task triggered periodically (i.e., user-defined parameter) generating a prediction label along with a RUL value • The utilisation of the SERENA scheduling service is under investigation.	In the future connection to the SAP MES will be considered	Already deployed MES system containing the entire production plan.

AR-based operator support	SERENA solution will be used for operator support.	-	-
Cloud based platform	SERENA cloud system to be used as deployed in ENG's infrastructure.	-	-

3.5 Hardware/Software requirements

Hardware

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	Workstation		1	A local workstation, provided by WHEMEA, will be used to run the SERENA Gateway on premises, being able to read the local database and send the rad data to the SERENA Cloud, using the defined data format and service endpoints.
2	Cloud Infrastructure		1	A cloud infrastructure will be provided by ENG in order to setup the SERENA Cloud Platform, in accordance to the specification of WP5. The infrastructure will be accessible via Internet, offering REST endpoints used by the local SERENA Gateway.

Software

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	Microsoft SQL Server 2012		1	Local mirror database containing all the raw data produced by the head.
2	SERENA Gateway		1	Implementation of a poller service able to check newly created data in the local database, pre-processing and preparing data in accordance to the SERENA data format and service endpoints.
3	SERENA Cloud		1	Implementation of a dedicated instance of the

				SERENA Cloud Platform providing storage and processing capabilities.
4	Docker (https://www.docker.com/) an open source application containerization facility	-	8	Docker is one of the most commonly supported containerization facilities in use today. Its ubiquity make it an ideal candidate for SERENA.
5	Docker Swarm (https://docs.docker.com/engine/swarm/) an open source container orchestration manager	-	1	The orchestration manager manages the deployment and lifecycle of the Docker containers. Several alternate orchestration managers, such as Kubernetes, were considered, and any one of them been suitable candidates, but Docker Swarm was selected by IPT as it had a small platform footprint.
6	Portainer (https://www.portainer.io/) a HMI for Docker and Docker Swarm	-	1	Portainer provides a full set of visualisations of Docker containers and Docker Swarm services, and grow out of the Docker community.
7	Apache HTTPD (https://httpd.apache.org/) a web server used to host the visualisation service	-	1	Is one of the most common open source web servers in use today.
8	Docker (https://www.docker.com/) an open source application containerization facility	-	8	Docker is one of the most commonly supported containerization facilities in use today. Its ubiquity makes it an ideal candidate for SERENA.

3.6 Deployment

Plan	1. Specify data access from local systems 2. Define required gateway hardware if needed 3. Prepare data acquisition flows and pre-processing
Demonstration scenario	The Whirlpool use case will be hosted on ENG's SERENA cloud environment. Process central experts and maintenance managers will examine in detail the results of data analytics, diagnostic and prognostic functions. Maintenance Supervisors and technicians will be involved in the analysis phase and will provide

	feedback on the system completing data evidence with tacit knowledge and experience.
Replicability of defects	Defects cannot be artificially induced since the machine on the use case is in production.
Validation approach	• First validation will be done on historical data: predictions will be compared with actual recorded machine events. • Second level validation will be performed by WHR maintenance experts thorough extra inspection of machine • Third level of validation will be performed through substitution of the components and a detailed examination of the substituted one The system will be transferred to the plant once the validation is turning positive. Initially the SERENA solution will be adopted in a standalone way with a plan of fully integration with the legacy system to be performed in 2 years. Moreover SERENA full or partial solution will be extended to other foaming equipment in others Refrigeration factories of the EMEA region (Siena IT, Wroclaw PL)
Reliability Metrics	N/A
Risk assessment/ mitigation actions	N/A
Current state	- Hardware Setup: preliminary planning - Data acquisition once per day from database and local CSV-files. - Configuration of connectivity and preliminary development of the SERENA Gateway software.

4 Elevators Industry Testbed

4.1 Concept description

KONE Industrial Car factory manufactures elevator cabins to the most special elevators around the world. Elevator cabin manufacturing includes thin metal sheet punching and bending which is a key process for the factory. Due to the criticality of the process, KONE has chosen to investigate and monitor the behaviour of this process. The process is executed with automatic machine and in detail the testbed is setup to monitor conveyor bearings and punching tool.

KONE use-case testbed is implemented to a production environment and it has been developed in cooperation with Finn-Power and VTT. The testbed development included installation of data collection devices and software, conveyor bearing vibration sensors and punching tool acousting emission sensor, vibration sensor and microphone. Testbed provides vibration and sound measures for the project to develop predictive maintenance algorithms and models.

The production process and measurement stages are presented in the following figure.

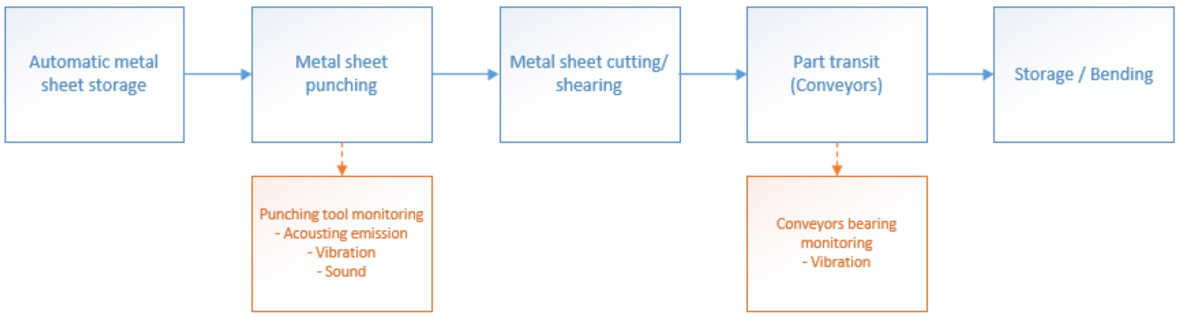

Figure 7. Production process and measurement stages

4.2 Problem identification investigated within the testbed

Cause	*Effect*	*Related parameters*	*Measurement method*	*Comments*
Bearing wear	Bearing breakdown	Vibration amplitude, FFT, Envelope Spectrum	Vibration sensor	Bearing breakdown causes the stoppage for conveyor.
Punching tool wear	Weared tool doesn't punch well and makes damages to the sheet metal.	Acoustic Emmission R.M.S value	AE-sensor	
Punching tool wear	Weared tool doesn't punch well and makes damages to the sheet metal.	Sound measurements	Microphone	
Punching tool wear	Weared tool doesn't punch well and makes damages to the sheet metal.	Vibration amplitude	Vibration sensor	

4.3 Testbed design

KONE use-case testbed includes four conveyor belt vibration sensors, two of them pointed out in the picture below.

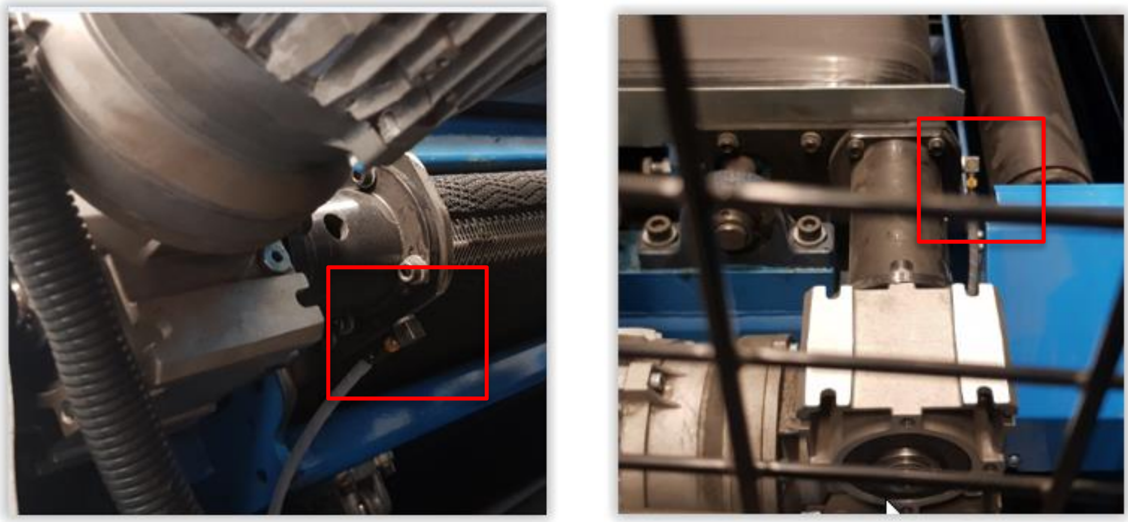

Figure 8. KONE use case testbed

Punching machine includes vibration, acoustic emission, and sound sensors. Picture below represent the measured tool holder and chosen tool.

Figure 9. KONE use case measured tool holder and chosen tool

The overall architecture of the testbed is presented below.

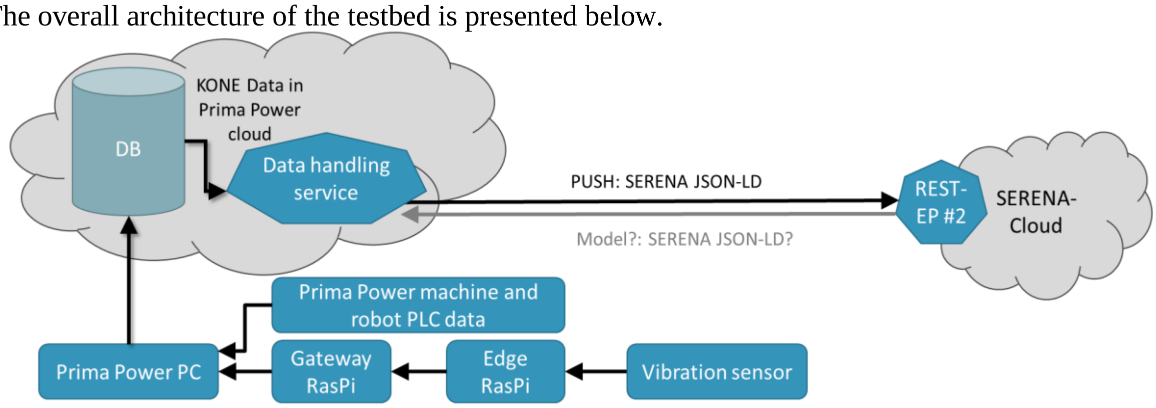

Figure 10. KONE use case architecture

4.4 SERENA solutions

	Technology	**External technologies**	**Justification**
Gateway / Data acquisition	No additional gateway hardware will be used in this use cases. All Serena functionality will be implemented on existing PrimaPower systems.	PrimaPower Cloud system	The KONE use case is already connected to the PrimaPower cloud system, including automated acquisition f the latest production data.
Maintenance planning and predictive analytics	The goal of the condition-based maintenance of the bearings is to detect the bearing faults by means of envelope analysis. This analysis is performed first with raw data in the Serena cloud, and in the second phase the analysis is taken to the edge level to be handled by a Raspberry and stored in MIMOSA. The results of these fault indicators are delivered to the Serena cloud, and based on this, MIMOSA is used to create an alert and estimation of the severity of the failure.		
AR-based operator support	The SERENA solutions will be used and tested.	PrimaPower Cloud system. Web Browser, mobile and wearable devices. 3D CAD export (STP files) of laser cutting machine in order to develop some applications for the VR/AR operator support.	The VR/AR-based Unity 3D app can be developed and deployed for multiple platforms and operating systems. In particular, two interactive VR/AR procedures are being developed for the maintenance of the laser cutting head, in order to demonstrate how these applications can be flexibly integrated into the SERENA architecture, to provide a valid and intuitive support to the maintenance operators: 1) Protection Windows Removal/Replacement 2) Lens Centering

Cloud based platform	SERENA cloud system to be used as deployed in DELL's INFINITE testbed.	PrimaPower Cloud system	Using the PrimaPower system as part of the Serena System demonstrates the flexibility of the Serena architecture.

4.5 Hardware/Software requirements

Hardware

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	IMC-Cronos measurement device	10 000	3	Vibration, Sound and AE measurements.
2	Measurement computer	2000	1	Needed for monitoring measurements.
3	External Hard Disk	100	2	Needed for saving measurements
4	Raspberry PI 3 measurement computer	20	1	Needed for comparing measurements with high cost and low cost devices
5	Vibration sensor	1000	8	Needed for getting measurements
6	AE-sensor	1000	1	Needed for getting measurements
7	Microphone	700	1	Needed for getting measurements
8	The SERENA cloud environment, see section 1.2.	-	1	Dell is providing a private cloud tenant environment to host the SERENA use case PoC.

Software

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	IMC Studio	1000	1	Measurement Software
2	Web Server (Apache/Tomcat)			The Unity 3D WebGL HTML5 Applications needs a web server to be deployed and accessible in a web page of the PrimaPower and SERENA cloud systems.
3	Javascript, REST API			To interface the Unity 3D WebGL HTML5 Apps with the PrimaPower and SERENA cloud.

4	Moodle e-learning platform			To integrate the Unity 3D WebGL Apps with LMS using SCORM for the PrimaPower Academy
5	Docker (https://www.docker.com/) an open source application containerization facility	-	8	Docker is one of the most commonly supported containerization facilities in use today. Its ubiquity make it an ideal candidate for SERENA.
6	Docker Swarm (https://docs.docker.com/engine/swarm/) an open source container orchestration manager	-	1	The orchestration manager manages the deployment and lifecycle of the Docker containers. Several alternate orchestration managers, such as Kubernetes, were considered, and any one of them been suitable candidates, but Docker Swarm was selected by IPT as it had a small platform footprint.
7	Portainer (https://www.portainer.io/) a HMI for Docker and Docker Swarm	-	1	Portainer provides a full set of visualisations of Docker containers and Docker Swarm services, and grow out of the Docker community.
8	Apache HTTPD (https://httpd.apache.org/) a web server used to host the visualisation service	-	1	Is one of the most common open source web servers in use today.
9	Node-red (https://nodered.org/) a data flow engine used by various services, it is used to implement a reverse proxy from the SERENA cloud to the Prima Power system.	-	1	Node-red is a commonly used data flow engine based on nodejs. Node-red has a graphical interface, which enables rapid application development.

4.6 Deployment

Plan	Steps to deploy the testbed/integrate to existing architecture 1. Establish connection with Finn-Power cloud 2. Apply additional measure devices 3. Start data acquisition 4. Develop prediction model

	5. Implementing SERENA solutions
Demonstration scenario	The Kone use case will be hosted on Dell's SERENA cloud environment. KONE testbed is included to the production line where the demo scenarios are generated by the current production schedule. During the conveyor bearing failure the punching machine must be stopped and bearing to be replaced. At the failure of punching tool noticed by system alert or bad quality the tool is replaced and maintained. Testbed application/scenario after the deployment, including - User/user stories - HMIs
Replicability of defects	The testbed is built to the production environment. Artificially induced failures are to be caused for punching tool by using not maintained tooling depending of the production schedule. Artificial failures cannot be caused for the conveyor bearing vibration.
Validation approach	SERENA solution will be validated when a failure occurs. In detail, SERENA solution has to provide the necessary information about the status of the machine with enough time to react, plan and take action so as to avoid any loss of accuracy or breakdown. How this is expected to be transferee to the plant/process SERENA solution will provide a possibility for the factory to schedule maintenance activities better, increase machine's availability and therefore to better meet the customer's requirements.
Reliability Metrics	N/A
Risk assessment/ mitigation actions	Main risk is related insufficient amount of data and failures. To mitigate the risk there is a plan to induce artificial failures the have reference data.
Current state	Hardware planning has to be finalized. Including the PrimaPower cloud system into the Serena environment is still to be done.

5 Metrological Equipment Testbed

5.1 Concept description

TRIMEK is one of the main manufacturers of metrological systems and solutions worldwide, and is the leading company in the Basque Country and Spanish markets in the field of CMM and measuring and digitalisation software. TRIMEK designs, manufactures and supplies components and fully integrated solutions to improve the quality control and dimensional metrology processes.

Serena project focuses on the operations and services usually associated with metrology laboratories. These scenarios are characterised by manual operation of CMM instrumentation, in highly controlled environments where statistical part control is performed usually at the end of the process by expert metrologists.

A bridge type CMM, in particular the SPARK model, has been selected for TRIMEK testbed. The CMM under study is currently used in TRIMEK's laboratory to provide services to our clients. The CMM is a dimensional inspection system specifically designed for the digitalization of physical objects/parts in order to create their virtual image (point cloud) which is subsequently analysed thanks to the M3 software, obtaining the corresponding geometrical dimensions and deviations based on the CAD model. These systems use non-contact sensors or touch probes for objects' scanning in the three coordinates axes XYZ. The three machine axes moves independently from one to another to enable the total coverage of the measuring volume.

Figure 11. Spark CMM.

The metrology equipment mainly consists of three different elements:

- The optical sensor which is in charge of obtaining high-accuracy 3D point-clouds (txt files) representing digital images of the manufacturing parts. Part information are captured using laser triangulation techniques and the selection of the specific optical sensor depends on the accuracy, speed, and fidelity required by the measurement. Touch probes may be considered as well.
- Mechanical parts: surface, arm, bridge…
- Control system: in charge of moving the sensor within the measuring volume according to the trajectories, paths, positions, and orientations previously defined in the digitalization program, measuring software.

The aim of the testbed is to monitor the performance of this CMM in order to correlate the results of the verification and calibration processes with the values of the operational condition. To achieve this, different sensor will be installed in the CMM to monitor main parameters that affect the operation of the machine. The overall performance of the machine is verified with an artifact, in particular a tetrahedron, whose dimensions are known so as to evaluate the trend of the accuracy of the machine.

Figure 12. Artefact for contact and non-contact sensors.

Next figure shows a simple schema of TRIMEK's testbed approach.

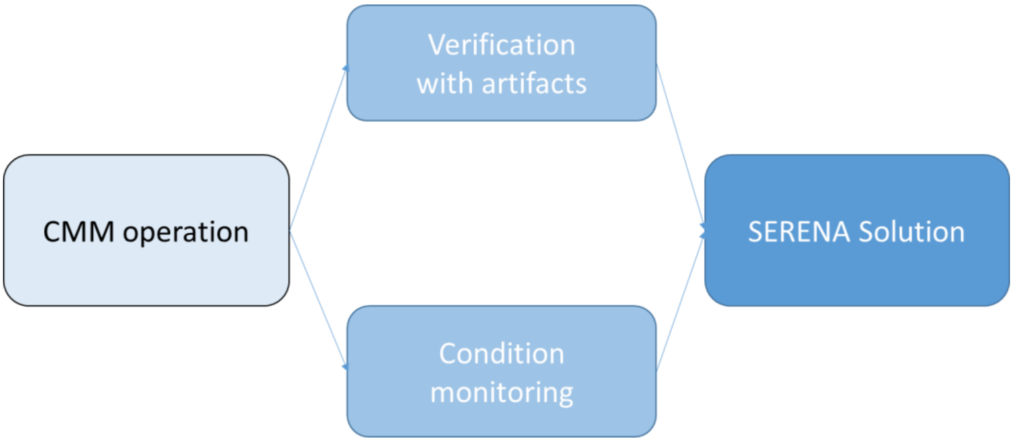

Figure 13. Simple schema of TRIMEK testbed.

In summary, SERENA will permit to develop the necessary services and applications to support the correct operation of the CMMs in the factory laboratory.

5.2 Problem identification investigated within the testbed

Cause	***Effect***	***Related parameters***	***Measurement method***	***Comments***
Soft breakdown	Loss of accuracy during measurements. The machine is not working well and needs some adjustment.	Metrological information, deviations, sensors raw data…	Verification process Data from local database, data from log files…	
Hard Breakdown	The machine could have a breakdown because of an engine failure, electronics, bearings breakdown…	Metrological information, deviations, sensors raw data…	Verification process Data from local database, data from log files…	

5.3 Testbed design

To guarantee that the physical product does not present any defect that might cause a further problem or waste of money to our clients is key to ensure the required accuracy of the CMM in each measurement. In this context, the SPARK CMM has been selected for TRIMEK testbed. The accuracy or the avoidance of unexpected breakdowns depend on the performance of the machine and its components- For this reason, based on TRIMEK's personnel experience we have selected the compressed air system as the main component to be monitor and the results of the verification process of the CMM operation to be analysed in order to correlate them and study trends and patterns. A schematic representation of the testbed is presented in the following figure.

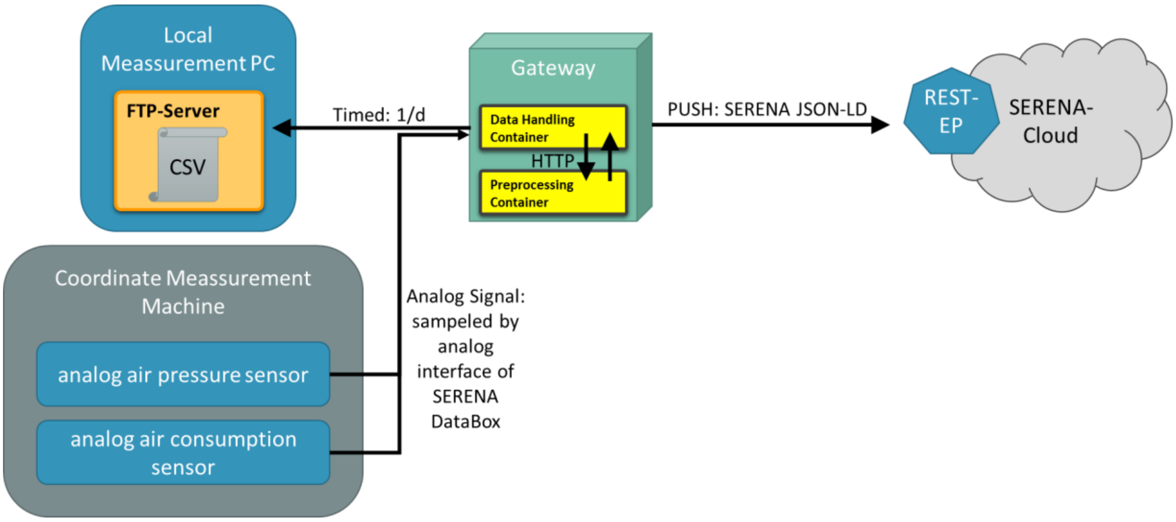

Figure 14. TRIMEK's testbed schema

5.4 SERENA solutions

	Technology	**External technologies**	**Justification**
Gateway / Data acquisition	Serena Databox for data acquisition will be used	-	-
Maintenance planning and predictive analytics	Serena Data analytics will be used: • Prediction model • Prediction label and RUL value • Scheduling service	-	-
AR-based operator support	Serena AR solution will be used for operator support	-	-
Cloud based platform	SERENA cloud system to be used as deployed in DELL's INFINITE testbed.	-	-

5.5 Hardware/Software requirements

Hardware

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*

1	CMM	-	1	The performance of this machine is the focus of the project.
2	Air Sensors	-	2	The sensors to be installed in the CMM are used to monitor the air parameters to study its influence in the performance of the machine.
3	The SERENA cloud environment, see section 1.2.	-	1	Dell is providing a private cloud tenant environment to host the SERENA use case PoC.

Software

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	M3 SW	-	1	It is in charge of capturing and managing all the metrological information.
2	Tetracheck	-	1	Verification system for CMMs.
3	Docker (https://www.docker.com/) an opensource application containerization facility	-	8	Docker is one of the most commonly supported containerization facilities in use today. Its ubiquity makes it an ideal candidate for SERENA.
4	Docker Swarm (https://docs.docker.com/engine/swarm/) an open source container orchestration manager	-	1	The orchestration manager manages the deployment and lifecycle of the Docker containers. Several alternate orchestration managers, such as Kubernetes, were considered, and any one of them been suitable candidates, but Docker Swarm was selected by IPT as it had a small platform footprint.
5	Portainer (https://www.portainer.io/) a HMI for Docker and Docker Swarm	-	1	Portainer provides a full set of visualisations of Docker containers and Docker Swarm services and grow out of the Docker community.

6	Apache HTTPD (https://httpd.apache.org/) a web server used to host the visualisation service	-	1	Is one of the most common open source web servers in use today.

5.6 Deployment

Plan	1. Setup local FTP-Server and prepare automated data transfer to FTP-folder 2. Apply additional air pressure and air consumption sensors 3. Prepare DataBox demonstrator device and setup data acquisition flows 4. Prepare data pre-processing and formatting flow for uploading data to the SERENA cloud system 5. Data acquisition 6. Develop TRIMEK prediction model 7. Implement the scheduling service 8. Develop AR tool customised for CMM maintenance activities
Demonstration scenario	The Trimek use case will be hosted on Dell's SERENA cloud environment. The demo scenario will consist of the metrology expert scanning a physical part (e.g. artifact) in the metrology laboratory and verifying the machine performance periodically. The resulted data will be gathered by the gateway and sent to the SERENA cloud for the diagnosis. If the prediction determines that the accuracy is close to threshold, an alarm should warn the expert to act. In addition, maintenance activities should be scheduled in the laboratory planning by the scheduling tool. Finally, the AR tool will be used to develop the required maintenance activity and train new maintenance personnel.
Replicability of defects	If no loss of accuracy or bad functioning of the CMM occurs throughout the project, the idea is to provoke/manipulate the air system and create artificial losses of accuracy of the CMM.
Validation approach	SERENA solution will be validated in TRIMEK's laboratory at the Automotive Intelligence Center where the required HW and SW are available. Thus, it can be validated in a real laboratory environment. SERENA solution will be validated by obtaining the proper answer when a failure (real or artificial) occurs. In detail, SERENA solution has to provide the necessary information about the status of the machine with enough time to react, plan and act so as to avoid any loss of accuracy or breakdown. Since TRIMEK's use case is aimed at the metrology systems used in the Metrology Laboratories at factories and the demonstrator will be implemented in a CMM used in a metrology laboratory, the solution will be easily transfer to our clients' metrology laboratories as a new service. No major update or changes are expected from the clients' side.
Reliability Metrics	The Tetracheck verification system will be used
Risk assessment/ mitigation actions	Main risk is the lack of failures during the project so the AI activities cannot be developed. To mitigate this risk, different approaches have been planned to induce "artificial" failures so as to be able to progress in each activity. Second risk is the inability to detect significant breakdowns or the loss of accuracy. Mitigation action: the parameters to be monitored have been selected based on maintenance team experience which ensure their correlation with the accuracy. In addition, all the expected failures modes as well as the normal operation will be studied and modelled in order to ensure the detection of any change in the performance of the machine.
Current state	Hardware planning has to be finalized. Additional sensor application and Data interface realization is ongoing.

6 Steel Production Testbed

6.1 Concept description

VDL Weweler has a production plant in Apeldoorn, The Netherlands, for producing trailing arms, mainly for trailers. The highly automated production process has the following steps:

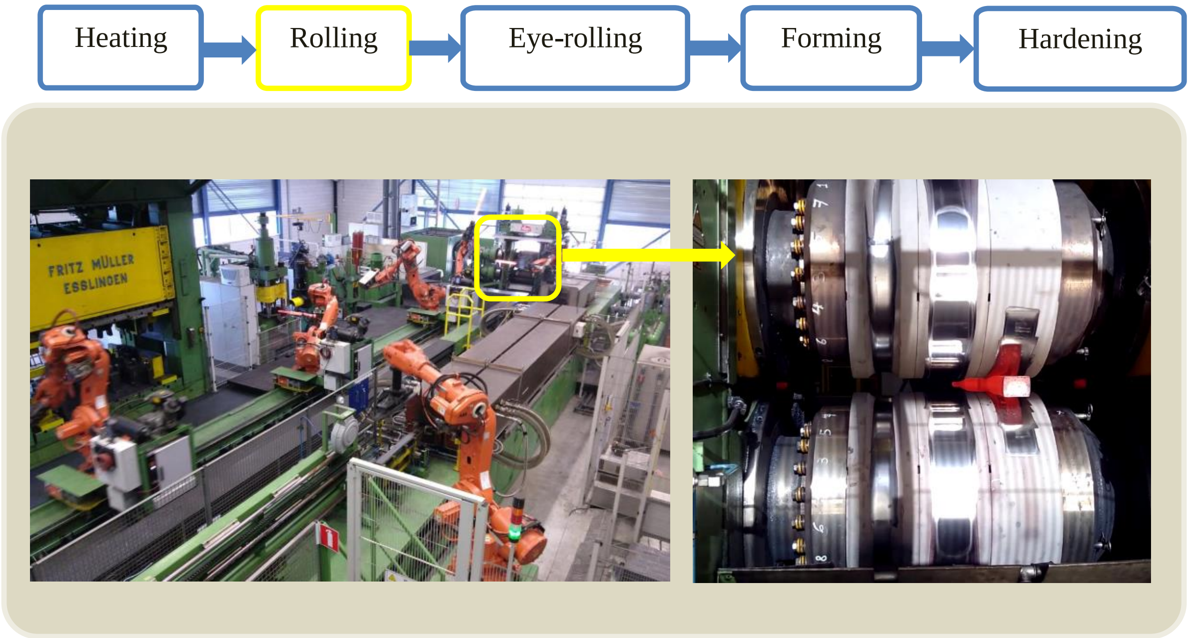

Figure 15. VDLWEW testbed details

The rolling mill has 3 top segments and 3 bottom segments. These segments have a wear-resistant coating. Although it is wear-resistant, it does wear. In case of complete wear, the underlying segment structure is damaged, and the segment must be replaced. If exchanged in time, the old coating can be removed, and a new coating applied: much cheaper.

The coating thickness cannot be measured during production. So, an indirect measurement will be applied to have an indication of the wear. Rolling mill process parameters will be logged and related to that the product produced will be measured. From these measurements, Serena should predict/estimate the current layer thickness and the RUL. To validate the outcome, layer thickness will be measured manually offline.

6.2 Problem identification investigated within the testbed

Cause	***Effect***	***Related parameters***	***Measurement method***	***Comments***
Segment Wear	Replacement of segments	Coating thickness	Direct 1. Machine tool parameters 2. Measurement machine 3. Coating thickness measurement	2. Measurement machine was custom made by VDL Coating thickness measurement not in place at the moment

6.3 Testbed design

The testbed will be the currently active production line. The rolling machine PLC program will be adapted to send the right data in high resolution. A measuring machine will be added for in-line measurement of the product produced. To validate the measurements and calculations, manual coating thickness measurements must be executed. The measurement machine is developed in-house by VDL Weweler.

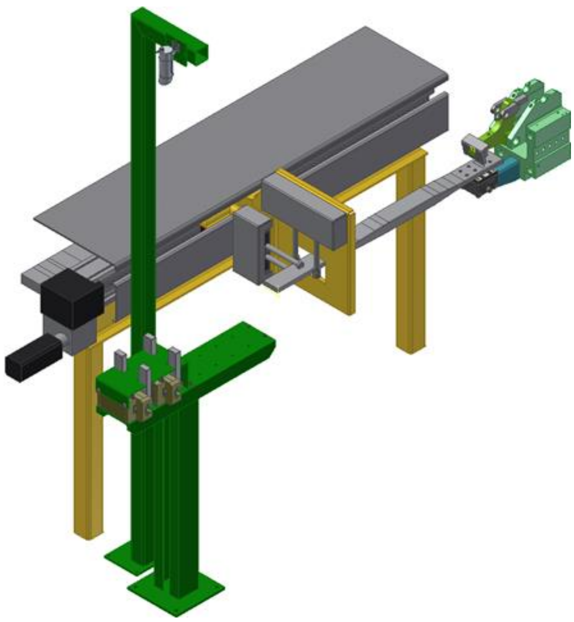

Figure 16. VDL measurement machine model

Figure 17. Measurement machine integrated into production line

Considering the wear of the bearing the maintenance activities include the following steps:

- Visual inspection of the segment: replace if damaged
- Exchange of segments when thickness reduced from .15mm to .05mm

6.4 SERENA solutions

	Technology	**External technologies**	**Justification**

Gateway / Data acquisition	Virtual gateway running on VDL servers on the basis of the SERENA data acquisition solution.	-	-
Maintenance planning and predictive analytics	- RUL based prediction of wear triggering a new maintenance task. - The utilisation of the SERENA scheduling service is under investigation.	Scheduling will be performed in existing Asset management system: Api-pro	Already deployed MES system containing the entire production plan. The pilot is based on real production line. The complexity it too high for migrating from existing scheduling system to another.
AR-based operator support	SERENA solution will be used for operator support and maybe guidance on segment thickness measuring.	-	-
Cloud based platform	SERENA cloud system to be used as deployed in DELL's INFINITE testbed.	-	-

6.5 Hardware/Software requirements

Hardware

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	Measuring machine	30k	1	Measuring the product thickness
2	The SERENA cloud environment, see section 1.2.	-	1	Dell is providing a private cloud tenant environment to host the SERENA use case PoC.

Software

No	*Item Description*	*Unit Cost*	*Quantity*	*Justification*
1	Docker (https://www.docker.com/) an open source application containerization facility	-	8	Docker is one of the most commonly supported containerization facilities in use today. Its ubiquity make it an ideal candidate for SERENA.
2	Docker Swarm (https://docs.docker.com/engine/swarm/) an open source container orchestration manager	-	1	The orchestration manager manages the deployment and lifecycle of the Docker containers. Several alternate orchestration managers, such as Kubernetes, were considered, and any one of them been suitable candidates, but Docker

				Swarm was selected by IPT as it had a small platform footprint.
3	Portainer (https://www.portainer.io/) a HMI for Docker and Docker Swarm	-	1	Portainer provides a full set of visualisations of Docker containers and Docker Swarm services and grow out of the Docker community.
4	Apache HTTPD (https://httpd.apache.org/) a web server used to host the visualisation service	-	1	one of the most common open source web servers in use today.

6.6 Deployment

Plan	The current plan includes the deployment of a Virtual gateway on VDL servers. A Node-red flow will be created to push data from the data on premise to the serena cloud and then to each service.
Demonstration scenario	- Data acquisition - RUL evaluation for the coating thickness - Suggestion to do a coating thickness measurement or a segment exchange - Operator support tool guide operator to carry out assigned activities The VDL use case will be hosted on Dell’s SERENA cloud environment.
Replicability of defects	Segment wear occurs every 1-2 weeks. Hence there is no need to artificially cause any defect.
Validation approach	Compare the evaluation from the data analytics with the layer thickness measurements. The demonstrator will take place on the production line directly.
Reliability Metrics	Comparison to manual coating thickness measurements
Risk assessment/ mitigation actions	N/A
Current state	Currently the activities undertaken target on pushing data to the SERENA cloud. This is considered a first step towards enabling any additional services. As a next step additional SERENA services integration will be investigated and if successful connected such as analytics, operator support, scheduling. These activities will be undertaken by M24.

7 Reusability of equipment

Based on a comparison of the hardware and software requirements for each testbed it can be supported that there is no direct and significant reuse of equipment. In their majority the hardware requirements are mostly related to measuring systems and sensors.

However, it should be noted that already portable devices such as the gateway are shared across the testbeds, considering that they are not required at the same time.

Moreover, the cloud infrastructure, not included in the project, has been provided by DELL which is also shared across the use cases for the current and future developments.

8 Conclusion

This deliverable aims to report the outcome of the activities carried out within SENERA WP6, and in particular of T6.1, during the first 18 months of the project's lifetime. Purpose of WP6 is to design and deploy the industrial demonstrators to test and validate the SERENA technical solutions enabling remote predictive maintenance for industrial processes and equipment.

With respect to the aforementioned the main conclusions of this deliverable are summarized as follows:

- The design and adaptation of the SERENA generic solution to the individual needs and requirements of each industrial case have been performed and presented in the context of this document.
- The approach to test and validates the SERENA solutions in each demonstrator have been described.
- The expected hardware and software requirements have been listed along with the foreseen deployment plan of the SERENA solutions.
- Additionally, the interconnection of the SERENA system to external systems and devices has been included.

A preliminary integrated proof of concept for the SERENA system has been already carried out in M14, which has supported the design and adaptation of the described testbeds. Moreover, all testbeds have already moved from the design stage to the implementation since M14 and are expected to be completed by M36.

Appendix A: Predictive analytics

The Polytechnic of Turin designed and developed a general Predictive Maintenance service to identify relevant events, e.g., machine failures, before their actual occurrence through data-driven intelligent systems. The service has been applied to two use-cases provided by COMAU and WHEMEA.
The service supports smart predictive diagnostics (prognostics) for devices, and it will be able to estimate the Remaining Useful Life (RUL).

The COMAU use case consists in predicting the right tension to apply to a motor belt of a robot. A proper tensioning of the belt is necessary to assure the correct functioning of the robot: low tensions cause slippage, overheating and premature wear of the belt and pulley, while contrariwise, too high tensions lead to excessive strain on the belts, bearings, and shafts. Moreover, tension losses occur on all the belts, ranging from 50% to 70% with respect to the original tensions, being a wide and unsolved general problem.

In the COMAU use case, the tensioning of a belt is measured by the number of washers needed to tension the belt itself. These values represent the labels assigned to each cycle of the motor, whose electric current consumption is measured. The goal is to predict, for each incoming cycle of the motor (current consumption), the correct tension for the belt in terms of number of washers.
The architecture of the designed analytics process is reported below.

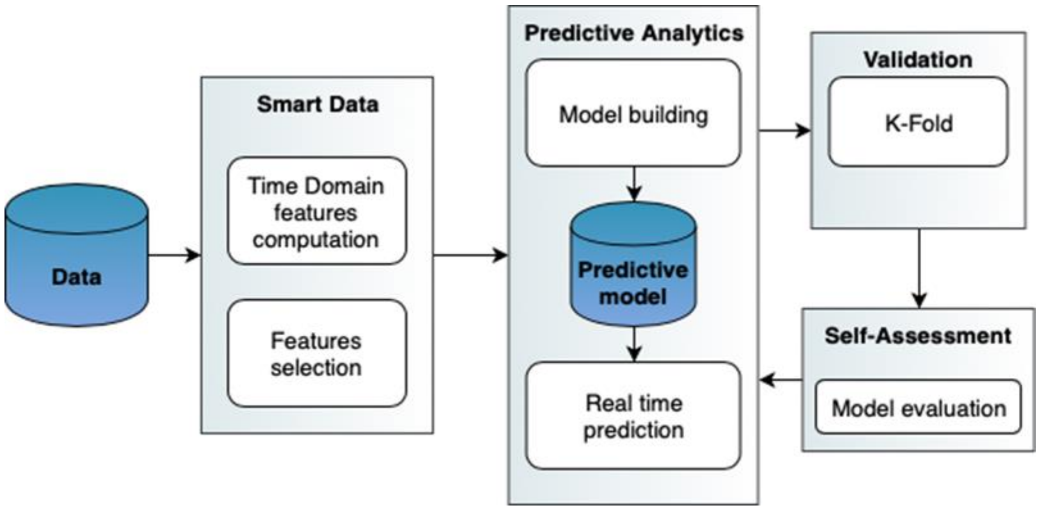

Figure 18: Data analytics architecture

The Smart Data component transforms and processes raw data, extracting the most relevant features that better characterize the dataset under analysis and computing statistical features in the time domain. To better characterize the variability of the input data in the time domain, each incoming cycle of current has been divided into splits. Each split has been then characterized by several statistical features (e.g. Mean, Std, Quantiles, Kurtosis, Skewness), for a total of 350 features. Then, a feature selection step is computed: by means of the correlation test, the framework automatically reduces the number of features removing highly correlated attributes. Both the performance and the quality of the built model will be affected from this phase.

The predictive analytics step consists of two sub-processes: Model Building, executed in the cloud, and Real-time Prediction carried out at the edge component. The model building process consists in a training phase extracting latent correlations between a historical set of data (historical signals) and its labels (events occurred for each signal). The real-time prediction process takes advantage of the model built in the previous step to predict the label (event) of new incoming data (new incoming signals). We plan to enrich the proposed methodology with self-tuning strategies to off-load the data scientist to manually set the specific algorithm parameters.

Once the model is built by applying the state-of-the-art algorithms (e.g., RandomForest, GradientBoosting, etc), it is validated to estimate its performance on unseen data. To this aim, the validation block exploits the Stratified K-fold cross validation technique. To evaluate the quality of the predictive model, precision, recall and f-measure (also known as f1-score) are computed.

classifier	label	precision	recall	f1-score
RandomForest	0	0.99	0.99	0.99
RandomForest	1	0.99	0.99	0.99
RandomForest	2	0.99	0.99	0.99
RandomForest	3	0.98	0.96	0.97
RandomForest	4	0.84	0.93	0.85
GradientBoosting	0	0.99	0.99	0.99
GradientBoosting	1	0.99	0.99	0.99
GradientBoosting	2	0.99	0.99	0.99
GradientBoosting	3	0.98	0.96	0.97
GradientBoosting	4	0.83	0.89	0.82

In the table above, the performance of the Random Forest and the Gradient Boosted Tree classifiers are reported. To reduce the number of features, an absolute average correlation of 0.5 has been used. The label column represents the number of washers used to tension the motor belt.

Furthermore, it is currently under design a self-assessment step to automatically trigger a model update, hence rebuilding the predictive model on a new training set. Generally, the more data are available in the training phase, the higher the accuracy of the model. However, if the physical processes under exam change over time or if new and different training data are available, the predictive model characterizing the phenomena might needed to be updated. This self-assessment is performed by evaluating the degradation of the current predictive model through unsupervised quality metrics (e.g., silhouette index) to quantify the cohesiveness of the predicted classes assigned to new unseen data.