VerSatilE plug-and-play platform enabling remote pREdictive maintеNAnce

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Summary:
This deliverable reports the deployment of SERENA's services on TRIMEK's use case, encompassing the procedure, experiments and results from the end-user perspective and specifications required; as the main outcome for TRIMEK's demonstrator.

Contents

List of Abbreviations

AIC	Automotive Intelligence Center
CMM	Coordinate Measuring Machine
HW	Hardware
KPI	Key Performance Indicator
SME	Small and Medium-Sized Enterprise
SW	Software
TRL	Technology Readiness Level

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Executive Summary

The purpose of this deliverable is to report the deployment of SERENA's services on TRIMEK's use case, encompassing the procedure, experiments, and results from the end-user perspective and specifications required; as the primary outcome for TRIMEK's demonstrator.

The document is structured as follows:

- Section 1 briefly describes TRIMEK's motivations as an end-user in the project SERENA, as well as the expected goals after the project implementation. Likewise, it indicates the testing environment and the most important aspects or characteristics of the project deployment in and for TRIMEK.

- Section 2 indicates the wise business objectives of TRIMEK along with the defined KPIs and metrics defined at the beginning of the project, the technical features and services to be tested, and a description of the main experiments performed for the validation of each service, defining the expected result, the scenario, the obtained results and the feedback as end-user.

- Section 3 summarizes the overall assessment of the SERENA system and the lessons learned from the end-user point of view.

1 Demonstrator overview

1.1 Motivation and goals

TRIMEK is one of the leading manufacturers of metrological systems and solutions worldwide and the leading company in the Basque Country and Spanish markets in the field of Coordinate Measuring Machines (CMM) (along with measuring and digitalization software), especially for the automotive, aeronautical, shipbuilding, energy, transport, and machine tool industrial sectors; all of them related to manufacturing processes that require high accuracy. Due to this, the actions of maintenance, calibration, results and performance evaluation, and failure detection on these machines represent an essential aspect of achieving this mentioned accuracy. They are considered crucial in the whole metrology process. However, they carry costs and time for an enterprise, despite being very stable machines.

The CMMs are dimensional inspection systems (devices) specifically designed for the measuring of the geometry of physical objects and its digitization and analysis with the M3software (High-Performance Software for capturing and analyzing point clouds), obtaining, in this way, the corresponding geometrical dimensions and deviations, based on the CAD model of the object. These systems use non-contact sensors or touch probes for objects' scanning through its displacement from a reference position in a three-dimensional Cartesian coordinate system (XYZ). In this sense, the three machine axes move independently of one another to enable the measuring volume's total coverage.

Figure 1. TRIMEK CMM SPARK model selected for SERENA

To guarantee that the physical product manufactured does not present any defect that might cause a further problem or waste of money to our clients, is critical to ensure the required accuracy of the CMM in each measurement part of the quality control procedure in the factories. For this, it is of major importance the early detection of machine errors, to avoid unexpected breakdowns, production stoppages and loss of accuracy, and the continued evaluation of the CMMs performance. The problem here is that CMMs, provided to customers, do not incorporate sensors to monitor operational parameters (this for keeping the cost of the products low and competitive, and also because this information does not provide any added value to the clients for their purposes in buying and using TRIMEK's products), and TRIMEK do not have access to the results of machines' performance once they are located in their facilities.

Consequently, tests need to be carried out in TRIMEK's factory or on the client's side for gaining a certain level of insight into the possible flaws that might occur during the standard operation of the equipment or even the state of the machine at a particular moment. In relation, the preventive maintenance process is scheduled following a theoretic approach based on a tentative number of calibrations and verifications per day/week/month/year. If the machine breaks down, it is necessary to check on-site the reason for the malfunctioning; a team of 1-2 people is dispatched from TRIMEK to the client's place to evaluate the problem and proceed with the required corrective actions.

Nonetheless, the wide variety of end-users results in high levels of customization that makes the number of tests and information that TRIMEK needs to collect and manage to be extremely large. Also, CMMs should be verified daily with verified artifacts (tetrahedrons), but clients hardly ever or never do it, and when the machine starts to measure wrongly or have an odd behaviour, sometimes it is too late to fix the problem because the client usually waits too much instead of calling TRIMEK when a failure is detected.

All these factors are transduced into economic losses to the competitiveness of the manufacturing company as well as deterioration of metrology solutions image and concept. Early detection of errors could reveal that the potential need for maintenance becomes imperative for the equipment manufacturer as well as for the owner in an early stage. Thus, making a shift from proactive and reactive maintenance strategies to predictive and entirely preventive ones could enable better planning and scheduling of maintenance activities based on TRIMEK and client's availability, enriching the services provided by TRIMEK to its customer, increasing the useful life of the equipment and making a more robust position of the equipment manufacturing company in the market, taking into consideration that to maintain products as competitive as possible, the detection of flaws or maintenance needs has to be performed with a cost and time-effective approach. In this sense, TRIMEK's goals are to enhance its products with advanced predictive maintenance solutions and real-time condition monitoring driven by the SERENA project.

1.2 Testing environment and timeline

SERENA solution is implemented and validated at TRIMEK's laboratory at the Automotive Intelligence Center (AIC) in Bilbao, where the required HW and SW are available, including a Bridge-type CMM machine, particularly the SPARK model; the product selected by TRIMEK for the project deployment. The SPARK CMM is manufactured with reduced complexity to keep it as robust as possible. This machine achieves high dimensional stability and precisely controlled movements. Each axis's measuring system is mounted on Robax (a thermally inert material), which, combined with the granite construction, makes the Spark an accurate and fast machine even under temperature variations.

Figure 2. Automotive Intelligence Centre (location of TRIMEK laboratory)

Determined by TRIMEK's personnel experience, an important sub-system of these machines and the most critical one, as they affect the operation and accuracy of the CMM, is the air bearing system. Air bearings can be linear or rotary. Its purpose is to float on air above its guideways, representing a high-stable non-friction system, which helps and plays a key role in delivering the precision required in metrology equipment. The most common causes of air bearings failure are air contamination and out-of-balance forces, causing vibration. For this reason, the compressed air system was selected as well as the main component to be monitored.

The timeline related to TRIMEK's use-case work during the project is provided hereafter.

- **M1-M6:** AS-IS/TO-BE, Specs. and requirements (inputs, outputs, interfaces, infrastructure, component, data availability, needed sensors, communications), KPIs; first discussions on general architecture, WP2, WP3, and WP5 services; testbed planning
- **M7-M12:** WP2 service redefining/assessment, WP3 architecture discussions, 1st set of data preparing, implementation of management tools created, better definition of the testbed (data flow, datasets, plan schema, sensors implementation, data availability)
- **M19-M24:** Sensors and Databox prototype installed and connected, Gateway connected, data acquisition assessment and setup. JSON-LD message definition to transfer semantic data. Dashboard for data visualization creation. Specific file data format to locally store the pressure and flow data. Adoption, customization of SERENA specific data model. WP3 architecture design intended analytics description, 1st dataset for WP3 services, development, and scheduler customization. Discussions on WP4 services, requirements, and purposes, platform architecture, preliminary tests to the step-by-step modeller 1st version
- **M25-M36**: Gateway fully installed (HW+SW), configured, updated, and integrated, fully connection setup with DELL's Infinite testbed, 2nd dataset for WP3 services, Workflow integration in operator maintenance support system, testing phase for testing and validation of service (scheduler, operator maintenance support system, data flow from the acquisition, monitoring to the storage and transfer)
- **M37-M43**: Final phase for testing and validation of all services (scheduler, connection to SERENA dashboard, data analytics), Demonstrator report, Demo preparation, and recordings.

1.3 SERENA system deployment

Remote factory condition monitoring and control

A Databox was developed and placed at the factory floor in the AIC TRIMEK's laboratory; consisting of multiple components combined in an industrial housing; a fan was also included to ensure proper cooling due to its environment location, having in this way an IP24 protection degree. The Databox acts as a mediator between existing CMM, its components, M3 software, etc., the newly added data sources and sensors, and the SERENA system's components.

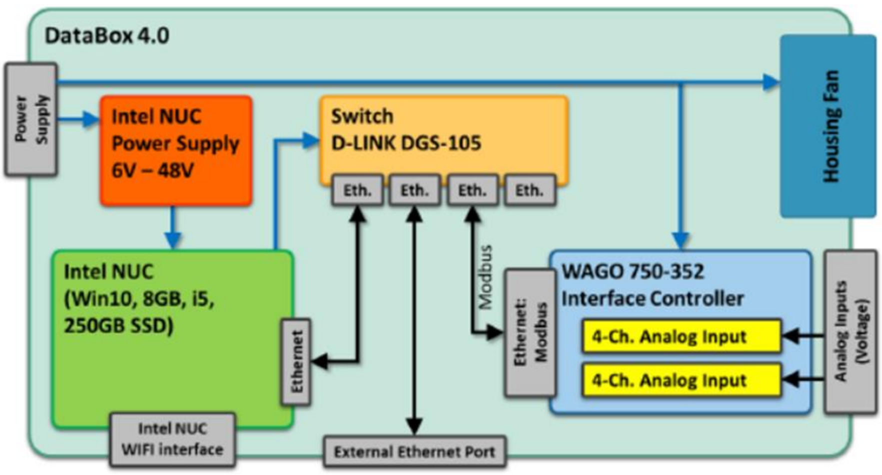


Figure 3. Databox internal architecture

Regarding the integration of the Databox in TRIMEK's facilities (Figure 4), different major activities were performed by involved partners, along with TRIMEK's personnel, regarding hardware requirement identification, the databox manufacturing, and configuration, creation of data acquisition and pre-processing container, etc.

Figure 4. Databox developed for TRIMEK use case and installed in AIC laboratory

The Databox was equipped to allow the creation of an internal network between internal components (WAGO interface module) and additional external components (sensors). WAGO was implemented to permit safe, maintenance-free connections for a flexible signal wiring application, to perform signal transmission and distribution in the control and field levels and connect electronics to electrical systems at the control level. This interface controller was equipped with two analogue voltage input modules (WAGO 750-459) and the input comes from the 6 sensors installed on each of the CMM axes (X, Y, Z) for monitoring the airflow and air pressure sub-system for the air bearings (Figure 5).

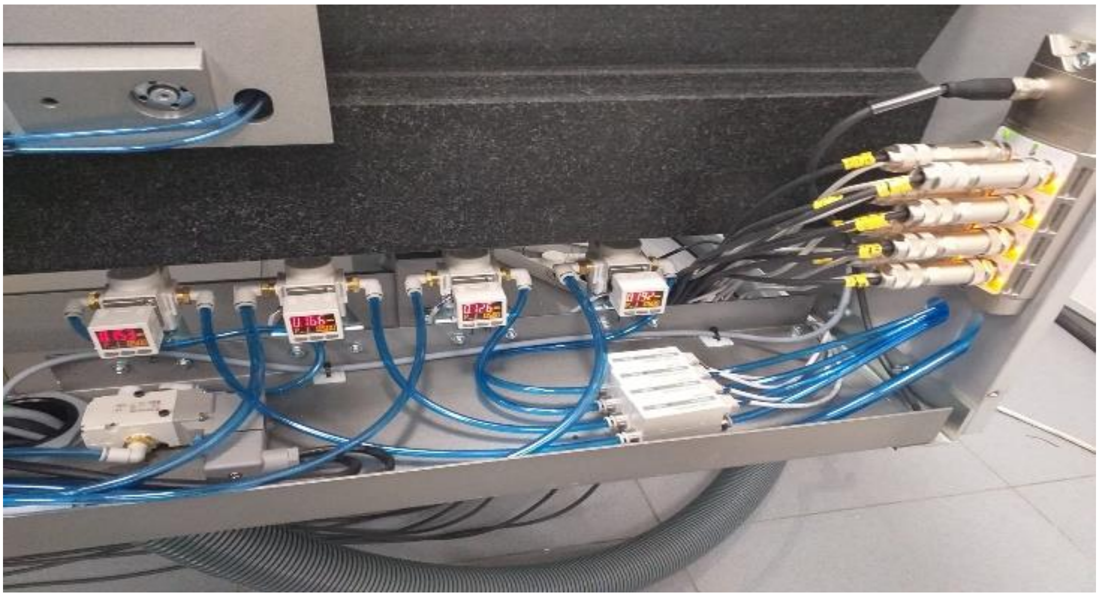


Figure 5. Airflow and pressure sensors installed in the CMM SPARK

To support also external networks, the Databox was equipped with an additional network adapter and port. In this sense, a DELL Edge gateway was used to aggregate, secure, analyse and relay the data from the edge sensors, bringing both legacy systems and the sensors to the internet to obtain real-time insights into the system studied in TRIMEK's pilot. The Gateway was configured to directly access and integrate the company network of TRIMEK and allow access to the SERENA cloud system; it was necessary to open a virtual private network (VPN), SSL encrypted, to connect the pilot with the SERENA system.

All communication between cloud and edge is done through the REST application interface, while JSON-LD is the standard message format.

The functionalities of the Databox are implemented using the NodeRed framework, based on a graphical block design and independent nodes with all functionalities needed to read and handle the incoming and outgoing data. The software modules are wrapped in Docker containers and stored in a local SERENA specific image repository. The Databox holds a local running data acquisition container that, once acquired, passes the data on to the pre-processing container; that extracts smart data from the raw data by filtering, smoothing or others. The correct timestamping of the data and proper synchronization of all component clocks are ensured.

Also, MIMOSA is used to integrate condition-based maintenance information and provide the place to store this information (metadata, all the asset registry, condition, maintenance, reliability information collected by the Gateway).

The above software solutions have been properly integrated into the TRIMEK use case to target the monitoring and control framework implementation.

<u>AI condition-based maintenance and planning techniques</u>

For TRIMEK, it is composed of a data analytics service to accurately provide insights on the correct/incorrect functioning of the equipment and the service of planning and scheduling maintenance activities in specific timeframes without interrupting the production process plan. Includes the following:

- Analysis of historical data and real-time
- Correlation of measurement data with event data, e.g., failures
- Monitoring of real-time data
- Detection and analysis of anomalies, alerting
- Maintenance aware operations planning and scheduling

The solutions operate in the docker environment of the SERENA Cloud Platform, as the central component where all the outcomes are consolidated and integrated.

The data analytics service for TRIMEK's pilot is focused on an anomaly detection capability based on repetitions of events related to the measurements coming from the air bearings system sensors. TRIMEK provided various datasets for the analytics modules, with a description of the limit values and the typical operational values; along with the understanding of the reasons for a possible failure and the link with the originally collected data, as it is of paramount importance. The aim is to automatically detect when the airflow or air pressure is out of normal. The solution includes graphs visualization showing the cumulative anomalies, the mean values and the standard deviation in a day/week/month period, with different analytics and KPIs to assess the data, like counting of anomalies, frequency of anomalies, alarm/notification when the value is out of threshold or when many continuous days are presenting odd or wrong behaviour.

The scheduler, on the other hand, is a tool built as a web application, that supports the connection to the central database, containing the data required for planning/scheduling of the maintenance activities. Its interface is used for visualizing multiple information and results and interact with Machines, Scheduling, Tasks and Resources UIs.

The inputs that TRIMEK as a user needs to provide to the Scheduling Tool, as well as the outputs generated, are described in WP3 deliverables. However, as the final visual result is offered, a Gantt chart for visualizing the result of the scheduling algorithm, with the different maintenance tasks assigned to the different resources in a timeslot. Moreover, another table is visualized, providing short information about the duration of a task and the maintenance tasks scheduled. The company's information is received by the SERENA Dashboard, then the Scheduling Tool automatically retrieves TRIMEK's information and workflows from the AR Workflows module, mapped and stored as resource and tasks.

AR-based technologies for remote assistance and human operator support

The system for AR-based step-by-step instructions to support service technicians on-site is a web application that can be used daily on computers, tablets and phones to perform maintenance tasks, whether they are scheduled maintenance cases or it is training for new personnel. The tasks can even be performed without an internet connection, having the manuals stored locally on the device. For this purpose, the application provides an instruction authoring interface for editing instruction sets to a database; to create multi-media instructions, correlating to experience levels and maintenance operations as well as display devices. A TRIMEK administrator or a maintenance expert can insert text, image, audio instruction and stored them. This was the case for the demonstrator: A set of videos and texts were uploaded regarding air filters unit maintenance. The system was developed by OCULAVIS and the output is the outcome of the user interaction with this interface constituting one or more maintenance instruction sets. In this context, as soon as a maintenance activity has been assigned to an operator by the WP3 scheduling tool, the operator support services are triggered.

Cloud-based platform for versatile remote diagnostics

All the services developed for TRIMEK, the related cloud storage, are implemented in a dedicated SERENA tenant cloud on DELL's Infinite testbed, as was mentioned before. All service can be accessed through the SERENA dashboard (Figure 6).

Figure 6. Part of the SERENA dashboard user interface

2 Experiments

2.1 Testing objectives

The business-wise objectives for TRIMEK, as well as the KPIs selected for the measure, are listed below:

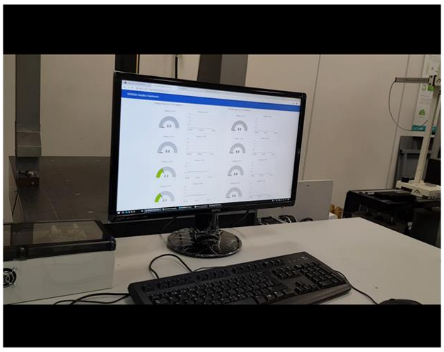
- Improve the portfolio of services provided with the sale of TRIMEK's products, strengthening its market position and increasing its competitiveness
- Increase customer satisfaction with the overall functioning of the machine, its state monitoring, and new maintenance approach
- Facilitate the knowledge of TRIMEK's different types of client machine's state and maintenance related data management
- Assess a shift from proactive and reactive maintenance strategies to predictive, at least in a partial manner
- Reduce the soft and hard number of machine breakdowns per year
- Reduce the cost associated with repairing and maintenance activities
- Extend the CMM machine lifecycle
- Improve the accurateness of the maintenance personnel sent to customers for problem solution and maintenance activities

2.2 SERENA features to be tested

- Access to the SERENA dashboard
- Remote airflow and pressure sensor data collection, data acquisition, and flowing (remote condition monitoring)
- Data analytics service for anomaly detection based on sensor data
- Planning and scheduling service for maintenance activities
- Operator support system for maintenance activities related instructions regarding air bearing component

2.3 Experiments & Results

<table>
<tr><td colspan="2">Objective 1. Proper visualization of air bearings flow and pressure sensor data collected from the CMM</td></tr>
<tr><td colspan="2">Facilitate the knowledge of TRIMEK's different types of client machine's state by evaluating the provided databox functioning in TRIMEK's laboratory along with the air pressure and airflow sensors installed, collecting machine data and streamlining it to the SERENA cloud for visualization (SERENA service to be also validated). The aim is to corroborate and verify the possibility of increasing customer satisfaction with remote monitoring of an accuracy-related parameter, reducing in this way failures and costs, and extending the lifetime of CMM</td></tr>
<tr><td colspan="2">Expected result</td></tr>
<tr><td colspan="2">Validate the deployment of the remote factory condition monitoring service for the air bearings sub-system of the CMM to improve the following aspects indirectly:
• Soft/hard breakdown (+2 years)
• Cost of repairing and maintenance activities (reduce 10-20%)
• Extension of CMM lifecycle (+1 year)
The improvement in the mentioned KPIs is expected with the SERENA solution services implemented as a whole or as a chain</td></tr>
<tr><td rowspan="2">Scenario 1</td><td>Scenario description</td></tr>
<tr><td>To turn on the Gateway for some time agreed between involved partners and laboratory availability, to collect a set of data from the air bearings of each machine axe, and then visualize its representation through the SERENA Databox Dashboard developed for TRIMEK; that shows two voltage inputs, due to electrical conditioning, two for each side</td></tr>
</table>

	of machine's X axe, one for Y, and one for Z. This experiment is to assess a remote monitoring system that allows TRIMEK to know the state of machines located at client's facilities, deployed in the first instance in TRIMEK's laboratory	
	Features to be tested	Target result
	Remote airflow and pressure sensor data collection, data acquisition and flowing (remote condition monitoring): Functioning of the Databox, sensor wiring and connections, Access to the SERENA Databox Dashboard, Correct visualization and representation of sensor data	To acquire the sensor data within the period tested and visualize it in real-time through a monitoring system and dashboard. In other words, to be able to monitor the air bearing system of the CMM machine
	Results	
	This experiment was performed twice during the project's validation period, collecting two datasets of sensor data from different periods (2 weeks approx./each one). In both times, the Gateway functioned as it was supposed to, and the data was correctly collected and visualized through the corresponding dashboard and also stored in SERENA's cloud. In this way, TRIMEK was able to monitor in real-time the airflow and air pressure signals of each of the machine axes.   **Figure 7. Monitoring system Databox Dashboard**	
	Feedback/Comments	
	Network issues in the facility blocked the data acquisition on some days: the Gateway was running without access to the internet. But this did not affect the overall data gathering (solved by TRIMEK). For a moment, I couldn't access the platform due to some other services that were taking up resources from DELL's INFINITE cloud (Solved in cooperation with ENG, DELL, and LMS)	
Achieved Metric/KPI value:	In conjunction with other experiments, the mentioned KPIs were assessed in their totality. Extension of	

	CMM lifecycle (0.5 years), Reduction of total maintenance cost (10-20%), Increment of availability of the machine (5-10%), Reduction of unexpected failures (5-10%)

<table>
<tr><td colspan="3">Objective 2. Have an analysis on the collected air bearing system data through an anomaly detection service</td></tr>
<tr><td colspan="3">Have a deep knowledge of the machine's state based on the air bearings sub-system by trying the data analytics service developed for TRIMEK, which is focused on anomaly detection of collected sensor data out of threshold or with an unusual frequency of occurrence. This, for being able to reduce the occurrence of failures by detecting the issue in an early stage, extending in this way the lifecycle assuming a more proactive and entirely preventive maintenance strategy, reducing at the same time the maintenance costs.</td></tr>
<tr><td colspan="3">Expected result</td></tr>
<tr><td colspan="3">To validate the deployment of the AI condition-based techniques, in this case, the data analytics service through anomaly detection when there is a failure in the air bearing system flow and pressure inputs. The system is expected to show graphs for visualization of the airflow behaviour and pressure values and measure the counting and frequency of anomalies, plus offering a notification when the values are passing the threshold. This, to indirectly improve the following aspects:
• Soft/hard breakdown (+2 years)
• Cost of repairing and maintenance activities (reduce 10-20%)
• Extension of CMM lifecycle (+1 year)
The improvement in the mentioned KPIs is expected with the SERENA solution services implemented as a whole or as a chain</td></tr>
<tr><td rowspan="4">Scenario 1</td><td colspan="2">Scenario description</td></tr>
<tr><td colspan="2">As the system is not expected to fail (the pressure and airflow are not expected to overpass the defined limits), the air supply system was manipulated to create artificial losses in the air system unit so that the sensors can sense these wrong values and the data analytics tool can perform an analysis on the data, providing some visual insights of the system status, showing the situation in real-time.

A group of KPIs defined for, particularly, being able to measure or analyse the results graphs provided by the sensor data collected and processed. They are the following:

<u>Counting of anomalies</u>:
• Number of anomalies per day/week
<u>Frequency of anomalies</u>:
• Cumulative number of anomalies over a week
• Distance between anomalies (in days)
<u>Notification</u>:
• When the values are out of the ±20% threshold
• When there are 3 continuous days of high values
• When the number of anomalies per day is higher than 15 to notify odd behaviour and higher than 20 to notify a critical issue, in this sense, the first colour notification will inform the operator that something might be happening and that he should in the coming days review the data and graphs to assess it, and a second colour notification will inform that is something more serious that needs an assessment sooner as possible.</td></tr>
<tr><td>Features to be tested</td><td>Target result</td></tr>
<tr><td>Data analytics service for anomaly detection based on sensor data. Also, for this, the</td><td>To obtain the proper answer when a failure (real or artificial) occurs, providing the</td></tr>
</table>

	remote airflow and pressure sensor data collection, data acquisition, and flowing (remote condition monitoring)	necessary information about the status of the machine air bearings condition with enough time to react, plan and act to avoid any severe loss of accuracy or breakdown
	Results	
	This service could not be integrated into the INFINITE testbed where all the SERENA platform was hosted, due to a time constraint. However, the results that the analytics tool can provide for TRIMEK were assessed and validated as an isolated service. These graphs and analytics are to give a quick deep knowledge to the operator and serve as a base to make further assessments and decisions on maintenance needs. The anomaly detection service was validated, including the service of a bar graph that updates itself every time an odd behaviour is found.	

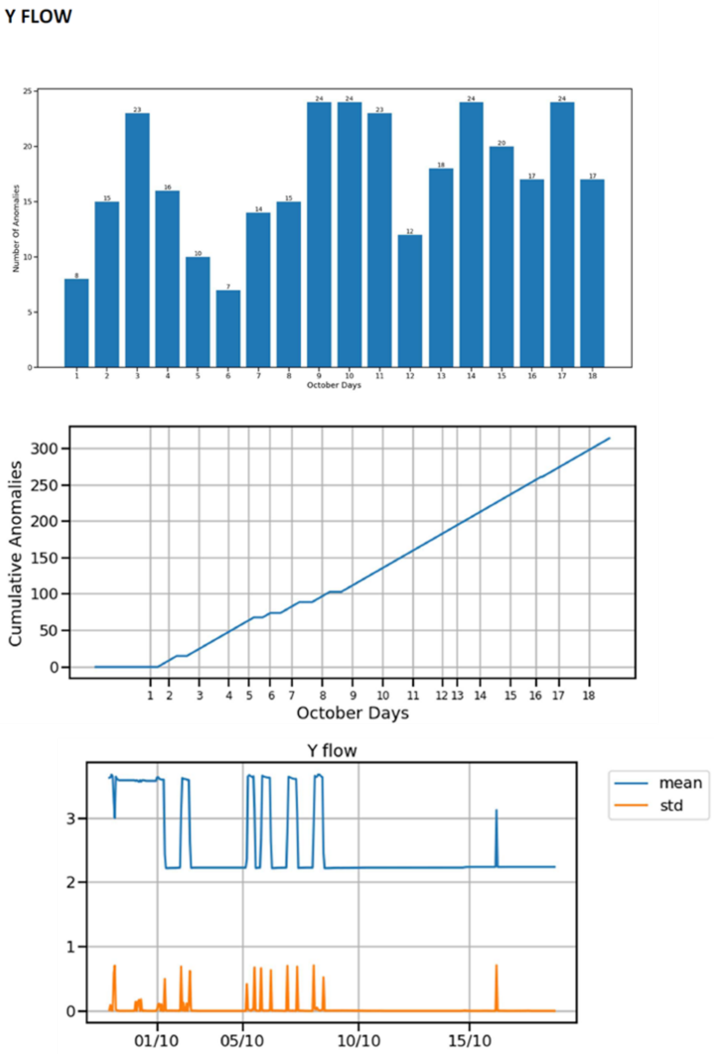


Figure 8. Graphs result from data analytics service

	Feedback/Comments	
	All mentioned measurement metrics were validated and agreed with the partners, for them to represent value results for TRIMEK: mean value, std deviation, number of anomalies per day, high values notification, a high number of odd values notification; which in TRIMEK's point of view help give the operator an idea of how high are the values.	
Achieved Metric/KPI value:	In conjunction with other experiments, the mentioned KPIs were assessed in their totality. Extension of CMM	

	lifecycle (0.5 years), Reduction of total maintenance cost (10-20%). Increment of availability of the machine (5-10%). Reduction of unexpected failures (5-10%)

<table>
<tr><td colspan="3">Objective 3. Schedule a maintenance visit within the adequate conditions</td></tr>
<tr><td colspan="3">Evaluate the scheduling tool by scheduling a maintenance visit within adequate conditions, taking into consideration the disturbance and availability in the company and clients. Also, validate all the sections in the scheduler application, the inputs required from the user side, and the proper visualization and understanding, besides validating the proper retrieval of the OCULAVIS tool's workflows. The aim is to improve, by the use of this tool, the accurateness of the maintenance personnel sent to customers for problem solution and maintenance activities, the planning of the overall procedure, and the automation at some level of it having a more organized protocol.</td></tr>
<tr><td colspan="3">Expected result</td></tr>
<tr><td colspan="3">To validate the scheduling tool and its interfaces interaction with the user/operator and obtain as a result a visit scheduled on a date and time where it causes the least possible disturbance for the company, incrementing the operator satisfaction, the availability of the machine in 5-10% and reducing the time spent on the whole maintenance protocol, from the noticing of a failure to the scheduling process in the factory and with the customer, and the maintenance execution.</td></tr>
<tr><td rowspan="7">Scenario 1</td><td colspan="2">Scenario description</td></tr>
<tr><td colspan="2">Based on a simulated alarm or notification that the values from airflow and pressure are odd or wrong, the operator, after assessing previous service result graphs and KPIs, will access the scheduling tool through the SERENA dashboard, introduce the required inputs and obtain a scheduled fictional visit for the application of the maintenance task related to air filters maintenance (assuming this is the issue solution, for the demonstrator)</td></tr>
<tr><td>Features to be tested</td><td>Target result</td></tr>
<tr><td>Planning and scheduling service for maintenance activities</td><td>The target result is a visit scheduled within the parameters described above</td></tr>
<tr><td colspan="2">Results</td></tr>
<tr><td colspan="2">The operator successfully acceded the scheduler app through the SERENA dashboard, checked the TRIMEK information retrieved, added the available resources (technician), and reviewed the maintenance task retrieved from the OCULAVIS tool linked the task with the available technician, plus adding the time for executing the maintenance task. After this, the proper scheduling of the activity received, presented in the Gantt chart.

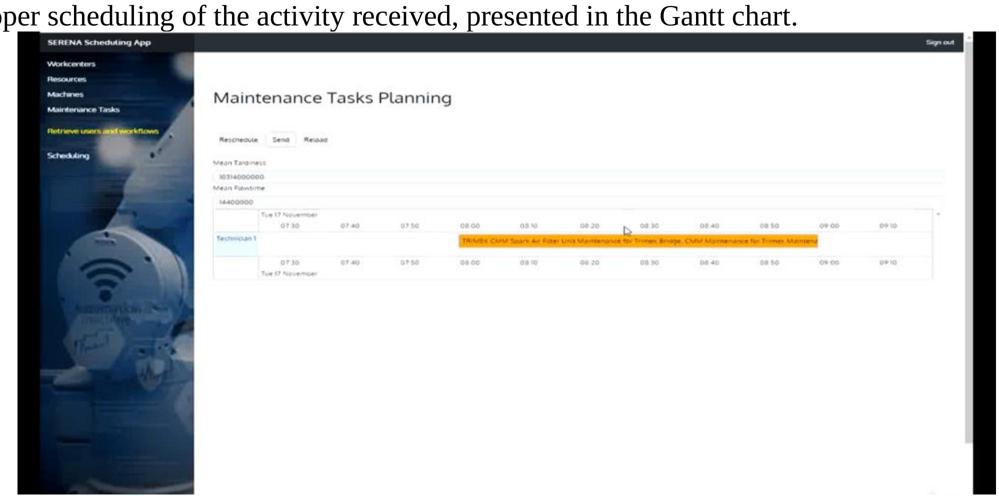


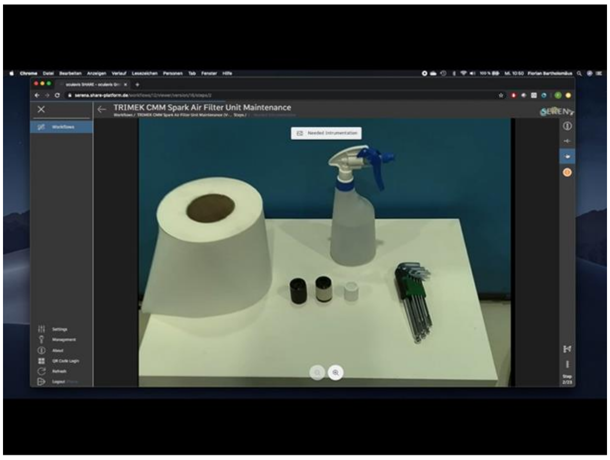
Figure 9. Scheduler user interface

This scheduler, during regular use, will help reduce the time needed for the machine to be operable again, thus, increasing the availability of the machine and the turnover as well as</td></tr>
</table>

	decreasing the costs associated with production breakdowns and the costs associated with personnel as the workload can be easily distributed.	
	Feedback/Comments	
	The SERENA Scheduling App cannot be used at the same time by different pilots because the data inputs and scheduling results are mixed (probably by the time of compiling this report, this issue is already solved by involved partners) Error when trying to update RUL: RUL value retrieval from the analytics service not available for TRIMEK. RUL value can be updated manually and then receive the maintenance scheduling recommendations. For the rest, good and easy-friendly visualization of the output, as well as a good understanding of the required inputs and the use of the application.	
Achieved Metric/KPI value:		In conjunction with other experiments, the mentioned KPIs were assessed in their totality. operator satisfaction in 2 points on a scale from 1 to 1, Reduction of person hour per maintenance process in 10-20 %, Increment of availability of the machine in 5-10%, Reduction of maintenance procedure time in 20-30%

Objective 4. Perform the air filter unit maintenance following the operator support workflow		
To improve the complete protocol procedure for a maintenance visit, the operator support workflow tool system deployed for TRIMEK will be assessed by performing a maintenance task following the instructions uploaded to the tool regarding the air bearings component selected for the project study; accessing the tool, navigating through it and obtaining the knowledge by interacting with it.		
Expected result		
Complete a maintenance activity with the expected outcome in a shorter time than without the use of the operator support system and reducing the need for 2 or more personnel for the achievement of the task. All this to validate the functioning and usefulness of the tool. Likewise, this service is expected to increment the operator satisfaction during the process in 2 points on a scale from 1 to 10, reduce the personnel needed for the process to one and the time required by 20-30%, improving in this sense the availability of the machine in 5-10%.		
Scenario 1	Scenario description	
	Based on a simulated scheduled visit for the maintenance of the air system, the operator will access the operator support system interface through a laptop, tablet, or phone and follow a maintenance workflow regarding the replacement of the air filtering unit in a CMM, following step by step the instructions.	
	Features to be tested	Target result
	Operator support system for maintenance activities related instructions regarding air bearing component	To increase the satisfaction of the operator with the procedure and its understanding. To have the option of verifying that the procedure has been performed correctly. To reduce the time needed for the performance of the air bearing maintenance activities
	Results	

The operator successfully accessed and moved through the OCULAVIS tool and executed the maintenance task related to SPARK CMM air filter unit maintenance, with a great understanding of the instructions, text and videos uploaded to the workflow in the platform.



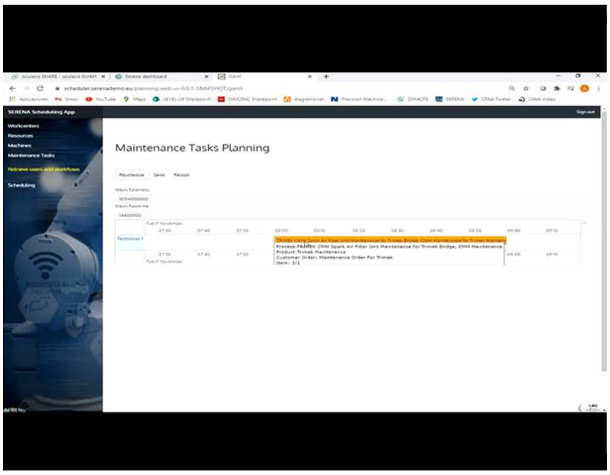


Figure 10. Operator support user interface

	Feedback/Comments
	A useful tool, easy to use, very exploitable
Achieved Metric/KPI value:	In conjunction with other experiments, the mentioned KPIs were assessed in their totality. For this experiment: Maintenance personnel reduce to one for the visits, Operator satisfaction increased (2 points in the scale), time for performing the maintenance reduced (20%), and machine availability increased (5%)

3 End-user evaluation

3.1 KPIs/Metrics

The general relevant KPIs used for the assessment of maintenance activities performed in TRIMEK, and in this case, the ones also selected for the pilot within SERENA, are defined and described in D1.1. They are:

- Soft breakdown
- Hard breakdown
- Cost of repairing and maintenance activities
- Extension of measuring machine lifecycle
- Correct maintenance personnel to be sent to the right customer

With the experiment and validation process, all of them were assessed through the execution of the sequential experiments. Most of the KPIs are correlated with the general SERENA solution with all the defined services for the TRIMEK use case.

In this sense, monitoring the machine in real-time and remotely, allows TRIMEK to improve production breakdowns frequency, calibration control, and early detection of failures. This reality affects the maintenance costs by tackling the machine issues on time, avoiding the appearance of significant damage. The monitoring is complemented with the data analytics, visualization, and anomalies detection, which provides to TRIMEK's operator a deep knowledge about the state of the air bearings system and the machine, plus more specific information to make further decisions about if it is needed a maintenance visit and the level of urgency.

Particularly, the KPI called "correct maintenance personnel to be sent to the right customer" was validated through the scheduler tool functioning validation. This tool can be exploited once included in TRIMEK's services by its use each time a maintenance visit has to be made at TRIMEK's client's facilities, as it represents a way for better planning considering clients and TRIMEK's availability, production schedule, workload, etc. Besides the manner of presenting the information and pending tasks through the Gantt chart. By its use, along with the operator support workflow system, the need for technicians per visit is reduced because the technical needs of the visit are predetermined, and knowing which components have failed, there is just need for a technician specialized in those specific components and technologies; counting with the fact that it will be more prepared maintenance personnel with the use of the maintenance-related instructions presented on the computer, tablet or phone.

In summary, all the tools and services functioning, correlation, assessment, and validation from our TRIMEK's perspective as end-user can be transduced into the following (also mentioned in the experiments section):

- Increment of operator satisfaction in 2 points on a scale from 1 to 10
- Reduction of person hour per maintenance process in 10-20 %
- Reduction of total maintenance cost in 10-20%
- Increment of availability of the machine in 5-10%
- Reduction of unexpected failures in 5-10%
- Reduction of maintenance procedure time in 20-30%
- The lifetime of components extended by 0.5 years
- Increment of turnover in 5-10%

3.2 Overall assessment of the SERENA system and its features

Based on the features tested and listed in section 2.2, the following table presents the pros and cons of SERENA's deployment on TRIMEK's use case, from the user points of view.

Table 1: Pros and Cons

Pros	Cons
The versatility of the solutions provided plus easy access and navigation through all of them centralized in the SERENA dashboard.	CMM are stable and we don't expect the system to fail, the pressure and airflow are not expected to overpass the defined limits. Different approaches to induce "artificial" failures into the air system were assessed to try to simulate them without it representing real damage to our machine.
Good, efficient, secure data collection mechanism and flow, implemented through the Databox, the sensors, and SERENA package of software solutions in a network cloud-based	The quality of the data in terms of its sufficiency, reliability and comprehensiveness represents a constraint when trying to develop AI algorithms in periods like the project duration
A good mechanism for monitoring collected data through a dashboard allowing easy access to components parameters under study. The remote monitoring and control of machine critics parameters change the whole dynamic for a maintenance approach, permitting early detection of errors and a real-time insight of the machine status. Much valued information for TRIMEK	During the testing phase was noticed that the SERENA Scheduling App cannot be used at the same time by different pilots because the data inputs and scheduling results are mixed (probably by the time of compiling this report this issue is already solved by the involved partners)
The scheduling tool/website is pretty intuitive, and also represents a valuable tool for better and quickly planning the maintenance visits to customer facilities. The tool might be fully integrated in future with more customization and information (inputs) from TRIMEK company.	
The operator support system is an intuitive website and tool, with a very didactic manner of presenting the instructions. Additionally, more operator support system workflows could be added in the future, of any particular topic regarding air bearings maintenance or installation, or even another machine component, as the tool is easy to use. It can be used for training maintenance personnel as well. On the other hand, the average time to solve a problem decreases thanks to the implemented maintenance workflows.	
The possibility to improve our maintenance methods changing into a better maintenance strategy, based on the SERENA tools	
Enrich the service that TRIMEK provide to its customers, increasing the general satisfaction with the machine functioning, lifecycle, maintenance procedures and having more availability of the machine	

In general words, as end-users, the expectation regarding participation in the SERENA project is fulfilled due to the varied pros mentioned in the above table. The outcome is useful in terms of the possibility of monitor an important sub-system in the CMM that permits to have a deep knowledge of the state of the machine related to the accuracy, a crucial aspect for TRIMEK and its clients; that along with the use of other tools (scheduler and operator support) allows to better solve the maintenance related issues, in terms of both planning and execution.

3.3 Lessons Learned

From the activities developed within the SERENA project, it became clearer the relation between the accuracy and good performance of a CMM machine and the good functioning of the air bearings system. It was proved or confirmed by TRIMEK's machine operators and personnel that airflow or pressure inputs and values out of the defined threshold directly affects the machine accuracy. This outcome was possible from the correlation made with the datasets collected from the sensors installed in the machine axes and the use of the tetrahedron artifact to make a verification of the accuracy of the machine, thanks to the remote real-time monitoring system deployed for TRIMEK's pilot. This has helped to reflect the importance of a cost and time-effective maintenance approach and the need to be able to monitor critical parameters of the machine, both for TRIMEK as a company and for the client's perspective.

Another lesson learned throughout the project development is related to the AI maintenance-based techniques, as it is required multiple large datasets besides the requirement of having failure data to develop accurate algorithms; and based on that CMM machine are usually very stable this makes difficult to develop algorithms for a fully predictive maintenance approach in metrology sector, at least with a short period for collection and assessment.

In another sense, it became visible that an operator's support system is a valuable tool for TRIMEK's personnel, mainly the operators (and new operators), as an intuitive and interacting guide for performing maintenance task that can be more exploited by adding more workflows to other maintenance activities apart from the air bearings system. Additionally, a more customized scheduler could also represent a useful tool for daily use with customers.

As with any software service or package of software, it needs to be learned to implement it and use it, however, TRIMEK's personnel is accustomed to managing digital tools.

4 Conclusion

SERENA represents, indeed, a versatile plug-and-play platform regarding industrial machines and its maintenance approach, offering diverse services for remote monitoring, AI-based analytics, maintenance activities scheduling and support to the operator in the performance of those activities. All of it centralized in a single general platform. In the case of TRIMEK, as being a company specialized in the metrology engineering sector, SERENA solutions represent a good set of tools to improve their portfolio of services and relations with the customer. As was expressed at the beginning of the project, when TRIMEK's CMM machines are sold to the customer, there is no way available for TRIMEK to remotely monitor the state of the machine, so preventive maintenance is done and/or TRIMEK's maintenance personnel go to the client's facility once the machine is broken or is having odd behaviour inaccuracy or any other terms, and they call TRIMEK for this. However, from the development of SERENA, the mentioned way of procedure can change by adding a remote monitoring system, supported by the rest of SERENA services and tools.

In the first instance, the project was implemented in a laboratory of TRIMEK, not directly on an already sold machine located at a customer facility. This influence the fact of not being able to provide an exact quantified impact on the KPIs selected for the measure. Nevertheless, as has been described through this report, the sequence of SERENA services, acting as an interconnected major service, positively affects the relevant aspects and metrics for TRIMEK.

From the outcomes, it was validated that the air bearings systems of the CMM are one of the most important subsystems and components of the machine, extremely related to machine accuracy and performance. Starting with that fact, a mechanism of data collection working with a network cloud-based was developed, along with a way to monitor this data by having it available on a dashboard and a procedure for making analytics and insights on the data; useful for TRIMEK's personnel, to improve TRIMEK's maintenance methods and to plan better preventive and practical maintenance. Additionally, two other tools were included for helping to achieve that, the scheduler, for a better organization of the maintenance interventions with improved decision time, and the didactic operator support, to guide TRIMEK's maintenance personnel in the machines interventions regarding the component investigated during the whole project: the air bearings system.

As a joint, the overall solution can enrich TRIMEK's service provided to customers, the end goal, resulting in good values for the different KPIs selected for the assessment, already mentioned in the above sections of this report.