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VerSatilE plug-and-play platform enabling remote pREdictive mainteNAnce

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Summary:
This deliverable reports the deployment of the SERENA solution in the KONE's use case. Additionally, contains, the requirements, the services, the experiment, and the results from the testing procedures based on the end-user's perspective.

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List of Abbreviations

AE	Acoustic Emission
AR	Augmented Reality
KPI	Key Performance Indicator
MTBF	Mean Time Between Failure
RUL	Remaining Useful Life
VR	Virtual Reality

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Executive Summary

KONE supply unit, located in Finland, provides elevators for customers around the globe. Timely supply of materials is key for end-customer satisfaction. The on-time delivery of materials is affected by the functioning of sheet metal punching machines. These punching machines generate parts for the elevator’s assembly processes; therefore, the machines' availability is crucial for providing continuous production flow.

Before the SERENA project, Finn-Power punching machine maintenance actions were traditional planned weekly and monthly. However, emergency maintenance work must sometimes be performed due to machine’s breakdown by surprise. The unexpected breakdowns usually cause late deliveries and are more costly in maintenance costs.

KONE joined the SERENA project in order to improve the predictability of upcoming failures of components in the punching machine. The project also acted as a good preliminary investigation for punching tool condition monitoring. Punching tool condition affects the quality of manufactured elevator parts. The monitored machine components are for bearings of the conveyors that transport parts to the next process and conveyors that move scrap metal to recycling bins. Although these components don’t seem important for the machine's successful operating, a breakdown of a conveyor bearing will cause an unexpected downtime for the whole production line.

The SERENA system is capable of calculating the Remaining Useful Life (RUL) of bearings through algorithms. This means that the traditional weekly or monthly planned maintenance work can be done more efficiently and cost-effectively. Maintenance personnel won’t have to check everything every time since the RUL values can be seen from the system, and an unnecessary bearing renewal won’t be made.

1 Demonstrator overview

1.1 Motivation and goals

Elevators are primarily built from sheet metal parts and components. These sheet metal parts are manufactured by punching and bending raw sheet metal with punching machines. This makes punching machines crucial machines in the manufacturing process of elevators. When unexpected breakdowns happen, turbulence is caused to the manufacturing processes and most likely cause late deliveries for the production orders. The supply unit's goal and ambition are to minimize the punching machines downtimes to guarantee the timely delivery of the elevators to the customers.

1.2 Testing environment and timeline

The SERENA testbed selected to be implemented to the Finn Power SB8 punching machine. The machine manufactures punched sheet metal parts for different elevator parts. Thus, the testing is in a live production environment. In more detail, the punching machine's monitored components are several bearings of conveyors that transport punched parts forward to the following process and scrap metal from punching to trash bins. Generally, if any component breaks, the machine would be out of use until the failure or breakage is fixed. Therefore, the bearings were selected to be monitoredvia vibration sensors attached to the hull of the bearings. Besides, the punching tool is also monitored. When the punching tool starts to dull after a period of production time, the sheet metal parts' produced quality starts to suffer. Measuring methods used for this are, acoustic emission sensor, microphone, and vibration sensor.

1.3 SERENA system deployment

Deployment of the SERENA system was executed by the following steps (Figure 1):

1. Establishing a connection to the Finn-Power cloud
2. Apply measuring devices to the testbed
3. Start data acquisition
4. Develop prediction model
5. Implement SERENA solutions

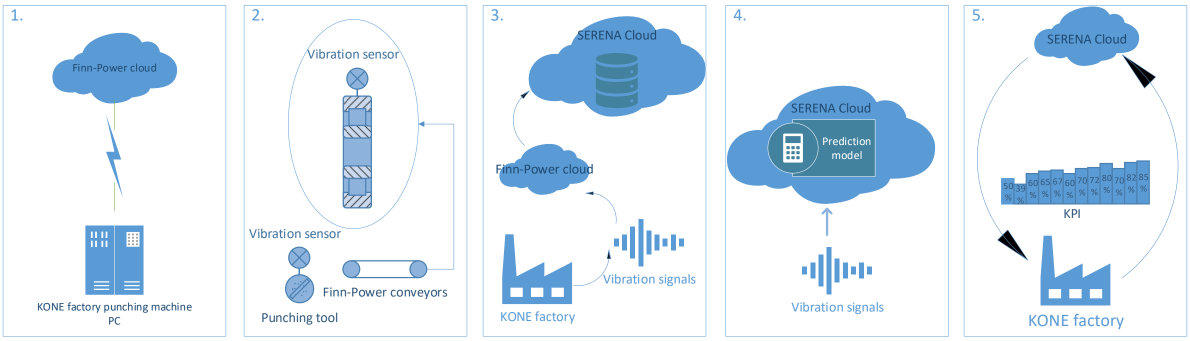

Figure 1: SERENA system deployment

Vibration sensors were installed on different parts of the testbed. The tool holder in the revolver had a vibration sensor installed on it (Figure 2). Conveyors, which transport complete sheet metal parts forward to the next process step, had a sensor installed to bearing housings (Figure 3). Also, a sensor was mounted to a scrap conveyor bearing housing.

Figure 2: KONE use case measured tool holder and chosen tool

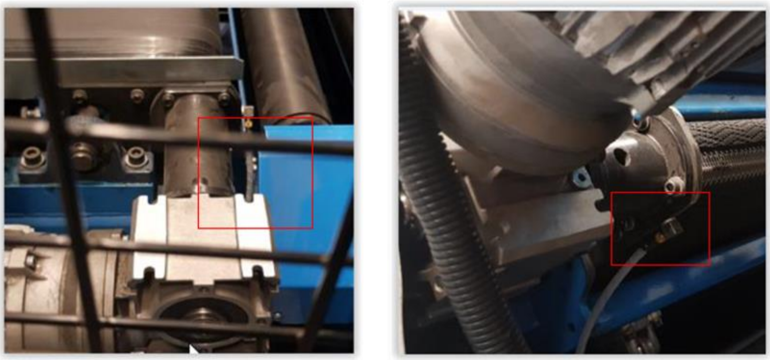

Figure 3: Installed vibration sensors

After the hardware installation to the testbed, data acquisition was enabled to the SERENA cloud. Afterward, the development of the predictive maintenance modeldevelopment could be started. The SERENA systems' detailed data flow model is represented in Figure 4.

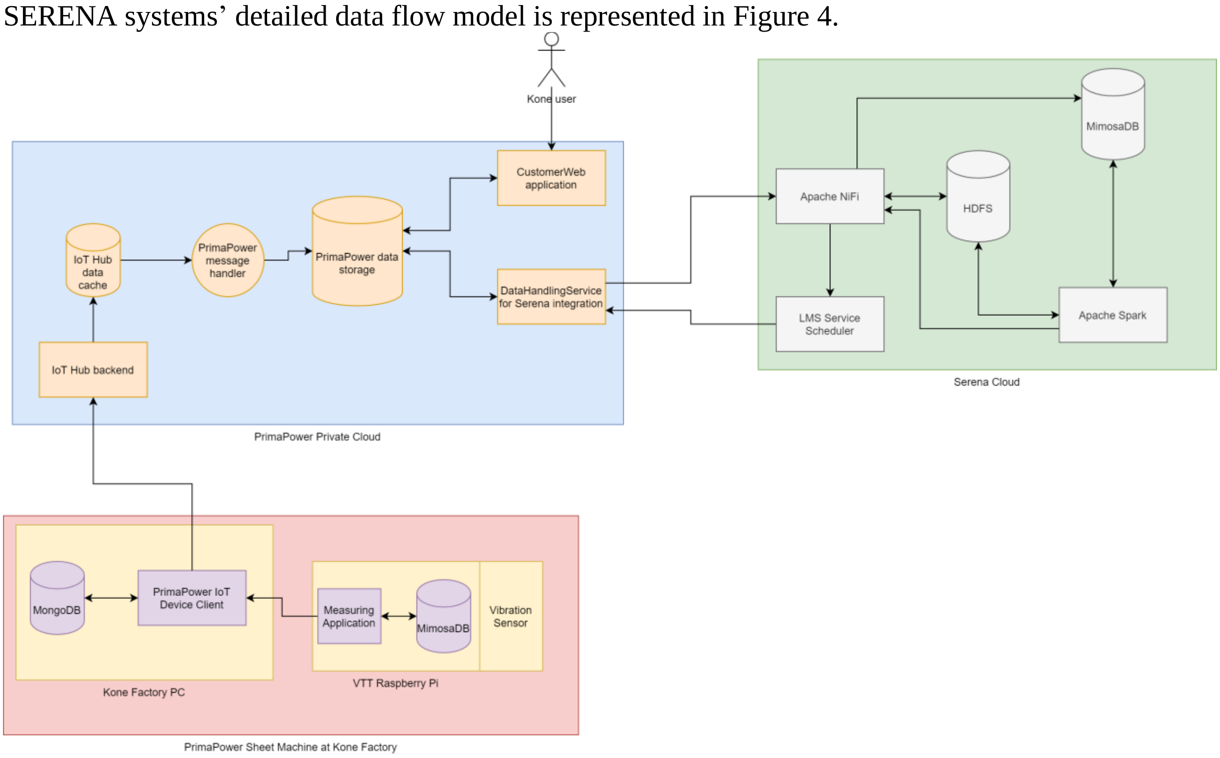

Figure 4: Serena system data flow model

Once the hardware was installed to the testbed and data acquisition was enabled, the predictive model's development began. The RUL value was developed for manufactured parts transporting conveyors. Finally, after the predictive model's completeness and after constant data flow into the SERENA system was available, the SERENA system implementation was completed. After the complete implementation, improvements could be identified in KPIs for which KONE set targets at the beginning of the SERENA project.

1.4 Roles & Responsibilities

1.4.1 KONE

KONE had the role and responsibility to provide and test the environment for the SERENA project. The testbed was chosen to be a punching machine, which plays a crucial role in the manufacturing process of elevator parts. KONE provided the time for the hardware installation to the testbed and the operation of the testbed. The data which flowed to the SERENA was real vibration data coming from the conveyor bearings whenever production was ongoing.

1.4.2 VTT

VTT's responsibility was to carry out proactive condition monitoring of the bearings of the punching machine's conveyors and punching tools. The aim was to determine whether low-cost sensor and data acquisition solutions can be used to determine bearing failure before it leads to production interruption reliably. Also, worn, and new punching tools were compared, and the differences observed in them were investigated based on the measurement data. The aim was to determine whether a worn tool can be detected before it affects the quality of the product being processed. The proactive condition monitoring solution for the bearings was then integrated into the entire SERENA cloud solution.

1.4.3 Finn-Power

Finn-Power's role and responsibility as a machine tool builder, was to prepare and provide the cloud infrastructure for VTT to collect vibration measurement data from the production line. Collected data was forwarded to SERENA-cloud, where was available for SERENA Service scheduler etc. Finn-Power has also been collecting data from the Punching-Shearing machine and Picking-Stacking robot. Data collected contains metadata, describing the machine and the environment, and timestamped data collected at runtime when the machine is working or at the event of machine error. This time-series data provides valuable insight for customers on how their machines are performing. That data is available for the production line supervisors and operators in SERENA Customer Web, which has also been part of Finn-Power responsibility areas.

2 Experiments

2.1 Testing objectives

The testing objectives have not changed since the D1.1 [1] deliverable. The two main metrics were technical availability rate and availability rate. The technical availability rate resembles the rate at which the testbed machine operates compared to the planned operating time. Availability, on the other hand, resembles the testbed machine's availability compared to 24 hours around the clock.

Table 1: Availability metrics

Metric	Explanation	Current state	Notes
Technical Availability Rate	The availability rate is calculated comparing availability for operating/working hours	~60%	SB8 punching
Availability	Availability for 24h	~30%	SB8 punching

2.2 SERENA features to be tested

- Improved monitoring by increasing data collection and combined with analytics
- Shorter maintenance reaction time based on SERENA remote access solution

IPR listed features:

- Finn Power Customer Web (explained earlier in chapter 1.4)
- Maintenance guidance and instructions with AR/VR solution

2.3 Experiments & Results

<table>
<tr><td colspan="3">Objective: Technical Availability rate</td></tr>
<tr><td colspan="3">Description: Technical Availability = actual working hours / planned working hours</td></tr>
<tr><td colspan="3">Expected result</td></tr>
<tr><td colspan="3">Increase technical availability rate</td></tr>
<tr><td rowspan="8">Scenario</td><td colspan="2">Scenario description</td></tr>
<tr><td colspan="2">Past data for testbed technical availability rate comparison to after SERENA implementation data. The testbed machine technical availability rate is constantly measured (24/7) by an individual system which also measures other KPI’s. The technical availability rate can be checked and compared from this system.</td></tr>
<tr><td>Features to be tested</td><td>Target result</td></tr>
<tr><td>Increased data collection and analytics, quick reaction time based on SERENA remote access. User-friendly SERENA customer web, including maintenance guidance.</td><td>Increased data and analytics, quicker reaction time, and root cause were found for the testbed machine. With the customer web and its features, maintenance actions can be carried out more efficiently and timely thus, the technical availability rate is expected to increase about 5%</td></tr>
<tr><td colspan="2">Results</td></tr>
<tr><td colspan="2">After comparing the technical availability rates before and after SERENA implementation, the technical availability rate has increased +4%</td></tr>
<tr><td colspan="2">Feedback/Comments</td></tr>
<tr><td colspan="2"></td></tr>
</table>

	Good groundwork/prototyping for more complex and extended solutions. KONE has similar machinery in other global supply units where SERENA solutions could be applied and contribute.	
Achieved Metric/KPI value:		It improved technical availability by 4%. However, other development actions were undertaken along the SERENA project timeline. It is difficult to say which actions (SERENA or other) influenced the KPI

Objective: Availability rate		
Description: Availability rate = machine availability hours / 24h. Although this KPI sounds similar to the previous, it is an important KPI to measure separately.		
Expected result		
Increase availability rate		
Scenario 1	Scenario description	
	Past data for testbed availability rate comparison to after SERENA implementation data. The testbed machine availability rate is constantly measured (24/7) by an individual system which also measures other KPI's. The availability rate can be checked and compared from this system.	
	Features to be tested	Target result
	Increased data collection and analytics, quick reaction time based on SERENA remote access. User-friendly SERENA customer web, including maintenance guidance.	Increased data and analytics, quicker reaction time, and root cause were found for the testbed machine. With the customer web and its features, maintenance actions can be carried out more efficiently and timely thus, the technical availability rate is expected to increase about 5%
	Results	
	After comparing the technical availability rates before and after SERENA implementation, the availability rate has increased +3%.	
	Feedback/Comments	
	Good groundwork/prototyping for more complex and extended solutions. KONE has similar machinery in other global supply units where SERENA solutions could be applied and contribute.	
Achieved Metric/KPI value:		Improved availability by 3%. However, other development actions were undertaken along the SERENA project timeline. It is difficult to say which actions (SERENA or other) influenced the KPI

3 End user evaluation

3.1 KPIs/Metrics

The testbed machine's technical availability rate before the SERENA implementation was about 60%, and after the implementation, it increased to 64%. The availability rate before was 30%, and after SERENA implementation, it increased to 33%. Therefore, the technical availability increased 4%, and the availability rate increased 3%. This can be justified with the previous sections' experiments and their results.

It can be supported that the SERENA project has most probably affected many metrics listed in the previous section. Since the machine has had extra condition monitoring running throughout the project, it would be wrong to say it did not impact the KPIs.

However, it is difficult to indicate which metrics/KPI’s have been affected and how significant the impact has been from the SERENA testbed features, since there have been other development actions to the testbed machine.

3.2 Overall assessment of the SERENA system and its features

Table 2: Overall assessment

Pros	Cons
Inexpensive hardware (Raspberry PI3)	Requires tailoring (expensive)
User-friendly (SERENA Customer Web)	
Low cost out-sourced preventive maintenance	Typically, inexpensive at first but then prices are coming slowly up.

SERENA Customer Web is a solution that provides an interface into customers' data presented in understandable and efficient visualizations. By design, customers are allowed to see only a limited environment that provides them access to their data while the application is implementing a scalable design that allows deploying the application easily for new customers.

3.3 Lessons learned

We have learned that with low-cost hardware like Raspberry PI3, it is feasible to practice predictive maintenance systems like SERENA. However, performance issues were caused by having a large sampling frequency (16kHz) and background processes running on the device, which affected the measurements. By lowering the sampling frequency, this issue can be reduced. Another way would be to obtain different hardware with buffer memory on the AD-card. In addition, a real-time operating system implementation would also work. It was found that the hardware is inexpensive to invest in, but the solution requires a lot of tailoring, which means that expenses grow through the number of working hours needed to customize the hardware into the final usage location. If there are similar applications thatimplement the same configuration, cost-effectiveness increases. Furthermore, the production operators, maintenance technicians, supervisors, and staff personnel at the factory need to be further trained for the SERENA system and its features and functionalities.

4 Conclusion

Overall assessment for the SERENA functionalities from the elevator industry KONE aspect is that it is a promising concept in all ways. Significantly, the scheduling of the maintenance, 3D maintenance working instructions, machine performance surveillance, and all other functionalities in the SERENA Customer Web had positive feedback from the operators and the production line supervisor.

The Customer Web and its different features got noticed since everything else in the SERENA system instantiation in the KONE case is hidden “under the hood” from the end-users.

The world is more and more moving towards and onwards with digitalization. Industries are also looking for ways to increase profits and improve their factories' output through different applications in the digitalizing world. SERENA project is a good first look into the third-party produced and managed predictive maintenance service application for industries.

References

[1] SERENA D1.1 deliverable, title: 'Report on use-case definition, evaluation metrics and end-users requirements'
[2] SERENA D6.1 deliverable, title: 'Test-beds design and adaptation.'