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Predictive analytics in the production of elevators

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Abstract

With the emerging role of digitalization in the industrial sector, more and more companies attempt to increase asset availability, improve product quality and reduce maintenance costs. Manufacturing companies are faced with the need to transform traditional services into remote factory monitoring solutions using big data and advanced analytics. Kone is a global leader in the elevator and escalator production industry, which is continuously looking for new ways of improving production efficiency and reducing machine downtime in order to run unmanned 24/7 production. However, the process of collecting data from equipment and utilizing it for predictive analytics can be challenging and time consuming. Therefore, during Serena project Kone cooperated with VTT and Prima Power, which provided necessary capabilities and competencies in the areas of data collection, analysis and utilization for developing and testing predictive maintenance solutions in the elevator manufacturing industry. As a result of this collaboration, VTT integrated sensors into Prima Power production line used at Kone and developed algorithms for measuring the remaining useful life of conveyor bearings. As a machine tool builder, Prima Power contributed to the project with a cloud environment for remote collection of vibration measurement data and Serena Customer Web analytics for condition-based maintenance.

1. Challenges and needs in elevator production industry

Trying to survive in times of competitive business environment, high uncertainty and low growth, manufacturing companies are looking for new opportunities to improve fleet reliability and reduce maintenance costs. The proliferation of connected machines, sensors, and advanced analytics in the age of digitalization creates multiple benefits for companies that know how to use them. In the elevator production industry, Kone is a leading manufacturing company with more than 50,000 employees and operating globally across 60 countries, which is eager to take advantage of digitalization and increase equipment availability through predictive maintenance.

Manufacturing of elevator cabins involves sheet metal processing through punching and bending. The machinery that Kone utilizes on the factory floor is provided by Prima Power, a large international provider of sheet metal processing machines and software. For the production of elevators Kone uses automated PSBB (Punching-Shearing-Buffering-Bending) manufacturing system to automatically process blank metal sheets into ready-bent, high-quality components. The summary of the production stages at Kone using Prima Power machinery is illustrated in Figure 1.

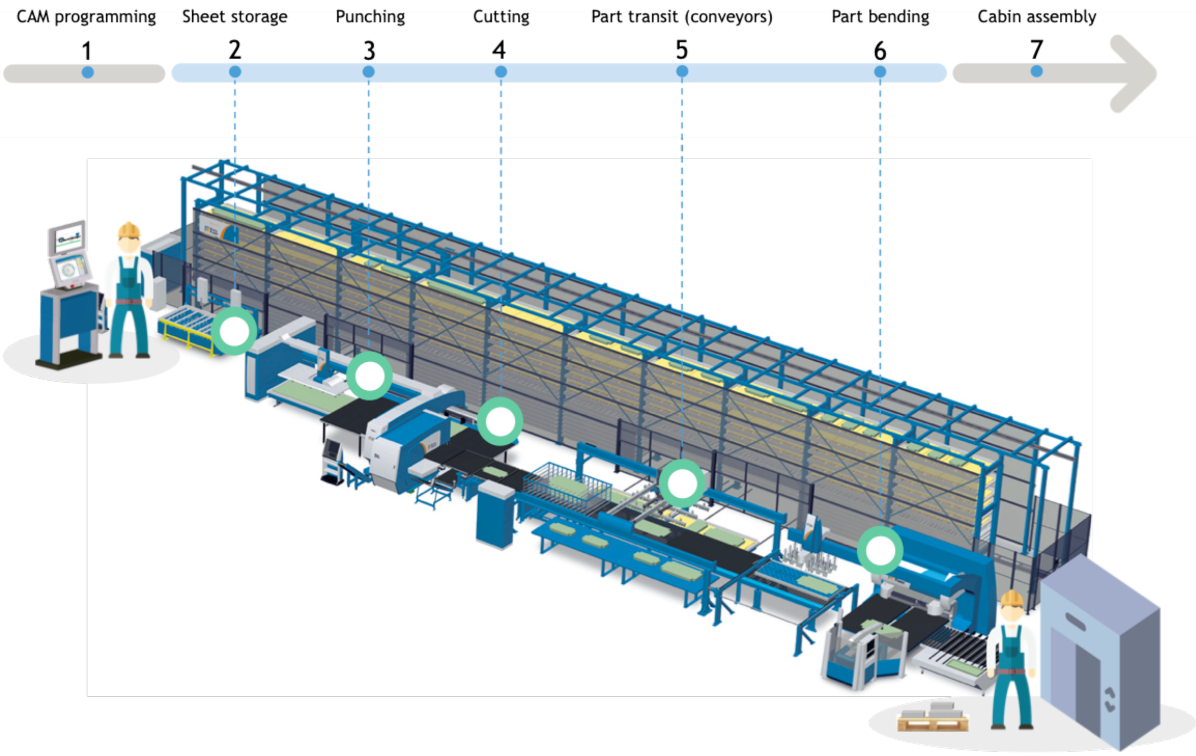

Figure 1. Production process of elevator cabins at Kone.

Due to the large-scale production of elevator cabins and demanding deadlines, Kone often has to run the production line unmanned during the night shifts. Therefore, the reliability of the manufacturing line during the evening and night shifts is crucial to the production effectiveness at Kone.

Based on the detailed Failure Mode and Effect Analysis (FMECA) conducted during the project, conveyor bearing and punching tooling have been identified as critical components at

Kone that affect performance of the production line and require additional attention. The unexpected wear or failure of these components can reduce part quality and lead to production interruption until the problem is resolved. However, these challenges can be solved by remotely monitoring the condition of conveyor bearings, predicting wear and scheduling preventive maintenance before the actual failure. Since data collection, analysis and utilization can be challenging tasks, Kone collaborated together with Prima Power and VTT Technical Research Centre during Serena project to combine expertise, capabilities and know-how.

During the project, Kone acted as a pilot in elevator manufacturing industry providing the real-time environment for testing predictive maintenance prototypes at an operating production facility in Finland. The collaboration between Kone, VTT Technical Research Centre and Prima Power involved data collection through installed bearing vibration sensors, punching tool acoustic emission sensors, and microphones in the production line (Figure 2.). Machine vibration and excessive noise are often related to the worn parts, and installed sensors help to detect excess vibration before it causes unplanned downtime. Data collected through sensors has been stored in Prima Power cloud and then further utilized to develop predictive maintenance algorithms and models in Serena Customer Web platform to accurately predict failures.

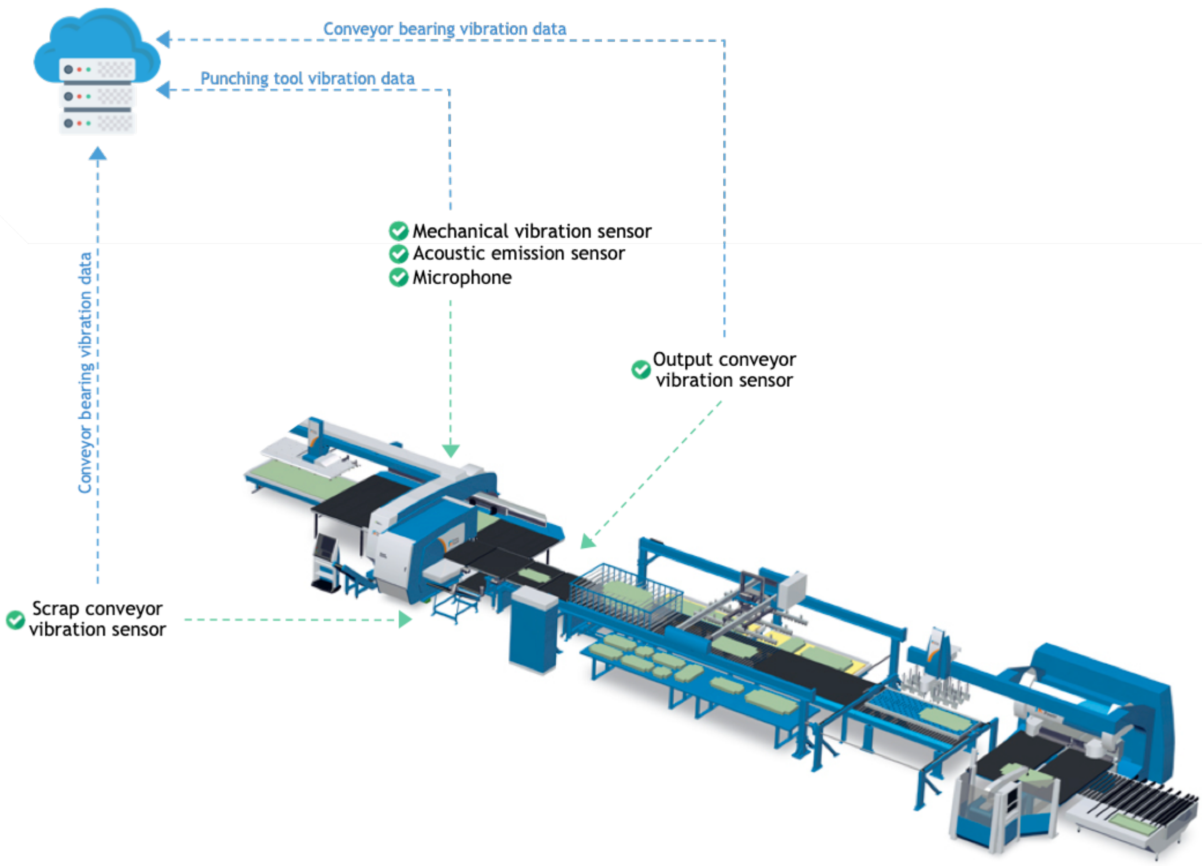

Figure 2. Data collection from the PSBB production line.

The overarching project goal for Kone, VTT and Prima Power was to gain an in-depth understanding of how to use big data to predict component life expectancy and forecast when conveyor bearings have to be replaced or when punching tools will need grinding in order to maintain high part quality. As a result, the planning and scheduling of preemptive maintenance activities as well as spare part ordering can be done in advance without interrupting the production process. In addition to improving the technical availability of the production line, maintenance costs can be reduced due to shortened waiting and repair time. Instead of a technician physically checking the condition of the production line on-site, it can be now monitored remotely in real-time.

2. Sensors and data acquisition devices for remote condition monitoring

During Serena project, VTT utilized low-cost components to develop the condition monitoring system with sensors and edge processing. One of the benefits of the low-cost solution for condition monitoring is that it can be easily implemented on a large-scale. Furthermore, maintaining a low-cost edge device requires fewer expenses since the part replacement is inexpensive. On the other hand, low-cost devices are often prone to failure over time and demand extra maintenance in comparison with the more expensive counterparts. Additionally, low-cost parts can lead to unforeseen development costs, for example, if the hardware components require additional tuning or device interfaces are not well developed. Also, lower cost devices might not be able to handle high sampling rates. To avoid the abovementioned pitfalls, during Serena project VTT decided to explore both popular and also less known system components to ensure a successful system implementation in a production line at Kone.

2.1. Development of a low-cost solution

The collection of vibration data from conveyor bearings (from the rolling element) and edge processing were implemented with a Raspberry Pi 3 single-board computer. This type of a computer was selected for the Serena project because it can take vibration measurements and also do light processing of data. One of the benefits of using the Raspberry Pi edge device is that it has a great wired and wireless connectivity, computing performance, and a relatively low price. However, even though the Raspberry Pi can connect to various sensors via its General-Purpose Input Output (GPIO) pins, it is only capable of collecting digital signals. Therefore, an external Analog to Digital Converter (ADC) is required for reading data from analog sensors. (Raspberry Pi Foundation, 2021)

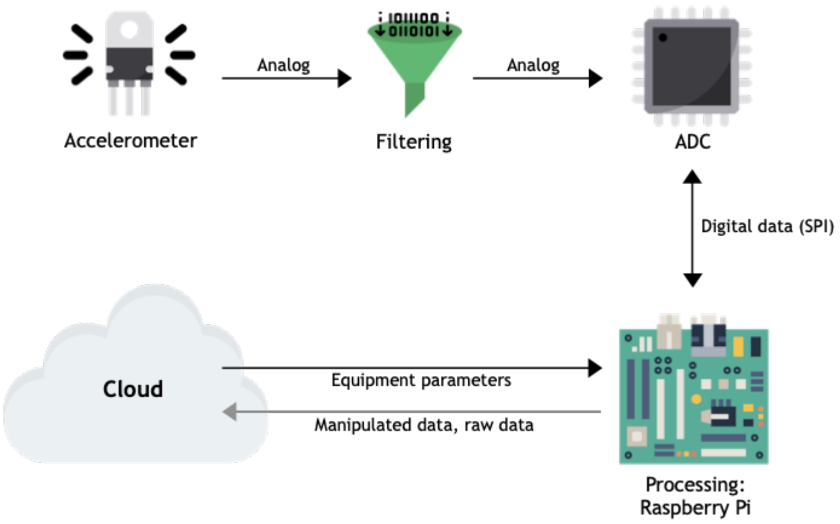

Figure 3. Measurement signal travel path within the low-cost measurement system built for vibration data collection from a conveyor bearing.

As a result of Serena project, the developed measurement system consists of an accelerometer, a low-pass filter, an ADC, and the Raspberry Pi (Figure 3.). The accelerometer produces an analog vibration signal, which is then processed with a low-pass filter to avoid the aliasing effect. Aliasing refers to the signal distortion in signal processing due to a sampling frequency that is too low for the signal bandwidth. When sampling an analog signal, the sampling frequency should be at least twice the frequency of the signal to be sampled according to Nyquist's theorem. Next, the analog signal is converted to a digital signal in the ADC and the data is communicated to the Raspberry Pi via Serial Peripheral Interface (SPI). Finally, the Raspberry Pi processes and transfers both processed and raw data to the cloud. In addition to this, the Raspberry Pi receives equipment parameters back from the cloud. (Larrañaga et al., 2020)

2.2. Edge processing

During the project, the edge analytics approach to data collection and analysis was selected because it ensures that data is processed and analyzed as close as possible to the object from which the information is collected. One of the benefits of edge processing is that it reduces the latency in data analysis enabling near real-time decision-making. For further information about edge analytics, please see Chapter 3.

In the bearing diagnostics, there are four major fault modes: outer and inner race, the rolling element, and the cage or train (Halme & Andersson, 2010). Each of these bearing faults has its own distinctive nominal pulse interval and one such example is demonstrated in Figure 4. These pulse intervals are determined by the rotating speed and the geometry of the bearing. Once the expected frequencies of the fault pulse intervals are calculated, the analysis can focus only on these fault frequencies. The amplitudes of the fault frequencies can then be monitored to determine the bearing health condition at each different part of the bearing. (Salokangas et al., 2021)

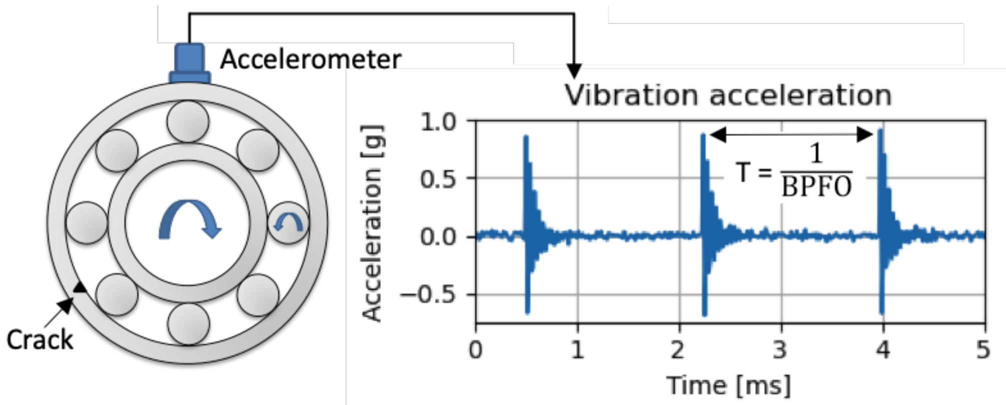

Figure 4. A crack in the outer race of a bearing is observed as repeated ringing pulses. The interval between the pulses corresponds to the ball pass frequency on the outer race (BPFO). (Salokangas et al., 2021)

One of the best methods to observe these fault frequencies is the envelope analysis. In the envelope analysis the unfiltered vibration acceleration time domain signal is band pass filtered around the bearing's natural frequency, which is typically between 500 and 3000 Hz, depending on the size of the bearing (Halme & Andersson, 2010). After band pass filtering the time domain signal is rectified and demodulated using the Hilbert transform (Huang et al., 1998). This produces an envelope signal for which the FFT transform is carried out. This envelope spectrum is used to monitor the amplitudes of pre-calculated fault frequencies. In this particular use case, the edge processing includes the both calculation of the fault frequencies and data manipulation with the envelope analysis so that the fault frequency amplitudes can be found from under the superimposed random vibrations. The fault frequency calculation is included to the edge analytics because these fault frequencies can be changed when the rotation speed of the bearing changes. During the envelope analysis, data was processed with the Raspberry Pi as follows. First, a band-pass filter was applied to the data to attenuate interfering signals caused by misalignment and imbalance and to eliminate the random noise outside the passband. In this special use case the goal was to identify the amplitudes of bearing fault frequencies and not to focus on misalignment and imbalance this time. After filtering, the ringing pulses were rectified with Hilbert transform (Huang et al., 1998) and calculated into a spectrum, which then revealed the pulses at fault frequencies. Finally, the energies of the identified nominal frequency peaks were computed. (Salokangas et al., 2021)

2.3. Use case results

Within the Serena project, VTT conducted two experiments by using the developed low-cost system to test the measurement accuracy and viability of the solution. First, the system was tested with a hand calibrator oscillating at set frequency of 160 Hz. Figure 5. and Figure 6. show promising results as the low-cost system evenly responded to the generated vibration signal and was able to correctly detect the frequency of the hand calibrator in the spectrum. (Larrañaga et al., 2020)

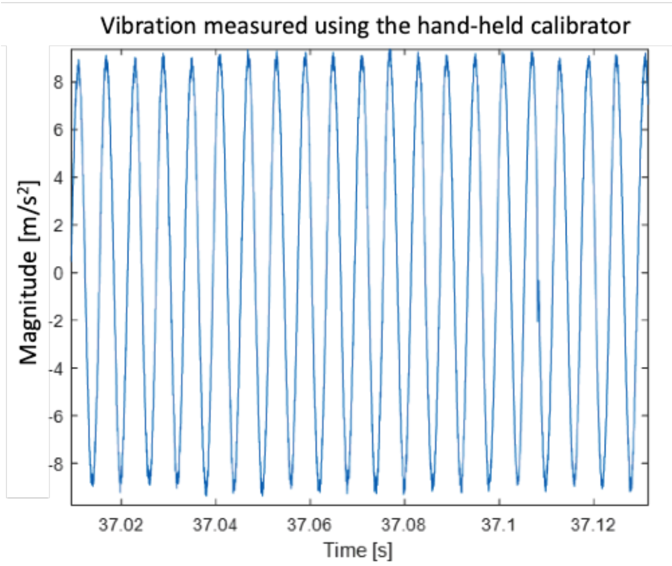

Figure 5. Vibration of the hand calibrator vibrating at 160 Hz in time domain as measured by the low-cost system. (Larrañaga et al., 2020)

Second, the system was compared to a higher cost sensor and data acquisition device, which offer better accuracy and signal-to-noise ratio. In this experiment, the data was analyzed using VTT O&M Analytics creating a spectrum of envelope signal from which the theoretical fault frequency magnitudes of the bearing can be compared. The fault frequencies used in this experiment were of the outer and inner rings of the bearings, at 25 Hz and 38 Hz respectively.

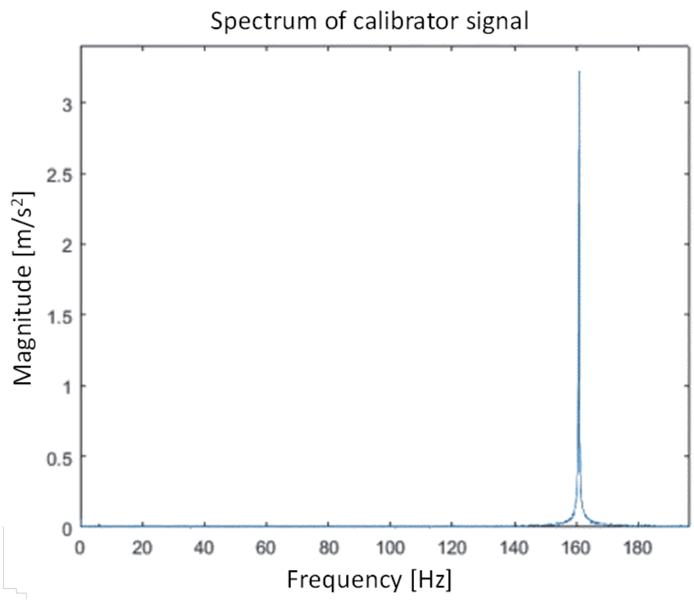

Figure 6. Spectrum of the vibration created with the hand calibrator vibrating at 160 Hz as measured by the low-cost system. (Larrañaga et al., 2020)

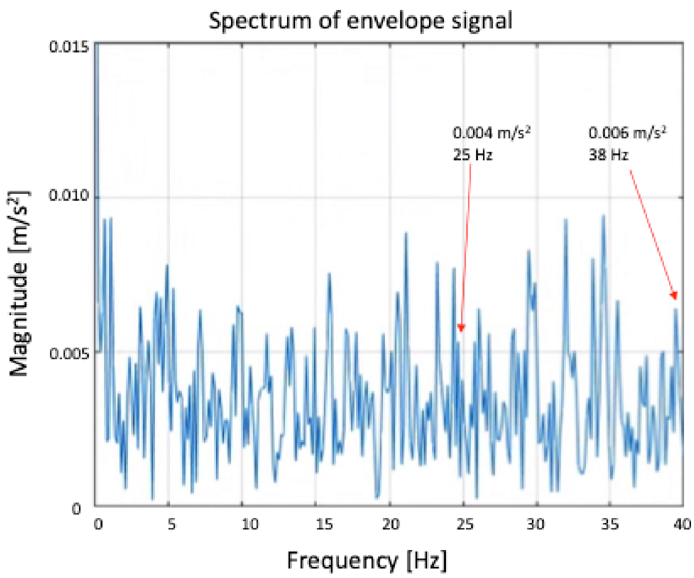

Figure 7. Envelope spectrum of a conveyor bearing vibration signal. Created with the low-cost system and analysed by VTT O&M Analytics. Low acceleration amplitude at outer (25 Hz) and inner (38 Hz) race fault frequencies indicate that the bearing is in good condition. (Larrañaga et al., 2020)

Figure 7. shows the envelope spectrum of the bearing vibration as measured with the Raspberry Pi of the low-cost system, and in Figure 8. can be seen the corresponding envelope spectrum measured with Cronos, which is a more expensive technical solution. The results show that the low-cost system could detect both outer and inner fault frequencies of the

bearing. Furthermore, the amplitudes of the fault frequencies are almost equal when compared to the measurements created with Cronos. (Larrañaga et al., 2020)

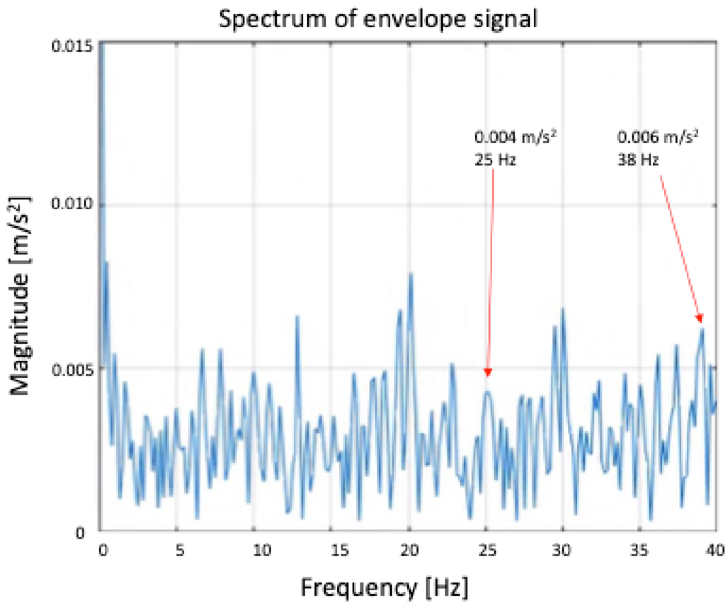

Figure 8. Envelope spectrum of a conveyor bearing vibration signal. Created with Cronos and analysed by VTT O&M Analytics. Low acceleration amplitude at outer (25 Hz) and inner (38 Hz) race fault frequencies indicate that the bearing is in good condition. (Larrañaga et al., 2020)

During the experiments, VTT faced some challenges while using the Raspberry Pi 3 as a part of the low-cost system. First, any running background processes interfered with the measurement of the vibration signal. As a result, all unnecessary background processes had to be disabled, even if they were the default operating system processes. If the processes were not disabled, a reliable measure could be obtained only for short periods of time. Another challenge is related to the high sampling rate of the measurements since the Raspberry Pi has a relatively low computing power compared to more expensive measurement systems. (Larrañaga et al., 2020)

2.4. Summary

In conclusion, the main goal of VTT's collaboration with Kone and Prima Power in Serena project was to monitor the condition of conveyor bearings in the punching machine located at KONE production facilities. During the project, VTT explored whether low-cost sensors and data acquisition solutions can be used to reliably determine bearing failure before it leads to production interruption. As a result of collaboration, VTT successfully utilized edge processing and integrated a proactive condition monitoring solution for conveyor bearings. In comparison with a more expensive Cronos system, the proposed low-cost solution by VTT is expected to provide significant monetary savings considering the large-scale implementation by manufacturing companies[1]. Low-cost sensor solutions and data acquisition devices

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[1] The exact savings from using the low-cost solution in comparison with the more expensive devices are difficult to accurately estimate due to large variation in equipment pricing levels and different levels of system implementation into the factory environment.

developed by VTT have promising results and are expected to be widely utilized in the industry in a cost-effective way.

3. Remote factory condition monitoring and predictive analytics

3.1. Remote connection to production line

Digitization of assets is one of the first necessary steps for machine manufacturers to take in order to provide customers with remote troubleshooting and data-driven products, reduce maintenance costs and increase customers' machine uptime. Remote access to equipment not only enables faster and smarter decisions, but it also creates interconnectivity and transforms business relationships between business partners.

During Serena project, the overall Prima Power objective was to implement a secure remote connection and data collection from a PSBB (Punching-Shearing-Buffering-Bending) production line used at the customer's factory (Kone) (Figure 1.) in order to achieve condition monitoring. With the knowledge and experience in remote equipment diagnostics, Prima Power utilized Tosibox VPN router (supplied by a third party) (Tosibox, 2021) to create a secure end-to-end remote connection between the production line and PC. Figure 9. summarizes the established remote connectivity to the production line at Kone through a Tosibox device during the project. For practical purposes historical and real-time data collected (e.g. conveyor bearing, punching tooling, alarms, triggers, machine utilization etc.) remotely from the manufacturing system has been first stored in Prima Power cloud and then transferred to Serena cloud (cf. Figure 17.).

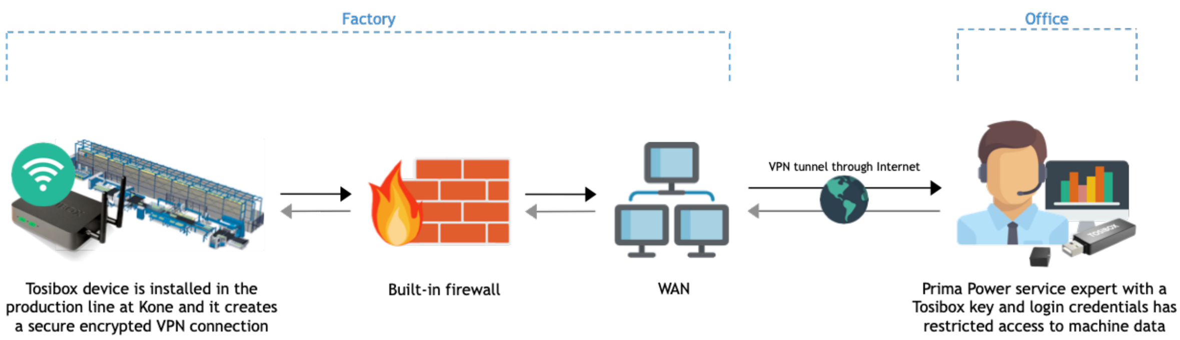

Figure 9. Remote connection to a production line.

From the perspective of data privacy and security, Tosibox VPN router is certified according to ISO 27001:2013 and IEC 15408 standards. Tosibox remote connection device has a built-in firewall, and the data processing procedure complies with EU General Data Protection Regulation (GDPR) 2016/679 (Proton Technologies AG, 2021). Access to the data collected from the production line at Kone and stored in Prima Power cloud is granted only to authorized persons with valid login credentials and a Tosibox key, a cryptoprocessing device. Tosibox key is a physical USB security key that provides user access to the collected data through safe encrypted VPN connection. The user permissions to access data can be easily granted or revoked by the organization that offers remote connection and condition monitoring service (i.e. Prima Power).

3.2. Versatile cloud-based platform for remote diagnostics

As a manufacturer of sheet metal processing machinery, Prima Power competitiveness on the market depends whether it can expand software portfolio and create new predictive maintenance and condition monitoring analytics that provide added value and satisfy customer needs. During Serena project, in addition to developing a solution for remote connectivity and data collection from the production line at Kone, Prima Power also built SaaS (software as a service) application on Microsoft Azure for analytics based on the captured data. Serena Customer Web is an instance from the Serena cloud and a cloud-based platform that contains a number of dashboards with predictive analytics for manufacturing companies to remotely monitor and optimize performance of Prima Power machines. Within Serena project, the developed solution has been piloted and tested together with Kone with respect to usability and user experience.

Serena Customer Web dashboards provide manufacturing companies (e.g. Kone) with machine historical data, real-time diagnostics, AI condition-based maintenance, service scheduling, AR-based assistance for operators and recommendations how to increase machine performance. Serena Customer Web helps to predict downtime and notifies users in advance when to schedule service maintenance, order spare parts and replace components. As a result, Serena Customer Web helps to increase reliability of the machinery during the unmanned shifts, reduce maintenance costs and use field technicians more efficiently. The key features of Serena Customer Web as a platform for remote factory monitoring include: machine utilization reporting, alarm analysis, and real-time machine condition monitoring.

First, machine utilization dashboard (Figure 10.) provides the summary of production line utilization (running, failure, idle times) by day, week or a month. The analysis of historical data enables users to identify performance trends and uncover opportunities for improvements.

Figure 10. Serena Customer Web dashboard: Machine utilization.

Then, alarm analysis dashboard (Figure 11.) gives the overview of frequent machine alarms showing which alarms are causing most of production downtime during the day, evening and night shifts. The purpose of this dashboard is to detect patterns and abnormalities, inform the manufacturing company and advise how to modify future production operations.

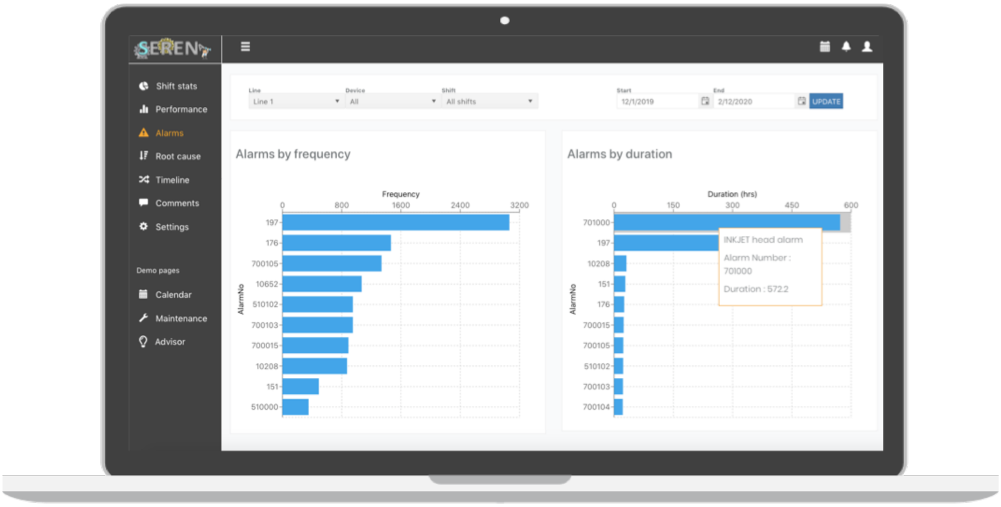

Figure 11. Serena Customer Web dashboard: Alarm analysis.

Finally, real-time machine condition dashboard (Figure 12.) demonstrates machine operations, performance and alarms in real-time to help diagnose and resolve bottlenecks during the day, evening or night shifts. This dashboard provides an overview of manual operations and alarms prior to the interrupted production process so it helps users to identify what triggered an alarm and caused unexpected failure. When the alarm is triggered, Serena Customer Web video server records short 2 min. video (through cameras installed in the machine) of what was happening prior to machine interruption. Watching these videos supports users in identifying the root cause of downtime.

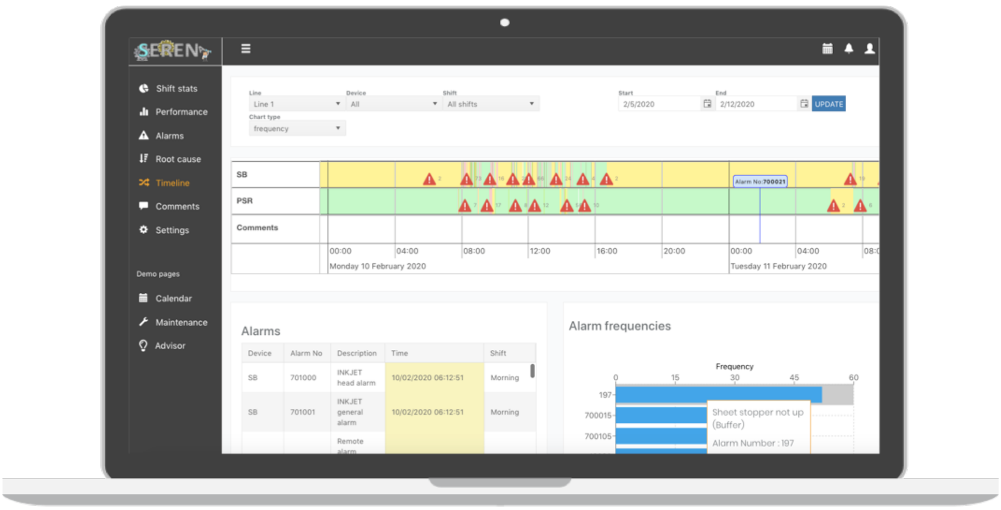

Figure 12. Serena Customer Web dashboard: Real-time machine condition.

3.3. Predictive AI condition-based maintenance and service scheduling

Serena Customer Web does not only monitor the actual condition of the production line but it also predicts which maintenance should be done and when in order to prevent unexpected machine downtime. In particular, during the project, Serena Customer Web was remotely collecting the conveyor bearing vibration data through the installed sensors (by VTT) in PSBB line at Kone factory and it was programmed to proactively schedule a service event in the calendar (Figure 13.) if it detected the wear of the components. The platform was developed in such way that it is continuously analyzing data from conveyor bearings and after the amount of vibration reaches a critical set limit due to decreased component performance, the AI-based system reacts by warning Kone to schedule a maintenance visit shortly. After the service technician performs the necessary bearing replacement, the remaining useful life (RUL) values are reset to the factory-specific values in the Serena Customer Web and a new data collection cycle begins.

During Serena project, regression models and deep learning principles were utilized to process data collected from various sources (sensors, past failure history and maintenance records) and to enable system make predictions about future failures. The goal was to automate as much as possible the process how AI collects various types of data and learns from it over time to determine the optimal time for service activity.

In contrast to the old-fashioned manually scheduled periodical maintenance, AI condition-based maintenance tool in Serena Customer Web is more efficient (see forthcoming 'Impact' section) since the maintenance is performed only on as-needed basis and only when the AI detects the decrease in the performance of the equipment. The condition monitoring and scheduling are performed while the production line is running without disrupting the daily operations in Kone, thus reducing average time the technician spends on maintenance.

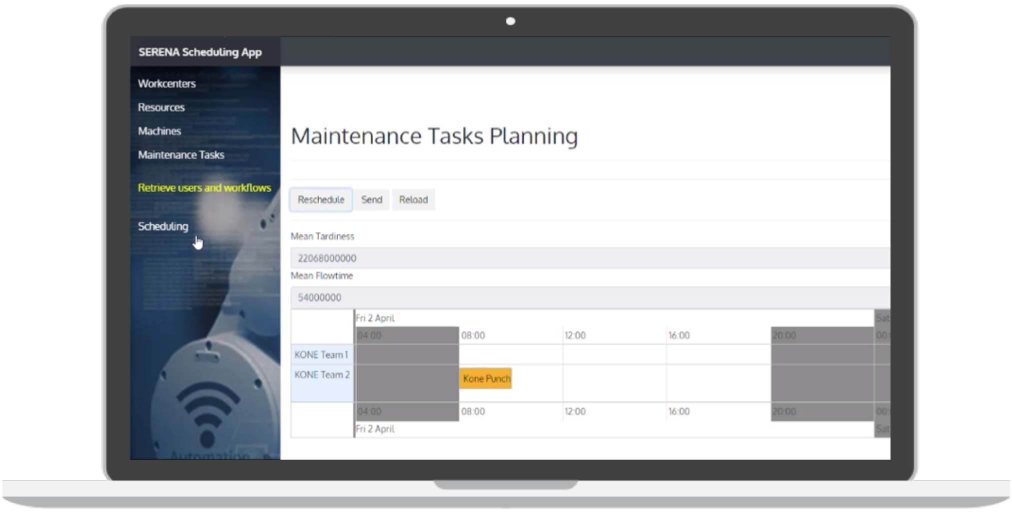

Figure 13. Serena Customer Web dashboard: Service scheduler.

3.4. AR-based assistance for operators during maintenance

In addition to the condition-based maintenance tool and proactive service scheduling, Serena Customer Web also helps operators to do maintenance work on the factory floor faster and more efficiently by providing them with the practical situation-specific assistance (Figure 14.).

As a result of Serena project, the interactive animated guidance showing operator how to replace tooling in Prima Power machine has been developed in cooperation with SynArea

(Figure 15.), while the tool grinding step-by-step video instructions have been designed together with Oculavis (Figure 16.).[2]

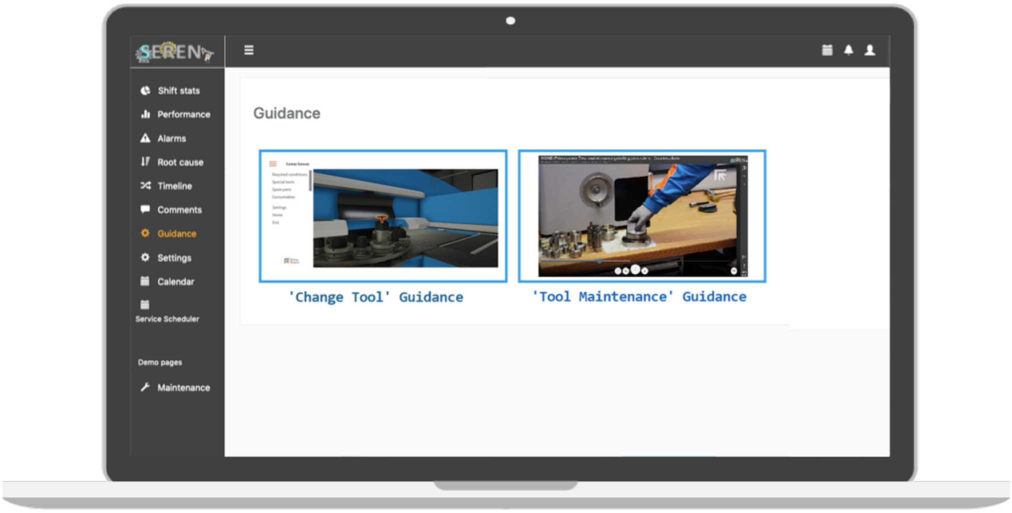

Figure 14. Serena Customer Web dashboard: Operator's guidance.

Both types of manuals available in Serena Customer Web have been piloted and tested together with Kone during the project. The tooling replacement guidance (Figure 15.) provides user with a 3D model of the punching machine and assists operator during the process through animated sequences for each step (e.g. open panel, lift tool, loosen screws). The tool grinding guidance (Figure 16.) contains brief video instructions for each step of the maintenance procedure that support operator from start to finish. Regardless of the operator's knowledge in maintaining the production line, Serena Customer Web manuals are designed to be easy to understand and can be used by both novice and expert field technicians. Digitalized guidance replaces paper-based manuals and takes maintenance to the next level by assisting operators through visual and voice commands, hence improving safety on the factory floor and reducing human errors. In the future (outside the Serena project scope), the AR-based assistance can be even further enhanced with the help of hands-free wearable technologies (e.g. smart glasses) that combine a computer-generated image with a real-life machine and provide real-time feedback to field workers.

[2] SynArea AR guidance and Oculavis video instructions can be accessed only by project partners with the valid login credentials to Serena Customer Web. However, to enhance readers' understanding of these functionalities, their screenshots are provided in Figures 14-16.

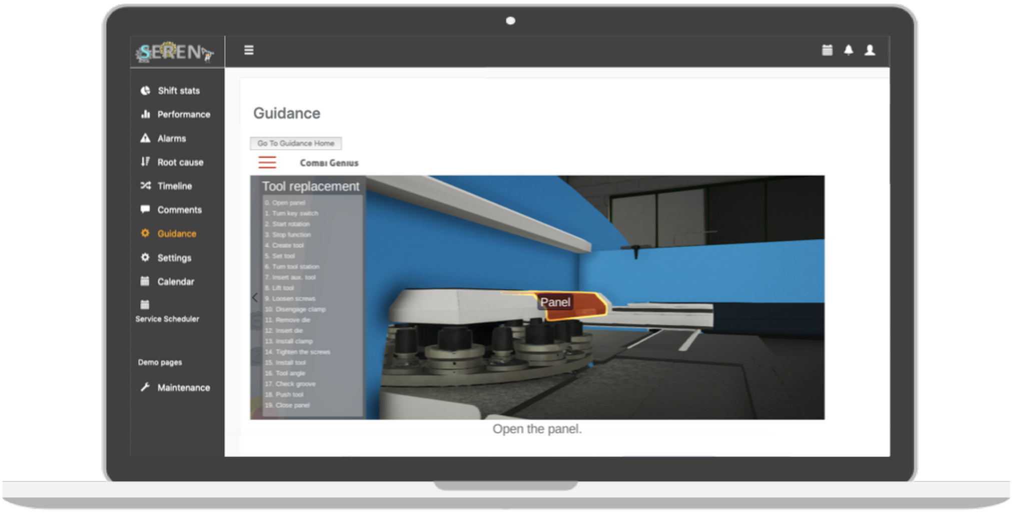

Figure 15. Serena Customer Web functionality: Guiding operator during tool replacement.

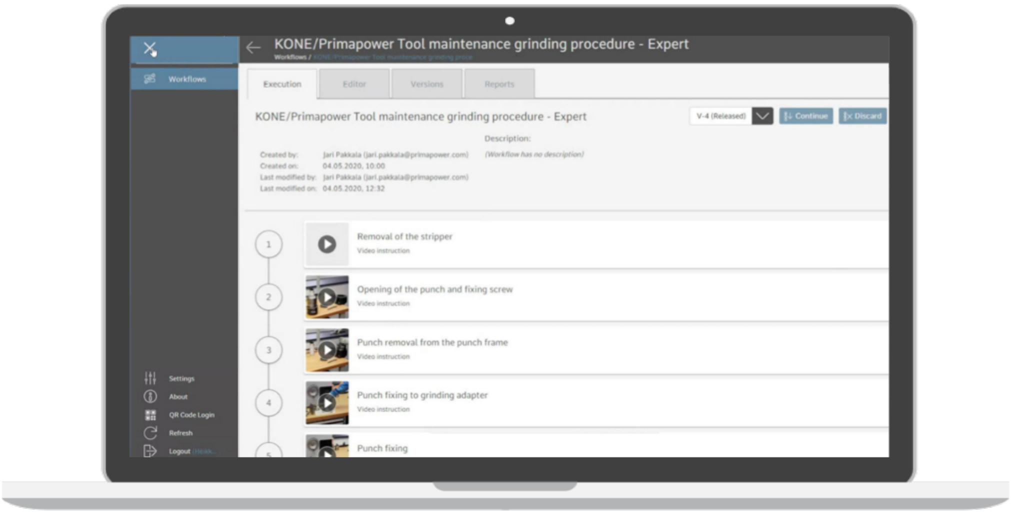

Figure 16. Serena Customer Web functionality: Guiding operator during tool grinding.

4. Integrated solution and technical architecture

The overall technical infrastructure for data collection and data processing, which was developed and utilized by Kone, VTT and Prima Power during Serena project is illustrated in Figure 17. Real-time data was collected from the production line at Kone using the Raspberry Pi and a Tosibox device to enable remote factory condition monitoring. Data was first stored in the Prima Power cloud and then it was moved to the Serena cloud as demonstrated in the figure below. Serena Customer Web platform (repeatedly mentioned in this book chapter) is a software solution for remote factory condition monitoring, which is based on Serena cloud and it provides an overview of customer's (i.e. Kone) data processed with big data analytics and presented through various visualization tools (Figures 10-16). Serena Customer Web platform was designed in such way that customers can get access only to their own production data, however because of the software scalability the same cloud environment can be replicated and extended for other customers. As a result, the supplier of sheet metal processing machinery (i.e. Prima Power) can provide remote condition monitoring and predictive maintenance solutions not only for Kone, but to the entire installed customer base around the world.

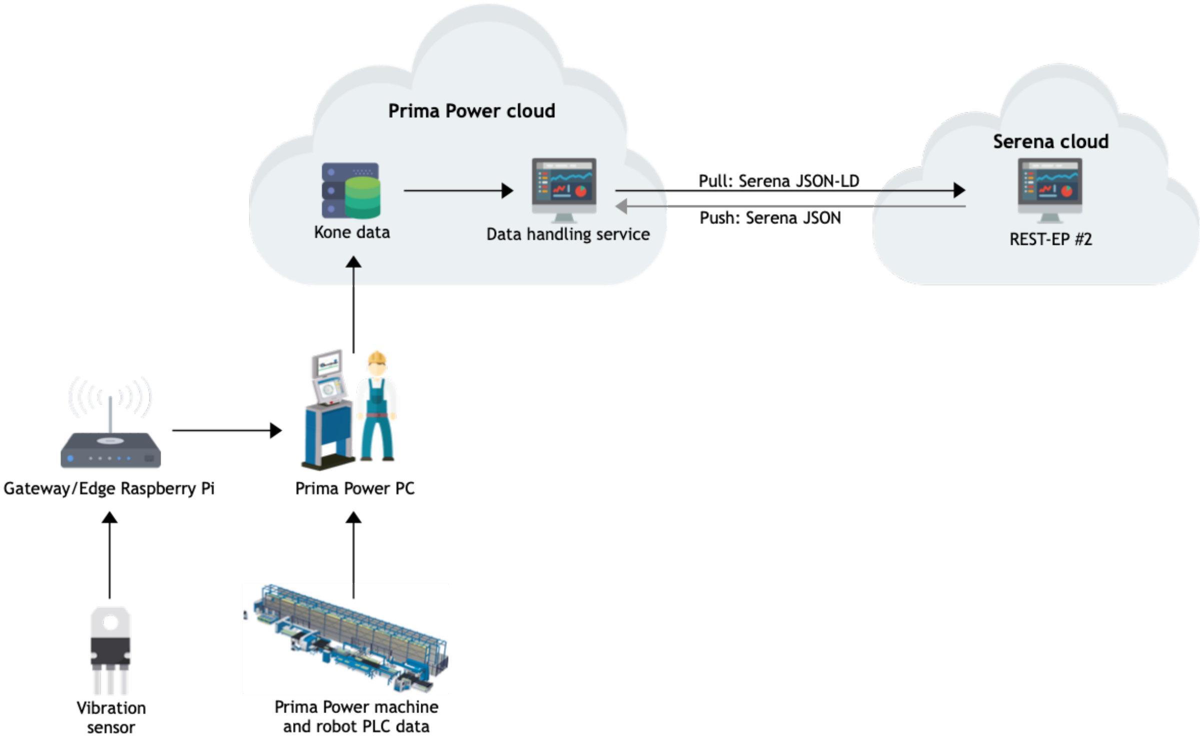

Figure 17. Technical infrastructure.

5. Impact

The benefits of close collaboration between Kone, VTT and Prima Power are twofold, because this kind of cooperation gave new insights to both industrial companies as well as the research partners involved in the project (including SynArea, LMS, Oculavis). Serena project results transformed business relationships between partners and helped to gain competitive advantage over competitors through a unique opportunity to develop and integrate predictive maintenance solutions in elevator production industry. For example, based on the KPIs measured in the beginning of Serena project and upon project ending it can be seen that Kone gained significant cost savings in the elevator production process in comparison with other players on the market (cost advantage). On the other hand, Prima Power followed the differentiation path, increased customer loyalty and gained a unique position in sheet metal processing industry by expanding product portfolio with predictive factory monitoring solutions. More detailed information on successful Serena project outcomes for Kone, VTT and Prima Power are provided in the rest of this section[3].

As a result of Serena project, Kone has been able to observe an approximately 5 per cent increase in technical availability through reduced failure rate and time spent during the repair. While, it can be challenging and time consuming to physically identify the root cause of the

[3] The exact performance indicators cannot be disclosed in this chapter due to strict confidentiality policies in participating companies. Nevertheless, to ensure that readers get an overall understanding of the successful project outcomes the key metrics are discussed in relative terms in this section.

reduced machine performance, Serena Customer Web real-time machine condition dashboard and alarm analysis help Kone to save time (est. 15-30 min. per resolving unexpected and non-scheduled service case) through remotely detecting and localizing the origin of the problem online.

Taking into account feedback from machine operators with varying expertise and skills, Serena Customer Web AR-based guidance tool is considered successful in assisting both novice and expert operators on the factory floor and it speeds up the tool changing process in Kone (est. 5-10 min. faster with AR-based and video guidance). Additionally, with the help of Serena Customer Web service scheduler Kone was able to reduce maintenance costs by about 10 per cent by eliminating unnecessary maintenance visits, scheduling preventive care in advance, using service labor more efficiently, ordering spare parts and replacing components on time without interrupting the production process. In addition to the reduced maintenance costs, Kone observed the 5 per cent increase in worker productivity through convenient automation of scheduling maintenance activities by Serena Customer Web, which means that no additional manual work is needed.

Furthermore, as a result of proactive condition monitoring and timely replacement of punching tools in Kone, the number of material defects and damages reduced and the overall quality of the sheet metal parts has improved. Finally, the VTT data collection devices and Serena Customer Web developed by Prima Power during Serena project increased the overall job satisfaction (based on the received oral feedback) of Kone operators' and managers' with the performance of the production line by simplifying maintenance procedures and reducing costs. Summary of measurable KPI values collected from Kone production facilities before and after implementing Serena testbed is demonstrated in Figure 18.

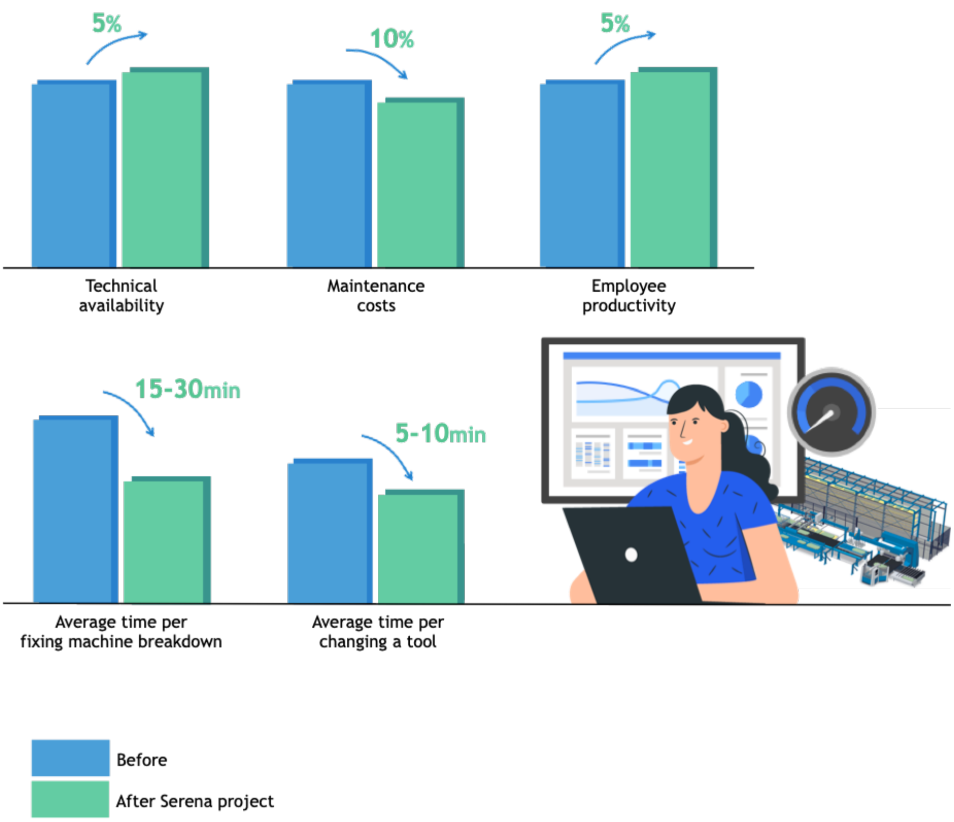

Figure 18. Impact of Serena project on Kone elevator production.

Despite the already visible positive impact of predictive maintenance solutions on elevator manufacturing industry, it should be acknowledged that the estimates provided in Figure 18. were collected during a relatively short period of time and therefore do not 100 per cent accurately reflect the full picture. It is expected that the more realistic numbers and long-term benefits of the project will be seen only after the project completion and after using remote condition factory monitoring solutions for 1-3 years in real factory environment.

The quality of the work done by VTT in Serena project has been demonstrated through numerous high-quality scientific publications. The low-cost solution that VTT implemented during the project has been proved successful in detecting bearing fault frequencies in the same way as a more expensive measurement solution (e.g. Cronos) (with a few small exceptions in the performance quality). From the scientific research perspective, this kind of experimental work hasn't been addressed before in the literature and therefore VTT extends existing academic knowledge by demonstrating the importance of the low-cost solution that provides significant potential savings to manufacturing companies in monitoring the condition of bearings.

In addition to the scientific value of project results, the joint research provided good piloting environment for testing and further commercializing Serena solutions. Serena Customer Web can save days of downtime and prevent large unforeseen costs from unscheduled maintenance for manufacturing companies (e.g. Kone) as well as provide practical monetization implications for machine tool builders (e.g. Prima Power). Taking into account successful piloting of Serena Customer Web with Kone during the project, Prima Power can use this experience as a unique advantage and expand its existing software portfolio with a new data-driven software product Tulus® Analytics beyond the scope of Serena program. This SaaS analytics software can strengthen Prima Power relationship with customers in a long term and it can help to increase customer satisfaction and loyalty. New condition monitoring and predictive maintenance solution will differentiate Prima Power software offering from the competitors and it will strengthen company brand and value to customers. Enabled by the Industrial Internet of Things and Serena project, Tulus® Analytics is a unique software that Prima Power can commercialize and offer to customers all over the world. As a result of Serena project, Prima Power will be able to increase its revenue stream by utilizing a subscription business model and billing customers a recurring fee for a monthly/yearly access to Tulus® Analytics dashboards and analytics. These insights that Prima Power gained from the project can also be useful to other industrial companies seeking to get business value from digitalization and predictive analytics in manufacturing sector. In conclusion, Serena project collaboration has positively influenced all involved parties and provided partner-specific advantages and valuable lessons learned.

6. Conclusion

The teamwork between Kone, VTT and Prima Power in Serena project has been an important milestone in capturing value of big data through the development of next generation predictive maintenance services in the elevator manufacturing industry. Serena project provided a unique environment for industrial companies and research organizations to bring together capabilities, share digitalization vision from different partners, and tackle the revolutionizing of maintenance, which companies couldn't handle separately by themselves. The close collaboration between Kone, VTT, Prima Power and other Serena project partners resulted in effective cross learning and successful know-how sharing.

In addition to the practical industrial implications, Serena project findings provide also valuable insights for the future research initiatives in the area of remote monitoring and predictive analytics beyond the scope of the program. In particular, with the increasing importance of predicting and preventing problems before they occur, there is a constant need to collect a larger variety of data (apart from bearings and tooling) from sheet metal processing machinery to enable uninterrupted, automated and unmanned production during the night shifts. Furthermore, manually created AI predictive models should be further improved to continuously self-adapt to changing conditions, learn and refine themselves over time in order to require minimum human involvement. In order to build the factory of the future, there is a need for self-learning smart machines on the factory floor that can monitor and evaluate their own performance, predict and prevent downtime by automatically ordering spare parts when necessary. As a result, further automating manual and error-prone activities is necessary in order to ensure maximized efficiency in elevator manufacturing industry. At the moment, one of the barriers to successful integration of predictive maintenance in the industrial sector is the high cost of data processing and tailoring AI-based analytics to a particular business context. As a result, future research activities should focus on seeking cost-effective hardware and software solutions for acquiring and analyzing vast volumes of data into actionable insights.

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