

Analytics for Wayside- detector data in Sweden and Norway – Useful for LKAB's work in preventive maintenance

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ABSTRACT: The iron ore producer LKAB are dependent on the railway to efficiently transport their products to the harbors. This is done on the iron-ore line in the north part of Sweden and Norway, stretching from Luleå to Kiruna and Kiruna to Narvik. The railway in the area is equipped with multiple types of wayside-detectors measuring various condition parameters on passing trains. By integrating and analyzing data from various data sources, the way of conducting maintenance can be shifted from corrective to preventive maintenance. This is done by adapting a cloud-based decision support tool to their maintenance process and information needs. By doing so a decrease in corrective maintenance action was achieved and the roles in the maintenance process has received decision support to help them in their everyday work based on analytics and integration of already existing data sources.

1 INTRODUCTION

This paper describes LKAB’s strategy to reduce their corrective maintenance and shift to a more preventive maintenance approach on their rolling stock assets by utilizing and refining the information provided by wayside-detectors. The goal with shifting towards a more preventive approach is to increase the plannability, availability, and to become more cost effective.

In fall 2016 LKAB and eMaintenance365 AB, together began to develop a tool for easy and reliable decision making within maintenance tailored for LKAB’s needs. In the project LKAB was responsible for setting up the strategic maintenance parameters and verification of deviations presented by the tool and eMaintenance365 AB was responsible for setting up collecting, analyzing, prediction models and visualization of the incoming mass data in their platform E365 Analytics®.

2 BACKGROUND

2.1 LKAB and the iron ore line

LKAB, a Swedish state-owned iron ore mining company above the Arctic Circle in northern part of Sweden owns and operates iron ore mines In Kiruna, Svappavaara and Malmberget. Iron ore products are transported on the iron ore line, Malmbanan-Ofofbanan, from the mining sites to the ports in

Narvik in Norway and Luleå in Sweden, see Figure 1. The line runs a total distance of 540 km with an elevation change of 537 m and with a maximum slope of 1.7% downhill. Temperature range from +35°C in the summer to -40°C in winter. Wagons are de-iced during winter time with either +40°C water spray or +200°C hot air. LKAB is dependent on a reliable and stable logistics chain in order to supply customers with iron ore products mainly in Europe but also in other parts of the world. Operation is ongoing 24 hours a day 365 days per year.

Malmbanan-Ofofbanan is equipped with several types of wayside detectors and measuring stations that collects data for each passing train such as track forces, wheel temperatures, bearing temperatures, bearing acoustics and wheel profiles. This data is used to monitor vehicle condition and trigger alarms if any safety limits are breached. All vehicles are equipped with RFID tags that contain the vehicle identity and wayside detector data is mapped to each individual for traceability.

LKAB has for many years collected data directly from wayside detectors and measuring stations both manually by accessing each detector/measuring station and by receiving different levels of alarms. This method is extremely time consuming and require

lots of condition-based data to be analyzed manually from different systems for correct identification and maintenance action. Often when alarms are triggered it is causing disturbance in train operation, handling in trainyards and in worse case cancelling of trains which increase cost and decreased availability.

Since a couple of years LKAB has investigated opportunity to adopt to Industry 4.0, the fourth industrial revolution, digitalization. As a result, LKAB developed a strategy called LKAB 5.0 were among other things increased automation and use of analyzed measuring data for decision making in maintenance are important parts.



Figure 1. Iron ore line map

2.2 E365 Analytics®

E365 Analytics® is a cloud-based decision support service tailored for the railway industry. It is built to serve the general functionality of the railway sector, but also to be easy adaptable to specific organizations and their needs for maintenance decision making. The information process in E365 Analytics® can be described as a generic knowledge discovery process.

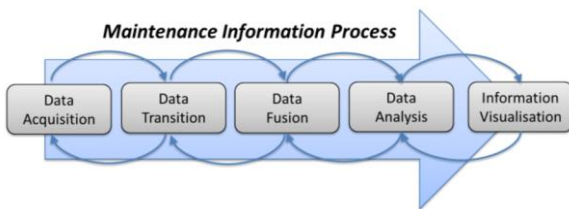


Figure 2. Generic knowledge discovery process (Karim et al., 2016)

E365 Analytics® enables data acquisition from multiple data sources with different protocols and formats, this to ensure that all required data can be included. Data is collected continuously as data is generated and the service is built to handle large amounts of data. Data fusion is an important step in the process. This enables the service to integrate data from different sources and utilize the correlation be-

tween datasets. To refine the data, analysis is performed. The service includes tailored algorithms to perform predictive analytics, giving the decision maker a better basis for their decisions.

Information visualization is about providing the correct information to a user which can interpret the information and benefit from it. For this, E365 Analytics® mainly uses a web portal. The portal includes generic applications to access and manage all data, but also customized dashboard for key roles within the organization. This to simplify for operative users and to only present relevant up to date information. Besides the web portal information can also be provided via APIs to other services within the organization.

Due to its cloud hosting and architecture E365 Analytics® is highly scalable and adaptable. Making it easy to include more data sources, analytics and perform changes whilst keeping the service online.

2.3 LKAB maintenance process

LKAB maintenance process harmonizes with the European standard SS-EN 13306, see Figure 3, as well as applicable parts of SS-EN 13460, SS-EN 13460 and SS-EN15341. Maintenance is divided in three major areas: Preventive Maintenance, Corrective Maintenance and Constant Improvements. Naturally the Preventive Maintenance should be the dominant activity and Corrective Maintenance kept as low as possible due to cost and availability reasons. Constant Improvements are an ongoing activity running parallel to other maintenance activities and cover things as reducing and/or eliminating faults, increase life and decrease down time of the assets. A fundamental strategy in LKAB maintenance process is to work with planned and scheduled maintenance to reduce the amount of costly unplanned work.

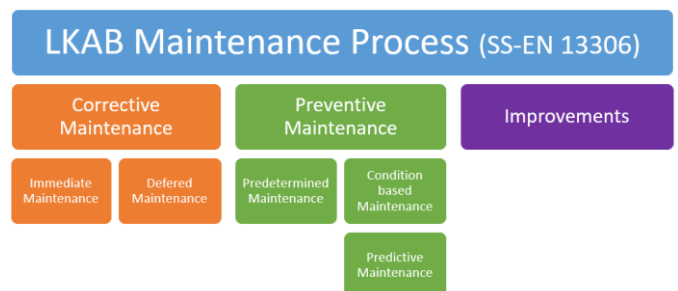


Figure 3. LKAB maintenance process

To be able to work with planned and scheduled maintenance the Preventive Maintenance leg is the route to go and from that LKAB has traditionally worked intensive with a mix of Predetermined Maintenance and Condition based maintenance. The Maintenance plan for the vehicles is based on vehicle condition checks, mileage interval (km) and in some cases, time based for outer safety limits on certain parts like wheel bearing grease and wheel bear-

ing life, see Figure 4. All Preventive Maintenance work orders are automatically generated by the maintenance system and flagged in the RFID system as well as the train planning system for easy detection of which vehicles to send for maintenance.

Maintenance Plan Fanoo / Fammoorr	Activity	Work-instruktion	Interval	80 000	250 000	500 000	600 000	750 000
Wagon Complete	Inspection	UI 2	80 000					
Draft gear Free play	Measure	AI 6.2		250000				
Car body Cracks	Inspection	AI 1.1			500000			
Wheelset Stax 32,5 t Wheel bearing	Revision	AI 4.3-4.4				600000		
Pneumatic brake system Air filter	Clean	AI 5.1-5.2						750000
Load changeover valve	Revision	AI 5.1-5.2						750000
Emptyload indicator	Revision	AI 5.1-5.2						750000
Draft gear Complete	Revision	AI 6.1-6.3						750000

Figure 4. Example of maintenance plan

Every 80000 km, which is the base of all Preventive Maintenance, the vehicles are scheduled for a condition check inside workshops where worn out parts are changed, function of subsystems are tested and required repairs are performed. On top of the condition check there are also mileage and/or time-based Predetermined Maintenance tied to each subsystem of the vehicle. The main goal is that the vehicle should be running in service without failure until next maintenance window. Unfortunately, there are vehicles in service that for some reason does not make the next maintenance window without failure and needs to be taken out of service either on the iron ore line or on the trainyards for unplanned Corrective Maintenance. In order to reduce or eliminate the need of Corrective Maintenance outside maintenance windows there is a need to predict degradation of components in service and that means working with Predictive Maintenance through online condition monitoring, see Figure 5. As the highest maintenance costs are connected to running gear the opportunity to use mass data from detectors and measuring stations to benefit operations were ideal.

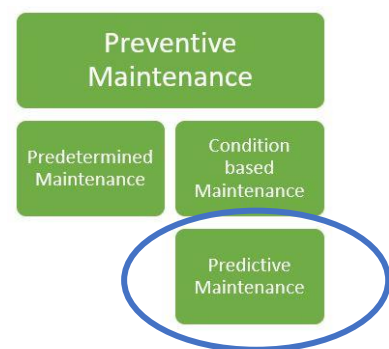


Figure 5. Online condition monitoring in maintenance process.

3 ADAPTION OF E365 ANALYTICS® TO LKAB MAINTENANCE PROCESS

The adaptation of the service to meet LKABs needs were implemented as a project for one year. Within the project an iterative process was conducted to continuously evaluate and improve the service. The project started with identifying each role in the maintenance organization, defining it's needs for information and how to present the information. The roles, information need and how to present the information were identified and listed in Figure 6.

Roles in maintenance organization	Type of information needed	Visualization / Views
Engineering	Status of vehicles, group of vehicles and fleet	Web browser - PC, Phone, Tablet
Follow up and analyze maintenance activities, vehicle performance, work with improvements and perform root cause analysis	- Wheel profile - Wheel temperature - Hot box - Bearing acoustics - Tracks forces - RFID tag	- Current deviations outside limits - Current data - Historical data - Prediction data - Combine and compare data - Wheel profile wear rates
Planning and Scheduling	Current and predicted vehicle deviations	Web browser - PC, Phone, Tablet
Planning and scheduling of preventive maintenance, prepare work orders and scheduling vehicles in and out of workshops	- Wheel profile - Wheel temperature - Hot box - Bearing acoustics - Tracks forces - RFID tag	- Current deviations outside limits - Predicted deviations (80000 km) and suggested actions - Status on specific vehicle ID - Status on predefined groups of vehicles
Workshop personnel	Current vehicle deviations	Big screen in workshop
Physical maintenance on the vehicles	- Wheel profile - Wheel temperature - Hot box - Bearing acoustics - Tracks forces - RFID tag	- Current deviations outside limits
Management	Key performance indicators	Web browser - PC, Phone, Tablet
In charge of workshops, strategic- and operational maintenance	- Utilization - Selected data	- Wagon fleet utilization - Locomotive fleet utilization - Condition based data

Figure 6. Identified roles and their needs.

With the maintenance parameters listed, and the needs defined, the next step was to set up the services to continuously collect mass data from the sensors, analyze the data, and create prediction models. The information need, which can be seen in Figure 6, mainly consists of data from wayside detectors along the track. The detectors and measurement stations included in the project can be seen in Figure 7.

Detector	Description	#
Hot box	Bearing temperatures	13
Hot wheel	Wheel temperatures	13
Wheel Impact Load	Wheel impact forces	5
Wheel profile	Wheel profile parameters	1
Bearing acoustic	Acoustic signatures on bearings and wheels	1
Track forces	Lateral and vertical track forces	1

Figure 7. Types, description and number of locations for detectors included in project.

Wheel profile, which is one of the key parameters regarding wheel maintenance for LKAB, requires more than just visualization of raw data. In this case estimates, wear rates and predictions are also needed to put more emphasis on the predictive maintenance. The lookahead required, based on the inspection interval, is 80 000 km. Since kilometer-based predictions are required, data collection from the existing RFID system was set up to feed kilometer data into the prediction models. The kilometer data is synchronized with the wheel profile measurements to transform the data series from time to distance. In Figure 8, an example visualization of a wheel profile prediction can be seen. The figure shows the last measurement in blue and a prediction line in green. From this prediction line the current value can be derived as the kilometers traveled since measurement in gray and the value at next planned maintenance in black.

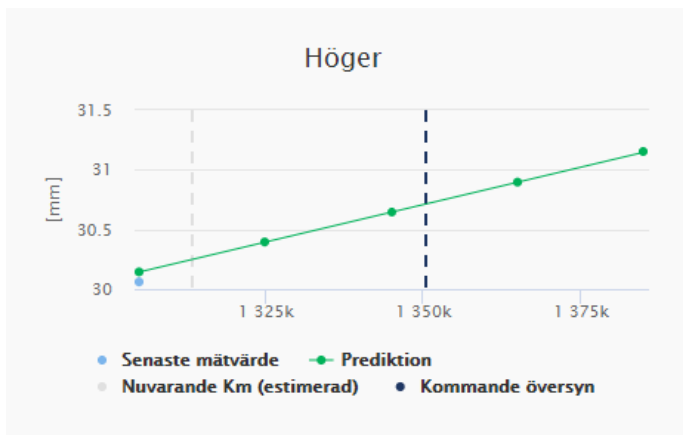


Figure 8. Prediction of Flange height for an individual wheel.

By relying on condition data to be collected, a dependency of the vehicle identification by RFID was needed. Losing information could be crucial and making the maintenance planning difficult or even faulty. Since two different data carriers are used on the vehicles in this case, it is possible to detect when all information is not acquired. This information, named RFID tag in Figure 6, is also defined as a deviation in the service which requires a maintenance action.

During the whole project period deviation definitions and its thresholds were continuously evaluated to find the correct level for each role. This to achieve a good level for the deviations that are not too defensive or aggressive in its classification.

In addition, incoming deviations on the vehicles were also verified in the workshops against actual physical condition. This was done during regular maintenance which could both result in input to a necessary adjustment or good examples to create user confidence.

Example of a worn wheel checked and measured against E365 Analytics® can be seen in Figure 9, 10 and 11.

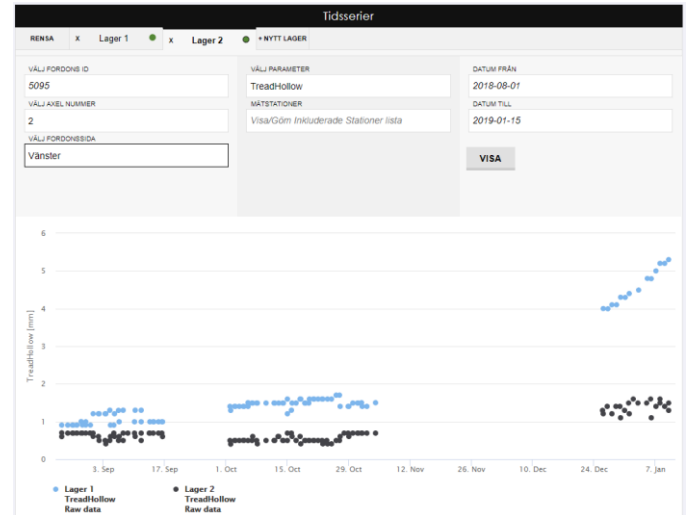


Figure 9. Tread hollow in blue 5.3mm, left wheel, axle 2 on wagon 5095

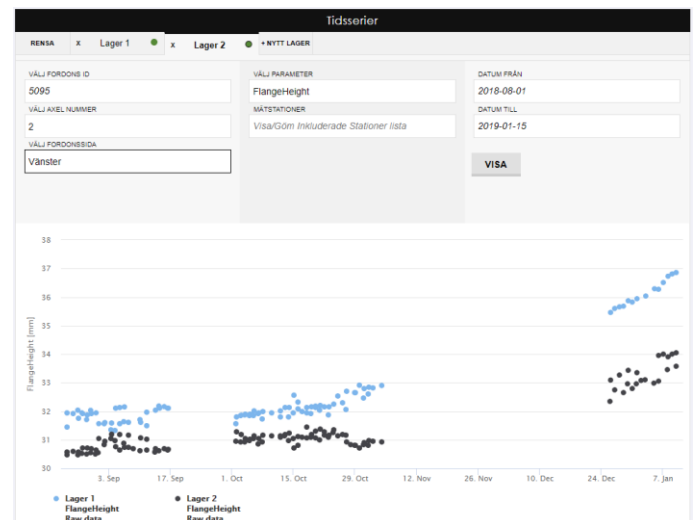


Figure 10. Flange height in blue 36.9mm, left wheel, axle 2 on wagon 5095

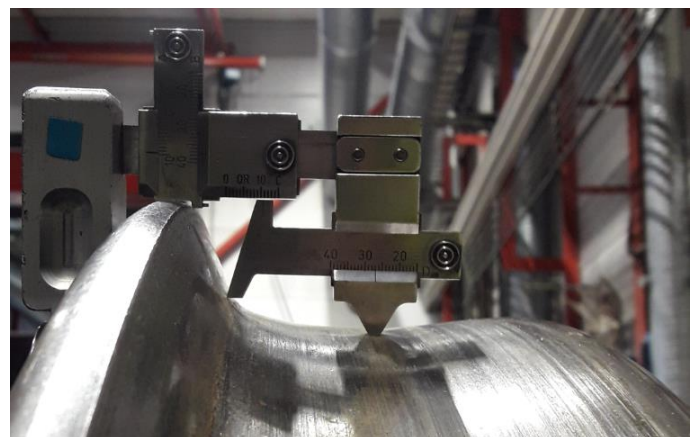


Figure 11. Physical measurement 5mm treadhollow, 37.5mm flange height. Left wheel, axle 2 on wagon 5095

The iterative process during the project also included evaluation and improvements of the user visualizations and information providing. Feedback and new ideas which came up was brought up for discussion with targeted roles. This to ensure that the information available was something that could benefit the users in their everyday work as smooth as possible.

4 DECISION SUPPORT THROUGH ANALYTICS FOR LKAB MAINTENANCE PROCESS

From the identified maintenance roles, their information needs, and the feedback from the users, the following decision support and tools was available in the service at the end of the project.

For Engineering a lot of tools was made available to enable manual analysis and handling of all generated data. This includes time series and distribution analysis and applications to filter out components due to a set of criterions. The users can also create custom vehicle sets to compare different vehicle types, components or maintenance strategies against each other.

A customized dashboard was also set up with the most common applications and some custom information. This custom information can be specific deviations or custom threshold alarms which requires a more operative monitoring.

Planning and Scheduling are only interested in deviating data. When a vehicle is in workshop it is critical to perform correct actions to keep it in traffic until the next planned maintenance is performed. In Figure 12 an application in which planners can list vehicles and overview deviations split by data is shown. This allows planners to take actions on vehicles which are predicted to reach the safety thresholds before next planned maintenance.

Figure 12. Planning list

For each vehicle, represented as a row in the figure, the planners can expand the list and view both status and recommended actions for the vehicle. Recommended actions are based on predictions until next revision. In Figure 13 an example of this is shown.

Figure 13. Recommended actions

The Workshop personnel has the need only to see the deviating information for the vehicles in the workshop. Since this is possible without any user interaction a large screen monitor is used for presenting this information to the personnel in the workshop. The monitor displays a list with the identification number for all deviating vehicles and highlights two of these vehicles at a time. The highlighted vehicles consist of a status overview similar the one presented in figure 13. A timer is used to iteratively change the highlighted vehicles after a few seconds so that each vehicle on the list is shown within a fixed interval.

Management views data from a more aggregated perspective and for this a dashboard focusing on key parameters is setup. This dashboard is shown in Figure 14 and includes utilization data divided by vehicle type and some key condition data. The dashboard is interactive and allows the user to select among multiple parameters to be viewed.

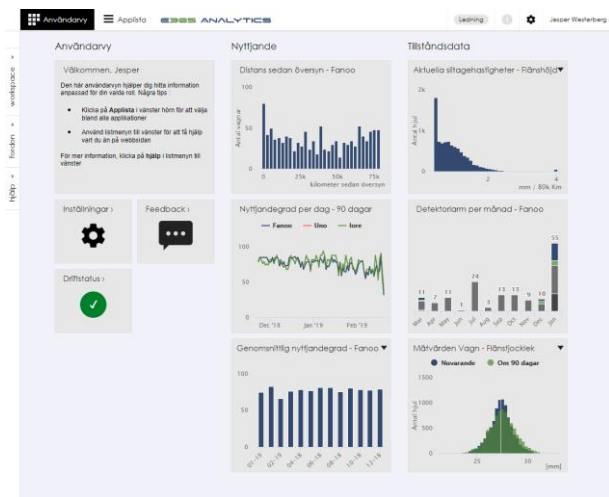


Figure 14. Management dashboard with KPI: s

5 CONCLUSIONS

The purpose of this project was to reduce the amount of corrective maintenance by shifting to more preventive maintenance. This by utilizing already available data in a more efficient manner to refine information within the data and by adapting decision support to key roles in the organization. The expected outcome was to get a better understanding of the components, their status and wear and thereby be able to optimize the maintenance cost and increase the availability of the assets.

A comparison on bearing failures in service before and after E365 Analytics was introduced shows that the number of failures in 2015 before the project started was 0,09 faults per million kilometers, in 2016 during early part of the project 0,06 and in 2017 at the end of the project 0,02, a decrease of 78%.

Wheel wear predictions helped to maintain wagons already in workshops which would not have completed the whole maintenance interval of 80 000 km without passing the safety thresholds. The verified physical conditions in workshop matched the data enough to create confidence for users to plan and perform actions based, not only on current physical conditions, but also predictions. Parameters such as Tread Hollow, which is difficult to measure accurately by hand, could be monitored and acted upon for all assets. Between 2017 and 2018, when the function was introduced to the workshops, there was an increase in number of wheelsets changed, during preventive maintenance, with fault code “Tread Hollow” from 41 to 227 which is an increase by 554%. This outcome has significantly reduced the need of corrective maintenance in operation.

By making it possible to monitor wear rates on individual wheels, interesting behaviors has been identified which gives a better understanding of how the wear rates changes over time.

By this, it can be concluded that LKAB did create benefit by utilizing condition data from wayside detectors for maintenance decision making.

6 FUTURE WORK

During the project there has only been one location measuring wheel profile, and this on the south route. This means that vehicles travelling on the north route for a long time will not have their wheel profile data updated, which is a limitation. It is still manageable in some sense due to the predictions, but the uncertainty of the predictions of course increases the further away from the last measurement they are used. In Figure 9 a time series for an individual wheel with around two months of north bound travelling can be seen. The figure illustrates the loss in data which and thereby information which occurs. This scenario also goes with the single bearing acoustics monitoring which is located on the north route. To reach full potential and benefit of this service the detector coverage should be complete.

Also, there are still some use-cases which requires a bit manual work from users that could be eliminated. Integrations with other systems in the organization could simplify the workflow to reduce this manual work. Auto creation of work orders in the maintenance system is one example of this.

7 REFERENCES

Karim, R., Westerberg, J., Galar, D., Kumar, U. (2016). Maintenance Analytics – The New Know in Maintenance.