e-Maintenance of Railway Assets Based on a Reliable Condition Prediction

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Abstract: To ensure a strong position within the transport market sustainable economical decisions and the implementation of new methods and techniques for achieving higher process efficiency are necessary for the railway infrastructure managers. Starting from a primarily time scheduled maintenance an improvement of the rail infrastructure asset maintenance can contribute to this aim, especially when considering that maintenance is a cost driver in the operation of railway systems. e-Maintenance for railway infrastructure is such a concept. Implemented in a reliable way it gives the infrastructure managers a better idea about the asset condition, reduces the number of maintenance activities to be taken manually and therefore the risk for maintenance workers in the track bed. Mandatory for an efficient e-Maintenance concept is a reliable condition diagnosis and prediction.

Keywords: Railway infrastructure, condition prediction, data interpretation, signal analysis, railway switch, maintenance strategy

1. Introduction

The increasing competition between the traffic modes asks the railway infrastructure managers for a more competitive service, which means high quality to compatible prices. Since the price of rail transportation is determined by the capital costs for the assets along the track and the expenses for their operation and maintenance, the choice of system development and maintenance strategies strongly influences the cost efficiency of the railway system. As the optimization of the infrastructure maintenance promises cost reductions of 20 to 30 percent [1], improvements in maintenance have a high effectiveness. In addition, intensive track utilization and the requirement for a high safety level for customers as well as maintenance workers ask for a high availability and maintainability of the railway infrastructure.

For this purpose e-Maintenance is a promising approach, especially with regard to the distributed structures of the railway infrastructure assets. Through the use of electronic measurement and transportation facilities to collect, forward and process information relevant for maintenance activities, the number of manual work with the asset itself and therefore higher risk and longer distances for the maintenance worker can be reduced.

e-Maintenance mainly relies on a good information quality achieved from data collected online via sensor technology. Whereas the number of diagnosis systems for railway infrastructure elements increases and therefore the amount of condition data, the number of maintenance activities has not decreased in a satisfactory amount. This is partly because such diagnosis systems record necessary data and do basic data interpretation
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(i.e., fault interpretation), but the information quality is not well enough (measured in accuracy and reliability) or not prepared user-friendly. Within this paper the necessity for an asset condition prediction model as well as ways and challenges in developing it will be outlined. Railway switches are the object of investigation.

2. Diagnosis and Prognosis

Condition diagnosis is defined as the accurate determination of the current asset condition based on condition describing measurements (i.e., corrosion level). Failure diagnosis gives crucial information about the reason(s) for failure including the failure location. In comparison a reliable condition prognosis allows the prediction of a possible failure occurrence [2]. This knowledge enables the person in charge to replace the asset before a failure event. In general prognosis models are based on pattern recognition of measured characteristic parameters. Selecting an appropriate model is an important step to succeed and can be supported using the methodology presented in [3]. The parameters itself can be measured with an online or offline monitoring technique, meaning either a permanent or punctual parameter definition. Condition diagnosis and prediction rely on the (1) definition of appropriate condition parameters, (2) their accurate collection as well as (3) processing based on the understanding of the degradation process. These three aspects are crucial when setting up a reliable diagnosis and prediction model. A well-working diagnosis and prediction model serves as an improvement of the asset maintainability [4] as they give more detailed condition information with which the time for search, recognition and positioning of the asset failure can be reduced. Even though the set up of a diagnosis and especially of a prediction model is rather complex because of the various existing interdependencies, the work is very useful as it allows the realisation of an efficient condition based maintenance management.

3. Approach

The major advantage of a reliable prediction model is obvious. A better picture of the near future avoids unmeant operation situations caused by sudden unavailability and makes the planning of maintenance activities more condition and less time based. Maintenance is done when needed not when scheduled. In addition through the use of diagnosis systems the fault evaluation is easier and less time consuming than by only visual inspections. The maintenance process efficiency increases.

The challenge within the creation of condition prediction models for rail infrastructure assets is the definition of the essential, most significant condition characteristics based on measurable parameters. Their interpretation has to allow specific and reliable maintenance recommendations. Of course, data measured by existing diagnosis systems is a good start. But the use of such systems not only asks for a collection of data, but corresponding to the idea of e-Maintenance, also for an intelligent data treatment. Only this way the system is usable. For establishing a reliable condition prediction model, the data processing has to be not only correct but also comprehensible by the user. This allows activities based not only on pure machine driven information but with the inclusion of the maintainer’s expertise.

This paper focuses on the right data processing with the aim of pattern recognition in the behavior of the condition data measured. An appropriate system usability meaning an efficient information preparation will not be discussed here.

For creating a reliable condition prediction model, three major questions have to be answered beforehand.

1. Which (internal and external) parameters influence the system condition?
2. Which characteristics describe the system condition? / Is there a characteristic condition function?

3. What influences take different maintenance activities on the condition?

After the condition characteristics are determined, existing methods for statistical as well as signal analysis and data mining are to evaluate with respect to their potential to identify patterns in the behavior of condition characteristics. With the identification of patterns, the work done by the Institute for Transportation Systems focuses on the long-term perspective of condition change processes. Short-term events, e.g., a stone between switch tongue and rails, will be rather difficult to detect in advance. Apart from that should the condition behavior schemes be of generic nature and have to

- recognize upcoming events relevant for maintenance;
- be reliable, which means to avoid false alarm;
- be manageable, that means the inclusion of only the most relevant characteristics which have to be of limited number;
- work mainly based on data achieved from already existing infrastructure and/or measurement advices. The number of sensors should be kept to a minimum.

4. Study

An adequate degradation model has yet not been developed for switches as it exists for rails [5]. In a first step the Institute lays its focus on the creation of a prediction model for railway switches. This is because of switches being one of the most expensive railway assets in maintenance. Not only do they ask for many maintenance activities, but because of their central role in the rail operation they also have a huge impact on the overall system availability and cause high unavailability fees in case of fault occurrence. This is true for all rail networks. Therefore the French rail network operator SNCF has already done research on the condition prediction for railway switches, but contrary to the French system, the German use of railway switches is not only more flexible – the switches can be used from both sides, but there is also a higher variety of switch motors in use. France only uses one type, which always needs the same repositioning time, no matter how long the switch is. Therefore generic condition pattern recognitions as described in [6] are easier to conduct. However, the same demand must be fulfilled in Germany regarding the high number of approximately 71,000 railway switches in use, even though the switch asset landscape and operation modes are more diverse.

For that reason the first findings as described below are based on data gathered from switch diagnosis systems used in the German rail network. Hence, no additional sensor information will be used. Instead characteristics measured at the switch motor are used as indicators for the switch condition.

4.1 Research Findings

The initial point for the modeling of the degradation process of switches is an understanding of their functionality. For switches there is a principle time-line of the repositioning process, which is shown in Figure 1. The characteristic values recorded by switch diagnosis systems are indicated. They correspond to the time phases. The figure shows that the process of switch control operation can be split into the phase of engine idle, the moving of the off-tongue, the moving of both tongues and the tongue locking phase. Throughout these phases the diagnosis system records the power values to determine the condition of the switch. The measurement readings recorded over several years of such diagnosis systems from different railway switches are the starting point for the conducted study on the condition change process of switches.
Whereas the French infrastructure operator has established a condition prediction of railway switches on the basis of a single switch operation with its characteristic behavior as shown in Figure 1 [6], the approach of the DLR is based on the values gathered from several switch operations over a longer period. With this the focus is set on the long-term perspective, which also allows the evaluation of maintenance strategies.

The findings recorded in this paper are based on the questions raised beforehand, as they were:

1. Which properties show the recorded condition characteristics and is it possible to set up a degradation function? (see 4.1.1)
2. How generic can a prediction model be if there is a diversity of switches in use? (see 4.1.2)
3. Can one measured value be used to forecast the behavior of another value? How much do the measured values influence each other? (see 4.1.3)
4. Does the behavior of measured values allow a prediction of critical system conditions? (see 4.1.4)

4.1.1 Which properties show the recorded condition characteristics and is it possible to set up a degradation function?

First of all the recorded data of about 2 years have been separated dependent on the switch operation direction (left or right movement). The recorded characteristic values (see Figure 1) from discrete switch operation events have been regarded as continues input (signal). An extract of the behavior of the characteristic plaufl is shown in Figure 2.
Figure 2: Evolution of $p_{au2}$ with Regard to the Number of Operations and Maintenance

Figure 2 demonstrates the following properties of the condition characteristics:

- The characteristics are indicators for a continuous degradation process.
- Fault clearance activities (represented by vertical lines) show clear condition improvements, indicated by a decreased need of power whereas preventive maintenance activities don’t cause direct changes in the values. Their long-term effect on the condition behavior has to be explored further.
- After fault clearance activities the achieved power values do resemble.

Since a resemblance of the characteristic’s behavior has been proven within the research work, the question regarding the creation of a degradation function can be answered positive. Such a degradation function describes the ongoing condition decline with respect to the wear parameters. A way for determining the degradation function is the use of interpolation of the separated time windows in-between two corrective maintenance activities - given an obvious similarity. Whereas the number of wear parameters describing the degradation function should be limited to not more than three to five. That way the condition behavior schemes are kept as generic as possible and with the limited influencing parameters easy to use and interpret.

4.1.2 How generic can a prediction model be if there is a diversity of switches in use?

It is necessary to have a usable prediction tool, what means to limit the number of different condition models for the critical railway assets. For that reason it has been analyzed how different the characteristic values behave depending on what switch type is recorded. The results gained are promising and ask for an ongoing in the determination of prediction models. Figure 3 shows the mean values of the characteristics recorded during a switch operation as they are indicated on the x-axis. Since every switch has a gradient, the values are shown separately for the up and down direction (left/right movement). All three switches are of the same type and supplier, but number 302 has a switch rolling system in addition. Further all three switches are in the same station and are inspected and maintained following the same schedule. The characteristics’ means are plotted on a line only for reason of demonstration.
Figure 3 shows a clear interrelationship between the switch technique and the values of the switch characteristics. It can be seen that because of the rolling system the power for moving the switch tongues is less for switch 302. The characteristics of the identical switches 328 and 332 show the same pattern in the ‘course’ of the characteristics’ mean. This leads to the conclusion that the creation of condition prediction models is suitable for groups of switches which show identical or similar technological properties. This is a good start towards a feasible condition prediction.

4.1.3 Can one measured value be used to forecast the behaviour of another value? How much do the measured values influence each other?

For answering the first question detailed statistical analysis has been conducted. Unfortunately no clear correlation or cross correlation could be proven which would either mean that two values are almost alike and therefore only one of them would be significant or allow the forecast of one value by another. That all of them are more or less indicators for condition changes has been proven, but existing interdependencies besides the ones existing because of functional and or structural reason were not found. Therefore it now has to be done a classification of which of the recorded characteristics do best reflect the condition change process. That the characteristics behave similar is demonstrated in Figure 4. All six characteristics show an ongoing change process and an influence of maintenance activities (indicated by dots). The dark dots show corrective maintenance activities, after which a condition improvement – decrease in needed motor power - is clearly visible for all characteristics besides pleer.
4.1.4 Does the behaviour of measured values allow a prediction of critical system conditions?

Furthermore, Figure 4 shows that a critical event prediction purely based on the behavior of the condition characteristics seems not to be feasible. By just looking on the value evolution of the characteristics, faults seem to occur rather sudden; the characteristics don’t always reach a specific value before fault occurrence or show a certain pattern. The identification of patterns within the value evolution before fault events has also been analyzed with methods of signal analysis. The measured values have been interpreted as signals and analyzed by the use of wavelets. But unfortunately, this as well didn’t give clear hints for a behavior pattern allowing the prediction of critical system conditions (see Figure 5).
However, even though the analysis didn’t deliver the results hoped for, Figure 4 shows an effect within the data evolution. PverschlPeakMax, the maximum power needed for the final switch locking (see Figure 1) reflects the long-term temperature changes, so-called seasonal influences. During summer months this power is less than during colder winter days, when material contracts and the lubrication loses viscosity. Not only show the measurements seasonal fluctuations, but also variations within a day (see Figure 6). This noise in the measurements is highly relevant for the condition monitoring and prediction. The exceeding or shortfalls of thresholds indicate a failure and results in an alert for maintenance staff. False alerts are often cause of daily fluctuations and therefore responsible for unnecessary maintenance costs. For a reliable e-Maintenance using condition monitoring and prediction the noise has to be reduced as much as possible.

**Figure 5:** Wavelet Analysis of Measured Condition Parameters
The combination of the known measurement data with weather data retrieve from nearby weather stations shows a relatively strong correlation coefficient of -0.792 between the power consumption and the temperature. The coefficient of determination is 62.78%, which means that from a statistical point of view the temperature explains 62.78% of the variation in the power. With these results it is possible to reduce the noise and get a “clearer” signal to monitor and predict the switch condition, as the little example in Figure 5 shows. Though the noise is reduced there is still fluctuation which needs to be explained with other parameters influencing the measurement, e.g., recent maintenance of the track bed, the number of trains crossing the switch.

However, the question if the behavior of measured values allows a prediction of critical system conditions can be answered positive. But for establishing a reliable prognosis tool, it has not only to be looked at the current condition (starting point) and wear (e.g., number of planned operations) but also at weather conditions and trends.

5. Conclusions

The paper states the necessity of an intensified use of potentials of e-Maintenance for rail infrastructure assets. However, the efficient use of electronic measurements needs an intelligent data processing unit which allows maintenance recommendations based on the predicted asset condition. The relevant aspects when establishing a manageable and especially reliable condition prediction tool have been outlined. Current research done at the Institute of Transportation Systems on the determination of switch condition prediction models has been demonstrated. On one hand these results give positive signals for the realization of a generic prediction model, even considering the diversity of switch types used in the German rail network. But on the other hand they also display the difficulties of describing the condition change process and also of identifying patterns for an early and reliable estimation of faults under the constraint of a limited number of condition characteristics to be analyzed. The results underline the expected aspect of
complexity when setting up a reliable diagnosis and prognosis model, but nevertheless the findings achieved so far are promising.

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**References**


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