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DETECTION OF BOGIE PERFORMANCE ISSUES USING WAY-SIDE MONITORING SYSTEMS

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ABSTRACT

Wayside detectors are nowadays used to not only preserve the infrastructure but also to detect abnormal behavior or condition of railway vehicles or locomotives. Typical way side detectors are hot box, hot wheel, wheel impact load detectors, wheel profile detectors and bearing acoustic detectors, which provide insights on the condition of wheels and bearings.

In this paper, a novel approach is presented to detect and analyze deviating bogie performance on railway vehicles using data from multiple wheel impact load detectors over time. The analysis of the wheel impact load time series can be used to identify bogies with deviating performance, which in turn, results in increased wear on wheels and bearings. An analytics scheme has been developed based on the load distribution deviations to detect bogies with performance issues on a fleet. The analytics scheme is then evaluated on a fleet operating in Scandinavia and deviating bogies have been inspected and further assessed to determine root causes for the deviating behavior.

It is concluded that railway vehicles with deviating behavior can be detected using the analytics scheme and that these deviating bogies exhibited errors requiring repair. The detection is possible well before the bogie problem would render an unplanned stop or pose a hazard for operation.

INTRODUCTION

The purpose and functions of railcar bogies are supporting the vehicle, ensuring stable run both on straight and curved track, providing comfort by absorbing vibrations caused by track irregularities as well as minimizing the generation of new irregularities and rail abrasions. The bogies are classified into different types depending on their configuration in number of axles and design and structure of suspension. Articulated bogies support the back end of a car and the front end of the car following. The set up allows for better comfort due to less noise and car ends not overhanging the bogie. In hauling applications though, non-articulated bogies are more common due to their less complex structure, and the fact that ride comfort being unimportant for the application. Regarding the less complex structure and build, the non-articulated bogie requires less maintenance actions (Okamoto,1998).

Bogie degradation increases the risk of derailment and can occur due to different underlying reasons. In Ekberg et al. (2013), the top derailment causes are identified, and their impact is described. One of the top influential parameters is described to be skew loading and especially lateral load imbalance. The skew loading of the wagon leads to bogie frame twist. This permanent deformation leads to increased lateral wheel-rail forces while negotiating a curve thereby making flange contact. As pointed out by Fröhlich and Hettasch (2010), poor steering capability of a bogie induces lateral forces which in turn lead to accelerated wheel flange wear. Increased flange wear ultimately requires more frequent maintenance actions together with higher material consumption to restore the desired wheel profile. Thus, wheel life length is compromised. Due to the nature of the wheel/rail contact, one of the most contributing factors to track damage is the poorly performing bogies (Hiensch et. Al., 2018). The performance of the bogie can deteriorate when the load it is carrying is not uniformly distributed along the length and width of the car body or when there is a fault in the suspension.

In addition, lateral skew loading can cause contact within the side bearer vertical bumpstop assemblies. This further adds to the reduction of safely negotiating track twist and curvature, exacerbating their effects on equipment.

Another influential parameter category found to mainly influence the risk of derailment was found in simulation to be the primary suspension stiffness of the bogie and more specifically its transitional behavior between loaded and unloaded conditions. In the report the limit on load imbalance of 1:1.25 is reconfirmed as appropriate and simulations show that lateral load imbalances exceeding this limit where likely to exceed the limits established in the standard EN 14363 and Ekberg et.al. (2013). Imbalances exceeding 1.7 yield a high risk for derailment according to simulations.

There exist several types of wayside equipment for detecting poor performing bogies with the most common ones being, Truck Bogie Optical Geometry Inspection (TBOGI), Truck Hunting Detector (TBD) and Truck Performance Detector (TPD). TBOGI is typically mounted along a tangent track and consists of a laser-based monitoring system and a high-speed camera to measure the performance on passing axles and cars. TBD and TPD can be based on either strain gauge or laser technology with the laser-based being like the TBOGI. Mounted in a tangent track a strain gauge TBD detector measures lateral forces whereas a laser-based system measures angle of attack and lateral axle position. TPDs are installed in s-curves and monitors both lateral and vertical forces in an array of strain gauges. Unfortunately, these detector types are not very widespread and access to their data is limited.

However, to monitor skew or asymmetric loading even a single Wheel Impact Load Detector (WILD) can be used. A challenge with solely relying on the WILD information is that the detectors span of 10 feet consequently, hence being unable to record the whole period of a hunting motion. Nevertheless, the imbalance ratios given by Ekberg et.al. (2013) could then be derived.

In this paper, we therefore propose a bogie performance assessment methodology based on analyzing wheel impact load data over time and from multiple detector sites located in Sweden, to identify consistent deviating bogie behaviors in terms of asymmetric loads. The paper focuses on freight wagons and hence delimits to bogie designs, requirements and properties associated with freight transports.

The paper is now organized as follows. We first present the field observations that were made and triggered the investigation and the development of the methodology, followed by the description of the analytics and detection scheme that can be employed to identify the abnormally behaving bogies, and how users can be supported in their decision-making process. We then present the results for a case example and discuss properties of the approach. The paper ends with some conclusions and an outlook.

FIELD OBSERVATIONS

In data science and analytics, it is common to identify anomalies in time series and relate those with field observations. In relation to issues in bogies a connection was drawn between reported repair actions on bogies in workshops and patterns in the time series of wheel impact load data from multiple of time aligned measurements of bogies.

Wheel Impact Load Detection

Wayside detector system for measuring wheel-rail impact forces are mature industrialized systems that can be installed on the main line. The detectors are measuring wheel impact forces of individual wheels during their passage over the detector site at normal speed. A summary of the measurement principle is given by Stratam, et.al. (2007) who also discusses the use of the detector for condition monitoring.

These detectors provide for each wheel measurements of the mean wheel-rail force F_M, of the peak wheel-rail force F_P for a complete rotation. The force values could be influenced by speed, track curvature and track gradients. The WILD sites are in track sections where the speeds are constant which means there is no acceleration or deceleration in this section. The section must be on a tangent track with no track gradients. The above requirements will make sure that the readings from the WILDs are not influenced by external factors. In addition, the ratio of left and right mean wheel-forces is provided denoted left-right load ratio along with information on the passage speed of the train.

Relation between WILD data and Bogie performance

For specific wagons, time series of the WILD data can be generated by combining multiple way-side detector station data along consecutive passages of wagons over time. In Figure 1, the left-right ratio data for one bogie comprising axles 3 and 4 is depicted. From inspection of the time series data points there is an obvious change in behavior after 2021-12. There, the left-right load ratio of the WILD data exhibits a value larger than one for axle 4 and a value smaller than 1 for axle 3 most of the time, and certainly for the mean of an arbitrarily chosen moving window before 2021-12.

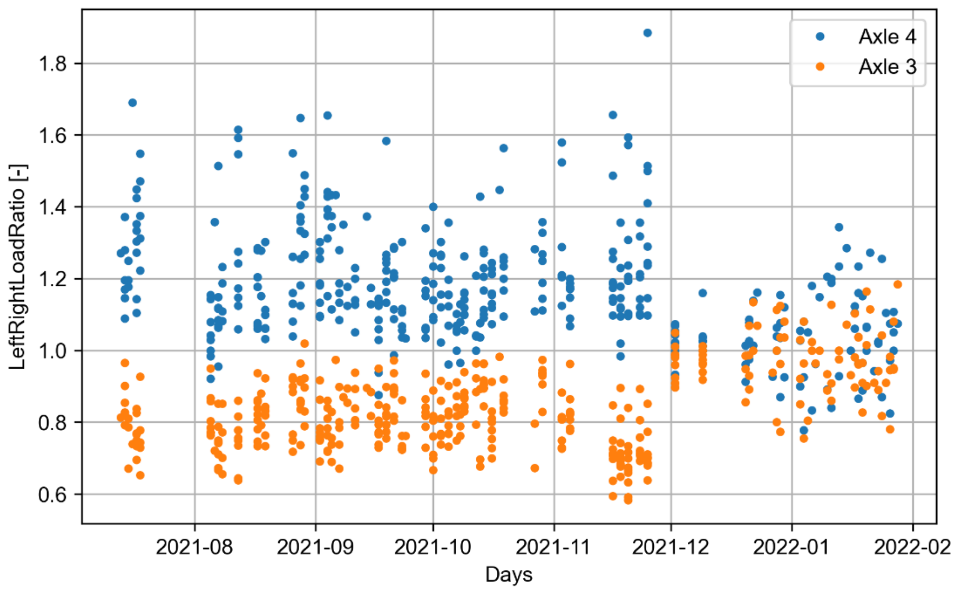

Figure 1: Left-Right Load Ratio for two axles in a wagon which were repaired in the workshop in December 2021. The left-right load ratio exceeded 1.2 before the visit.

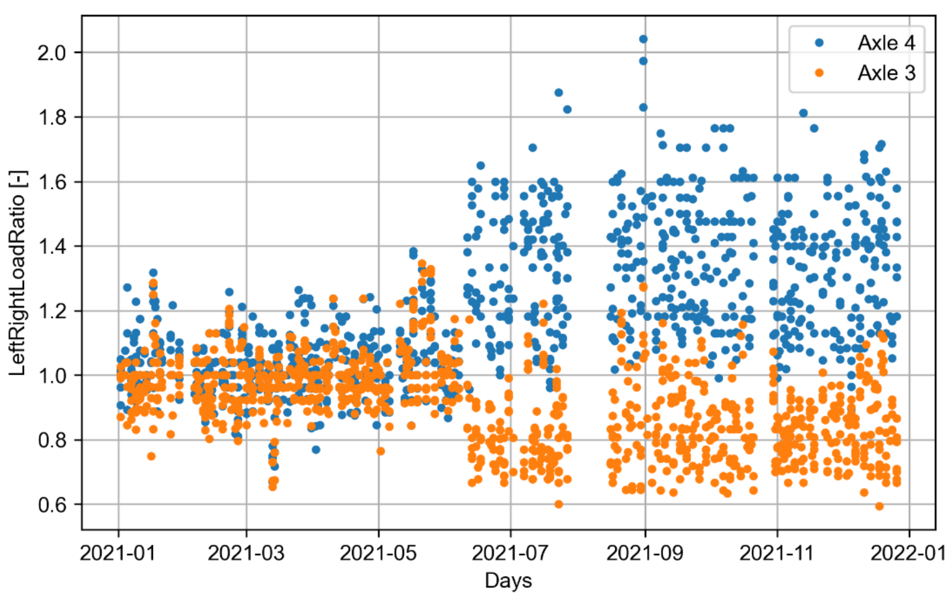

Figure 2: Left-right load ratio data for a wagon which has not been into the workshop for a bogie issue.

Similarly, in Figure 2, the values for the left-right load ratio of the two axles of the rear bogie of a wagon are close to one until 2021-05, whereafter the values are starting to diverge and occasionally even exceed the value two. It is important to note that the ratio is a nonlinear function and is not symmetric around one, namely that a value of 0.5 is equally bad as 2. It can also be concluded from these two examples that changes may occur swiftly and become persistent over time. Such a change can be detected by time series analysis, as is outlined in (Gustafsson, 2000) and (Box, et.al. 2015).

Vehicles exhibiting largely deviating values from one could therefore be seen as candidates for bogie performance issue. While instantaneous deviations in for a bogie might have many reasons, a consistently deviating value should indicate a persistent issue.

Naturally, a root cause could be skewed loading of a wagon could be loaded such that the wagon is leaning, but this should only be true for one specific loading scenario and thus for a limited amount of time, unless it is a systematic issue in the loading procedure. It was therefore concluded that wagons which exhibit such a behavior have a bogie issue. To confirm these historic bogie issue, workshop reports can be used to confirm the presence of these issues. On the contrary, wagons which exhibit varying left-right load ratio value, would not be candidates for such issues.

Beside these few examples there several similar events could be identified in the data sets of several freight companies operating in Sweden, which were also confirmed by the inspections and in the workshop with subsequent repairs.

Unfortunately, the scientific evidence and theoretical relationships between the load ratio and the bogie issue are not well understood. As a result, the connection between the load ratio values over time and the root cause are not established. Moreover, the connections derived from the data-driven perspective are not unique, which means that there are multiple root causes which lead to the observed behavior in the data. It is thus the belief of the authors that further studies are needed to underpin the field observations with a sound theoretical foundation.

ANALYTICS AND DETECTION SCHEME

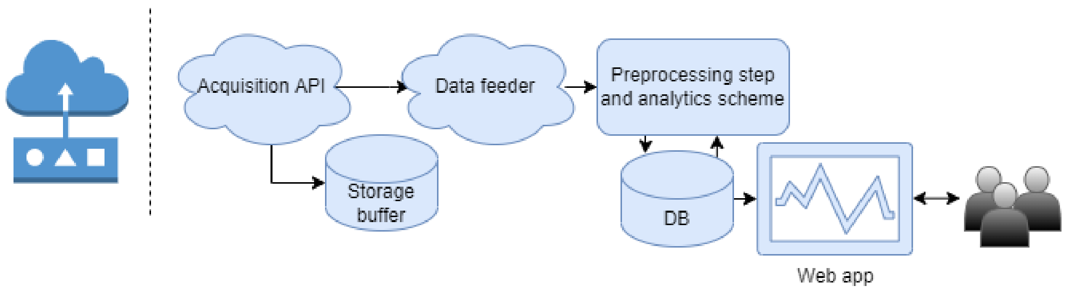

Figure 3: Principal sketch of the realization of the analytics and detection scheme.

A flow diagram of the analytics solution is shown in Figure 3. Wheel Impact Load Data is measured on train passages and pushed to an acquisition API that is set up by Predge AB. The data is backed up and then fed to the preprocessing step which extracts features such as the laden conditions of the wagons corresponding to the wheel measurements and the history of the bogies corresponding to the specific wheel measurements.

The bogies are analyzed for deviations both on the axle level, by studying the load ratio and on an aggregate level by studying the sum of axles in a two-axled bogie. The analyses are stated as follows:

The raw data from the WILDs are used to estimate the bogie performance. Firstly, the left-right load ratio is estimated by dividing the mean forces on the left and right wheels. To get a clear value of the load ratio in percentage, the factor is adjusted should the value be less than 1, meaning that the load is shifted to the right. For an axle the factor is now calculated as follows

$$Q_n = \begin{cases} \frac{F_{ML}}{F_{MR}} & \frac{F_{ML}}{F_{MR}} \geq 1 \\ -\frac{F_{MR}}{F_{ML}} & \text{otherwise} \end{cases} \tag{1}$$

Where Q_n denotes the load ratio on axle n, F_{ML} and F_{MR} denote the mean force for the left and the right wheel, respectively.

Thresholds are set for capturing deviating bogies. The thresholds are set based on the derailment safety limits which are 25% (Ekberg et al. (2013)). In other words, should the lean be above 25% on the axle, there is a risk that the corresponding bogie is faulty.

$$Q = Q_1 + Q_2 \tag{2}$$

The sum of the load ratios Q_n will be around 0 for bogies which are defective as the wheels tend lean on one side all the time. The conclusion cannot be made based on just one value of this parameter as the alternating loads can only be detected by using the measurements of several detector station. Since the detector stations may not cover the whole period of a hunting motion, and different stations have slightly different tunings, a moving average window is used to assess the load ratios per axle. Each detection of deviating behavior is aggregated on the bogie until a threshold is met, thus marking the bogie as degenerated. For this end a typical CUSUM detector could be used (Gustafsson, 2000). Should normal behavior on the bogie be recorded for a certain number of measurements in a row, the bogie is assumed to be repaired and the algorithm automatically resets the bogie to not deviating.

DECISION SUPPORT FOR MAINTENANCE PLANNING

Defective wagons can now be identified using the above analytics scheme and the user can be provided by actionable insights to decide on shunting wagons directly to a workshop or to perform a prior inspection in the field to confirm the information. The interaction with the user is implemented in a web application as indicated in Figure 3. The platform that is used for realization of such a decision support system is discussed in (Karim et.al. 2015 & 2016).

RESULTS AND DISCUSSION

The analysis was performed on wagons classified both as loaded, unloaded, and without taking the laden condition into account. The unloaded wagons gave better insights on the condition of the bogie since the loading condition might have an influence in the measurements and eventually leading to misinterpretation of the results. Therefore, the analysis was performed on unloaded wagons and classified as defective if the wagons underwent similar behavior as in the loaded case.

The analytics scheme was run on a fleet of freight wagons and has identified several wagons from such a fleet which have poorly performing bogies and one such wagon (referred in Figure 1) has been sent to the workshop for further investigation. The results of the load ratio before and after the visit is as shown in Figure 4. It can be observed that the load ratio Q_3 and Q_4 dominate one of the sides suggesting that the bogie was leaning on the same side for a long period of time before the visit. This can be confirmed by the estimated sum of the ratio Q value as can be seen in Figure 5. The Q values are close to zero suggesting that the wheelset are leaning on the same side. However, after the workshop visit there is a proper mix of Q_n values (Figure 4) and Q values (Figure 5) are alternating between above and below zero hinting that the bogie is performing as expected. The reports from the workshop suggest that the bogie frame has undergone a twist hence, the bogie was replaced.

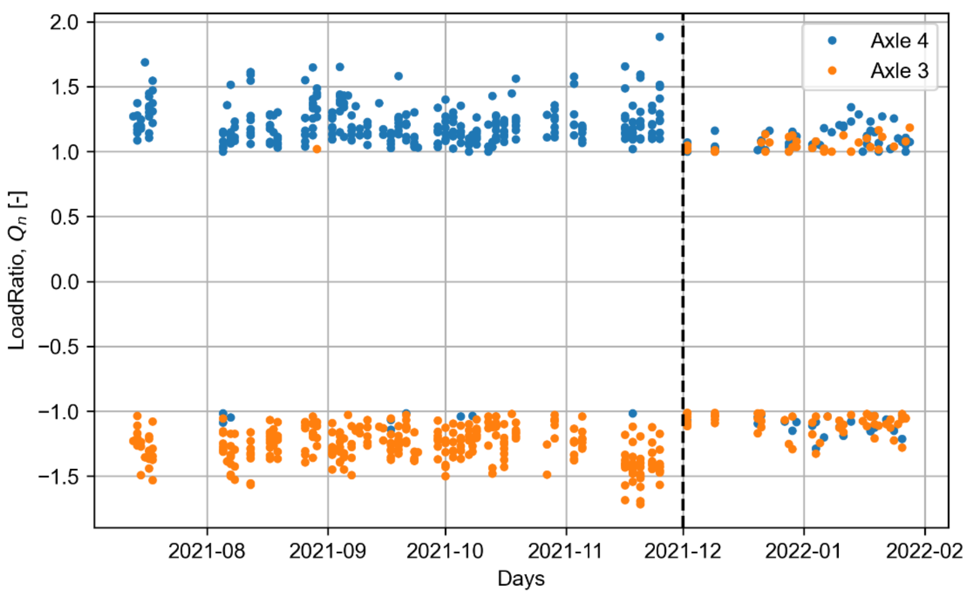

Figure 4: A potentially damaged bogie before and after the maintenance (marked with the dashed black line).

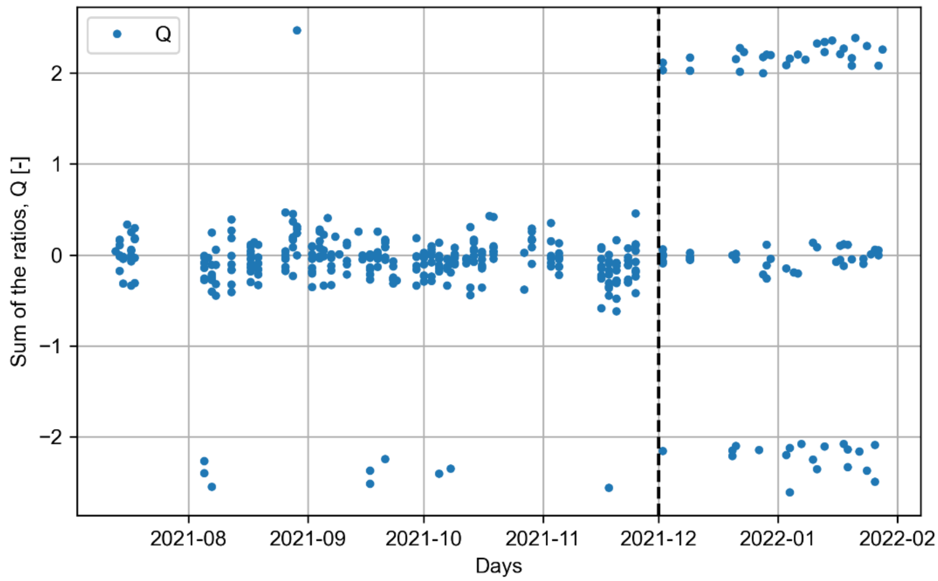

Figure 5: The sum of the ratios, Q, for a potentially defective bogie before and after the maintenance (marked with the dashed black line)

Conclusion & Outlook

This paper proposes a novel yet simple method to detect bogie with abnormal behavior and performance during normal operation on the basis on wayside data. Field observation in the WILD data directed towards the notion that asymmetric loading conditions can lead to identifying an inaccurately aligned or defective bogie. Monitoring the vertical load for different wagon loading conditions and early detection of deviations can help to remove misaligned and defect bogies from operation, increasing the safety and enabling more preventive maintenance actions.

The study has been performed on data from freight fleets operating in Sweden and have shown that valuable insights can be derived from available field data combined with an analytics scheme. Still, the approach is limited in the way that the root cause cannot directly determined requiring deeper inspection. Further integration of more data sources and combining different analytics methodologies, the authors see great possibility in isolating distinct failure modes within the bogie and wheel damages

A foreseen extension of the bogie performance assessment is to integrate wheel profile changes over time, such as the flange height and thread hollow to predict degradation of bogies.

It is also the belief of the authors that more in depth theoretical and simulation studies would be of interest to determine the connections between root causes and the made observations in the field.

References

Box, G. E., Jenkins, G. M., Reinsel, G. C., & Ljung, G. M. (2015). *Time series analysis: forecasting and control*. John Wiley & Sons.

Ekberg, A., Pålsson, B., Sala, D., Nicklisch, D., Kabo, E., Braghin, F., ... & Pineau, M. (2013). Guidelines derailment analysis prevention. Deliverable D3.3 F3 of the D-Rail project within the 7th European Framework Program (Technical Report). Available at https://d-rail-project.eu/Results (accessed 2022-05-10).

Fröhling, R. and Hettasch, G. (2010). Wheel-rail interface management: a rolling stock perspective. Proc. IMechE Part F: J. Rail and Rapid Transit,224(F5):491–497.

Gustafsson, F. (2000). *Adaptive filtering and change detection* (Vol. 1). New York: Wiley.

Hiensch, M., Burgelman, N., Hoeding, W., Linders, M., Steenbergen, M., & Zoeteman, A. (2018). Enhancing rail infra durability through freight bogie design. *Vehicle System Dynamics*, *56*(10), 1532-1551.

Karim, R., Birk, W., & Larsson-Kråik, P. O. (2015). Cloud-based emaintenance solutions for condition-based maintenance of wheels in heavy haul operation. In *International Heavy Haul Association: The 11th*

International Heavy Haul Association Conference will be held 21-24 June 2015 in Perth 21/06/2015-24/06/2015. International Heavy Haul Association.

Karim, R., Westerberg, J., Galar, D., & Kumar, U. (2016). Maintenance analytics–the new know in maintenance. *IFAC-PapersOnLine*, *49*(28), 214-219.

Okamoto, I. (1998). How bogies work. Japan railway & transport review, 18, 52-61.

Shahidi, P., Maraini, D., Hopkins, B., & Seidel, A. (2014). Estimation of bogie performance criteria through on-board condition monitoring. In Annual Conference of the PHM Society (Vol. 6, No. 1).

Stratman, B., Liu, Y., & Mahadevan, S. (2007). Structural health monitoring of railroad wheels using wheel impact load detectors. Journal of failure analysis and prevention, 7(3), 218-225.

EUROPEAN COMMITTEE FOR STANDARDIZATION. (2016) Railway Applications-Testing and Simulation for the acceptance of running characteristics of railway vehicles - Running Behavior and stationary tests. Ref. No. EN 14363:2016 E.