USING AUTOMATED WAYSIDE SYSTEMS FOR CONDITION-BASED MAINTENANCE AND CRITICAL EVENTS REPORTING

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Abstract

Wayside condition monitoring systems are efficient tools for monitoring vehicle components, such as brake shoes and wheels. Apart from providing frequent measurements for trending and maintenance purposes these systems also identify critical events for immediate action. The systems discussed in this paper are based on machine vision technology, which not only provides accurate measurements but is also user friendly enough to enable quick and reliable review of data.

1 Introduction

Timely and accurate reporting of critical events is crucial for safe and cost-effective railroad operations. Critical events that are not reported in time can lead to equipment failure, derailments, infrastructure damage, personal injury and death. Traditionally, railroads have attempted to forestall critical events through periodic maintenance routines supplemented by manual train inspections, either in the workshop or on the track. This process has several drawbacks:

• It assumes that components wear in a linear, calculable process (assumes faultless material, workmanship, assembly, etc.)
• It assumes that train inspectors will find critical faults (human subjectivity & tiredness)
• It involves disruption to train operations, since inspections are carried out on a stationary train or at very low speeds (cost implications)
• It may come too early or too late (cost and safety implications)

Recent technological advances in the area of automated train inspection systems have moved condition-based maintenance into the realm of the possible, thereby offering railroads the chance to improve their maintenance practices while minimizing operating costs and increasing safety and reliability.

But perhaps one of the most important features that automated inspection systems can provide is frequent, systematic, and quantified monitoring of vehicle components. This is especially important for the timely detection of critical events, because experience has shown that critical events do not necessarily arise in a foreseeable manner and can occur before scheduled inspection and maintenance. For example, wheels can wear prematurely due to a variety of factors, such as manufacturing faults, track condition, material defects, or incorrect installation. In one instance (as show below in figure 5), a wheel flange became dangerously thin after only 58,000 km, rather than the expected 1,600,000 km. Periodic maintenance would have come too late to prevent failure. Physical inspections did not pick up the problem, because it is hard to see and it is logistically prohibitive to measure wheel parameters manually during every walk-by or drive-by inspection. Other vehicle components are not exempt from sudden or unexpected failure, especially those that are used intensively and dynamically, such as brake pads.

2 Automated wayside inspection systems

2.1 Machine vision

Lynxrail started developing wayside inspection systems in 1998. After initially evaluating laser-based technology, the company decided to use machine vision for most monitoring functions. Some of the advantages of machine vision are:

• Meaningful accuracies are easily achieved. In a railroad environment it is unnecessary to work to micro-measurements. In any case, components are not manufactured to such measurements and most have some inherent manufacturing deviations. For example, newly machined wheels generally have grooves of up to 0.5 mm left by the cutting tool. (see figure 1)
• Users readily accept and understand the processed data, because it is presented as images along with measurements (what you see is what you get). The user does not need to trust computer-generated plots or numbers alone, but can reference the results to the image of the component. If manual review of data is called for, it is easy and quick, especially where measurements can be performed on screen.
• Images can be taken of components that are difficult or impossible for human inspectors to
see during routine inspections (such as components attached on the undercarriage)

- Data is stored as images (and measurements) and can easily be reviewed at a later date or trended for predictive maintenance (e.g., for procurements, incident investigation, and reporting).

The machine vision-based wayside inspection systems underwent numerous iterations in their development until consistent image quality could be achieved for all lighting and most weather conditions. The key to obtaining reliable and repeatable measurements that are not affected by speed is a highly accurate triggering system, along with cameras with fast shutter speeds and high-powered custom built flash modules.

2.2 Wheel Measurement System
The Wheel Measurement Systems (WMS) installed in commercial applications report on the following:

- Flange height
- Flange width
- Vertical flange
- Hollowing depth (calculated, not measured)
- Rim thickness
- Wheel diameter
- Back-to-back
- Angle of attack

The accuracy of measurements is ±1 mm. The train can travel at speeds between 5 km/h to 120 km/h without affecting the performance of the system. Each wheel is referenced to its location on the car using AEI. Repeatability of measurements is better than 0.5 mm.

The WSM system was checked for Reliability and Repeatability (R&R) by an independent body, and in 2006 it was subjected to Six Sigma approval by BNSF Railway, which checked for 99% of wheels correctly processed automatically in one pass.

2.3 Brake Shoe Measurement System
The Brake Shoe Measurement Systems installed in commercial applications report on the following:

- Brake shoe thickness (top and bottom)
- Missing brake shoes
The accuracy of measurements is ±2 mm, with a repeatability of 1.5 mm. Each brake pad is referenced to its location on the car using AEI. In one pass, 90% or brake shoes are correctly processed automatically. Trains can travel at the same speeds as for the WSM system.

![Image 1](image1.jpg)

**Figure 3**: Images taken by the Brake Shoe Measurement System of top and bottom parts of brake shoes.

2.4 Triggering and reliability

The systems that are currently installed are designed to capture clear images at train speeds of up to 100 km/hr. Image quality is not affected by speed, thanks to the sophisticated triggering system, which is based on fast-response wheel sensors with a sampling rate of 24 microseconds (see Figure 4). This allows the system to track the wheels as they pass through the sensor array. Prior to triggering the cameras, the system is thus able to survey the rolling stock vehicles before the optimal triggering strategy is chosen. The exact point at which cameras are triggered depends on the type of vehicle that is passing and on the type of components that are to be photographed. Soft triggering allows the system to photograph a component in the right spot and at the right time, independent of wheel size, condition, and train speed (hard triggering would be affected by these variables).

![Image 2](image2.jpg)

**Figure 4**: Images of wheel flanges taken by the WMS at 42 km/hr at a BHP Billiton installation (top) and at 115 km/h at on a VIA train at the installation for Canadian National (bottom).

In the WMS each image contains a reference marker that makes the system immune to vibrations of the rail, different wheel sizes, and speeds to ensure measurement accuracy. In its fully automated mode, a stand-alone WMS system (i.e., not a network of systems) can achieve 99% reliability on a
single pass, and a BSM system can achieve 85% on a single pass. Reliability of the BSM can be increased to practically 100% with the addition of manual review of images that the system was not able to process automatically (usually because of something obstructing the image). A network of systems can achieve a similar result without human on-screen review.

4 Condition-based maintenance

The system assesses a particular component over time, measuring it each time it passes by. Ideally, a system should see a component frequently to establish data confidence. For brakes and wheels, a 1000 km interval between measurements is recommended. Brake shoes wear relatively quickly, and frequent assessment is advisable. And although wheels wear quite slowly, there are instances when they wear more rapidly than expected. In such cases, frequent automated assessment can reliably detect abnormal wear, as can be seen in figure 5 where the left wheel flange of a wheel set wore unexpectedly quickly, whereas the right flange did not wear at all. Such extreme instances do not occur often, but when they do they can lead to unexpected failure of the wheel. The system is able to assess uneven wear on a wheel set, and if unexpectedly high flange wear is encountered, the wheel can be flagged for immediate action before it becomes critical. For example, a wheel with a vertical flange is difficult to re-machine, and a lot of material needs to be removed to correct the profile. If left too late, a vertical flange may be impossible to machine and the wheel needs to be scrapped. However, if abnormal wear is detected early enough, the wheel set can be removed from operation, thereby saving repair costs and minimizing the impact of the high wearing wheel on the rails.

Figure 5. Abnormal wear of the left wheel flange of a wheel set. The top images show two newly machined flanges, the bottom images show the flanges after 56,000 km travel. The left flange shows abnormal wear.

No matter how reliable a system is generally, there is always a chance of it making a wrong call. Although the system gives measurements of single data points (which is necessary for checking for criticals), the data becomes more reliable the more data points are taken per component. Ideally, consecutive measurements should be taken at the same location of the component to get the best results. In practice, however, this is difficult to achieve because of the dynamics of the railroad environments. Consecutive measurements can therefore show a scatter, whereby some data points are obvious “outliers” (see Figure 6). The system uses a median filter to filter out these “outliers” and to normalize the measurements within the specified system tolerances (see Figure 7). This improves the reliability of the system’s data and allows the railroad to make a confident decision about when the system should flag a component for replacement.

Figure 6. Data scatter (the peaks are the “outliers”)

Figure 7. Normalised data with good trending line
If there are enough data points to allow for normalization of data, the system can automatically track the brake shoe over time and flag it when it needs replacement without the need for on-screen review. If the history of a particular component’s wear is available (and the wear is not abnormal), then the railroads can decide for themselves how far they want to drive the component before replacing it.

The system is able to provide trending of component wear rates and can assess the expected remaining life of each component. This information can then be used by the railroad to develop strategies for maintenance planning. Current installations do not have enough data points to turn on the trending function, because the measurements are not frequent enough to be confident. This is because the systems are relatively new and railroads want to try them out before committing to a network of systems. Unfortunately, this diminishes the full benefits that automated systems can provide; however, it is expected that with increased acceptance of and railroad’s confidence in these systems, installing networks of systems (for increasing the number of data points and therefore the data’s reliability) will become more prevalent.

At the time of writing, railroads that have the systems installed use them mostly for detecting worn components and issuing work orders to maintenance personnel before the train arrives. A good example is the way QR National (an Australian heavy haul operator) uses the brake shoe module. Because QR National does not have a network of automated brake shoe inspection systems, there are fewer data points per brake shoe than would be ideal. In order to improve the system’s output, QR National supplements the automated assessment with on-screen review of the images. By confirming the system’s recommendations and checking images that could not be processed automatically (see figure 8), railroad personnel can thus drive the system’s reliability to close to 100%.

![Figure 8](image)

Figure 8. Example of an image the system cannot process automatically. In this instance, automated processing is not possible because debris obstructs the camera’s view of the brake pad. This image can nevertheless be processed with on-screen review.

This on-screen review process can be greatly diminished with more systems in place to provide more data points taken more frequently for each component and thus achieve full automation. However, supplementing the automated functionality of a stand-alone system with on-screen review of “flagged” images is relatively cost-effective, because the system’s automated features significantly reduce the amount of investigation that a human inspector would otherwise need to perform. The on-screen review process is very quick, since only “problem” and flagged images are reviewed on-screen (on average, railroad personnel would review about 6% of the images per train). Because of safety concerns, the system is designed to over- rather than underestimate, especially when the median filter cannot be applied, because there are not enough data points.

In the case of QR National, using the BSM system as a maintenance planning tool has reduced the railroad’s brake pad replacement on each Reliability Engineering maintenance inspection by 83%. This railroad also uses the system to assess the wear rates of different types of brake pads. [1]

The BSM system sends work orders (by email or other means) based on automatic assessment of brake pads directly to the relevant users. Most railroads decide to set the critical level at 10 mm, at which point the brake shoe is flagged for replacement. The work order contains the measurements along with the image of the brake shoe. This eliminates unnecessary work, since maintenance personnel can immediately ignore the outliers. The same applies to the wheel measurement system.

The system also allows railroads to filter a particular component according to measurements. For example, they can elect to see all brake shoes below or above a certain threshold. This gives them added flexibility as to how to develop their preferred maintenance strategies (they may choose to replace pads earlier or later, depending on their financial and technical objectives). Because the data is pictorial, adjacent components that the system is not programmed to deal with can also be seen. These include items such as brake beams, broken bogie braces, keys, etc. (an example of an unrelated critical found through the BSM system is shown in figure 11).

A similar maintenance strategy is used for wheels. The WMS is inherently more reliable in its fully automated form than the BSM, because the WMS system has a self-calibration feature that checks the wheel parameters with reference to calibration markers, which ensures that the dynamics of the wheel and rail do not affect the accuracy of the measurements.
4 Critical events and their notification

The client railroad can set its own critical limits, depending on its regulatory environment and its preferred operating practices. The system then reports on abnormal wear as defined by the railroad. However, the system is designed to err on the side of caution and to over-report critical, even if it means there are some false positives. For this reason it is necessary to include a picture of the component in question so that railroad personnel can visually assess whether the critical called up by the system is indeed a critical event. This ensures that no critical events are overlooked by the system. There are algorithms built into the system software that check related parameters in the region of interest (key features, type of equipment installed, etc.) to ensure that there are as few false positives as possible. So far, the systems have not overlooked a critical event, but they do over-report.

Currently, considerable R&D effort goes into reducing false positives; however, the main objective of critical events reporting is to ensure that no critical is overlooked. This feature is not necessarily a client favourite, because it requires the railroad to review the flagged images on-screen. Railroads would naturally prefer a black box solution that requires no human interaction with the system. However, the current state of the technology is not ready for confident fully automated reporting of critical events, because of the risk that a critical may be overlooked (since full automation can never be guaranteed to be 100% reliable). For this reason, the software is designed for easy interaction with railroad personnel in the case of a critical event notification.

Examples of critical events seen by the systems:

![Figure 9. Missing brake shoe](image)

![Figure 10. Thin flange](image)

![Figure 11. Broken cross-brace (seen during a review of BSM system criticals)](image)

4 Conclusion

Automated wayside inspection systems are efficient tools for maintenance and safety-critical applications. Although they are very reliable as stand-alone systems with on-screen review features, their efficiency can be improved by installing them as an interconnected network of systems.

References