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Worn Wheel Profile Variation and Implications on Wayside Measurement

Kenny Morrison and Tony Sultana

Summary

A study by Transportation Technology Center, Inc. (TTCI) of the variation found within worn wheel profiles and its effect on measurements made by wheel profile monitoring systems (WPMS) showed that the variation in some of the measured wheels could result in two separate detector passes measuring different amounts of wear, depending on the part of the wheel viewable by each detector at the time of the wheel pass. As part of the Association of American Railroads' (AAR) Strategic Research Initiatives Program, TTCI examined the variation found within worn wheel profiles in order to further understand its effect on the measurements provided by WPMS and to help determine the best approach to validate detectors in the field.

The wheels of 49 wheelsets were measured at evenly spaced locations around each wheel. The measurements taken at each location were flange height, flange width, maximum tread hollow, tread hollow position, back-to-back gage, and rim thickness.

Analysis found that eight measurements should be taken to account for all the variation in rim thickness and back-to-back dimension. As few as three evenly spaced measurements are required to account for variation in other dimensions.

Statistical analysis shows that variation in flange width and flange height increases with wheel wear and wheel life. Variation in maximum tread hollowing and the lateral position of greatest hollowing decreases as the wheels wear.

Further analysis was conducted in order to establish the reliability for WPMS technologies measuring at one or three points on the circumference of the wheel. This is done for consideration of differing vendors' technologies. More detector measurements increases the chance of measuring the most worn part of the wheel.

This is the first part in an ongoing effort to develop WPMS standards that includes the following

- A comprehensive survey of WPMS vendors.
- Analysis of temperatures and loading effects on back-to-back measurements.
- Automated equipment identification (AEI) matching.
- Validation of vendor's detection technology.

Please contact **Kenny Morrison (719) 584-0608** with questions or concerns regarding this *Technology Digest.* E-mail: Kenneth_Morrison@aar.com.

INTRODUCTION

Automated machine vision wheel profile monitoring systems (WPMS) use wayside cameras and/or lasers to measure critical dimensions on wheels and wheelsets. As part of the AAR Strategic Research Initiatives Program, TTCI examined the variation of selected measures within worn wheel profiles in order to further understand its effect on the measurements provided by WPMS and to help determine the best approach to validate detectors in the field.

Methodology

In total, 49 wheelsets were measured at Transportation Technology Center in Pueblo, Colorado and at Burlington Northern Santa Fe Railway's (BNSF) Havelock shop in Lincoln, Nebraska. Of the 49 wheelsets, 5 were new and had AAR-1B profile wheels. The rest had been used only in revenue service and not for any other testing. The wheels measured represented early, medium, and late wheel life in terms of wear. If available, relevant information belonging to each wheelset was recorded including date manufactured, class, design, manufacturer, car mark, traffic type, removal Why Made Code, and date of removal. Multiple evenly spaced measurements were taken around each wheel in order to capture variation. In the event of shelling, tread build-up, or a flat spot, the measurement location was moved slightly as it was not the purpose of this effort to investigate large defects. If the defect could not be avoided by a modest movement, the measurement was taken at the location and the defect was noted. The following tools were used to collect measurements of the critical dimensions:

- MiniProf™ wheel system
- Back-to-back gage with digital indicator
- Standard steel wheel gage (finger gage)

Flange height, flange width, maximum tread hollow, tread hollow position, and maximum flange angle were determined using the MiniProf™ profile. Flange height and flange width were calculated to be comparable to Rule 41.1.c from the *Field Manual of the AAR Interchange Rules* by simulating the placement of the associated standard gage on the profile.[1] Maximum tread hollow was calculated by finding the point of deepest hollowing and its position across the width of the tread. Figure 1 shows the MiniProf™ Wheel System being used to take a wheel profile measurement.

A back-to-back gage was fitted with a digital indicator in order to acquire an accurate back-to-back measurement. Rim thickness was measured using the finger gage and was recorded in 1/16-inch increments.

Figure 1. MiniProf™ Wheel System

Analysis

Sixteen measurements, spaced about 7 inches apart, were taken on each wheel of an initial set of 11 wheelsets. The number of measurements per wheelset was reduced going forward without a significant loss in variance based on an autocorrelation analysis. The wheel with the highest standard deviation for every measurement type was selected and the difference between sequential measurements was calculated. Then differences between every second, third, fourth, and fifth measurement were calculated to represent 8, 5.3, 4, and 3.2 measurements, respectively. The distributions for the different number of measurements were statistically and practically compared to determine how many samples should be taken for each measurement.

Figure 2 is an example of the statistical comparison for the back-to-back measurement. There is no statistical difference between the 16 and 8 measurement groups (**blue**) while the 16 measurement group is statistically different from the other groups (**brown**). Therefore, it is acceptable to take eight measurements of back-to-back but not less.

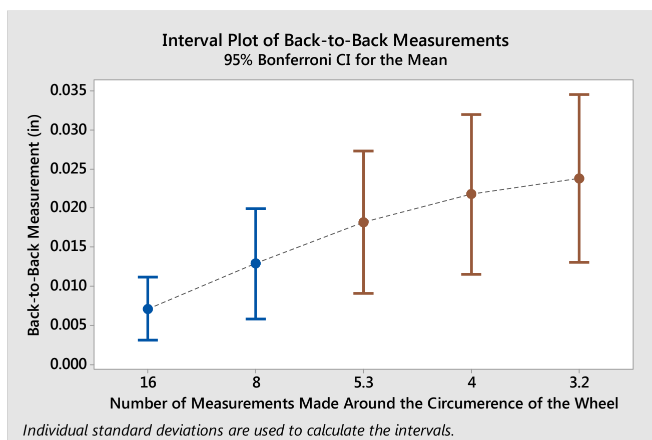

Figure 2. Interval Plot of Back-to-Back Difference Distributions

The analysis of flange height and maximum tread hollow concluded that it is acceptable to reduce the amount of measurements to three evenly spaced measurements.

Analysis of flange width concluded that eight measurements is acceptable, but could be as low as three since the practical difference between the groups is small. Analysis of rim thickness concluded that a minimum of eight measurements is sufficient.

To confidently capture all of the variation for the number of measurements, the remaining wheelsets were measured using eight equally spaced measurements around each wheel due to the minimum reduction for rim thickness and back-to-back. Using eight to nine measurements, 38 more wheelsets were measured (spaced at about 14 inches apart). Eight measurements were taken for 33- and 36-inch wheels. Nine measurements were taken on 38-inch wheels.

The measurements for each critical dimension from all of the measured wheels and wheelsets were collectively analyzed using the constant variance test to determine patterns in variation over the life of the wheel. The following general conclusions were found from the analysis:

- Variation increases for flange width and flange height as the wheels wear.
- Variation decreases for maximum tread hollow and the hollowing position as the wheels wear.

Figure 3 is a visual representation of the constant variance test. The summary data for flange height from each wheel is split into low and high halves separated by the dotted red lines. The data in the middle area between the dotted red lines, representing 20 percent of the data, are excluded from the test. The two halves are compared to determine if there is a statistical difference in the variation between the low and high flange wheels.

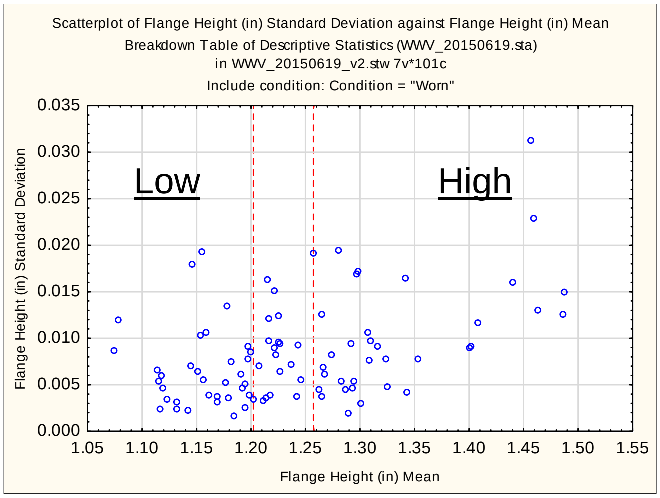

Figure 3. Visual Representation of Constant Variance Test

The measurements for each critical dimension from all of the measured wheels and wheelsets were further analyzed in order to determine the chance a WPMS would have to measure the most worn part of the wheel with a single measurement. This was done for technologies that may only take one measurement per pass in consideration. The most worn measurement from each set of measurements from each wheel was taken and the accuracy for the standard gage was added. The accuracies used were ±1/32 inch for flange height, flange width, rim thickness and ±1/50 inch for tread hollow.[2,3,4,5] The accuracy used for back-to-back was 0.01 inch based on the back-to-back mounting gauge.[6] The other measurements from each set in the range, with measurement accuracy added in, were also considered to be the most worn part of the wheel. The percentage of measurements from the most worn part of the wheel was calculated based on the number of measurements taken for that wheel. All of the probabilities for each of the different measurements were found for each of the 98 wheels and 49 wheelsets.

Figure 4 shows the percent chance of measuring the most worn part for each of the wheels for rim thickness when taking one measurement. Each observation represents one wheel. For 15 out of 98 wheels, the detector has between 90 and 100 percent chance of measuring the most worn part of the wheel.

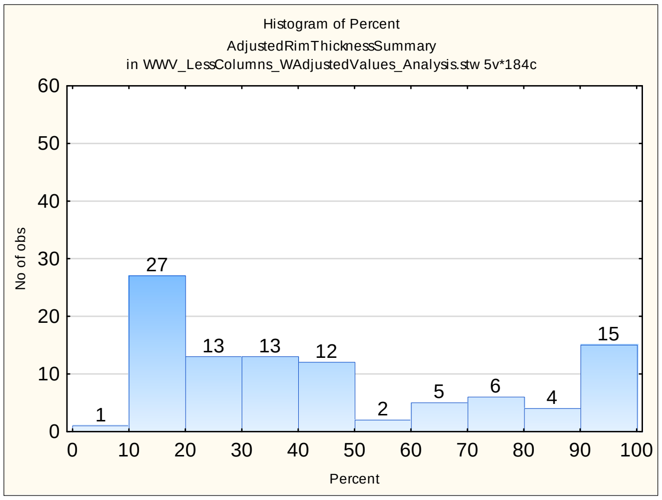

Figure 4. Percent Chance to Measure most Worn Part of Wheel with One Measurement

For each critical dimension, the number of wheels or wheelsets with over 90 percent chance of measuring the worst part with a single measurement is as follows:

- 94 of 98 flange widths measure the thinnest part
- 75 flange heights measure the highest part
- 93 treads measure the deepest hollowing
- 15 rims measure the thinnest part
- 3 of 49 back-to-back measure an exceeded tolerance using one measurement. §

§ Back-to-back measurements require three measurements per AAR Rule 41.A.1.q[1]

The percent chance of measuring the worst part of the wheel with a single measurement is high for flange width, flange height, and tread hollowing. The chance of measuring the worst part of the wheel for rim thickness is lower due to higher variation. The chance of measuring the worst part of the wheel with a single measurement is low for back-to-back.

Taking into consideration WPMS technologies that may take three measurements at different areas on the wheel per pass, the distributions of critical dimensions from each wheel were further analyzed to determine the chance of measuring the most worn part of the wheel with three equally spaced measurements. Figure 5 shows the percent chance of measuring the most worn part for each of the wheels for rim thickness when taking three equally spaced measurements. For 52 out of 98 wheels, the detector has between 90 and 100 percent chance of measuring the most worn spot on the wheel.

The cumulative results with over a 90 percent chance of measuring the most worn part of the wheel with three equally spaced measurements are as follows:

- 98 of 98 flange widths measure the thinnest point
- 91 flange heights measure the highest point
- 97 treads measure the deepest hollowing
- 52 rims measure the thinnest point
- 33 of 49 back-to-back measure an exceeded tolerance

Technologies that measure at three equally spaced locations have improved chances of measuring the most worn part of the wheel for the critical dimensions shown.

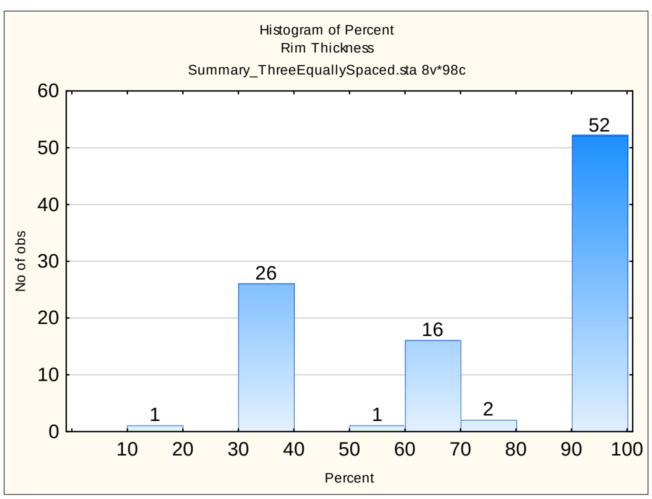

Figure 5. Percent Chance to Measure the Most Worn Part of Wheel with Three Equally Spaced Measurements

CONCLUSION

The variation in the measured wheels could result in two separate detector passes measuring different amounts of wear depending on the part of the wheel viewable by each detector.

The likelihood of a WPMS measuring the most worn part of the wheel depends on how much of the wheel is scanned per each pass. As the number of measurements around the wheel increases, so does the chance of measuring the most worn part of the wheel. For flange width, flange height, and hollow tread, one measurement per detector pass has a high chance of measuring the most worn part of the wheel.

If trending analysis is to be done using measurements from WPMS then technologies that take three measurements per wheel per pass will provide more reliable trending. For flange width and flange height there will be more variation in trending later in the life of the wheel and reduced trending effectiveness. Maximum tread hollow and the hollowing position will show more variation earlier on in the life of the wheel and trend analysis may be less effective before a certain hollow depth is attained. The hollow depth is not estimated at this time due to the limited dataset.

Acknowledgements

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