

The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Industry-wide Wheel Impact Measurement Variation

RB Wiley and Abeer Elsalebby

Summary

The Association of American Railroads' Equipment Health Monitoring Committee (EHMC), formerly known as the Advanced Technology Safety Initiative/Equipment Health Management System Steering Committee, tasked the Transportation Technology Center, Inc. to quantify the reliability of wheel impact load detector (WILD) measurements.

All sample readings were confirmed or accepted as good and reliable data. Further, 99.95 percent (7,701 of 7,705) of the sample wheels were confirmed to be high impact wheels with no anomalous readings found. These all had repeatable measurements indicating high impact wheel forces. The remaining four wheels of the sample did not have enough runs past the detector to confirm the variation of the data; however, the readings were deemed valid given the reliability of all of the remaining data.

The primary conclusion of the studies completed thus far is that the repeatability of WILD measurements is more a function of normal variation in rail vehicle operating circumstances and conditions. There is virtually no relationship to the measurement system's capability. A small fraction of wheels, (approximately 2%) has less than one reading every two months, representing limited opportunities to obtain optimal WILD measurements. As stated in *Technology Digest* TD-11-007, optimal opportunities for repeatable WILD measurements depends on repeated visits with consistent loads, speeds, load balance, and wheel tracking.

More extensive studies were requested by EHMC involving larger datasets. This TD reports on a 2-day study of 7,705 alerted wheels representing data from 6,256 vehicles having 9,179 wheel visits across 133 WILD sites. The results of the analysis again show that WILD measurements are repeatable with some variation, given a variety of factors. None of the larger sample of wheels showed clear evidence of anomalous WILD readings.

This TD builds upon the work presented in TD-11-007 in reviewing aspects of variation observed in WILD measurements.



BACKGROUND AND INTRODUCTION

Transportation Technology Center, Inc. (TTCI) was tasked by EPMC to quantify the reliability of WILD measurements.

An initial study of 60 wheels identified by WILD but questioned by a car owner has been analysed.¹ Data from all 60 wheels suggests that the data from the detectors is reliable using tests of previous and subsequent data from multiple detectors (the H₀ reliability test¹). No data suggested unreliable detector data. During this investigation, however, six factors were identified with the potential to limit the accuracy of the interpretation of WILD data leading to the possibility of misidentification of a very limited subset of alerts (estimated to be less than 1 per million):

- F₁: Number of visits to WILD sites
- F₂: Number (or percentage) of loaded visits to WILD sites
- F₃: Zero additional visits to WILD sites
- F₄: Reduced speed (below 50 mph)
- F₅: Truck warp or hunting
- F₆: Wheelsets replaced

Algorithms can be developed that account for these factors and further improve already high interpretation reliability.

The objective is to evaluate and further quantify the industry-wide nature of WILD measurement variation relative to major contributing factors. This TD covers Phase 2: Industry-wide WILD Alert Sample Review. It reports on a 2-day study of 7,705 alerted wheels representing data from 6,256 vehicles having 9,179 wheel visits across 133 WILD sites.

ANALYSIS METHODOLOGY

TTCI obtained history of the identified wheels between January 1, 2009, and May 3, 2010. The nearly 17-month data query range produced 1,176,550 wheel readings for analysis.

The standard methodology followed two initial analysis steps:

1. Exploratory Data Analysis (EDA). EDA is a series of statistical methods for the purpose of gaining maximum insight into the data. This establishes the incidence if high dynamic loads either prior or post the 2-day measurement and whether they were trending up or down; this would confirm the presence of high impact wheels.
2. Determine data reliability. If a reading (e.g., WILD max_vert) is questioned, the subject data is evaluated as meeting the hypothesis (H₀) of being good, reliable data versus the alternative (H_a) that the reading is anomalous or improperly assigned to the subject wheel or vehicle.

TTCI determined that for the great majority of the sample wheels, a sufficiently large wheel reading history could be obtained by using a similar query date range as in the Phase 1 study.

The 2-day’s sample of alerted wheels (7,705) represents 6,256 vehicles with 9,179 alerted wheel visits (some vehicles had multiple wheels and multiple visits at WILDs over the 2 days). The nearly 17-month data query range produced 1,176,550 wheel readings for analysis. Eighteen vehicle types are represented with a majority (almost 60%) being:

- intermodal cars,
- covered hoppers cars, or
- coal gondola cars (Umler J type).

Scenarios for Classifying Wheel WILD History

Following the EDA, each alerted wheel is tested for reliability to determine acceptance or rejection of H₀ (that the alert readings in question are from good and reliable data). The dynamic vertical force measurement is tested (dyn_vert = max_vert – avg_vert). Each wheel’s reading history can be examined individually using a rule-of-thumb evaluation that repeated readings of speed and load corrected (adjusted) dyn_vert ≥ 20,000 pounds indicate a high impact wheel.¹

It was impractical to individually examine each of 7,705 wheel’s histories. Each wheel’s speed and load adjusted dynamic vertical force history was compiled in a categorized statistical breakdown table to identify if each wheel had at least two adjusted readings ≥ 20,000 pounds.¹

Prototype algorithms to account for the six factors identified in Reference 1 were applied. Over 86 percent of all adjusted dynamic vertical force readings are ≥20,000 pounds during the last 30 days prior to the alert opening. This contrasts with less than one-third being ≥ 20,000 pounds during the period from 6 to 12 months before alerting (see Figures 1 & 2).

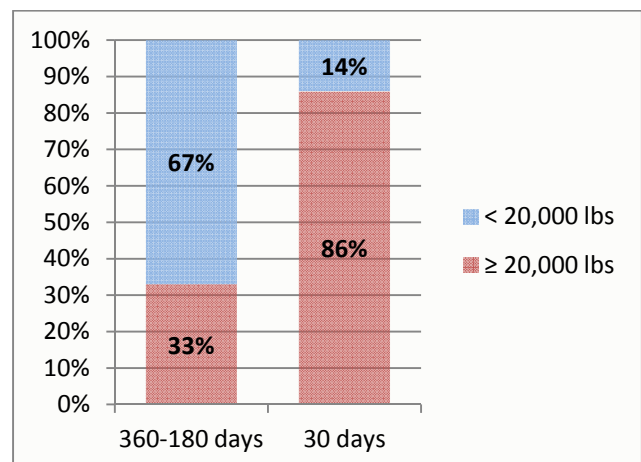


Figure 1 . Percent of Speed Adjusted Dynamic Vertical Force Readings ≥ 20,000 pounds (by Days before Alert)

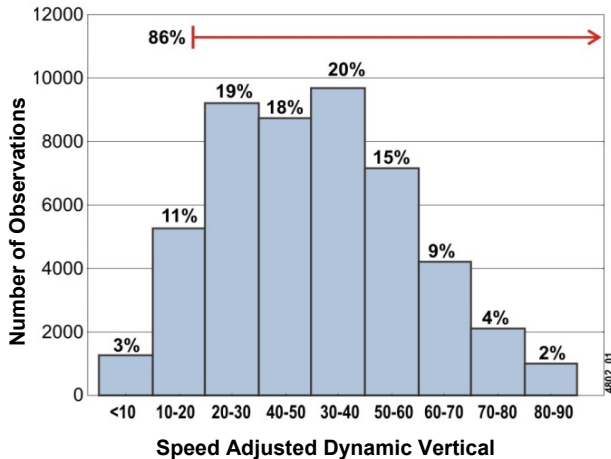


Figure 2. Percent of Speed Adjusted Dynamic Vertical Force Readings ≥ 20,000 pounds (by 10,000-pound ranges)

There is generally enough data to readily confirm that a high impact wheel exists. Often, as with the remaining 14 percent in the final 30-day period, there is not enough data from optimal opportunities for WILD measurements (see Figure 2), or the pattern in the data is not so clearly defined. In no case was the accuracy of the WILD site suspect. No anomalous readings or unexpected variation were found.

During this exercise, an additional three factors were identified that affect the interpretation of WILD data:

- F₇: total load variation
- F₈: Imbalanced loads
- F₉: Variable imbalance location

As with the six factors identified in the previous exercise,¹ algorithms can be developed that account for these factors and further improve already high interpretation reliability.

Wheels passing the acceptance test H₀ (confirmed high impact wheel) have further evaluations made to classify the nature of the WILD readings' repeatability.¹ This larger, industry-wide study produced one additional scenario of a verifiable cause of WILD reading variation as follows:

H₇: Load imbalance causing measurement variation.

The original scenarios are not repeated here. Non-homogenous loading of one truck or truck side leads to an increased avg_vert.

Mitigation of Variation Factors

The two most important factors confounding interpretation of WILD measurement variation are the limited number of visits to WILD sites and the percentage of those when the vehicle is loaded. Figure 3 summarizes the overall frequency of WILD visits for the industry-wide sample. Of the 7,705 subject wheels, three passed a WILD only one time during 16-plus months — the same time the high impact occurred. Obviously, repeat visits are not observed. Just over 2 percent passed WILDs less than eight times over the 16 months. Conversely, over 91 percent of the vehicles studied passed a

WILD site at least once per month with over 76 percent at more than twice per month. This industry-wide WILD visit frequency indicates that, in general, there are sufficient opportunities to obtain optimal WILD measurements for most alerted wheels.

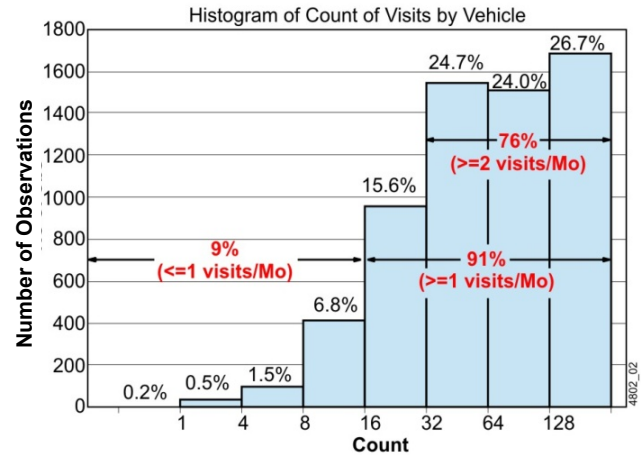


Figure 3. Visit Frequency Distribution of Industry-Wide Sample

While there is no substitute for sufficient data (number of visits), some factors of variation can be mitigated by standardizing (adjusting) the readings, such as for speed and/or load. These adjustments are discussed in detail in TD-11-007¹ and are briefly summarized here. The speed adjustment factor is based on the ratio of the train speed when the reading is taken versus a standard speed of 50 mph:

$$\begin{aligned} \text{speed} > 50; & \quad SC_dyn_vert = dyn_vert \\ 20 \leq \text{speed} \leq 50; & \quad SC_dyn_vert = (50/\text{speed}) * dyn_vert \\ \text{speed} < 20; & \quad \text{remove the reading from the sample} \end{aligned}$$

The load adjustment is made by finding the largest avg_vert value for each subject wheel and adding it to the respective speed corrected dyn_vert. This is done as a final step to include both speed and load adjustments for simultaneous evaluation as the LCSC_max_vert.

The load adjustment might be considered unrealistic in terms of the *expected* maximum loaded weight of a wheel. However, there were more than 16 percent of wheels found with over 5 percent estimated imbalance and more than 1 percent over 10 percent estimated imbalance. For the examples found, the estimated imbalance repeats regularly, indicating that such influence can dominate an individual wheel's readings, thus increasing the magnitude of high impacts if the wheel is out-of-round. Conversely, Figures 4 and 5 illustrate the estimated imbalanced wheel load and the potential affect on a wheel's WILD readings as alertable when they should not be. The box plot in Figure 4 shows the left wheel having twice the vertical force of the right wheel. In Figure 5, the speed corrected dynamic vertical force shows the same left wheel *not* to be a high impact wheel at all. Yet, subsequent imbalanced readings caused the left wheel to be falsely alerted at a window open level.

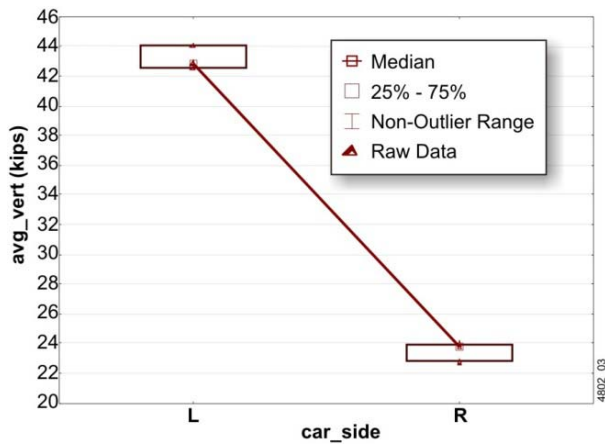


Figure 4. Loaded Wheel Average Vertical Force

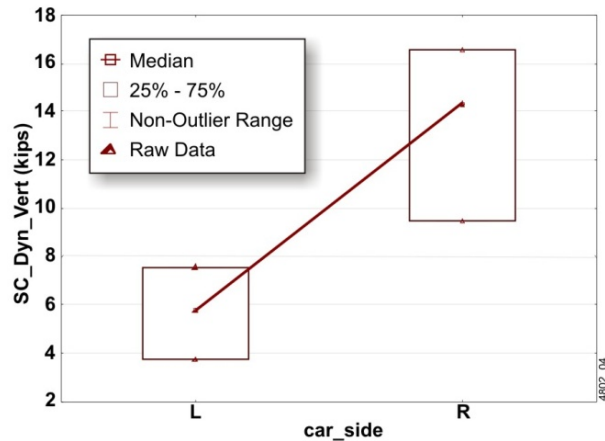


Figure 5. Wheel Speed Corrected Dynamic Vertical Force

Following the EDA, the data reliability test confirms H_0 ; i.e., all of the readings of the 7,705 sample wheels should be considered as good and reliable data. All sample wheels were high impact wheels, having reliable evidence from multiple WILD readings. Three vehicles having only a single visit and one having only two visits are exceptions to the repeat high reading observation. These are accepted as being high impact wheels based on the confidence provided by the other 7,701 wheels in the sample.

A primary finding of the Phase 2 study is that, while varying, impact forces increased over time. The repeated high readings not only confirm the wheels to be out-of-round, but they continue to degrade over time. Figure 6 shows the median (speed and load corrected) maximum vertical force (peak impact) increasing over time.

The highest median value occurs during the last 30 days before the alert opens at either the 80,000- or 90,000-pound impact level (opportunistic or condemnable levels). The rate of increase in the median impact force accelerates increasingly over the 180 days prior to the alert opening.

In showing the median impact force in Figure 6, the variation of individual sample wheels' WILD readings is acknowledged and represented. The variation remains in spite of speed and load adjustments being made.

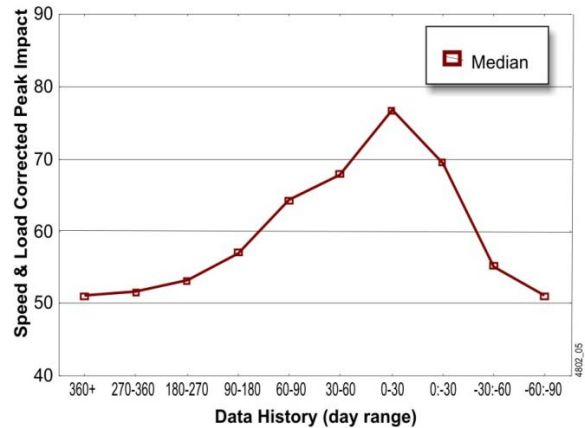


Figure 6. Median Speed & Load Corrected Peak Impact

CONCLUSIONS

All sample readings are confirmed or accepted as good and reliable data. Further, 99.95 percent (7,701 of 7,705) of the sample wheels are confirmed to be high impact wheels with no anomalous readings found. The four remaining wheels (0.05%) of the sample did not have enough runs past the detectors to confirm variation; however, the readings were deemed valid given the reliability of all of the remaining data.

As Figure 3 shows, the great majority of vehicles have opportunities for repeat visits over WILDs. That, coupled with the trend illustrated in Figure 6, supports the general observation that high impact wheels, once identified, have increasing impact forces over time.

This larger sample provides further insight into the causes of variation in WILD readings as well as factors influencing that variation. Further analysis of even more data may find other scenarios of variation and additional influencing factors.

Data adjustments were made to allow for consistent evaluation of overall WILD variation for the study. Speed adjustments should be made followed by an adjustment for car load condition. The potential for imbalanced or excessive wheel loads to increase wheel vertical forces can cause increases in peak vertical force readings. The result can be significant variation in WILD readings.

REFERENCE

1. Wiley, R.B. and A. Elsaeiby, March 2011. "A Review of Wheel Impact Measurement Variation," *Technology Digest* TD-11-007, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colo.