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Integrated Freight Car Truck Curving: Part 2-Analysis Procedure

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Summary

In the first part of this *Technology Digest* (TD) series, Transportation Technology Center Inc. (TTCI) provided a proposed truck curving test procedure.¹ The proposed test procedure uses traction ratios (T/N) on the lead axle low rail (LALR) wheel as the metric. Reduction in LALR T/N is an indication of steering improvement. T/N is a key criterion in high impact wheel and hollow wheel formation. By using a non-steering reference truck simultaneously with the test truck, relative curving performance of the test truck as compared to the reference truck is measured. Testing the reference truck and test truck simultaneously makes it possible to account for changes in the test environment, particularly friction coefficient. TTCI conducted five tests using the proposed test methodology. This research is tasked and funded under the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) Program.

Data from five trucks was used to prove the proposed method. Two trucks were of the M-976 type. Three trucks had improved curving performance according to the so-called Integrated Freight Car Truck (IFCT) regime developed under this SRI. For each curve and test run, T/N values were calculated for the test truck and reference truck. Then the relative performance of test truck compared to the reference truck was quantified by calculating the percent improvement of the test truck for each test run in each curve. The majority of the LALR T/N distributions were unimodal, but some test results showed bimodal distributions. The median for unimodal distributions and a modified median for bimodal distributions was used for the percent improvement calculation.

The objective of this TD is to provide a standardized data analysis procedure for the test procedure presented in the first part of this TD series.¹ Using the proposed test and data analysis methods, a percent improvement of LALR T/N for IFCT and M-976 trucks is proposed. Proposed minimum improvements were found because truck test results showed that LALR T/N reductions for M-976 and IFCT concepts could be grouped in different zones. The proposed minimum improvement for IFCT over the reference truck is 45 percent in a 3-degree curve, 0 percent in a 10-degree curve, and linearly interpolated in between. The proposed minimum improvement for M-976 trucks over the reference truck is 15 percent in a 3-degree curve, 0 percent in a 10-degree curve, and linearly interpolated in between.



OBJECTIVE

The IFCT research program aims to take the improvements made with the M-976 trucks one step further. This TD outlines the data analysis methodology for tests conducted according to first part of the TD series¹ and provides LALR T/N reduction limits for IFCT and M-976 trucks in the proposed curving test.

ANALYSIS METHODOLOGY

Figure 1 shows an example comparison of the LALR T/N distribution and time history data for sample IFCT and the reference truck in the 5-degree curve in the clockwise (CW) direction on Wheel/Rail Mechanism (WRM) loop at the Transportation Technology Center (TTC). The green and red lines show the median of the IFCT and reference truck data, respectively. Both histograms show continuous shape with only one significant peak, a unimodal distribution. Most of the data analyzed as part of this test series was unimodal. The data that was not unimodal was handled slightly different from data that was. This will be described in detail later in the TD.

For each truck tested, data from the 3-, 4-, 5-, 7.5-, and 10-degree curves was processed in this manner. Three runs were performed in each direction, CW and counterclockwise (CCW), around the WRM loop. Figure 2 shows a plot of the median for each curve and each run.

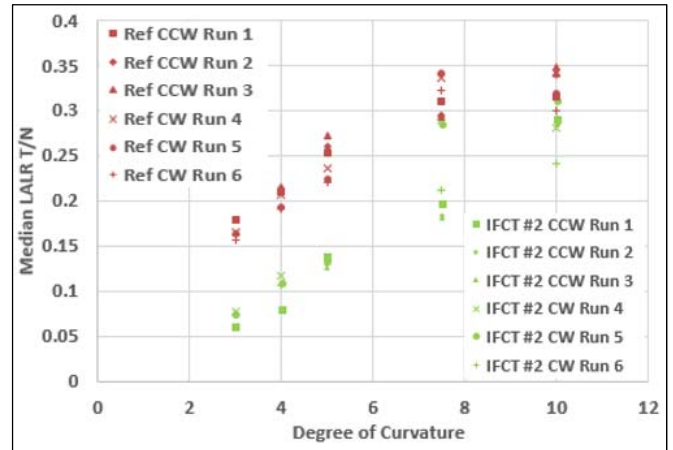


Figure 2. Comparison of IFCT #2 and Reference Truck Median LALR T/N

Reliable quantification of steering improvement via reduction in LALR T/N is essential. The following equation calculates the percent difference between the test and the reference truck LALR T/N for each run and curve. Figure 3 shows these values as the run-to-run comparison.

$$\text{Percent Difference} = \frac{\text{Reference Truck} - \text{Test Truck}}{\text{Reference Truck}} \times 100\%$$

Both the reference truck and the test truck sometimes perform better when curving in one direction than the other. Because of this, the overall performance of the test truck is calculated for each curve using the average of worst case direction for the test truck compared to the average of the best case direction of the reference truck.

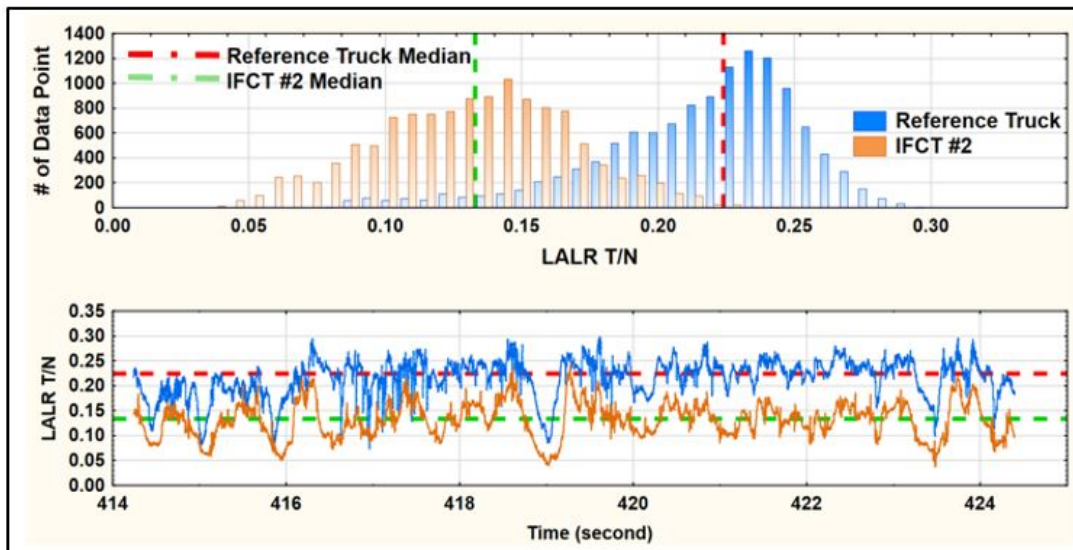


Figure 1. Sample Distributions and Time Series of LALR T/N: Reference and IFCT #2, 5-degree Curve, CW

The following equations describe this methodology:

$$Ref\ Truck = \text{Min}[Avg(CW\ LALR\ T/N), Avg(CCW\ LALR\ T/N)]$$

$$Test\ Truck = \text{Max}[Avg(CW\ LALR\ T/N), Avg(CCW\ LALR\ T/N)]$$

Figure 3 also shows the overall performance calculated in this way as IFCT #2 performance. It is expected that test data from candidate trucks will be presented in this way. In the 7.5-degree curve, the IFCT #2 performance is below the proposed IFCT limit line even though the run-to-run performance is close to the line. This is because both the reference and the test truck had higher traction ratios in one direction.

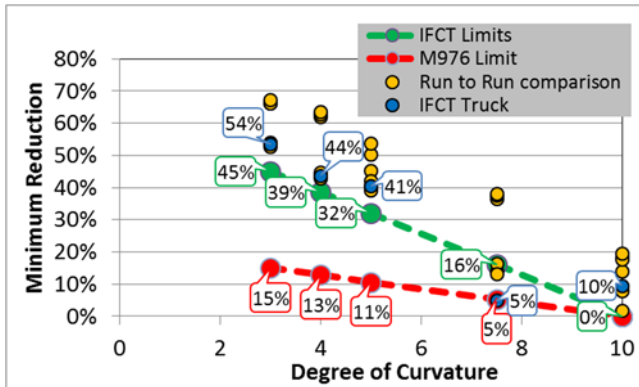


Figure 3. Percent Difference for IFCT #2

Bimodal Distributions

As shown in Figure 1, most of the test results (truck type, direction, curvature, and run) showed the unimodal distribution. However, some of the data showed bimodal or multimodal distribution. Figure 4 shows an example run with a very distinct bimodal distribution and its time

history. This behavior may be attributed to the truck’s vertical suspension and steering characteristics. The median value, shown with a dashed black line, occurs at a traction ratio that is in a trough in the distribution. Because of this, the median does not actually represent a commonly occurring value of the data. To account for this, and to be conservative regarding truck performance, the minimum value between the two peaks in the distribution is found and the median of the upper portion of the data (called modified median) is calculated. Figure 4 shows this with a dashed dark red line. The median and modified median lines are also shown on the time history.

To consistently identify bimodal data and calculate the median of the upper mode (modified median), if it exists, a standard process is proposed. For the examples shown in this TD, the following formula is used to calculate the number of bins to sort the data:

$$\# \text{ of bins} = \text{round up} \left(\frac{(\text{max} - \text{min})}{\text{standard deviation}} \times 5.15 \right)$$

If the calculated number of bins is less than 10, then 10 bins are used.³

After calculating the number of bins, the distributions were generated. The bottom bin begins at the minimum value of the data and the bin size is calculated with the following formula:³

$$\text{bin size} = \frac{(\text{max} - \text{min})}{\# \text{ of bins}}$$

It is important that any distribution be recreated this same way for consistency. After the distributions are generated with the appropriate bin counts, the analysis can

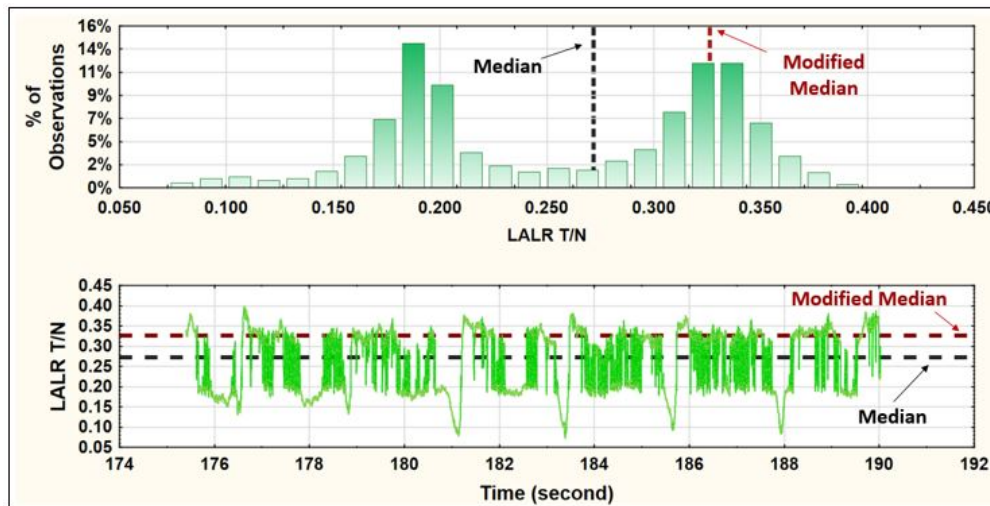


Figure 4. Sample Bimodal Distribution and Time History for IFCT #1, 10-degree Curve, CW

be conducted to determine if a data set is considered bimodal by using the following steps:

Step 1. Make a list of the top 10 largest contributing bins in the distribution and rank them from highest to lowest. Label these bins in descending order (b1, b2, b3...).

Step 2. Count the number of bins between the largest bin and each of the other top 9 bins.

Step 3. If in any case a bin is more than b(n)+1 bins away from b1, then the data is to be labelled as bimodal.

Figure 5 shows a distribution for an extreme case, where the 10th bin triggers the flag for the data set to be labelled as bimodal.

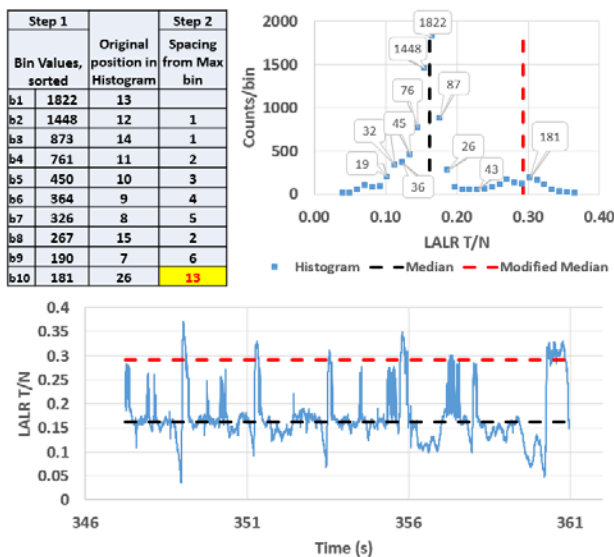


Figure 5. Bimodal Distribution for IFCT #1, 7.5-degree Curve CCW

If the data has been determined to be bimodal, the next step is to determine the trough between the two peaks so that the data can be separated and the modified median taken for the larger distribution. To determine the trough, find the bin with the smallest count that lies between b1 and the first bin to violate the b(n)+1 condition. In the example, the first violation occurs at b10. The smallest trough between b1 and b10 is at the bin with 43 data points in it. The center of this bin (0.2292) is used to determine a separation point for the data. The median of the set of data larger than 0.2292 is then reported. Figure 5 shows a dashed red line at the modified median both at the distribution and time history along with bin values.

CONCLUSION

Reduction in LALR T/N is an indication of steering improvement. Based on the proposed curving test¹ and data analysis methodology described, minimum LALR T/N improvement limits are proposed to distinguish non-steering, M-976, and IFCT in Figure 6.

The proposed minimum improvement for IFCT over the reference truck is 45 percent in a 3-degree curve, 0 percent in a 10-degree curve, and linearly interpolated in between. The proposed minimum improvement for M-976 trucks over the reference truck is 15 percent in a 3-degree curve, 0 percent in a 10-degree curve, and linearly interpolated in between. Figure 6 shows these lines and data measured with M-976 and IFCT truck designs.

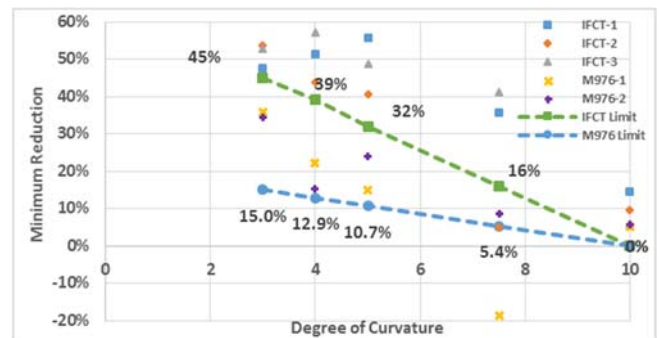


Figure 6. Proposed Limits

FUTURE WORK

TTCI is working with the AAR Equipment Engineering Committee to support potential rulemaking relevant to this work. Durability testing of IFCTs are being conducted under heavy axle load operation at TTC. Dynamic performance of IFCTs will be provided in future TDs.

ACKNOWLEDGEMENT

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