

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

Relating Warp Index, Truck Gage Spread Force, Track Curvature, Friction, and Axle Load

Benjamin Madrill, Harry Tournay, Travis Wolgram, and Sam Chapman

This Technology Digest (TD) describes the relationships between warp index and truck gage spread force, track curvature, friction, and axle load. It complements a second TD, TD-07-009, which describes the basic development of a truck warp index for truck performance detector data.

Summary

A truck warp index (WI) was developed by Transportation Technology Center, Inc. to identify poorly performing cars using truck performance detectors (TPDs) and to quantify the warp state of a truck in a curve. This work was part of the process to develop algorithms to identify poorly performing cars using TPDs and to relate the poor performance to car and car component conditions by means of a series of teardowns of identified cars.

The following relationships between WI, truck gage spread force (TGSF), track curvature, friction, and axle load are presented:

- WI and TGSF are both useful TPD metrics
- WI and TGSF both appear dependent on track curvature, with the former relationship revealed as essentially linear in the ranges of track curvatures used for TPD sites
- WI may depend on the friction coefficient between wheel and rail at a given TPD site
- WI seems relatively independent of axle load; whereas, TGSF appears quite dependent on axle load

This work was sponsored by the Association of American Railroads as part of its Strategic Research Initiatives Program.



INTRODUCTION

Transportation Technology Center, Inc. (TTCI) was tasked by the Association of American Railroads, as part of its Strategic Research Initiatives Program, to:

- Analyze TPD data
- Develop algorithms to identify poorly performing cars using TPDs
- Relate this poor performance to car and car component conditions by means of a series of teardowns of identified cars

TTCI investigated and reported on TPD data and performance indices.¹ This led to the development of a WI.² WI enables discrimination between substantially warped and unwarped trucks. It provides a quantification regarding the warp state of a truck in a curve and can be used in conjunction with other TPD metrics to determine truck condition. WI has proven to be a reliable indicator of truck performance.

TGSF¹ has also proven to be a reasonable TPD metric. It indicates possible damaging forces and wear caused by warped trucks. Unfortunately, TGSF does not discriminate between an unwarped truck with high lead axle angle of attack and a warped truck with lesser lead axle angle of attack.

This TD reports that:

- WI and TGSF both appear dependent on track curvature, with the former relationship revealed as essentially linear in the ranges of track curvatures used for TPD sites
- WI may depend on the friction coefficient ($\mu_{\text{site friction}}$) between wheel and rail at a given TPD site
- WI seems relatively independent of axle load; whereas, TGSF appears quite dependent on axle load.

Development of a Relationship between WI, TGSF, and Track Curvature

TPD sites in North America have track curvatures varying between 3 and 9 1/2 degrees. Consequently, in order to reliably quantify truck performance, its relationship to track curvature must be understood.

TGSF versus WI was examined at distinct track curvatures in an attempt to discern any effect of track curvature on the metrics. For example, data was analyzed from two reverse curves, of different curvatures, at one TPD site. All data was associated with trucks under (coal) cars having the same loads (thereby eliminating any potential influence of axle load). Figure 1 shows TGSF versus WI from the 9-degree curve at the site. There, two relatively distinct sub-samples emerge: (1) unwarped trucks with a WI below 45 percent and a corresponding TGSF below 33 kips, and (2) warped trucks with a WI above 65 percent and a corresponding TGSF above 25 kips. This differentiation is fairly evident in this curve.

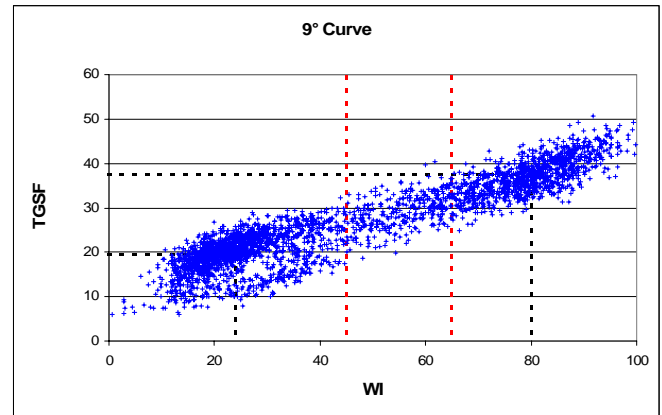


Figure 1. TGSF vs. WI for a 9-Degree Curve

For the purposes of this analysis, the trucks with WI between 45 and 65 percent remain undefined (neither definitively warped nor definitively unwarped).

The average values of WI and TGSF for the two sub-samples are:

- Warped trucks:
 - Average WI = 80%
 - Average TGSF = 37.4 kips
- Unwarped trucks:
 - Average WI = 24%
 - Average TGSF = 19.7 kips

Figure 2 shows TGSF versus WI from the 6-degree curve at the site. There, two sub-samples are not as distinct.

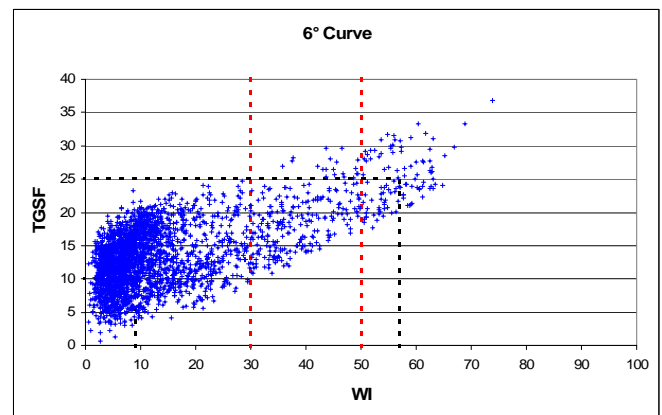


Figure 2. TGSF vs. WI for a 6-Degree Curve

There seems to be a grouping of trucks with a WI below 30 percent and a corresponding TGSF below 25 kips. These are, evidently, substantially unwarped trucks. The grouping of warped trucks is less distinct. Here warped trucks are defined as being those trucks having a WI above 50 percent and a corresponding TGSF above 17 kips.

For the purposes of this analysis, the trucks with WI between 30 and 50 percent remain undefined (neither definitively warped nor definitively unwarped).

The average values of WI and TGSF for the two sub-samples are:

- Warped trucks:
 - Average WI = 57%
 - Average TGSF = 25.0 kips
- Unwarped trucks:
 - Average WI = 9%
 - Average TGSF = 12.7 kips

Notwithstanding the rather loose definitions of warped versus unwarped trucks just described, it may be clearly observed that both warped and unwarped trucks have WIs and TGSFs that are influenced by track curvature.

Consequently, data from each TPD site was examined on a similar basis. It was found that trucks from all sites and track curvatures might generally be classified as Figure 3 shows, a guideline for assessing the warp state of a truck using WI with consideration of TPD site track curvature.

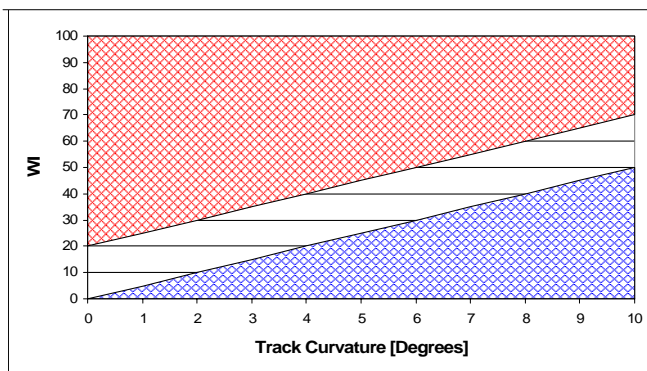


Figure 3. Guideline for Assessing Warp State of a Truck

Referencing Figure 3, the warp state of a truck may be determined by locating where a given WI crosses with a given track curvature. Any crossing in the red area indicates that a truck is warped, while any crossing in the blue area indicates that a truck is unwarped. Any crossing within the white, lined section of the graph dividing warped and unwarped areas indicates that a truck is undefined (neither definitively warped nor definitively unwarped).

For example, if a truck has a WI of 40 percent in a 3-degree curve, then it is warped; however, if a truck has a WI of 40 percent in a 9-degree curve, then it is unwarped.

A linear relationship has been chosen between WI and track curvature (measured in degrees). This seems reasonable because the lead axle of a truck generally has an angle of attack (measured in milliradians) equal to track curvature (measured in degrees) and lateral forces generally proportional to angle of attack (given constant wheel/rail contact conditions – profile and friction).

Data from 20,000 trucks per TPD site (roughly 5 days of data per site) was examined. Trucks having the top 1 percent of WI for each site were identified (200 trucks per site). Figure 4 shows the top 1 percent sub-samples and how they relate to curvature. The WI guideline boundaries from Figure 3 are also displayed for reference.

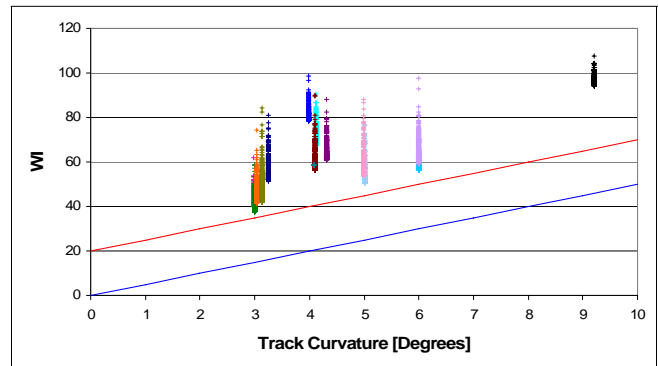


Figure 4. Top 1% of WI per TPD Site vs. TPD Site Track Curvature: All Sites, All Axle Loads

The described data seems to trend linearly, as expected, with a few site exceptions. These exceptions are believed to result from site wheel/rail friction conditions substantially different from those of the other TPD sites.

Effect of μ_{site} friction on WI

The same data from 20,000 trucks per TPD site was studied further regarding μ_{site} friction. The data for each TPD site was sorted according to WI in order to separate warped trucks. Subsequently for each site, an average lead wheel, low rail L/V was calculated for identified warped trucks and is displayed in Figure 5. This average L/V should approximate μ_{site} friction for the low rail at a site because the lead axle of a warped truck has a high angle of attack and should approach limiting friction.

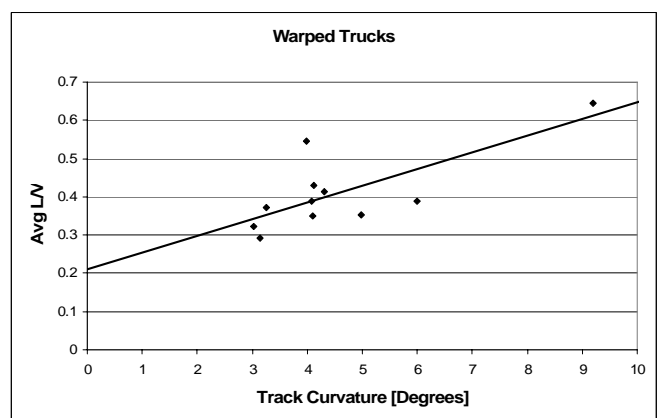


Figure 5. Average Lead Wheel, Low Rail L/V vs. TPD Site Track Curvature with Trend Line

Comparing Figures 4 and 5, the sites that have higher WI are the same sites that have higher average L/V; furthermore, many of the sites with slightly lower WI show slightly lower average L/V.

TTCI is running several NUCARS® models to simulate, among other things, the influence of $\mu_{\text{site friction}}$ on TPD metrics.

Effect of Axle Load on WI and TGSF

The effect of axle load on WI and TGSF was examined. Data was obtained from a number of TPD sites of differing curvatures and for various axle loads. For each TPD site, data was sorted according to WI to separate warped trucks and then further sorted by axle load. The average TGSF and WI for given axle load ranges were found. Figures 6 and 7 show these axle load range averages per TPD site track curvature for identified warped trucks.

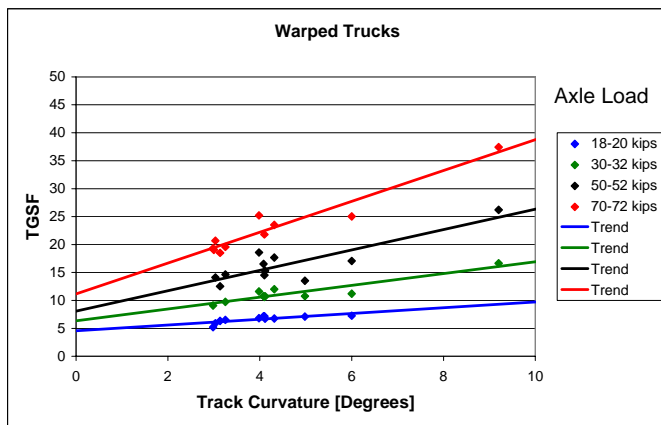


Figure 6. Effect of Axle Load on TGSF

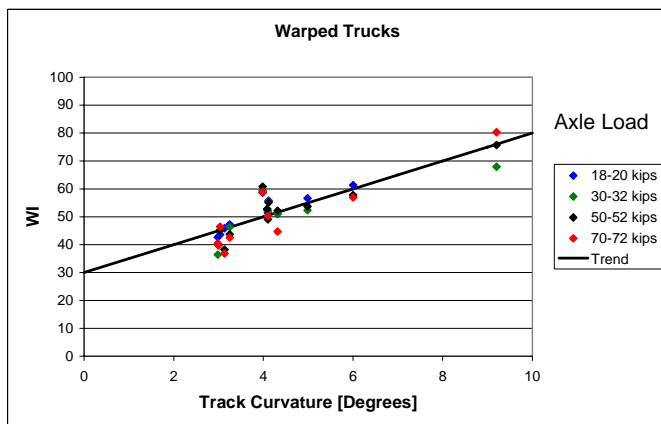


Figure 7. Effect of Axle Load on WI

TGSF appears considerably influenced by axle load, whereas WI seems only slightly so, if at all.

The major drawback of using TGSF in a TPD performance analysis is that it is influenced by axle load, and thus only useful when comparing cars having equal loading. In other words, TGSF can have utility when comparing the performances of coal cars but not of intermodal cars, for example. Alternately, WI comparison can occur across all axle loads.

TGSF is practical for identifying those cars that induce the highest stresses or wear on themselves and track. WI is the preferred metric when investigating the warp state of a truck.

CONCLUSIONS

- WI and TGSF are both useful TPD metrics.
- WI and TGSF both appear dependent on track curvature, with the former relationship revealed as essentially linear in the ranges of track curvatures used for TPD sites. A produced WI guideline allows determination of the warp state of a truck at any TPD track curvature.
- WI may depend on $\mu_{\text{site friction}}$ between wheel and rail at a given TPD site.
- WI seems relatively independent of axle load; whereas, TGSF appears quite dependent on axle load. WI comparison can occur across all axle loads.

FUTURE WORK

The effect of $\mu_{\text{site friction}}$ on WI needs further scrutiny. Different site conditions (e.g., rain, snow, and rail lubrication) suggest that a universal, direct comparison of WI across all TPD sites at all times may be inappropriate.

Further investigation should also occur regarding potential benefits of using WI and TGSF in conjunction.

REFERENCES

1. Tournay, Harry M., et al. July 2006. "Interpreting Truck Performance Detector Data to Establish Car and Truck Condition." Research Report R-977, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
2. Madrill, Benjamin, et al. April 2007. "Development of a Truck Warp Index." *Technology Digest* TD-07-009, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.