Statistical Analysis of Lateral Wheel Loads Using Truck Performance Detectors (TPD)

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Outline

• Motivation
• Summary of Truck Performance Detectors
• Effect Size Statistical Analysis
• Leading Versus Trailing Axles
  – Car Type
  – Curvature
• Conclusions
• Future Work
Motivation

• Current components have been designed empirically through trial over time
• Accelerated rate of component wear in certain areas
• Wear can be minimized by understanding the loading conditions
• Drive towards mechanistic design of components
Overview of Mechanistic Design

• Design approach utilizing forces measured in track structure and properties of materials that will withstand or transfer them

• Uses responses (e.g. contact pressure, relative displacement) to optimize component geometry and materials requirements

• Based on measured and predicted response to load inputs that can be supplemented with practical experience

• Requires thorough understanding of load path and distribution

• Allows load factors to be used to include variability due to location and traffic composition

• Used in other engineering industries (e.g. pavement design, structural steel design, geotechnical)
Truck Performance Detectors (TPD)

- 6 cribs with strain gauges on the base and web of the rail
- For each wheel,
  - Labels by vehicle type
  - Measures peak vertical and lateral load
TPD Site Information

- Eight TPD locations located in six states across the US
- All TPDs located on concrete crosstie track
- Degree of Curvature: Range from 3 to 6 degrees
- Superelevation: Range from 1 to 4 inches

<table>
<thead>
<tr>
<th>Location</th>
<th>Curvature</th>
<th>Superelevation (in)*</th>
<th>Balance Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Curve 1</td>
<td>Curve 2</td>
<td>Curve 1</td>
</tr>
<tr>
<td>Argyle_1, IA</td>
<td>4° 5’</td>
<td>3° 4’</td>
<td>3.63</td>
</tr>
<tr>
<td>Argyle_2, IA</td>
<td>4° 5’</td>
<td>3° 4’</td>
<td>3.63</td>
</tr>
<tr>
<td>Elmira, ID</td>
<td>4° 23’</td>
<td>4° 9’</td>
<td>3.63</td>
</tr>
<tr>
<td>Joppa, MT</td>
<td>4° 30’</td>
<td>3° 36’</td>
<td>2.06</td>
</tr>
<tr>
<td>Ludlow_1, CA</td>
<td>4° 5’</td>
<td>4° 6’</td>
<td>3.63</td>
</tr>
<tr>
<td>Ludlow_2, CA</td>
<td>4° 7’</td>
<td>4° 19’</td>
<td>3.63</td>
</tr>
<tr>
<td>Ludlow, CO</td>
<td>5° 0’</td>
<td>6° 0’</td>
<td>2.77</td>
</tr>
<tr>
<td>Pomona, MO</td>
<td>3° 55’</td>
<td>4° 10’</td>
<td>3.48</td>
</tr>
</tbody>
</table>
Summary of Current Findings

- Based on previous analysis, it was found that car weight was the most significant predictor of vertical and lateral wheel load
  - Degree of curvature, speed, and cant deficiency were found to have a relatively small impact

Questions to be Answered

- How do the leading axles of cars differ from the overall distribution?
  - Car weight
  - Degree of curvature
Effect Size Summary

• For large samples, even very similar distributions will have statistically significant difference when using T-test.

• T-test effect size can determine whether difference between average of two groups is meaningful.

• Effect size is a quantitative measure of the strength of a phenomenon.

• Three levels of effect size:
  – 0.3 = Small  Hardly visible
  – 0.5 = Medium Observable
  – 0.8 = Large  Plainly evident

• Compare populations with each other and calculate effect size.
  – Car type, degree of curvature
Variation According To Car Type

Lateral Load Statistical Analysis

Positive

Negative

Gauge

Field

Intermodal Freight Cars

Freight Locomotives

Unloaded Freight Cars

Loaded Freight Cars

All Car Types

Percent Exceeding

Lateral Load (kips)
Car Type Effect Size

- **medium effect**
- **small effect**

Effect Size

- IFC vs FL
- FL vs UFC
- UFC vs LFC
- IFC vs UFC
- IFC vs LFC
- FL vs LFC

Car Type Distribution Comparisons
Car Type – Leading and All Axles

- Unloaded Freight Cars (all axles)
- Loaded Freight Cars (all axles)
- Unloaded Freight Cars (front axles only)
- Loaded Freight Cars (front axles only)
Locomotive – Leading and All Axles

- Freight Locomotives (all axles)
- Freight Locomotives (front axles only)
Car Type Effect Size – Leading Axles

- **Effect Size**
  - Small effect
  - Medium effect

- **Car Type Distribution Comparisons**

- **Comparison Groups**
  - FL vs UFC
  - UFC vs LFC
  - FL vs LFC
Degree of Curvature
Loaded - Degree of Curvature – All Axles

- 3~4 Degree
- 4~5 Degree
- 5~6 Degree
- >=6 Degree

Lateral Load (kips)

Percent Exceeding

Positive
Negative
Gauge
Field
Degree of Curvature Effect Size

Effect Size

Degree of Curvature Distribution Comparisons

- 3° - 4° vs 4° - 5°
- 4° - 5° vs 5°
- 5° vs 6°
- 3° - 4° vs 5°
- 3° - 4° vs 6°
- 4° - 5° vs 6°
Loaded - Degree of Curvature – Leading Axles

- 3~4 Degree
- 4~5 Degree
- 5~6 Degree
- >=6 Degree

Degree of Curvature

- Positive
- Negative

Gauge Field

Percent Exceeding

Lateral Load (kips)
Degree of Curvature Effect Size – Leading Axles

Effect Size

Large effect
Medium effect
Small effect

Degree of Curvature Distribution Comparisons

- 3°– 4° vs 4°– 5°
- 4°– 5° vs 5°
- 5° vs 6°
- 3°– 4° vs 5°
- 3°– 4° vs 6°
- 4°– 5° vs 6°
Conclusion

• Truck performance detectors can be used to quantify and predict the lateral wheel load of rail cars

• Car type is the most significant predictor of lateral wheel loads when considering all wheels

• Leading axles impart statistically significantly higher lateral loads than trailing axles

• Degree of curvature has a significant effect when solely considering leading axles, in particular for loaded cars
Future Questions to Answer

• Do higher degree of curvature (6+ degrees) curves change the lateral load distribution?

• Do 4 axle locomotives impart different lateral loads than 6 axle locomotives?

• Does truck type affect lateral load?
  – Articulated vs. standard

• Can the factors that affect lateral load be combined using a regression analysis to provide a prediction of lateral load?
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Individual TPD Site Degree of Curvature Analysis
Argyle_1 All Axles

- High rail, 3.067 degree of curvature
- High rail, 4.083 degree of curvature
- Low rail, 3.067 degree of curvature
- Low rail, 4.083 degree of curvature

Y-axis: Percent Exceeding
X-axis: Lateral Load (kips)
Argyle_1 Leading Axles Only

Percent Exceeding

-25  -15  -5   5   15  25
Lateral Load (kips)

- 90%   80%   70%   60%   50%   40%   30%   20%   10%   0%

- High rail, 3.067 degree of curvature
- High rail, 4.083 degree of curvature
- Low rail, 3.067 degree of curvature
- Low rail, 4.083 degree of curvature
Ludlow_CA_1 All Axles

- High rail, 4.083 degree of curvature
- High rail, 4.1 degree of curvature
- Low rail, 4.083 degree of curvature
- Low rail, 4.1 degree of curvature
Ludlow_CA_1 Leading Axles Only

- High rail, 4.083 degree of curvature
- High rail, 4.1 degree of curvature
- Low rail, 4.083 degree of curvature
- Low rail, 4.1 degree of curvature

Percent Exceeding

- 100%
- 90%
- 80%
- 70%
- 60%
- 50%
- 40%
- 30%
- 20%
- 10%
- 0%

Lateral Load (kips)

-25
-15
-5
5
15
25
• The curve specific variability of measured lateral wheel loads is high
  – Even within one curve, two curves with similar degree of curvature can behave very differently