Identification of Aberrant Railroad Wayside WILD and THD Detectors: Using Industry-wide Railroad Data

June 10, 2014
Agenda

• Background / Overview

• Solution Approach

• Groupings Criteria
  • Sites
  • Speed
  • Weight
  • Car Type

• Solution Architecture (with SAS)

• REPORTING: Dashboards to Analyze WILD Sites
WILD: WHEEL IMPACT LOAD DETECTOR
WILD Detectors Data Collection

Wheel Impact Detector Circuit

Railinc

TTX
158 WILD detectors in N. A.
TTX receives 375,000 records per day.
**Project Overview**

**Wayside Detectors**
- Located at about 158 WILD sites in the North America
- Detect Wheel impacts
- Can exhibit aberrant behavior (e.g. due to flooding etc.)
- Aberrant detector can lead to wrong detection and unnecessary wheel repair expenses

**Business Problem**
- An aberrant detector could lead to removal of 200-500 healthy wheels (costing $2-3K each) before it is identified (cost = $1M+)
- Once suspected, it takes at least 2-3 weeks of manual work to analyze data and verify it

**Goals**
- Build an interactive tool for rapid identification of aberrant wayside detectors / health diagnostics using **INDUSTRY-WIDE DATA**
- Evaluate readings grouped by **Speed, Weight and Car type** for better precision
- Advanced **Enterprise Reporting system & Insights** (Dashboards/UI, email alerts)
TTX-CARS ONLY WILD DATA

PREVIOUS WORK/BACKGROUND
Variables affecting Alerts from Detectors

Factors that influence Number of Alerts from a Detector

- Variability of measurement system
- Alerts differ across time (seasonality, winter temperature)
- Alerts differ across detectors (railcar types, location)

Metrics

- APW: Alert per 10,000 wheels passed
- Defined for each alert level
Variability is Normal in WILD Detectors

Repeat WILD readings of a good wheel

Impact in 1,000 pounds (kips)

53,000 pounds

35,000 pounds

SPEED (MPH)

50 mph

90,000 pounds = alert

Graphs from Wild Impact Load Detector Tests and Development of Wheel-flat Specification, R - 829
More WILD alerts during winter months
Colder winter leads to more alerts

*TTX-CARS ONLY WILD DATA
Example of grouping sites based on similar environmental criteria not by rail road.
Grouping*
Used to handle seasonality and temperature related effects

*TTX-CARS ONLY WILD DATA
Detector Specific Variations*

APW differs from detector to detector

*TTX-CARS ONLY WILD DATA
Normalized APW
Normalization for comparison across sites

Normalized APW

*TTX-CARS ONLY WILD DATA
Group Average and Standard Deviation

*TTX-CARS ONLY WILD DATA*
Group Average is the Benchmark

*TTX-CARS ONLY WILD DATA
Detector Scoring

Score = \( \frac{\text{Observed} - \text{Group Avg}}{\text{Std.Dev.}} \)

**SCORE**: How far from the average is aberrant?

**Yellow**: Score > 2

**Red**: Score > 3

*TTX-CARS ONLY WILD DATA*
Example of Normal site

*TTX-CARS ONLY WILD DATA
Example of Faulty Detector (1)

*TTX-CARS ONLY WILD DATA*
WILD

INDUSTRY WIDE DATA
Site Groupings* (Industry-Wide Data)

*Site Groupings is for Industry-wide data and is based on similarity in APW/Base APW (= S) trends, domain knowledge, geography and environmental criteria.
Comparison of Data Size

Average Wheel Count Per Day for 2012

- **All Cars**: ~ 1,650,000
- **TTX Only**: ~ 375,000

Approx. 4X more data

**Industry Wide Data Volume**
- ~ 1.5 - 2M rows of data PER DAY (~ 200 MB size)
- ~ 200 - 220 GB of data over last three years
- Stripped Car Numbers and Car Initials for anonymity purposes
Solution Approach

Separating the signal from the noise - typical site

1. Compute $S = \frac{\text{APW}}{\text{Base APW}}$

2. One time
   Group sites based on similarity in APW/Base APW (= S) trends, domain knowledge, geography

3. Determine benchmark = Group average

4. Score $= \frac{\text{Observed} - \text{Group Avg}}{\text{Std.Dev.}}$

APW = \frac{\text{Alerts}}{\text{Wheels}} \times 10000

Green: Score < 2
Yellow: Score > 2
Red: Score > 3

Detected Trend
Benchmark Trend

[Graph showing normalized APW over time with different color markings for green, yellow, and red.]
TTX-ONLY CARS / INDUSTRY WIDE DATA COMPARISON
Parameter S – TTX Cars vs. All Cars
Group 1 (Site A)

* For Alert Level 1, Site Direction 1

(8/15/2011) **65% higher** standard deviation.

The lines form a very tight band.
Example from Group 6 (Site B)

Normalized APW for Detector

TTX Cars *

All Cars *

(8/15/2011) **360% higher** standard deviation.
ANALYSIS FOR SPEED, WEIGHT AND CAR TYPE FACTORS
Comparison of Observed APW for Site D Track 1 – By Speed*

Higher APW at higher speeds

* For Alert Level 1 and Site Direction 1
Comparison of Data: Sample Data Point - May 1\textsuperscript{st}, 2011

<table>
<thead>
<tr>
<th>Speed</th>
<th>30 Day Alerts</th>
<th>30 Day Wheels</th>
<th>Alerts / 10k Wheels</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 40 mph</td>
<td>379</td>
<td>88,496</td>
<td>43</td>
</tr>
<tr>
<td>40 – 60 mph</td>
<td>5,608</td>
<td>288,855</td>
<td>194</td>
</tr>
<tr>
<td>60 – 80 mph</td>
<td>42</td>
<td>8,760</td>
<td>48</td>
</tr>
</tbody>
</table>

* For Alert Level 1 and Site Direction 1
Mid-range (160,000 – 240,000 lbs) is further split into buckets of 20,000 lbs each.

**Avg. # of Wheels per Month per Site**

- Empty (0 - 160,000 lbs): 149,854
- Mid (160,000 - 180,000 lbs): 6,196
- Mid (180,000 - 200,000 lbs): 4,323
- Mid (200,000 - 220,000 lbs): 4,350
- Mid (220,000 - 240,000 lbs): 8,422
- Fully Loaded (240,000 - 320,000 lbs): 105,460
- Above Fully Loaded (320,000+ lbs): 157

**Avg. # of Condemnable Alerts Per Month Per Site**

- Empty (0 - 160,000 lbs): 7
- Mid (160,000 - 180,000 lbs): 4
- Mid (180,000 - 200,000 lbs): 4
- Mid (200,000 - 220,000 lbs): 6
- Mid (220,000 - 240,000 lbs): 14
- Fully Loaded (240,000 - 320,000 lbs): 298
- Above Fully Loaded (320,000+ lbs): < 1

*2010-13 data for all sites*
### Comparison of Data: Sample Data Point - May 1<sup>st</sup>, 2011 *

<table>
<thead>
<tr>
<th>Car Weight</th>
<th>30 Day Alerts</th>
<th>30 Day Wheels</th>
<th>Alerts per 10,000 Wheels (APW)</th>
<th>% of Total Wheels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty (0 – 160,000 lbs)</td>
<td>6</td>
<td>67,148</td>
<td>1</td>
<td>50.3%</td>
</tr>
<tr>
<td>Mid (160,000 – 240,000 lbs)</td>
<td>18</td>
<td>1,423</td>
<td>126</td>
<td>1.1%</td>
</tr>
<tr>
<td>Fully Loaded (240,000 – 320,000 lbs)</td>
<td>4,041</td>
<td>64,685</td>
<td>625</td>
<td>48.5%</td>
</tr>
<tr>
<td>Above Fully Loaded (320,000 lbs +)</td>
<td>11</td>
<td>117</td>
<td>940</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

* For Alert Level 1, Site Direction 1, Speed Range 40 – 60 mph
Site D Track 1 – Empty Versus Fully Loaded

Comparison of Z-Score for Site D Track 1 – By Weight*

* For Alert Level 1, Site Direction 1, Speed Range 40 – 60 mph, Hopper & Tank Cars
Final Groupings Summary for All Data

### Speed

<table>
<thead>
<tr>
<th>Speed Group</th>
<th>Train Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0-40</td>
</tr>
<tr>
<td><strong>S2</strong></td>
<td>40-60</td>
</tr>
<tr>
<td>S3</td>
<td>60-80</td>
</tr>
<tr>
<td>S4</td>
<td>80+</td>
</tr>
</tbody>
</table>

- 40 – 60 mph is the most stable speed range
- Speeds lower than 40 mph do not produce sufficient load impact
- The detector readings become unstable at higher speeds

### Car Type

<table>
<thead>
<tr>
<th>Group</th>
<th>Car Umler Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Box Cars</td>
</tr>
<tr>
<td>C2</td>
<td>Covered Hopper / Tank Cars</td>
</tr>
<tr>
<td>C3</td>
<td>Gondolas</td>
</tr>
<tr>
<td>C4</td>
<td>Flat Cars</td>
</tr>
<tr>
<td>C5</td>
<td>Equipped &amp; Unequipped Hoppers / Gondolas-GT</td>
</tr>
<tr>
<td>C6</td>
<td>Refrigerator Cars</td>
</tr>
<tr>
<td>C7</td>
<td>Vehicular Flat Cars</td>
</tr>
<tr>
<td>C8</td>
<td>Locomotives</td>
</tr>
<tr>
<td>C9</td>
<td>Conventional, Intermodal &amp; Stack Cars</td>
</tr>
<tr>
<td>*<em>X</em></td>
<td>Caboose, Passenger, Containers, Trailers, Special Types</td>
</tr>
</tbody>
</table>

### Weight

<table>
<thead>
<tr>
<th>Weight Group</th>
<th>Car Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>0-160,000 lbs</td>
</tr>
<tr>
<td>W2</td>
<td>160,000 -240,000 lbs</td>
</tr>
<tr>
<td><strong>W3</strong></td>
<td>240,000 - 320,000 lbs</td>
</tr>
<tr>
<td>W4</td>
<td>320,000 lbs +</td>
</tr>
</tbody>
</table>

- W1: Fully Empty / Nearly Empty
- W3: Fully Loaded / Almost Fully Loaded (+-10%)
PERFORMANCE OF CAR GROUPS
### Site D Track 1 – By Car Type

#### Comparison of Data: Sample Data Point – Jan 1st, 2012 *

<table>
<thead>
<tr>
<th>Car Type</th>
<th>30 Day Alerts</th>
<th>30 Day Wheels</th>
<th>APW</th>
<th>% Total Wheels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Cars</td>
<td>56</td>
<td>1,112</td>
<td>503</td>
<td>1%</td>
</tr>
<tr>
<td>Hopper &amp; Tank Cars</td>
<td>2007</td>
<td>67,386</td>
<td>298</td>
<td>76%</td>
</tr>
<tr>
<td>Gondolas</td>
<td>374</td>
<td>10,560</td>
<td>354</td>
<td>12%</td>
</tr>
<tr>
<td>Vehicular Flat Cars</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Box Cars &amp; Refrigerator Cars</td>
<td>23</td>
<td>616</td>
<td>373</td>
<td>1%</td>
</tr>
<tr>
<td>Stacked &amp; Intermodal Cars</td>
<td>34</td>
<td>9,071</td>
<td>37</td>
<td>10%</td>
</tr>
</tbody>
</table>

* For Alert Level 1, Site Direction 1, Speed Range 40 – 60 mph & Weight Range 240,000 - 320,000 lbs
Site D Track 1 – By Car Type

* For Alert Level 1, Site Direction 1, Speed Range 40 – 60 mph & Weight Range 240,000 – 320,000 lbs
### Investigation 1 – Aberrant Site

#### Selected Site Health Summary

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Site_ID_Direction</th>
<th>Group ID</th>
<th>Detector Name</th>
<th>Avg. Z-score</th>
<th>Total_Wheels</th>
<th>Total_Alerts</th>
<th>Benchmark_Alerts</th>
<th>Observed_APW</th>
<th>Expected_APW</th>
<th>Site_Base_APW</th>
</tr>
</thead>
<tbody>
<tr>
<td>806_1</td>
<td>7</td>
<td>806_1</td>
<td>AI_Track_1</td>
<td>4.6</td>
<td>468,348</td>
<td>116</td>
<td>30</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>806_2</td>
<td>7</td>
<td>806_2</td>
<td>AI_Track_1</td>
<td>3.1</td>
<td>468,348</td>
<td>90</td>
<td>31</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>792_2</td>
<td>7</td>
<td>792_2</td>
<td>ABI_Track_1</td>
<td>3.3</td>
<td>20,008</td>
<td>18</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>805_1</td>
<td>8</td>
<td>805_1</td>
<td>DIO_Track_1</td>
<td>3.3</td>
<td>91,052</td>
<td>11</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>700_2</td>
<td>2</td>
<td>700_2</td>
<td>BA_Track_1</td>
<td>3.2</td>
<td>96,004</td>
<td>339</td>
<td>152</td>
<td>35</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>700_1</td>
<td>2</td>
<td>700_1</td>
<td>BA_Track_1</td>
<td>2.5</td>
<td>96,004</td>
<td>363</td>
<td>165</td>
<td>37</td>
<td>19</td>
<td>7</td>
</tr>
<tr>
<td>596_1</td>
<td>7</td>
<td>596_1</td>
<td>AA_Track_1</td>
<td>2.8</td>
<td>4,768</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Control Panel
- **Avg Z-Score**: 2.5
- **Data As of Date**: April 3, 2014
- **Alert Type**: 3.4

#### GROUP ID
- **Null**
- **1**
- **2**
- **3**
- **4**
- **5**
- **6**
- **7**
- **8**
- **9**
Both rails are above the group average with Z-scores > 3.
Investigation 1 – Comparison of Cars

Covered hoppers

Open hoppers

Gondolas

All car types representing 90% of the traffic had high alerts.
Railroad asked TCCI to investigate a detector giving a large number of alerts.

No, the Z-score is 1.8.
- All mid west detectors were higher due to the long, cold winter.
- The traffic pattern changed.
  - A lot more cars
  - More weight per car
Conclusions

Change the state of the art

1. From gut feel to clear statistical signals.

2. Weekly, automate analysis of 11.5 million signals from 158 detectors, and send notifications of abnormal readings.

3. Rapid process to investigate suspicious detectors.