Autonomous VTI Monitoring Systems
2009 AREMA TECHNICAL CONFERENCE

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PRESENTATION OUTLINE

• Overview of VTI technology
• What does it measure?
• How does the railroad use the data?
• What enhancements are we working on?
• What’s next?
Vehicle / Track Interaction (VTI) Overview

Central Server
- Data Processor
- Database
- UP Track Maintenance Planner

Cellular Communications
- GPS Location
- Communications
- Processor
- Sensors
- On-board Monitor

Field Repair

Locomotive Installation

Carbody
Truck
Axle Impact

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Vehicle / Track Interaction (VTI) Instrumentation

- Core Processor
- Truck Sensor
- Axle Sensor
- GPS/Cell Antenna
- Carbody Sensor
VTI Carbody Vertical Acceleration Monitoring

Track Geometry Surface Deviations
VTI Carbody Lateral Acceleration Monitoring

Track Geometry Alignment Deviations
VTI Axle Vertical Acceleration Monitoring

Wheel/Rail Impact Detection
Vehicle / Track Interaction (VTI) at UPRR

• Between 2005-2008, UP deployed 53 VTI Systems across the railroad

• In 2009, we started sharing real time data between UPRR and BNSF, effectively doubling our fleet of VTI units. CSX also shares data from their units while traveling on UPRR

• The data collected by these systems was integrated into UP’s Track Maintenance Planner system

• The strategy is to provide field personnel immediate notification of critical locations, and next-day reporting of a manageable number of recommended maintenance locations.

• The goal is to observe an overall improvement in track quality.
30 Day VTI Coverage Map

Legend
- 30DayVTI.txt Events
- UP Owned Track
- UP Track Rights

255,000 Miles Aug 2009
2.0 Million Miles YTD

Prepared By: ENSCO, Inc.

Date Range: 8/2/2009 - 8/29/2009

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Vehicle / Track Interaction (VTI) at UPRR

- **Current Stats:**
  - Of 53 units equipped, average 33 units reporting defects on a daily basis, plus another 32 average BNSF units reporting
  - Covered 2.03 million miles YTD 2009
    - 2.42 million miles total 2008
  - Recorded Defects YTD:
    - 2,629 High Level (Critical)
    - 6,146 Medium Level (Urgent)
    - 0.43 Hits / 100 miles Tested
  - Repeat locations within 90 days:
    - 1,698 repeat hits at 567 locations (+/- 50 feet)
    - Standards & Technology group follows up on high repeaters (>4 in 90 days) to resolution

<table>
<thead>
<tr>
<th>Exceptions</th>
<th>High Priority</th>
<th>Medium Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB Vertical</td>
<td>&gt;1.3 G</td>
<td>&gt;1.15 G &lt;1.3 G</td>
</tr>
<tr>
<td>CB Lateral</td>
<td>&gt;.8 G</td>
<td>&gt;.7 G &lt;.8 G</td>
</tr>
<tr>
<td>Truck Lateral</td>
<td>&gt;.45 G</td>
<td>&gt;.41 G &lt;.45 G</td>
</tr>
<tr>
<td>Axle Vertical</td>
<td>&gt; 130 Kips</td>
<td>&gt;115 Kips &lt;130 Kips</td>
</tr>
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</table>
Vehicle / Track Interaction (VTI) at UPRR

VTI Repeat Hit Report:

- Shows repeat VTI locations within specified time frame (90 days)
- Can drill down into each line item location to see a summary of defect measurements and closure comments

### Chicago Service Unit (Northern)

<table>
<thead>
<tr>
<th>Track/Segment</th>
<th>Mile Post</th>
<th>Event Type</th>
<th>Repeat Count</th>
<th>Last Hit Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIDE (8380-0)</td>
<td>287.228</td>
<td>AXV</td>
<td>2</td>
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<tr>
<td>SIMN (8380-0)</td>
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<tr>
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<tr>
<td>OIMN (0000-0)</td>
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<td>AXV</td>
<td>2</td>
<td>09/10/2009</td>
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</table>

### Geneva Sub

<table>
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<tr>
<th>Track/Segment</th>
<th>Mile Post</th>
<th>Event Type</th>
<th>Repeat Count</th>
<th>Last Hit Date</th>
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<tr>
<td>NO 1 (8322-0)</td>
<td>55.440</td>
<td>AXV</td>
<td>2</td>
<td>06/23/2009</td>
</tr>
<tr>
<td>NO 1 (8323-0)</td>
<td>63.039</td>
<td>AXV</td>
<td>2</td>
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<td>NO 1 (8323-0)</td>
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<tr>
<td>NO 1 (8323-0)</td>
<td>73.234</td>
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<tr>
<td>NO 1 (8323-0)</td>
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<td>AXV</td>
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<td>08/28/2009</td>
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<td>74.127</td>
<td>AXV</td>
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<td>75.280</td>
<td>AXV</td>
<td>5</td>
<td>09/12/2009</td>
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</table>
Vehicle / Track Interaction (VTI) at UPRR

VTI Repeat Hit Detail:

- Shows detail data for all defects found within the specified time frame at that location
- Also shows what closure comments were entered into the TMP for that defect

VTI Repeat Detail Report

<table>
<thead>
<tr>
<th>Alert Time</th>
<th>Event Type</th>
<th>Car Nbr</th>
<th>Car Type</th>
<th>GPS Speed</th>
<th>GPS Direction</th>
<th>Force Reading</th>
<th>Original Track Type</th>
<th>Calculated Mile Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/18/2009 05:23:08</td>
<td>AXV1</td>
<td>1995</td>
<td>SD-70ACE</td>
<td>29</td>
<td>E</td>
<td>116.00</td>
<td>NO 2</td>
<td>75.276</td>
</tr>
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<td>06/18/2009 05:23:16</td>
<td>AXV2</td>
<td>1995</td>
<td>SD-70ACE</td>
<td>29</td>
<td>E</td>
<td>146.20</td>
<td>NO 2</td>
<td>75.276</td>
</tr>
<tr>
<td>06/18/2009 06:22:28</td>
<td>AXV2</td>
<td>1995</td>
<td>SD-70ACE</td>
<td>31</td>
<td>E</td>
<td>135.80</td>
<td>NO 2</td>
<td>75.278</td>
</tr>
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<td>06/24/2009 05:02:10</td>
<td>AXV1</td>
<td>5277</td>
<td>GE DC EVO</td>
<td>33</td>
<td>W</td>
<td>120.50</td>
<td>NO 2</td>
<td>75.273</td>
</tr>
<tr>
<td>07/11/2009 01:29:05</td>
<td>AXV2</td>
<td>1995</td>
<td>SD-70ACE</td>
<td>24</td>
<td>E</td>
<td>123.70</td>
<td>NO 2</td>
<td>75.277</td>
</tr>
<tr>
<td>09/12/2009 03:26:29</td>
<td>AXV1</td>
<td>4006</td>
<td>Dash 9</td>
<td>31</td>
<td>W</td>
<td>138.20</td>
<td>NO 2</td>
<td>75.273</td>
</tr>
</tbody>
</table>

TMP Closure Details

<table>
<thead>
<tr>
<th>Defect Date</th>
<th>MP</th>
<th>Comp. Date</th>
<th>Comp. By</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/18/2009</td>
<td>75.276</td>
<td>06/19/2009</td>
<td>DODW348</td>
<td>ok</td>
</tr>
<tr>
<td>06/21/2009</td>
<td>75.273</td>
<td>06/26/2009</td>
<td>D0000450246</td>
<td>RAIL KING</td>
</tr>
<tr>
<td>07/11/2009</td>
<td>75.277</td>
<td>07/14/2009</td>
<td>D000350346</td>
<td>WELDERS WORKED ON WELDING DIAMODS</td>
</tr>
<tr>
<td>09/12/2009</td>
<td>75.273</td>
<td>09/12/2009</td>
<td>DODW348</td>
<td>welded diamond</td>
</tr>
</tbody>
</table>
Vehicle / Track Interaction (VTI) Stats:

Percent VTI Close-out by Code YTD August 2009

Close-out Analysis:

- Field forces are now required to enter a close-out code when they show a VTI defect repaired
- Highest reported repair codes are all related to track surface repairs (tamping) – 45%
- Repairs to track components (frogs, switches, ties, joints, etc.) account for only 13% of repairs
- Still have 41% in “Other” closure codes, including “No Defect Found”
Vehicle / Track Interaction (VTI) Stats:

VTI Trends:

• In the first two years of VTI implementation, the number of hits dropped dramatically and now has leveled out
• In 2008, we added more UP units and started sharing the data from the BNSF units
• These additions made the “Hits/100 miles” metric change dramatically
• We have stabilized the number of units in 2009, which will give us a good base for goal measurement going forward
VTI Technology Development

• Since inception of VTI program, UP continues to support technology improvements

• Major past initiatives include:
  – Freight RR threshold recommendations
  – Wheel/Rail force estimations
  – Filtering on false alarms
  – Repeat “hit” counts
  – Data sharing between railroads

• 2009 focus on addition of new measurements:
  – 10’ Mid Chord Offset (MCO)
  – Freight Car Carbody Roll Angle (CBR)
10’ Mid Chord Offset (MCO) Background

• 2007 FRA Office of Research study to assess effectiveness of axle acceleration monitoring concludes:
  – Axle accelerations are effective for detecting wheel impacts;
  – Localized conditions lacking support structure (primarily at joints) and at risk of failure can go undetected;
  – Axle Accelerations can be used to derive space curve and calculate MCO. 31’- 62’ MCO likely miss target conditions;
  – 10’ chord recommended and detection added to VTI.

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Carbody Roll Angle (CBR) Background

- 2008 controlled test conducted over TTCI Precision Test Track with BNSF, UP and TTCI participation.
  - BNSF coal car equipped with VTI traverses Twist and Roll Zone - Tangent track, 10 repeated sinusoidal profile deviations – 39’ wavelength
  - Existing VTI sensors not excited to a level of concern
  - Data suggests addition of roll angle sensor could provide early warning of rock off hazards
- Roll sensor added to VTI Equipped Coal Car to determine roll angle peak to peak over 1 sec
Evaluating the Results of MCO and CBR

- **Test Equipment:** Coal Car 601043 (MCO & CBR) and Locomotive 5725 (MCO only) operate in consist

- **Consist Run Dates:** July 31, 2009 - August 9, 2009

- **50 Site Visits:** Hand measurements, photos & site ratings

Silver Lake, KS to Hays, KS – KP Line MP 78.3-282.9
Site Visit Rating Scale

Each site visit was rated high, medium or low for correlation of measurement to maintenance necessity

<table>
<thead>
<tr>
<th>Definition of Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High</strong></td>
</tr>
<tr>
<td>Requires immediate repair or slow order</td>
</tr>
<tr>
<td>Significant risk of failure</td>
</tr>
<tr>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td>Requires attention, but not immediately</td>
</tr>
<tr>
<td>Could potentially become severe</td>
</tr>
<tr>
<td>Maintenance personnel should be aware of issue</td>
</tr>
<tr>
<td><strong>Low</strong></td>
</tr>
<tr>
<td>Does not require attention or event could not be found</td>
</tr>
</tbody>
</table>
MCO & CBR Test Objectives

• MCO Test Objectives
  – Assess the accuracy of the measurements
  – Validate the detection of poor support conditions
  – Develop preliminary recommendations for thresholds

• CBR Test Objectives
  – Understand and validate the conditions detected
  – Develop preliminary recommendations for thresholds
10’ Mid Chord Offset (MCO) Accuracy Results

- Site visits compared VTI readings with 10’ MCO string line measurement. Vertical deflection also recorded.
- VTI readings correlated well with string line measurement.

<table>
<thead>
<tr>
<th>VTI vs. String line Measurement Variance (in)</th>
<th>% Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>66.6%</td>
</tr>
<tr>
<td>0.25</td>
<td>20%</td>
</tr>
<tr>
<td>0.5</td>
<td>6.7%</td>
</tr>
<tr>
<td>&gt; 0.5</td>
<td>6.7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean</th>
<th>0.12”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation (σ)</td>
<td>0.19”</td>
</tr>
</tbody>
</table>
10’ MCO Condition Detection

- 22 (78.5%) sites visited occurred at joints
  - Missing spikes: 15
  - Missing plate/severe cutting: 5
  - Tie replacement required: 6
  - Cracked joint bar: 1

- 6 (21.5%) sites visited did not occur at joints
  - Switch support: 2
  - Mud hole: 1
  - Crowned Weld: 1
  - Bridge transition: 1
  - Bad tie cluster: 2

- Rail batter was not observed at sites – consistent with premise that MCO measurement will detect poor support conditions, not wheel/rail impacts
10’ MCO Example Site Visits

-0.67 in MCO

© AREMA 2009 ®
10’ MCO Example Site Visits

-0.69 in MCO

-0.71 in MCO
## 10’ MCO Threshold Recommendation

<table>
<thead>
<tr>
<th>MCO Site Visits</th>
<th>Site Rating</th>
<th>&gt; ±0.8 inches</th>
<th>±0.6 - ±0.8 inches</th>
<th>±0.4 - ±0.59 inches</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>2</td>
<td>14</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2</td>
<td></td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td><strong>Site Visit Summary</strong></td>
<td>2</td>
<td>6.1%</td>
<td>18</td>
<td>54.5%</td>
<td>13</td>
</tr>
</tbody>
</table>

- Distribution suggests that a 0.6 inch threshold is a suitable starting point.
Carbody Roll (CBR) Condition Detection

• 20 sites with CBR angles 0.5° - 2.29° were examined

• 2 locations visited (min and max) were already under slow order
  – 0.5° CBR – mud spot, possibly dry at time of measurement
  – 2.29° CBR – twist deviation in spiral

• Most CBR events occurred at locations that showed crosslevel deviations or clusters of bad ties
CBR Sample Site Visits

1.72° CBR

1.94° CBR
CBR Threshold Preliminary Comments

<table>
<thead>
<tr>
<th>CBR Events Examined</th>
<th>Site Rating</th>
<th>&gt; 1.75°</th>
<th>1.25° - 1.75°</th>
<th>0.75° - 1.24°</th>
<th>0.50° - 0.74°</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>3</td>
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<tr>
<td>Medium</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>Low</td>
<td>5</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Site Visit Summary</td>
<td>9</td>
<td>45%</td>
<td>9</td>
<td>45%</td>
<td>1</td>
<td>5%</td>
</tr>
</tbody>
</table>

- Initial assessment of the distribution suggests that a 1.75° roll angle may be a suitable starting threshold.
Next Steps

• Implement recommended thresholds on MCO and CBR exceptions
• Develop a Variable Length MCO
• Variable defect thresholds for light vs. heavy cars
• Car Buckling Risk Prediction
Summary

- UP and other North American roads have been successfully using VTI technology for around 5 years.
- UP started with a locomotive platform, and now have successfully implemented a car based platform which adds new measurement capabilities.
- UP has seen improvement in track quality.
- We will continue to develop the technology on both platforms to refine existing measurements and also find new ways to predict potential failures.
- We will continue to use the data to find and remediate potential risks that other inspection methods are not finding.
- Questions?