AAR Strategic Research Initiatives Program to Improve Safety and Efficiency

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Damage Prevention and Improved Safety

♦ Presentation Outline

● Railroad Facts

● Strategic Research Related to Lading Environment
  ▲ Longitudinal Forces and train make up
  ▲ Improved Truck Suspension Systems
  ▲ Dynamic Load Environment and UDEs
  ▲ Vehicle/Track Inspection and Monitoring Systems
Railroad Facts and Figures

♦ $77.7 billion in Operating Revenue ($17 b Can, $2.8 b Mexico)
♦ 95,600 miles of road owned (30k miles CN & CP, 7.5k Mexico)
♦ Major US freight RR s own 60,000 bridges
  ● Over 1,400 miles or 7.6 million feet
  ● Each major RR owns more than 10,000 bridges
♦ Over 26,000 locomotives
♦ Over 1.56 million freight cars
♦ Average length of haul: 1006 m
♦ 1.85 trillion revenue ton miles
♦ Almost 72 cars per freight train
♦ 479 RTM/gal of fuel

North American Technology Developments
AAR Strategic Research Initiatives Program

♦ Strategic Research Initiatives Program (SRI) addresses current and future strategic issues relating to the North American rail industry

♦ Research Objectives

- Improve Safety
  - Reduce track and equipment-related derailments through technology development

- Improve Reliability
  - Reduce or eliminate line-of-road failures

- Improve Efficiency
  - Increase productivity and reduce costs
2016 AAR Strategic Research Program

♦ Wheel/rail interface management
  ● Wheel/rail interface maintenance
  ● Root causes of rolling contact fatigue

♦ Improved car performance
  ● Integrated Freight Car Truck
  ● Dynamic load environment

♦ Vehicle/track performance
  ● Effects of short cars on bridges/track
  ● Effects of Impact Loads on Rail failure
  ● Loaded tank car/track interaction

♦ Heavy axle load implementation
  ● FAST/HAL Operations
  ● HAL revenue service monitoring
  ● HAL Revenue service-Northern megasite
  ● Track structure for HAL coal lines

♦ Improved braking systems
  ● Improved brake system performance

♦ Train condition monitoring
  ● Technology driven train inspection
  ● Automated cracked wheel detection

♦ Track integrity monitoring
  ● Phased Array rail flaw inspection

♦ Improved car components and materials
  ● Strategies to prevent wheel failure
  ● Optimized HBD performance

♦ Special trackwork
  ● Improved special trackwork designs and materials

♦ Bridge research
  ● Bridge life extension

♦ Improved track components
  ● Improved rail welding
  ● Improved rail performance

♦ Improved performance track
  ● Investigation of Rail Wear Limits
  ● Improved tie/fastener system performance

♦ New technology implementation
  ● Equipment health monitoring technology
  ● Equipment and track technology implementation
Strategic Research Related to Lading Environment
Damage Prevention and Improved Safety

- Longitudinal Impact Loads
- Improved Truck Suspension Systems
  - Reduce vehicle/track derailments
  - Reduce stress state of the railroad
  - Reduce dynamic loads generated at the wheel/rail interface
    - Vehicle Dynamics Forces
    - Rail rollover derailments
    - Flange Climb derailments
    - Truck and track component damage
    - Lading damage
- Vehicle/Track Inspection
Longitudinal impact loads

- Cushioning units protect lading in yards, but create challenges during service movements
  - Measure load environment in service
  - Expand simulation capability of draft systems
  - Investigate optimal makeup for manifest trains
- Un-Desired Emergency brake applications (UDE) have potential to generate large longitudinal forces
  - Analyze locomotive event recorders prior to UDEs
  - Relate end hose gladhand dimensions to separation forces

Vibration

- Wheel impact loads (due to shells, flats, etc) may potentially be influenced with the use of tread conditioning brake shoes
  - Report on historical service tests
  - Conduct testing in a laboratory environment
Revenue Service Testing

♦ For accurate definition of relative coupler load severity

- Two loaded car types:
  - Boxcar with 15-inch cushion units (TD13-027)
  - Autorack car with 10-inch cushion units (TD15-021)
- Over 20,000 miles of data recorded for each car type
- Manifest and unit train service

- Data recorded: coupler force & displacement, acceleration, speed
- Max draft load 610 kips
- Max buff load 320 kips
- Draft loads > 200 kips not uncommon
Cushion Unit Characterization

- TOES™ uses fluid dynamics equations to represent cushion units.
- Adding capability to directly define force versus displacement and force versus velocity characteristics – similar to NUCARS®.
- Aim to define the target characteristics of a draft system that could protect lading in yards and reduce challenges during normal train operations.

Collecting Cushion Unit Characteristic Data using TTCI’s Simuloader

- Cushion Unit
- Load Cell
- Hydraulic Actuator
Significant Simulation Results *(TD15-010)*

- Block size of cushion unit cars and position of the block within the train more important than total number of cars for large draft forces.
- When placed in the middle or rear third of a train, block sizes of 20 EOC cars or more produced damaging draft forces.
- For a block of 20 autorack cars, substituting standard draft gear for cushion units resulted in a 30% decrease in maximum draft force.

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Computer Simulation of Max. Coupler Force in Train

<table>
<thead>
<tr>
<th>EOC Block Location:</th>
<th>Number of EOC Cars in a Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>5, 10, 20, 40</td>
</tr>
<tr>
<td>Middle</td>
<td>5, 10, 20, 40</td>
</tr>
<tr>
<td>Rear</td>
<td>5, 10, 20, 40</td>
</tr>
</tbody>
</table>

- Draft
- Buff

Max. Coupler Force (kips)

- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350

<table>
<thead>
<tr>
<th>Number of EOC Cars in a Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
</tbody>
</table>

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UDE Root Cause Analysis

♦ Un-Desired Emergency brake applications (UDE) can potentially produce large buff or draft forces.

♦ Handling Conditions Prior to UDE (*TD16-019*)
  ● Allow better assessment of likely causes.
  ● Locomotive event recorder data.
    ▲ Two Class I railroads.
  ● Train brakes were released immediately prior to the UDE for the majority of events analyzed.

![Bar Chart]

- RR A: 34 Released, 55 Applied
- RR B: 39 Released, 72 Applied
- Combined: 73 Released, 127 Applied

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UDE Root Cause Analysis

♦ Service Brake Applications Immediately Prior to UDE
  ● UDE sensed by loco or end-of-train device typically within 12 seconds of service application
    ▲ Median value = 8-9 sec
    ▲ Time includes roundtrip propagation of air pressure fluctuation
  ● UDEs typically occurred during a minimum service application

<table>
<thead>
<tr>
<th>Brake Application Time Prior to UDE (sec)</th>
<th>UDE Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>18</td>
</tr>
<tr>
<td>4-6</td>
<td>16</td>
</tr>
<tr>
<td>7-9</td>
<td>14</td>
</tr>
<tr>
<td>10-12</td>
<td>13</td>
</tr>
<tr>
<td>13-20</td>
<td>8</td>
</tr>
<tr>
<td>21-45</td>
<td>4</td>
</tr>
<tr>
<td>&gt;45</td>
<td>2</td>
</tr>
</tbody>
</table>
UDE Root Cause Analysis

♦ Longitudinal slack action prior to UDE

● Analyzed throttle and dynamic brake commands prior to UDE for trains with brakes released

● Slack action brake pipe pressure fluctuations:
  ▲ Kink/un-kink hoses
  ▲ Momentum of air in the brake pipe

● Large percentage of mechanically caused UDEs with train brakes released show at least reasonable possibility of run-in or run-out prior to UDE
Air Hose Separations

♦ Air hose separations can potentially produce large buff or draft forces

♦ How does Gladhand Wear Affect Separation Forces? (*TD pending*)

♦ Laser scanner allows 3 dimensional evaluation of critical dimensions (guard arm and lip)
  ● New, as-manufactured
  ● Used, removed from service for typical causes
  ● Paired sets removed from coupled cars known to have separated in service
Air Hose Separations

♦ Gasket clearance not a critical factor

♦ Lack of lip bead can produce low separation force

![Graph showing separation force vs. gasket clearance](image)

![Graph showing separation force vs. bead height](image)
Air Hose Separations

These two worn gladhands separated from each other while in service.

Notice the complete lack of a lip bead

However, this condition was unique among service separated gladhands
Damage Prevention and Improved Safety

- Reduce dynamic loads generated at the wheel/rail interface
  - Vehicle Dynamics Forces
  - Rail rollover derailments
  - Flange climb derailments
  - Truck and track component damage
  - Lading damage

- Improved Truck Suspension Systems
  - Reduce vehicle/track derailments
  - Reduce stress state of the railroad
  - Reduced rolling resistance
Components of Vehicle/Track System and a 3-piece Standard Truck Suspension System

1. Car - Body
2. Bogie
3. Wheel Set
4. Contact Rail Pad
5. Tie Ballast
6. Subgrade

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Typical Freight Car Truck Design

● “Standard” 3-Piece truck design
  ♦ Evolutionary design over past 100+ years
  ♦ Friction damping
  ♦ Durable and cheap to make
  ♦ Can have warp problems
  ♦ Clearances and tolerances
  ♦ No primary suspension
  ♦ Coil spring secondary suspension
  ♦ Likely to hunt at high speed (70+ mph)
  ♦ Poor ride quality
Rigid body modes
- Rock-and-roll
- Pitch-and-bounce
- Yaw-and Sway

Curve negotiation

Straight track lateral stability: hunting

Wheel Impact Forces
- Wheel surface defects
- Special Trackwork
  - Frogs and curve entry
A longer or shorter wavelength will excite the car body various rigid body modes of vibration.
Why Use improved Suspension Systems

Potential for Failure Where Equipment Places Stress on the Track at a Level Higher than the Localized Track Strength
Reduce the Stress State of the Railroads and Potential Lading Damage: Next Generation Freight Car Truck

♦ Test & evaluate proposed OEM truck suspension designs: Loaded & empty car hunting; vertical & lateral track forces; curve resistance

♦ Seven truck types have been tested:
  ● **Truck 1**: Improved wedge design, rubber pads, increased longitudinal clearance between adapter & pedestal
  ● **Truck 2**: Frame bracing, rubber pads, increased longitudinal clearance between adapter & pedestal
  ● **Truck 3**: Spring plank, polymer pads, increased longitudinal clearance between adapter & pedestal
  ● **Truck 4**: Frame bracing, rubber adapter pads increased longitudinal clearances
  ● **Truck 5**: Spring plank, polymer pads
  ● **Trucks 6 & 7**: Radial trucks
Can we further reduce the stress state of railroads by track friendly truck suspension systems?

♦ **Radial Truck**
  - Adapter pads & warp restraint by directly coupling wheelsets in shear:

♦ **Next generation IFC Truck**
  - Adapter pads & warp restraint by shear plate

![Diagram of Radial Truck with adapter pads and shear plate](image1)
![Diagram of Next generation IFC Truck with adapter pads and shear plate](image2)
Optimum suspension damping reduces vertical accelerations.
Loaded Car Hunting subjects the lading to high lateral accelerations.
Loaded Car Hunting
Vehicle/Track Health Monitoring Systems

- Vehicle/Track Health Monitoring Technology
  - Improve safety
  - Identify poorly performing cars
  - Identify track anomalies which generate high vehicle/track loads and accelerations
  - Prevent lading damage
Equipment Health Monitoring in North America
Why Monitor Vehicle Health?

Potential for Failure Where Equipment Places Stress on the Track at a Level Higher than the Localized Track Strength

Increase vibrations and accelerations on vehicles and lading
Technology Driven Train Inspection

The Vision

Wayside Performance Detection

- Truck Hunting Detector (THD)
- Truck Performance Detector (TPD)
- Wheel Impact Load Detector (WILD)
- Warm Bearing Trending (WBT)
- Wheel Temperature Trending (WTT)

Database (InteRRIS®)

- Cracked Axle Detector (CAD)
- Cracked Wheel Detector (CWD)
- Thermal Scan (TS)
- Acoustic Bearing Detector (ABD)
- Low Air hose Detector (LAD)
- Dragging Equipment Detector (DED)

Wayside Machine Vision Inspection

- Wheel Profile Module (WPM)
- Brake Shoe Module (BSM)
- Automated Safety Appliance Inspection System (ASAIS)
- Automated Inspection of Structural Components (AISC)

Vehicle Health Report in Lieu of Train Inspection
Wheel Impact Loads

RADIAL RUNOUT FOR 36” DIA. OUT-OF-ROUND WHEEL

EFFECT OF RADIAL RUNOUT ON IMPACT LOADS
O.O.R. Wheels, 100-Ton Loaded Cars

Graph showing the effect of radial runout on peak impact loads for 100-ton loaded cars.
Impact Load Detectors

Electronic Equipment

TTCl Testing of Impact Load Detectors
AAR Interchange Rule Wheel Impact Load (Rule 41)

- >65 and <80 kips:
  ▲ Advise the car owner – RR cannot unilaterally charge for the repair;

- >80 and <90 kips:
  ▲ Can change wheel at next time on a repair/shop track and bill the car owner; and

- >90 kips:
  ▲ Can change wheel without limitation and bill the car owner

Furthermore, a well-established practice, but not reflected in any AAR rule, is that for cars above 140 kips, wheels are changed and not interchanged.
Rate of Wheel Impact Readings in North America

Wheel Impact Statistics
140 kip+ WILD Hits/1000 Wheels*

[Graph showing data for 140 kip+ WILD Hits/1000 Wheels]
Imbalance Load Detectors

♦ Wheel Impact Load Detectors or weigh in-motion systems
♦ Side-to-Side Imbalance (STS)*
   • STS  = (Heavy Side – Light Side) / Overall Gross Weight

End-to-End Imbalance (ETE)*
   • ETE  = (Heavy Truck – Light Truck) / Overall Gross Weight

Applies to cars loaded to 40% of rated load or more
## Imbalance Load Alarm Levels

### Definitions of Imbalanced Load Overload Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Definition</th>
</tr>
</thead>
</table>
| STS¹       | \[
|            | \((\text{Heavy Side} - \text{Light Side}) / \text{Overall Gross Weight}\)  |
|            | \* 100                                                                      |
| ETE¹       | \[
|            | \((\text{Heavy Truck} - \text{Light Truck}) / \text{Overall Gross Weight}\) |
|            | \* 100                                                                      |
| Car OL     | \[
|            | \((\text{Overall Gross Weight} - \text{Rated Load}²) / \text{Rated Load}\) |
|            | \* 100                                                                      |
| Truck OL   | \[
|            | \((\text{Truck Weight} - \frac{1}{2} \text{Rated Load}) / \frac{1}{2} \text{Rated Load}\) |
|            | \* 100                                                                      |
| Side OL    | \[
|            | \((\text{Side Weight} - \frac{1}{2} \text{Rated Load}) / \frac{1}{2} \text{Rated Load}\) |
|            | \* 100                                                                      |

¹Applies to cars loaded to 40% of rated load or more
²Rated load = Stenciled load limit on the car

### Example Imbalanced Load and Overload Alarm Levels

<table>
<thead>
<tr>
<th>Condition</th>
<th>Alarm Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>STS</td>
<td>20 percent</td>
</tr>
<tr>
<td>ETE</td>
<td>38 percent</td>
</tr>
<tr>
<td>Car OL</td>
<td>30 percent</td>
</tr>
<tr>
<td>Truck OL</td>
<td>30 percent</td>
</tr>
<tr>
<td>Side OL</td>
<td>30 percent</td>
</tr>
</tbody>
</table>
Hunting Detector

♦ Instrumented cribs measure vertical & lateral wheel loads
  ♦ to establish a hunting index (HI) over a length of track

● THD alerts in the AAR Field Manual — Rule 46.A.1.e
  ▲ A single LBFoster, Salient Systems, detector absolute value at least 0.50
  ▲ Tbogie optical detector system
  ▲ Tracking indices
♦ Machine-vision Inspection of Truck Details

● Three vendors chosen to demonstrate truck detail inspection modules at FAST
Technology Driven Train Inspection
Fully Automated Train Scanning System

Fully Automated Train Scanning System:

♦ Ongoing applications include:
  ● Car underbody
    ▲ Truck component details
    ▲ Coupler securement/draft pocket inspection
    ▲ Brake rigging details
  ● Top and side views
    ▲ Shifted / imbalanced loads
    ▲ Unsecured lading
    ▲ Top chord condition
  ● Security applications
    ▲ Tank car inspection
    ▲ Foreign object detection
Technology Driven Train Inspection

Current Projects

♦ Fully Automated Train Scan System (FATTS)
  • Total car imaging
  • Developed and tested
    at FAST w/SRI funding and direction
Duos VUE™ Train Imaging Portal

♦ Train Inspection Portal

Top

Side

Axle

Bottom
Track Inspection and Health Monitoring in North America
TRACK CONDITION MONITORING SYSTEMS

♦ Visual Inspection

♦ Automated Track and Vehicle/Track Inspection
  ● Track Geometry and New Technologies
  ● Machine Vision based Track Measurement Systems
  ● Vehicle Mounted Track Geometry Measurement Systems
  ● Wheel/rail Interface Measurement Systems
  ● Wheel/Rail Friction Measurements
  ● Rail Profile Inspection
  ● Rail Defect Detection
  ● Rolling Contact measurement
Track Geometry Cars (TGC)

♦ TGCs measure and report on exceptions:
  ● Track gage
  ● Curvature
  ● Cross-level
  ● Alignment and Surface

♦ Additional systems commonly found on TGCs include:
  ● Rail Profile and Corrugation Systems
  ● Machine Vision Systems
VTI/Track Geometry Measurement Systems

- Vehicle mounted inspection systems
  - Vehicle/Track Interaction (VTI) systems
  - Instrumented freight cars (IFCT)
  - Performance-based track inspection
  - Rail restraint measurement systems
  - Machine vision track inspection
Muddy ballast location detected, field-verified and required subsequent surfacing and tamping

- Suspension displacement = 1.1 in.
- Bolster load = 250 kips
- Speed = 34 mph

Rough geometry surface (maximum 1.5 inches) that does not constitute a maintenance exception
IFC Revenue Service Exception Example (Top-Chord Buckling)

- The same track location identified twice (3-months apart)

<table>
<thead>
<tr>
<th>Date</th>
<th>Channel Description</th>
<th>Value</th>
<th>Criteria</th>
<th>Units</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Speed (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23-Jan</td>
<td>Axial Top Chord Stress B-End Left Side</td>
<td>-20956</td>
<td>-20000</td>
<td>psi</td>
<td>-104.291</td>
<td>38.253</td>
<td>48.8</td>
</tr>
<tr>
<td>23-Apr</td>
<td>Axial Top Chord Stress B-End Left Side</td>
<td>-41031</td>
<td>-20000</td>
<td>psi</td>
<td>-104.291</td>
<td>38.253</td>
<td>55.3</td>
</tr>
</tbody>
</table>

Inphase surface deviations (~ 1.25 in. with max. of 57-ft wavelength) combined with operating speed excited the car into bouncing mode producing large compressive stresses that led to top-chord buckling. The deviations are not maintenance exceptions.
Thank you for your support.