AAR 28TH ANNUAL RESEARCH REVIEW

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28th Annual
Association of American Railroads
RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS
MxV RAIL

June 26-28, 2023 | Pueblo, CO

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Railroad Wireless Communications Research and Testing

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Overview

- **Wireless Communications in Railroad Operations**
- **Railroad Radio Spectrum**
- **Wireless Communications – Industry Goal**
- **Introduction to IEEE 802.16t**
- **IEEE 802.16t Railroad Applicability**
- **IEEE 802.16t Testbed and Testing at MxV Rail**
- **Summary**

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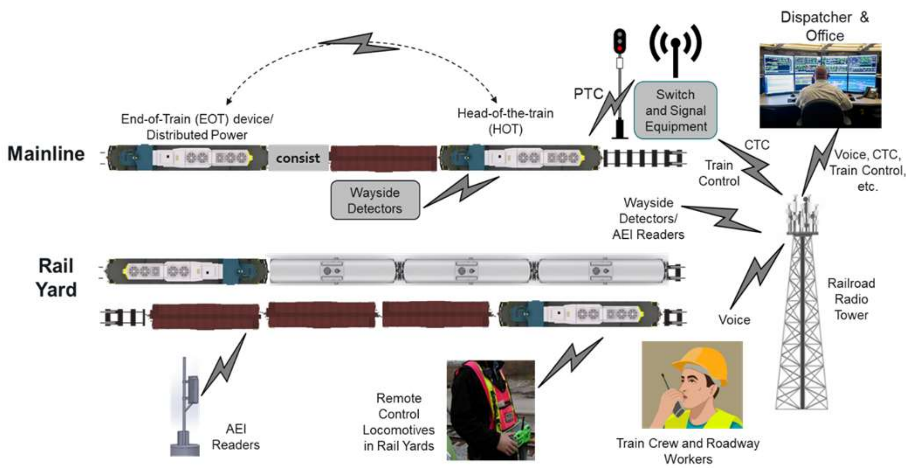
Wireless Communications in Railroad Operations

- **Integral part of day-to-day railroad operations and safety**
- **Supports technological advancements and safety improvements**



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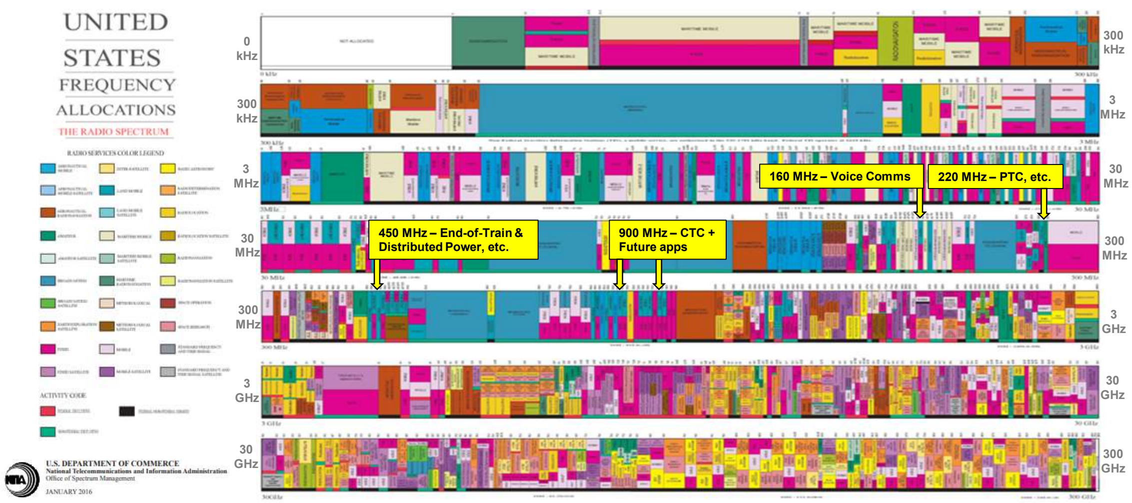
Railroad Radio Spectrum – FCC Licensed



Spectrum -> **Frequency bands** -> **Channels**

Railroads have licenses for ~3.3 MHz out of 300,000 MHz

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Wireless Communications – Industry Goal

- **Efficient use of limited wireless spectrum is critical to support increasing number of RR applications**

Present Applications

Voice Communications
Positive Train Control
Centralized Traffic Control
Yard Remote Control Locomotives
End-of-Train/Head-of-Train
Hi-rail Limits Compliance System
Distributed Power
Energy Management System
Wayside-based Vehicle Monitoring
Drones (command and control)

Future Applications

Quasi-Moving Block
Full-Moving Block
+ **Employee-in-Charge Portable Remote Terminal**
+ **Advance Grade Crossing Activation**
+ **Centralized Interlocking**
+ **Road Remote Control Locomotives**
+ **Differential GPS/Real-time Kinematic**
Next-Generation End-of-Train/Head-of-Train Pacing

+ Indicate new applications, all other future applications are evolution to present applications

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What is IEEE 802.16t?

- **IEEE 802.16 is a wireless communications standard**
  - IEEE 802.16**t** is a new amendment to support needs of mission-critical industries like railroads, utilities, etc. with limited spectrum
  - Class 1 RRs, MxV Rail and railroad suppliers contributed to the amendment
- **Key features and capabilities**
  - Supports narrower channels available to railroads
  - Non-contiguous channel aggregation to increase throughput
  - Higher order modulations pack more data in the same channel
  - Adapts to dynamic demands of multiple applications

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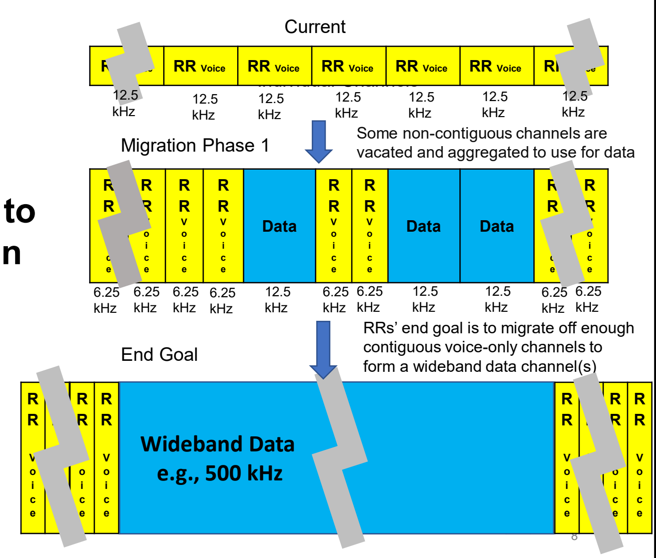
IEEE 802.16t for RR 160 MHz Band

- **160 MHz is largest of all railroad bands**
  - 1.4 MHz and primarily used for voice communications
- **802.16t creates an opportunity to support data along with voice in the same band**
- **Non-contiguous channel aggregation (CA) feature simplifies migration from today's radios to 802.16t**



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900 MHz Rebanding by FCC

- **Recently, FCC repurposed spectrum in the 900 MHz band for LTE**
- **RRs must vacate current 900 MHz spectrum by Sept 2025**
- **FCC assigned new 900 MHz spectrum to railroads as replacement**
  - 70% more bandwidth than the current spectrum
  - Rare opportunity for the RRs
- **Railroads proposing an interoperable 900-MHz radio network to support various applications across multiple railroads**
  - Dynamic spectrum allocation to support applications with rapidly changing load
  - Shared infrastructure

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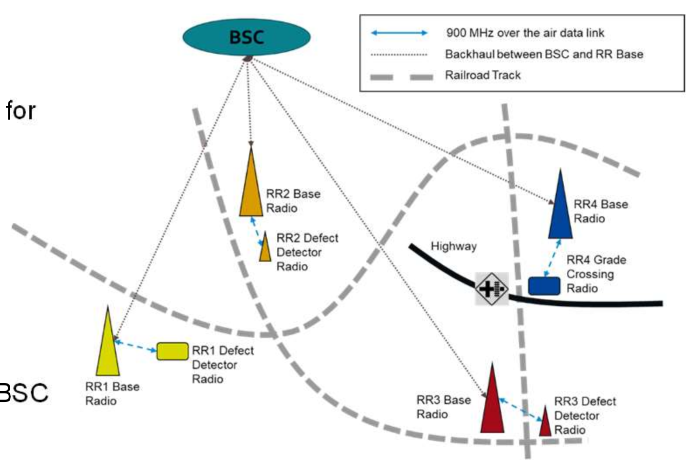
Interoperable 900 MHz Network Concept

- **Main components**
  - Radios
    - Enables wireless communications for railroad applications
  - Base Station Controller (BSC)
    - Dynamically manages the channel-timeslot allocations across all base stations (BS) based on demand
    - If a BS can't satisfy a surge in traffic demand, it requests additional channel-timeslots from BSC
    - BSC responds with appropriate channel-timeslot allocations



- **IEEE 802.16t standard is a potential solution**

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IEEE 802.16t – Industry Objectives

- **Evaluate IEEE 802.16t standard for railroad adoption**
- **Develop supplemental AAR standard to address specific interoperable railroad needs**
  - Base station controller
  - Enhanced radio security
  - Desense/blocking performance requirements[1]
- **Addition of Direct Peer-to-Peer (DPP) mode**
- **Test 802.16t-compliant radios and BSC**

[1] Radio receiver's ability to process desired signal in-presence of a strong undesired signal

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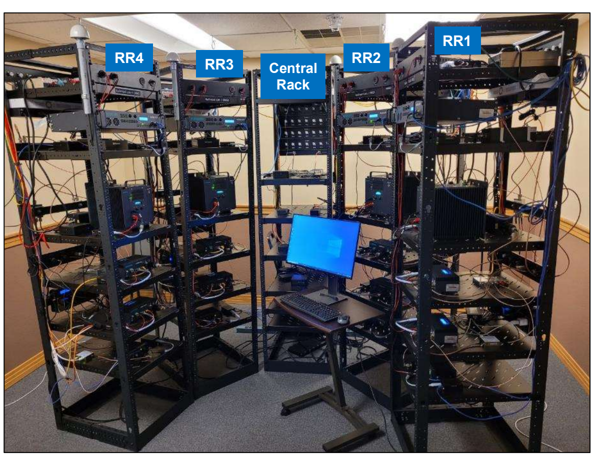
IEEE 802.16t Radio Testbed at MxV Rail

802.16t Testbed at MxV Rail



- **Four racks each represent a railroad radio network that includes:**
  - 802.16t radios
  - Raspberry Pi's emulating servers
  - GPS
  - Splitter/combiners, RF coaxial cables
  - Fixed and variable attenuators (electronically controlled)
- **Central rack**
  - Spectrum analyzer and signal generator (interferer)
- **External antenna on the rooftop for outdoor field testing**

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Aspects of IEEE 802.16t Testing

- **Radio Performance**
  - Interference rejection
  - Signal sensitivity
  - Channel aggregation
  - Scheduling/load handling
  - Quality of service/priority handling
- **Base Station Controller Performance**
  - Dynamic spectrum allocation for multiple base stations under varying conditions where stations are within interference range of one another

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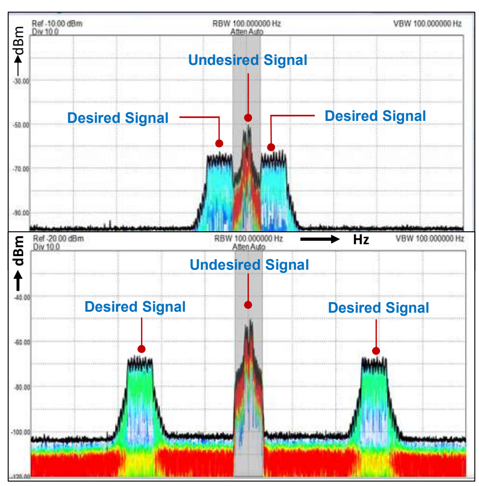
IEEE 802.16t Testing – Interference

- **All radios have limited ability to reject undesired in-band signals even though they may be on different channels.**
- **Many real RR scenarios require listening to a weak distant radio while another in-band signal is received at a much higher level.**
- **We tested interference effects between undesired and desired 802.16t signals at various spectral separations**



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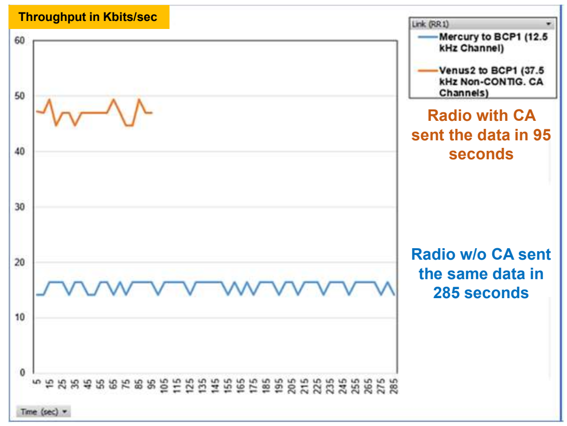
IEEE 802.16t Testing – Channel Aggregation

- **Compared radio performance with/ without channel aggregation (CA)**
  - First radio transmitted on one 12.5-kHz channel – No CA
  - Second radio transmitted on three channels (37.5 kHz total bandwidth) – non-contiguous CA
  - App provided data at a rate of 75 kilobits/sec for 60 seconds to transmitting radios
- **Radio with CA was able to send data faster than the radio with no CA**

Theoretical Uplink Throughput Mapping			
FEC Code	Modulation	Channel Width (kHz)	UL Throughput (Kbps)
7	64QAM 5/6	12.5	15.954
7	64QAM 5/6	25	32.418
7	64QAM 5/6	37.5	48.882



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IEEE 802.16t Testing – Quality of Service

- **Compared radio performance when handling data with different priorities**
  - Radio is using 37.5 kHz channel
  - Started with low priority (LP) data at a rate of 75 kbps
  - After 30 sec, started high priority (HP) data at a rate of 15 kbps
- **Radio initially used full BW to send LP packets**
- **Once HP packets were introduced, throughput of LP packets reduced by the amount needed to fully serve the HP packets**
- **When HP packets ended, higher throughput of LP packets resumed**

Theoretical Uplink Throughput Mapping			
FEC Code	Modulation	Channel Width (kHz)	UL Throughput (Kbps)
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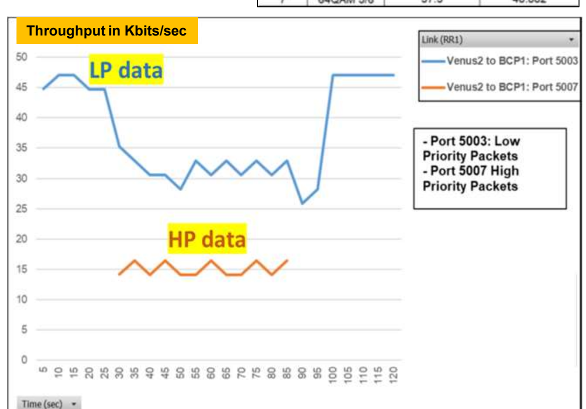

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Summary

- **Wireless communications is an integral part of railroad operations and safety, supporting multiple applications across several radio spectrum bands**
- **Railroads have a significant and rare opportunity with 900 MHz rebanding**
- **AAR is anticipating IEEE 802.16t as the potential solution for:**
  - Maximizing spectrum efficiency – particularly at 160 MHz and 900 MHz
  - Meeting demands to have more applications use wireless communications
- **MxV Rail set up the IEEE 802.16t testbed and is running various tests to support current and future wireless communication needs of the industry**

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Acknowledgements

Railroad Advisory Groups

AAR's Wireless Communications Committee (WCC)

Railroad Network Security Experts

MxV Rail Project Team

Alan Polivka, Bivesh Paudyal, Sarat Eruvuru, Matt Holcomb

802.16t Suppliers

Siemens Mobility and Ondas Networks

supplied the necessary hardware and software for the testbed

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Overview

- **Historical Perspective**
- **Test and Evaluation Process**
- **Advantages of In-Service Tests**
  - Facility for Accelerated Service Testing (FAST)
  - Revenue Service Testing
- **Overview of plans for new FAST**
- **Overview of Revenue Service Testing**
  - Including highlights from recent projects
- **Summary and Acknowledgements**

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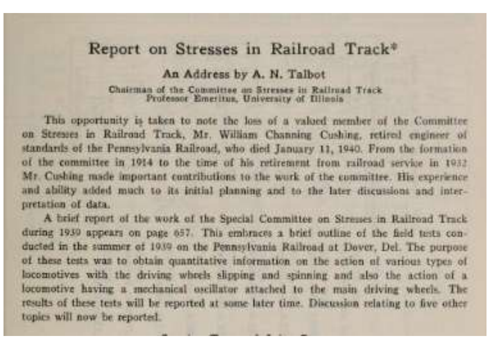
History of RR In-Service Testing

- **Talbot Reports 1918-1940**
- **Individual railroads, since 1930s at least**
- **AAR Research & Test Department ~1934**



Report on Stresses in Railroad Track*

An Address by A. N. Talbot

Chairman of the Committee on Stresses in Railroad Track
Professor Emeritus, University of Illinois

This opportunity is taken to note the loss of a valued member of the Committee on Stresses in Railroad Track, Mr. William Channing Cushing, retired engineer of standards of the Pennsylvania Railroad, who died January 11, 1940. From the formation of the committee in 1914 to the time of his retirement from railroad service in 1932 Mr. Cushing made important contributions to the work of the committee. His experience and ability added much to its initial planning and to the later discussions and interpretation of data.

A brief report of the work of the Special Committee on Stresses in Railroad Track during 1939 appears on page 657. This embraces a brief outline of the field tests conducted in the summer of 1939 on the Pennsylvania Railroad at Dover, Del. The purpose of these tests was to obtain quantitative information on the action of various types of locomotives with the driving wheels slipping and spinning and also the action of a locomotive having a mechanical oscillator attached to the main driving wheels. The results of these tests will be reported at some later time. Discussion relating to five other topics will now be reported.

AAR Chicago Technical Center 1950-1995

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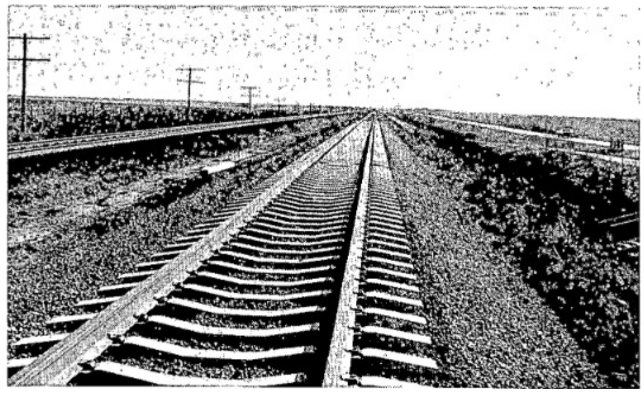
History of RR In-Service Testing

- **Kansas Test Track 1973-1975**
- **FAST started 1976**
- **AAR vehicle performance tests 1980s (M-1001, etc.)**
- **FRA high speed passenger tests 1990s (Class 6 and higher)**



1.8-mile Kansas Test Track along AT&SF Rwy.

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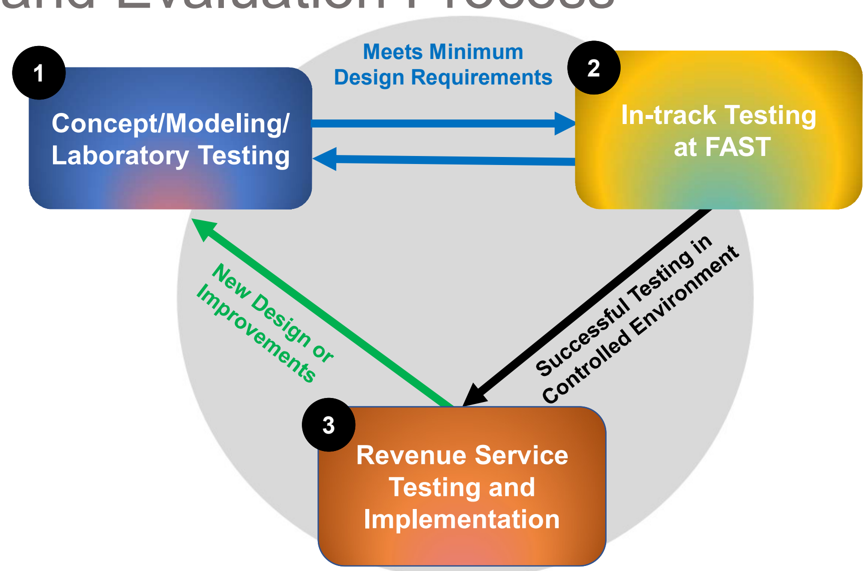
Test and Evaluation Process



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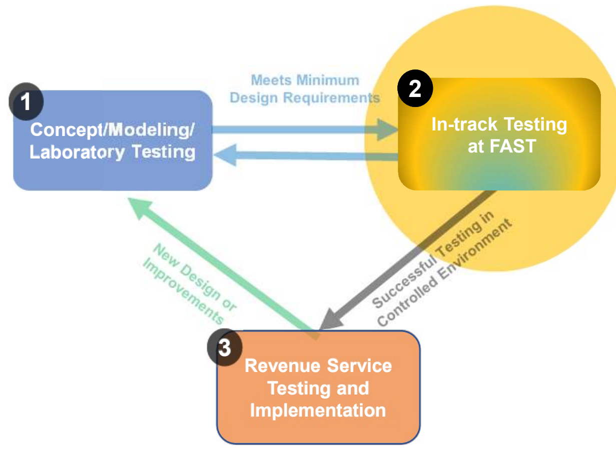
Testing at FAST



- **Proof testing with:**
  - Heavy train load
  - High tonnage accumulation
  - Frequent measurements
  - Frequent inspections
  - High level of control
- **Reduced risk**
- **Increased safety**
- **Root cause investigations**
- **Quantified component performance**
- **Essential step towards implementation**
- **Conduct testing not appropriate for revenue service**

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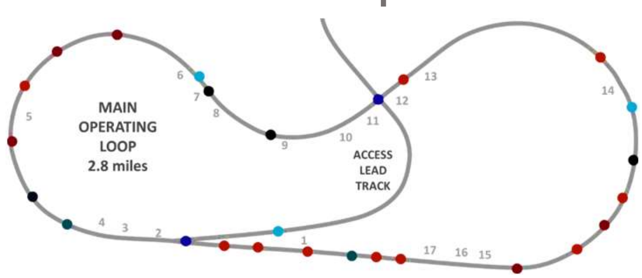
Plans for New FAST Loop



- **2.8-mile loop**
- **Train of ~114 cars, 18,000 tons**
- **Rapid tonnage accumulation**
  - ~140 MGT per year
- **Single, longer tangent**
  - 1,200-ft. bypass planned for Phase 2
- **One-Way Low-Speed (OWLS) crossing for access to outside world**
  - Able to run traffic on both routes over crossing diamond
- **Only three curves – 5 and 6 degrees**
  - Longer, sharper unlubricated reverse curve
- **Train turning and storage inside loop**
  - Earthwork in Phase 1, Track in Phase 2

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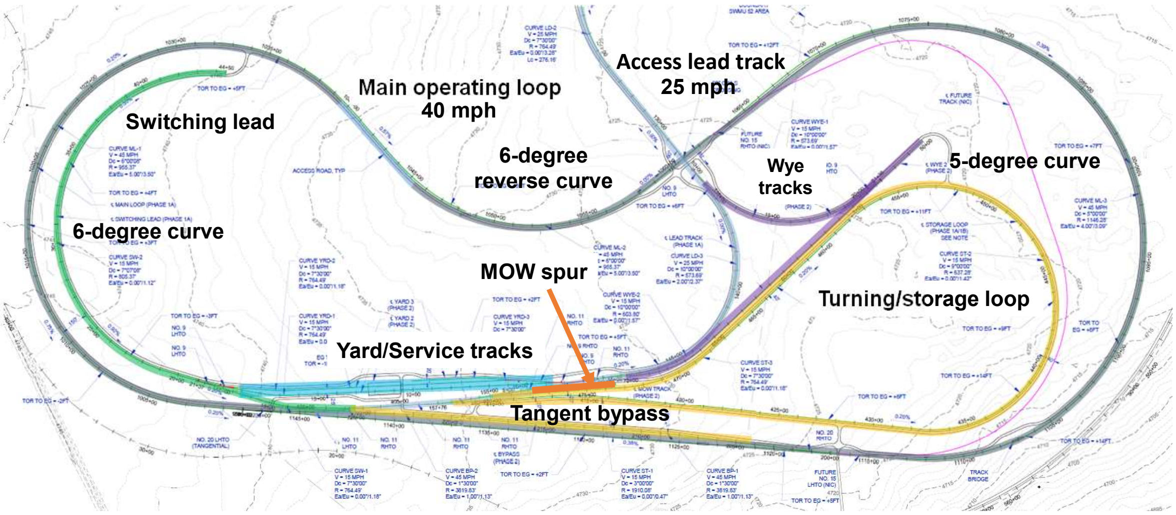
New FAST Loop

Phase 1 Operational 3rd Quarter 2023



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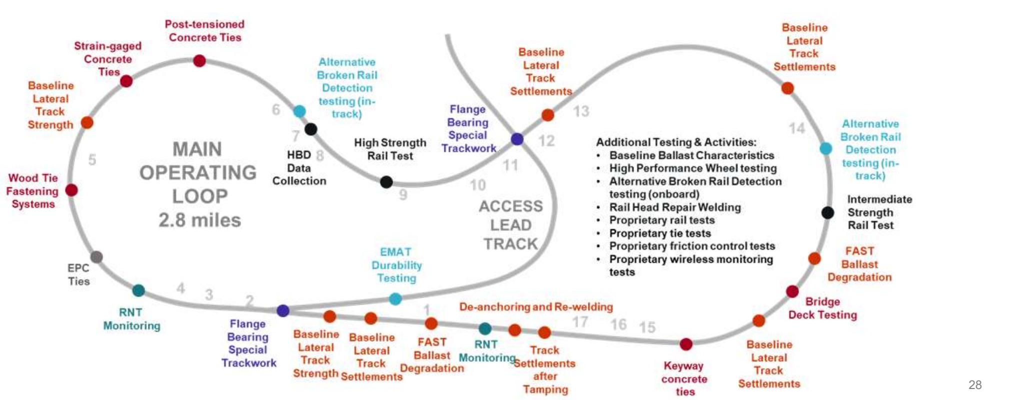
FAST Loop Phase 1

23 tests planned:

- **Premium rail**
- **Intermediate strength rail**
- **Special trackwork**
- **Bridge deck materials**
- **Track stability**
- **Elastic and spike fasteners**
- **Timber, concrete and composite ties**
- **Subgrade and ballast monitoring**
- **Alternative broken rail detection**
- **High performance wheels**



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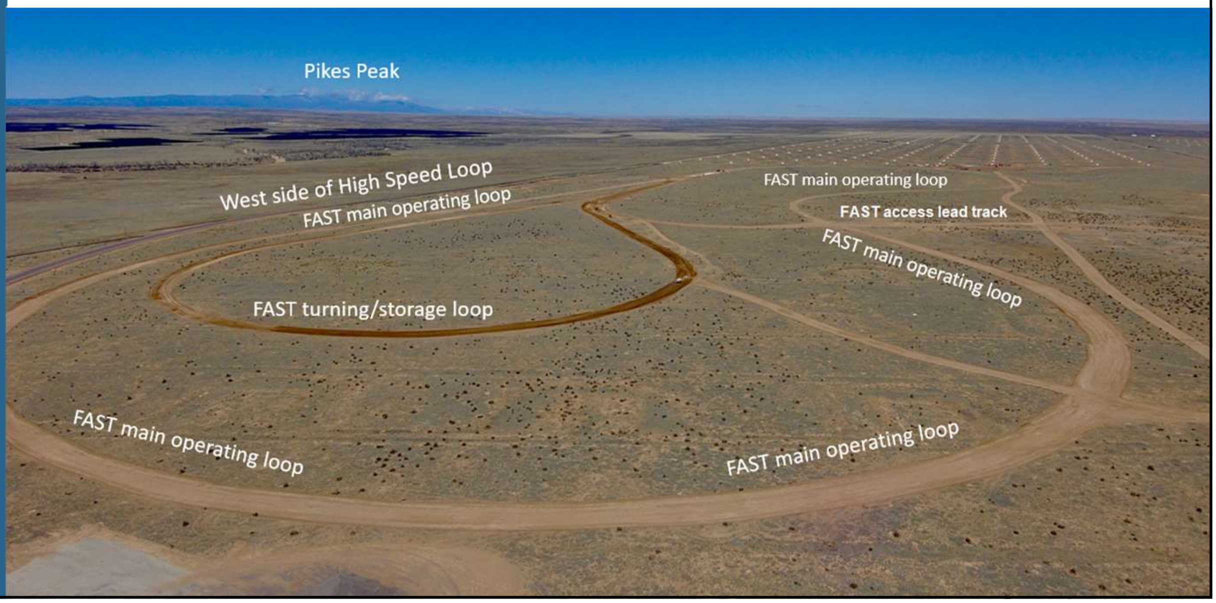
FAST Construction



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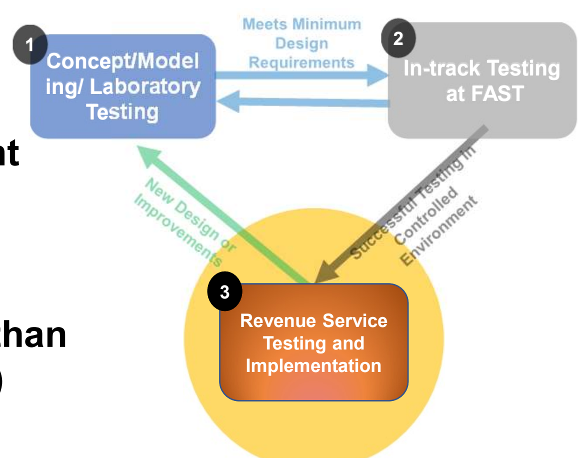
Testing In Revenue Service

- **Evaluation of new designs, methods, and components in revenue service**
- **Testing in environments different from FAST (weather, grades and curves, speeds, traffic mix, lubrication, etc.)**
- **Able to test in larger quantities than at FAST (e.g., special trackwork)**
- **Final evaluation step before wider implementation**



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Testing In Revenue Service

- **Most track-related testing over past ~20 years focused on eastern, western, and northern mega sites**
- **Flange-bearing trackwork testing conducted at other locations as needed**
- **Most bridge-related testing conducted at other locations as needed**
- **Mechanical and vehicle-track interaction tests conducted on various lines and routes as needed**
- **Recently, the revenue service testing is diversifying to include additional sites and host railroads**

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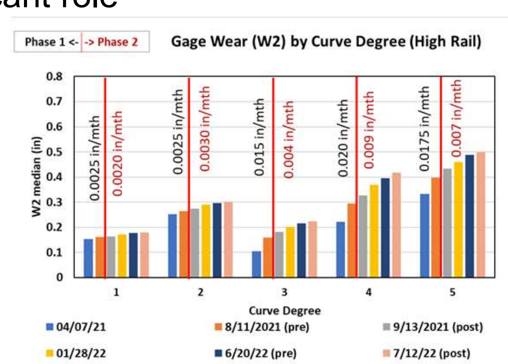
Recent & Ongoing Revenue Service Tests

- **Rail wear, grinding, and lubrication**
  - Testing on multiple railroads
  - Proximity of lubricators plays a significant role
  - Degree of curve a major factor



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Ongoing Premium Rail Tests

- **Mild curve rail test ongoing in 2023**
- **Cold weather rail test completed in 2022**
  - No rail defects detected
  - Welds breaks observed in all tests
  - New test for higher degree curves planned

Rail test curves on UP

Rail profile measurement

Rail test curve on CN

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Recent & Ongoing Revenue Service Tests

- **Rail inspection technologies**
- **Rail welds**
- **Each test on multiple railroads**

At installation

RCF measurement trolley

After approx. 110 MGT

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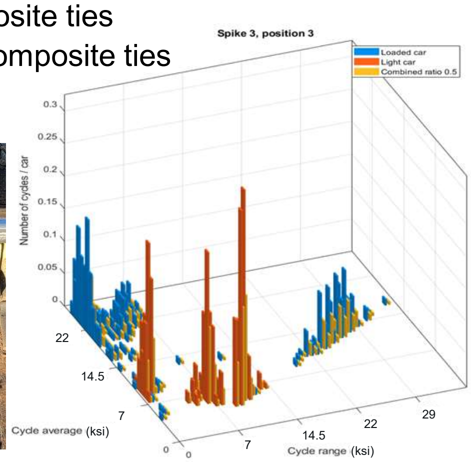
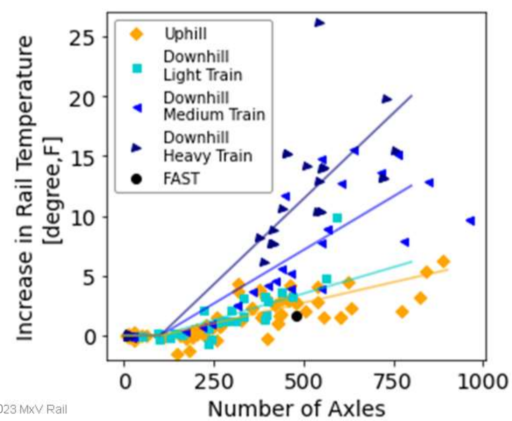
Recent & Ongoing Revenue Service Tests

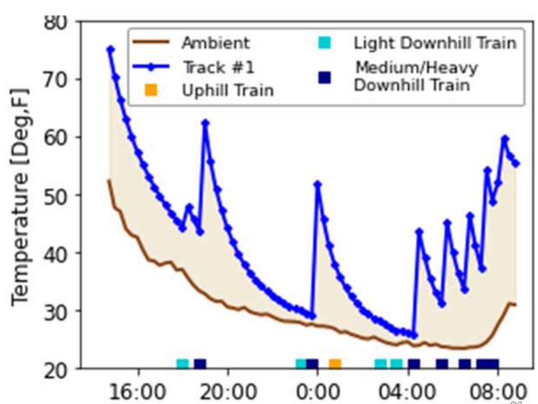
- **Ties and Fasteners**
  - Fiber-reinforced composite ties
  - Engineered polymer composite ties
  - Spike breakage



Recent & Ongoing Revenue Service Tests

- **Track geometry, ballast and subgrade**
- **Track stability and buckling prevention**





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Recent & Ongoing Revenue Service Tests

- **Special Trackwork**
  - Crossing diamonds, OWLS, and flange bearing trackwork
  - Support for FRA waiver process

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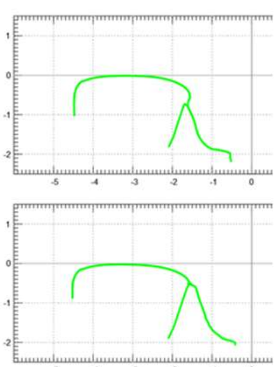
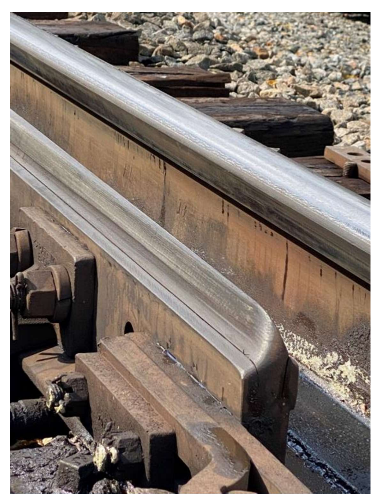
Recent & Ongoing Revenue Service Tests

- **Special trackwork**
  - Frogs and switches
  - Insulated joints





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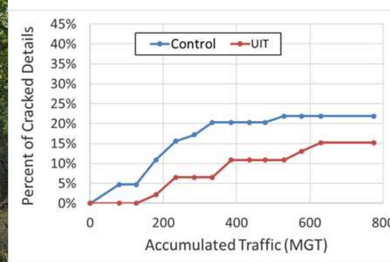
Recent & Ongoing Revenue Service Tests

- **Bridges**
  - Loading and fatigue effects of short cars, intermodal traffic
  - Long-term monitoring of span performance
  - Long-term effectiveness of retrofits and repairs



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Recent & Ongoing Revenue Service Tests

- **Combined infrastructure issues**
  - Special trackwork and continuous welded rail issues
  - Alternative ties for special trackwork applications
- **Wheel performance**
  - Multiple suppliers
- **Over-the-Road tests**

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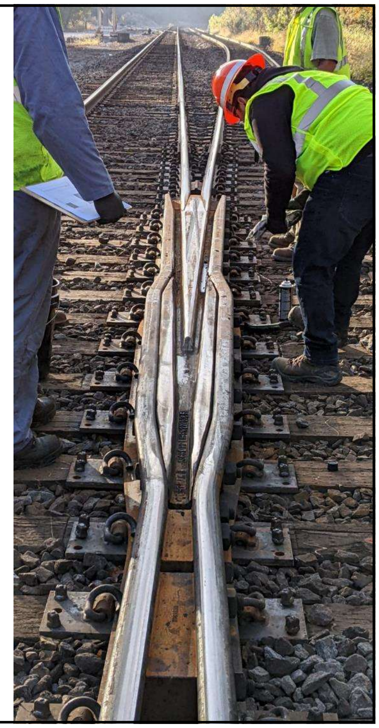
Benefits of In-Service Testing

- **Example: Improvements in special trackwork in recent decades**
  - Collaborative effort between railroads, suppliers, industry committees, researchers, and regulators
  - Frog life improved from ~100 MGT to ~400+ MGT
  - Insulated joint life improved from ~200 MGT to ~800+ MGT
  - Implementation of flange bearing trackwork for heavy freight service
- **Better designs, better materials, better processes**
- **Improved safety**



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Summary of Railroad In-Service Tests

- **Long history**
- **FAST – New loop under construction**
- **Revenue service – Details in following presentations**
- **Essential part of implementation process**
  - Improved performance
  - Improved safety

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Acknowledgements

Host Railroads

BNSF, CN, CPKC, CSXT, NS, UP

Federal Railroad Administration

Co-funding of selected tests for ~20 years

U.S. Department of Transportation
Federal Railroad Administration

MxV Rail staff

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Ballast and Subgrade Research

Stephen Wilk, Ph.D.

Principal Investigator

stephen_wilk@aar.com

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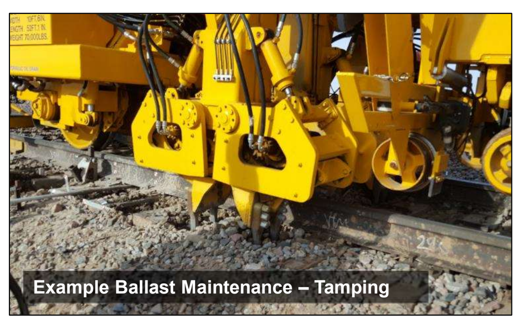
Objectives

Evaluate substructure performance in heavy axle load environment and provide information to aid ballast maintenance decisions

- New inspection technologies
- Performance evaluation
- Ballast maintenance practices
- Subgrade Remediation

Example Ballast Condition – Mud Pumping



Example Ballast Maintenance – Tamping

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Outline

1 Ballast Recompaction after Maintenance

3 Tamping Procedures

2 Drainage Improvement with Shoulder Cleaning

4 Geosynthetic Installation

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Topic 1: Ballast Maintenance and Recompaction

- **An important ballast function is constraining the tie against lateral and longitudinal movements**
- **Ballast maintenance inherently breaks up ballast structure**
- **Reduces track structure strength against tie movement and buckling**

Tamper on Class 1 track

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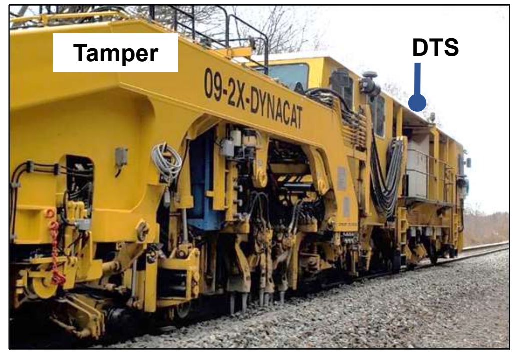
Topic 1: Ballast Maintenance and Recompaction

- **Speed restrictions typically placed after maintenance until ballast is recompacted**

Tonnage under Speed Restriction

Dynamic Track Stabilizer (DTS)



Tonnage requires 6+ train passes while DTS requires only one

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DTS Testing – Test Objective

- **Compare effectiveness of truck-based DTS at increasing lateral strength versus tonnage**

(Click photo for video)

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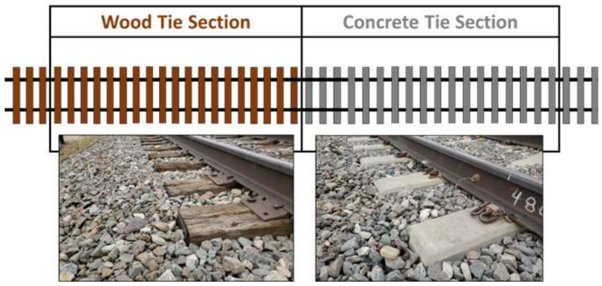
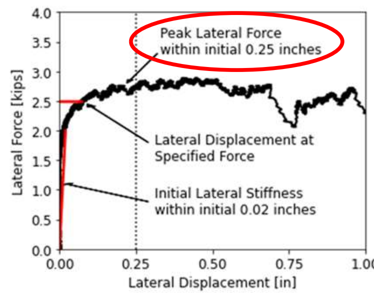
DTS Testing – Test Layout





- **Wood and concrete test zones**
- **Test situations:**
  - Post tamping
  - 0.1 MGT tonnage or Post-DTS
  - 22 MGT

(Click photo for video)

Single Tie Push Test (STPT)

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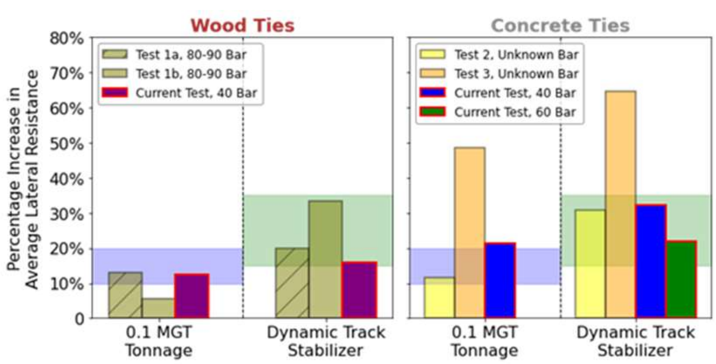
DTS Testing – Tonnage versus DTS



Key Findings

- **DTS increased lateral tie resistance by 15 to 35%**
- **0.1 MGT tonnage under speed restriction tonnage increases from 10 to 20%.**
- **No evidence that down-pressure (within operating range) is a significant factor in lateral tie resistance.**
- **DTS may be more effective for concrete ties.**

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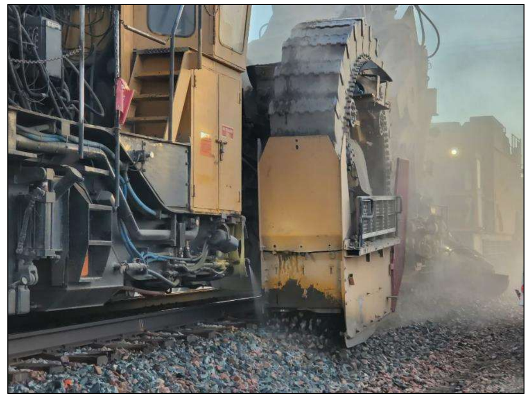
Lateral Track Strength – Moving Forward

- **Lateral track strength estimation:**
  - Which parameters can and cannot be measured
  - Effect of different maintenance practices
  - Convert to "Rail Neutral Temperature (RNT) equivalent"
- **Better characterize increases in lateral track strength with different tonnage increments**
- **Different ballast maintenance disturbs ballast differently**



Shoulder Ballast Cleaner

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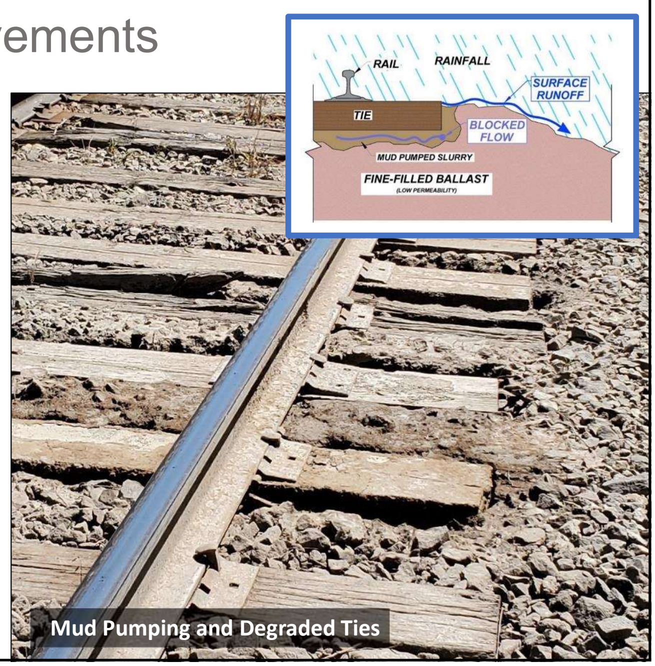
Topic 2: Drainage Improvements with Shoulder Cleaning

- **Drainage is important for the health of the entire track structure**
- **Accumulation of fines from ballast degradation or external sources will eventually block drainage**
- **Ballast replacement ideal but not always realistic**
  - Alternative measures to extend time before ballast replacement is required



Mud Pumping and Degraded Ties

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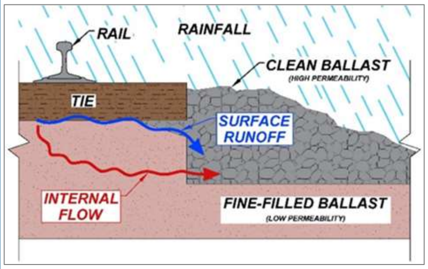
Shoulder Ballast Cleaning (SBC)

Diagram



Production

Spot

- **SBC option to extend time before undercutting (UC) required**
  - Opens up shoulder drainage
  - Higher production rate (more track miles compared to UC)
  - Does not replace center ballast (UC replaces center ballast)
  - Potentially “washes away” center ballast fines

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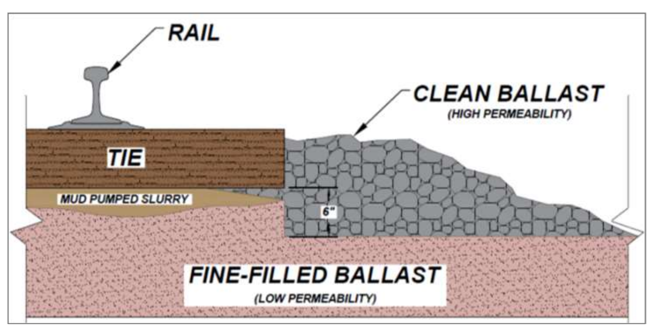
Spot Cleaning Test Objective

Compare track performance before and after shoulder cleaning during wetting events at a mud spot location

Test Section after Shoulder Cleaning



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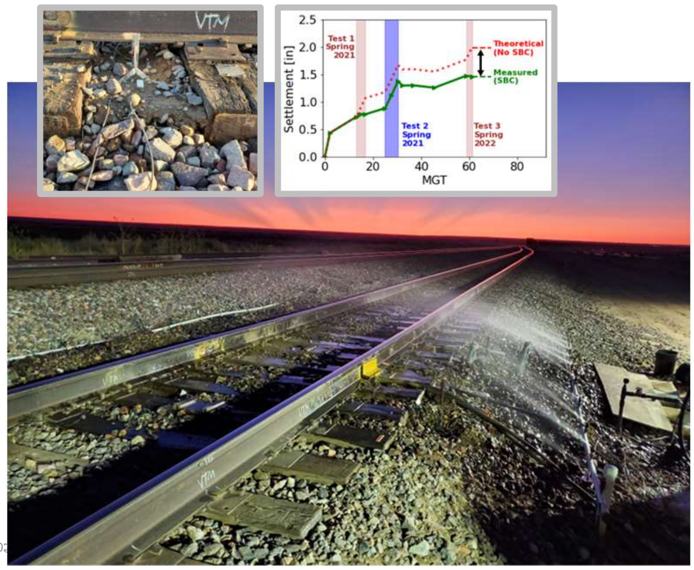
Spot Cleaning Test Results



Key Findings

- **No surface mud pumping from wetting tests**
- **Section drained in hours compared to days (pre-maintenance)**
- **Less susceptible to high settlement rates (extends surfacing cycle)**

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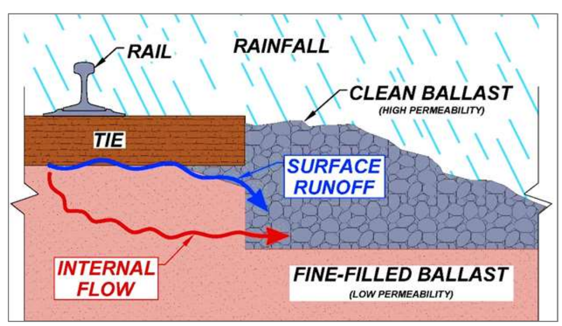
Fine Migration

- **Multiple studies suggest fine migration can occur in certain situations**
- **Internal "cleaning" most effective when fines are smaller than open drainage paths**
  - Suggests Ballast Fouling Index (BFI) between 15 to 30
  - More sand-size particles
- **For high BFI situations (BFI>30), fine migration typically from surface runoff or lateral mud pumping**



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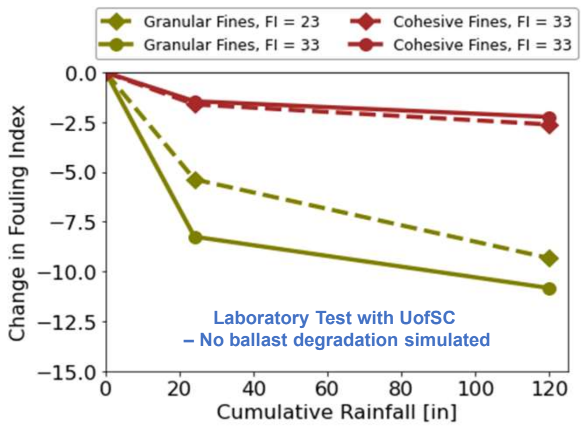
Fine Migration

- **Primarily "loose fines" (recently degraded) will wash away**
  - Maintaining clean shoulder likely optimal for track experiencing high levels of ballast degradation or external fines



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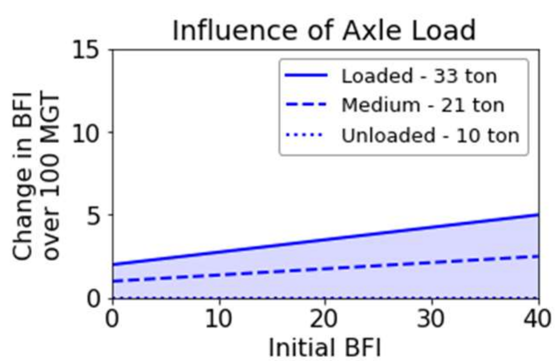
Ballast Degradation and Cleaning Cycles

- **Ballast degradation is affected by multiple parameters:**
  - Axle load and MGT
  - Ballast quality
  - Tie type, track speed



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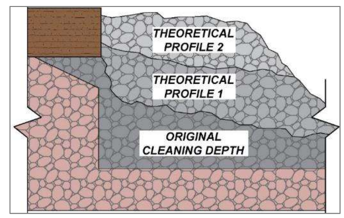
Shoulder Cleaning – Moving Forward

- **Longevity of SBC**
  - How long does SBC last?
  - Important parameters affecting longevity?
- **Research Implications**
  - Selecting appropriate SBC cycles
  - Avoid cleaning “clean” ballast
  - Extending time before undercutting

Shoulder Ballast Cleaner



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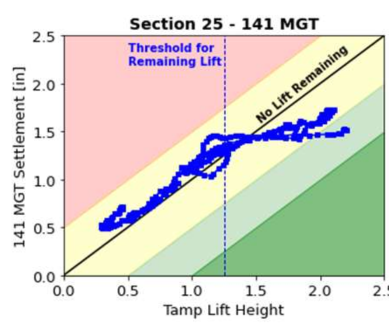
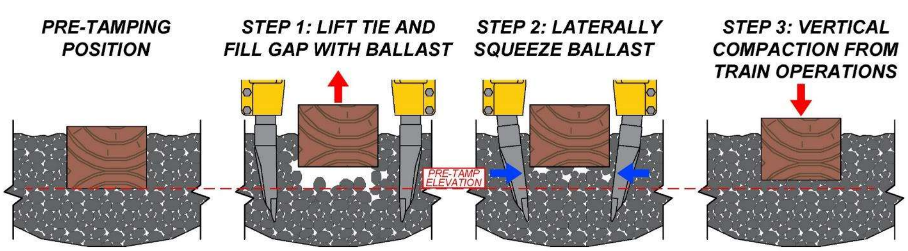
Topic 3: Tamping Procedures

- **Test tamping techniques to extend time before tamping required again in future**
  - Extend surfacing cycles
  - Relevant for settlement from ballast compaction





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Topic 4: Geosynthetic Installation

- **Installed various geosynthetics at different fouled ballast locations**
  - Tracking condition over time


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Summary

- **Truck-based DTS had a similar compaction effectiveness as 0.1 MGT compaction tonnage and previous DTS**
- **Spot shoulder cleaning a mud spot improved drainage and could theoretically extend tamping cycle**
- **Shoulder cleaning to extend ballast life is dependent on multiple factors but likely most effective in ballast experiencing high rates of degradation or fine infiltration**

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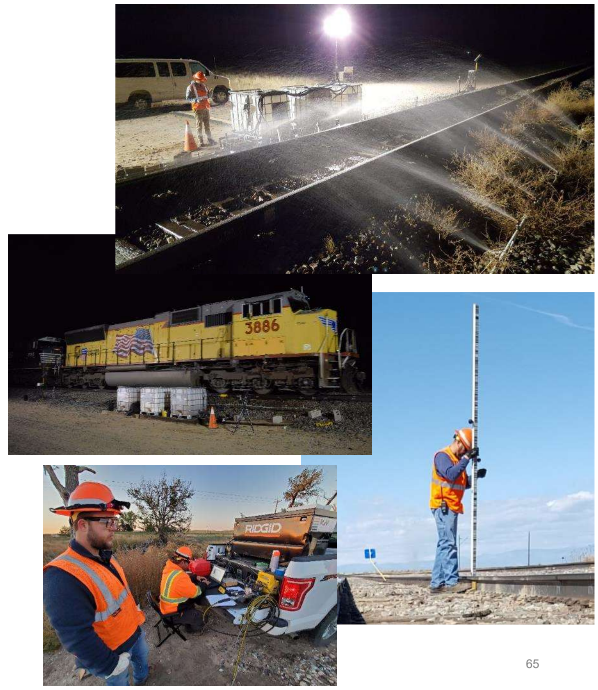
AAR 28TH ANNUAL RESEARCH REVIEW

Acknowledgements

Class 1 Railroads
BNSF Railway: DTS Test
CN Railway: Geosynthetics Test
MxV Rail Track, Instrumentation, and Engineering Teams
Dante DeVencenty, Dingqing Li
University of South Carolina (UofSC)



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Crosstie and Fastener Research

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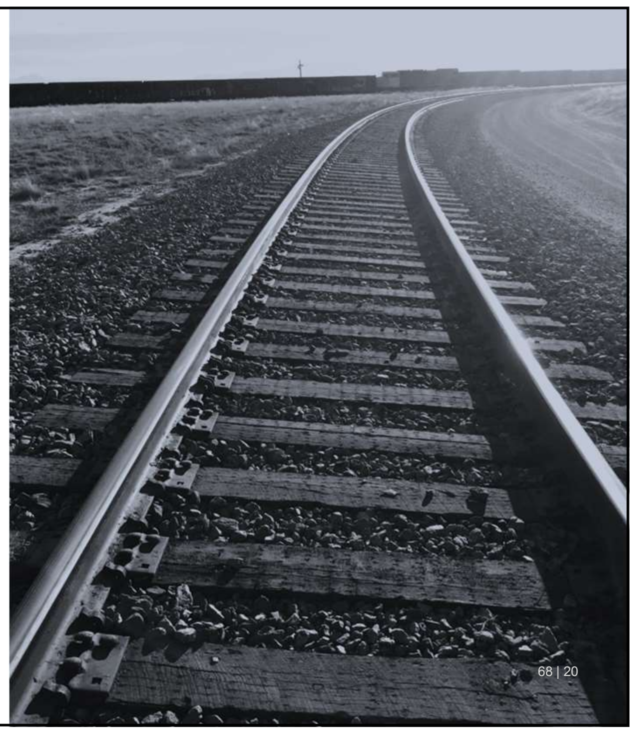
AAR 28TH ANNUAL RESEARCH REVIEW

Overview

- Project Objectives
- Concrete Tie Update
- Engineered Polymer Composite Tie Update
- Wood Tie Update
- Summary
- Acknowledgements



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AAR 28TH ANNUAL RESEARCH REVIEW

Project Objectives

- **Evaluate performance of new and existing designs in ties and fasteners**
- **Improve understanding of tie and fastener failure mechanism for best practice in maintenance and inspection**

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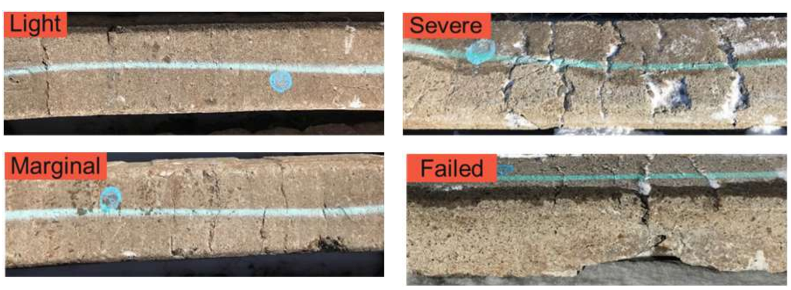
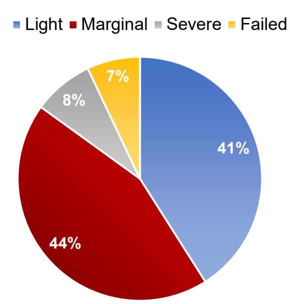
Concrete Tie Life Extension Study





- **Tie categorized by condition upon receiving**
  - Based on the severity of center cracking (inspected with railroad members)
  - FRA considers ties failed when rebar is exposed

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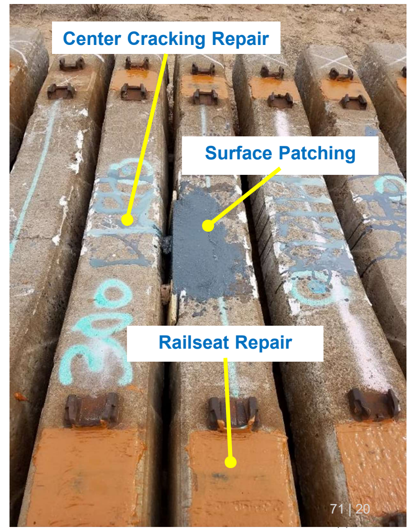
Concrete Tie Life Extension Study

- **Light, marginal and severe ties met AREMA center negative bending test**
- **Four repair methods**
  - Center cracking repair
  - Shoulder wear repair
  - Railseat repair
  - Surface patching

Shoulder Wear Repair



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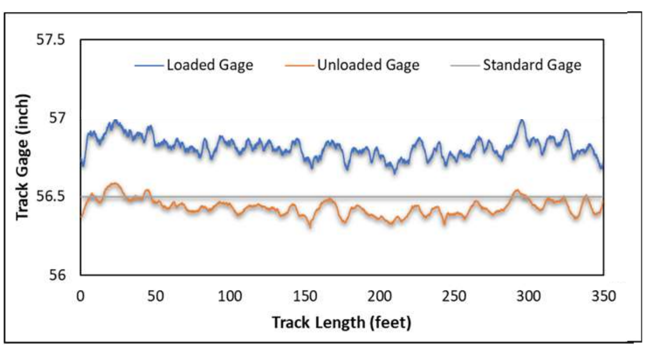
Concrete Tie Life Extension Study



- **Track loading vehicle (0 MGT)**
  - 33 kips vertical force; 18 kips lateral force
  - An average 0.4-inch gage widening for the test zone
  - Similar to adjacent newer concrete ties at FAST

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Concrete Tie Life Extension Study

- **Shoulder wear repair performed well**
  - (a) New shoulder wear repair assembly worked well
  - (b) Uniform wear on rail seat repair
- **Center cracking repair**
  - (c) Epoxy shelling and cracking (~30%)
  - (d) New cracks found on ties (~5%)
- **One tie with surface patching cracked**

(a)


(c)


(b)


(d)


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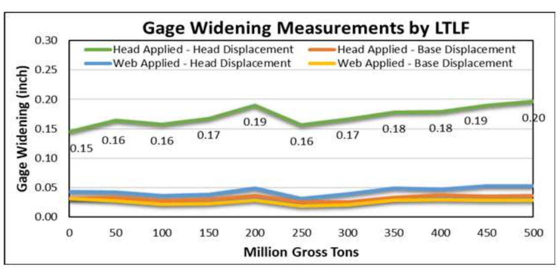
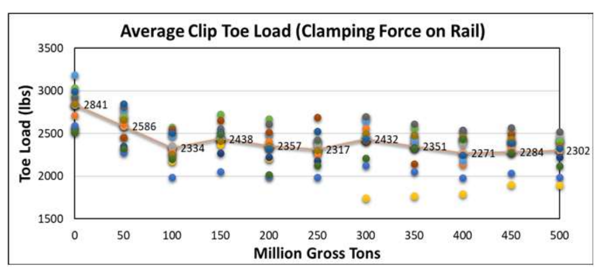
Concrete Tie Life Extension Study





- **548 MGT: Sufficient of gage holding strength**
  - Similar strength to the other concrete tie zones at FAST
- **Average toe load decreased 9% after 50 MGT, 17% after 100 MGT and remained at the same level**

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Engineered Polymer Composite Tie

- **Center cracking and spike hole cracking found in two EPC tie sections at FAST**
  - 655 MGT: center cracking, 7/100
    - Mainly occurred in a mud pumping zone
    - Suspect one railseat cracking
  - 1024 MGT: spike hole cracking, 12/80
    - Found on both cut spikes and lag screws

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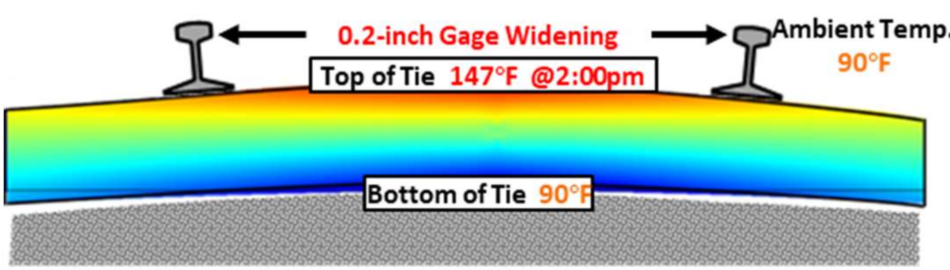
Engineered Polymer Composite Tie

- **Previous studies showed gage widening and tie shape variation due to temperature change in EPC tie zones**
- **Modeling effort to understand what thermal properties contribute to the thermal effect on EPC ties**



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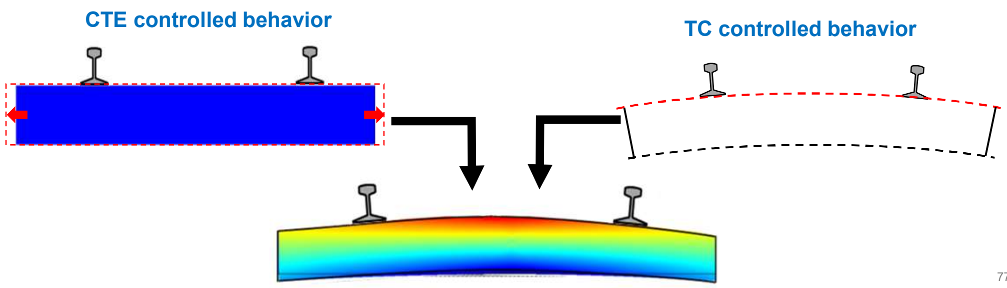
Engineered Polymer Composite Tie

- **Finite element modeling**
- **Tie length change due to temperature change – Coefficient of thermal expansion (CTE)**
- **Tie straightness change due to temperature change – Thermal conductivity (TC)**



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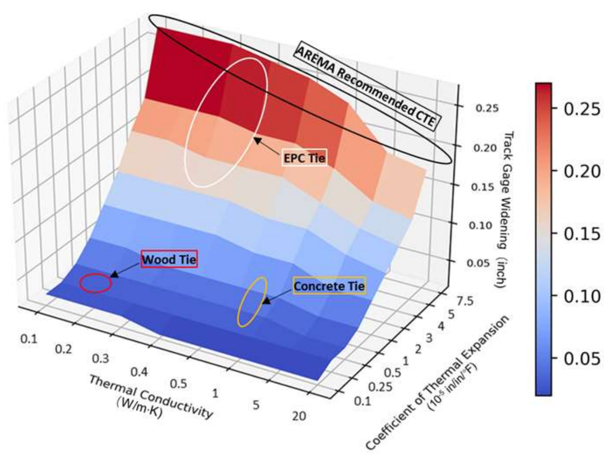
Engineered Polymer Composite Tie

- **Thermal effect on track gage variation by modeling**
  - Two thermal properties (TC and CTE)
  - Do not exceed the FRA safety standards for any track class
  - Need to consider temperature when installing and maintaining EPC ties



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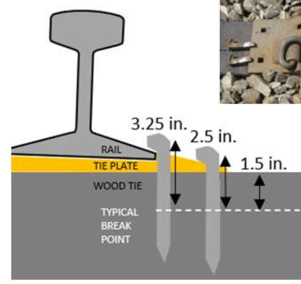
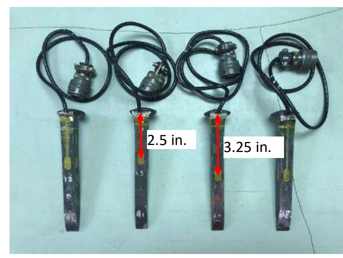
Wood Ties - Spike Breakage Study

- **Broken spikes found on elastic fastener in revenue service and FAST**
  - Usually found on high degree curves, high-grade territories
  - Cannot identify the issue by visual inspection
- **Instrumented spikes to evaluate spike loading environment**
  - Load level, distribution
  - Fatigue analysis





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Spike Breakage Study

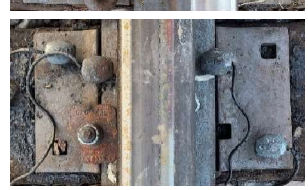
Four different fastening systems

Test Case	Fastener	Rail Anchors?	
Case 1	18-inch elastic fastener	Yes	No broken spike in 300 MGT
Case 2	18-inch elastic fastener	No	27 broken spikes at 200 MGT (27/300)
Case 3	16-inch curve block plates	Yes	No broken spike in 300 MGT
Case 4	AREMA 18-inch plates	Yes	No broken spike in 740 MGT

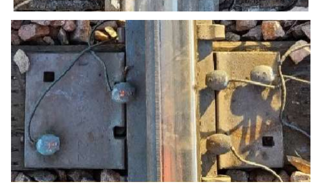
Case 1

Case 2

Case 3



Case 4



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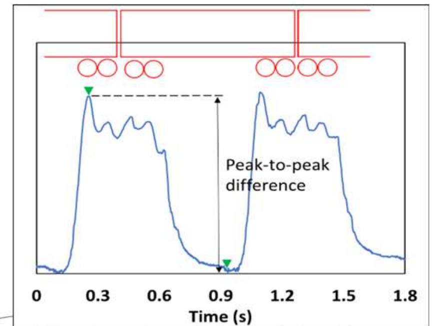
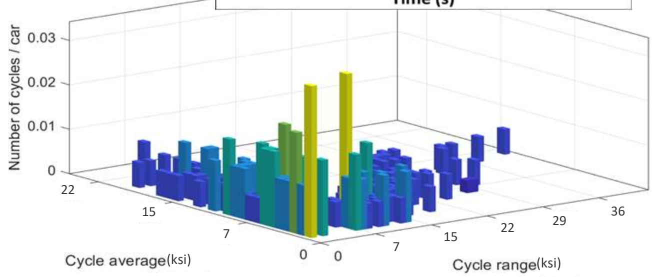
Spike Breakage Study

- **Spike loading level was above the fatigue limit of spike material**
- **Load transferred to spikes was carried by one or two spikes on a plate**
- **Load cycle average and range were considered to estimate the fatigue life of spikes**





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Spike Breakage Study

- **Estimate spike fatigue life based on spike steel material**
  - FAST operating condition: 65 MGT (spike with 95 percentile load)
  - Fatigue analysis shows that evenly distributing the total spike load to four spikes (for Case 2) could increase the spike life (the highest loaded spike) by 10 times (~ 600 MGT)

MGT at Which Spike Failures Start Occurring

CASE 1: **320 MGT**	CASE 2: **65 MGT**
CASE 3: **340 MGT**	CASE 4: **870 MGT**

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Summary

- Moderate repairs can extend service life of concrete ties that were removed from revenue service
- Coefficient of thermal expansion and thermal conductivity identified as two dominating properties contributing to the gage widening on EPC ties due to temperature variation
- Working with AREMA on recommendations for thermal conductivity
- Fatigue analysis shows that even distribution of spike load could increase the spike life
- Continue to test new tie and fastener designs as requested from Class I railroads

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Acknowledgements

Tie and Fastener Manufacturers

Class I Railroads

MxV Rail Instrumentation and Track teams

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Track Stability Research

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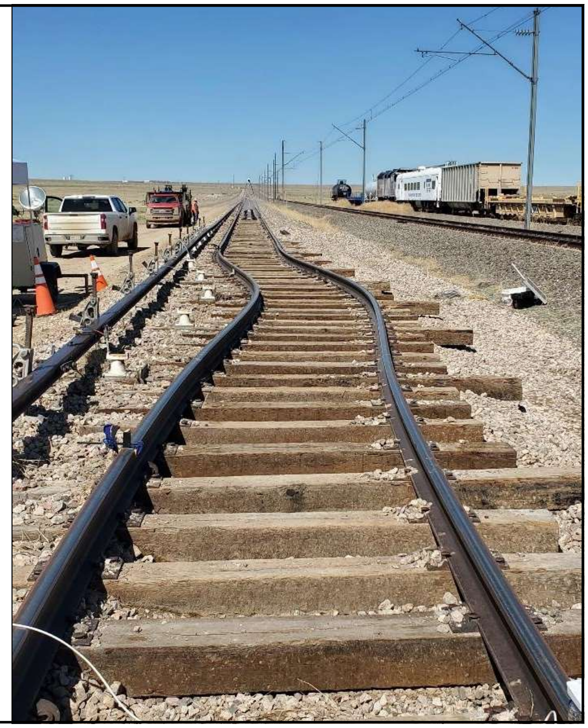
Objectives

- **Provide tools and information to aid track buckling risk management and best maintenance practices**
- **Track buckling involves many different forces and resistance factors**
  - Isolate various factors and their influence then combine into a single risk assessment
  - Estimate changes in buckling risk from changes in track structure and operations
  - Simplify so actionable decisions can be made in the office or in the field



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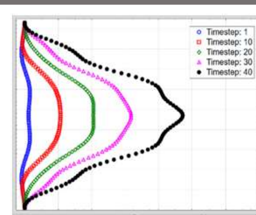
Outline

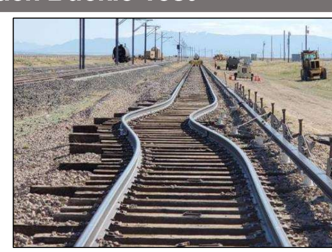
1 Rail Temperatures from Train Operations

2 Rail Neutral Temperature (RNT) Measurement Technologies

3 AAR/TAMU Track Buckling Model



4 Track Buckle Test



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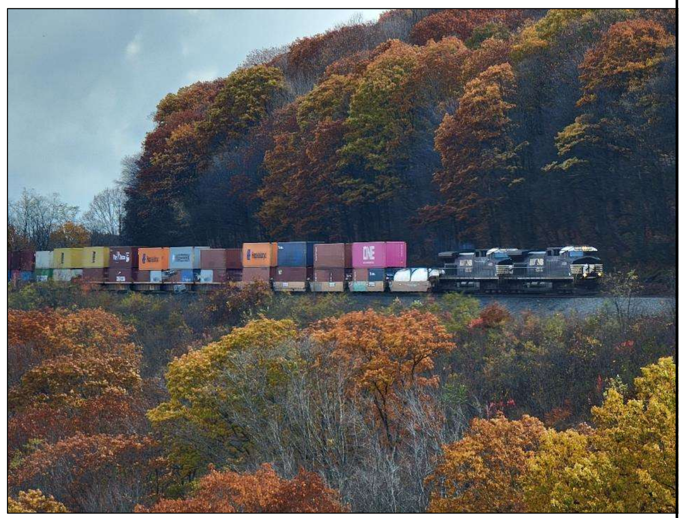
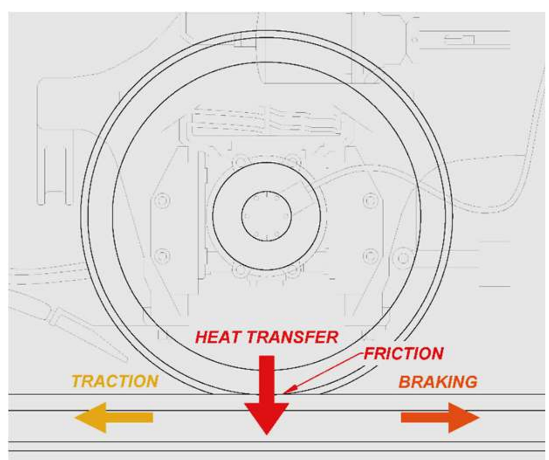
Topic 1: Longitudinal Rail Forces from Train Operations

- **High longitudinal rail forces can negatively affect track from rail/track movement or track buckling**
- **Largest influence is from ambient temperature and solar radiation**
- **For this study, focus on induced forces from train operations**
- **Identify risk and mitigation methods**



Longitudinal Rail Forces from Train Operations

- **Rail temperatures:**
  - Ambient and solar radiation (non-train operations)
  - Wheel/rail friction contact
  - Heat transfer from sustained air braking
- **Mechanical forces:**
  - Traction
  - Braking



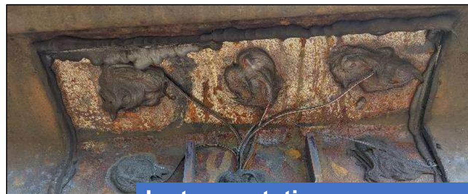
Values from each component will vary significantly depending on geographic condition, grade, curvature, and train operations

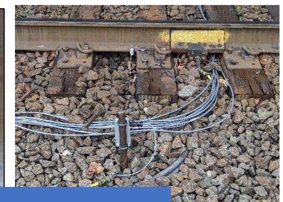
AAR 28TH ANNUAL RESEARCH REVIEW

Test Location and Instrumentation

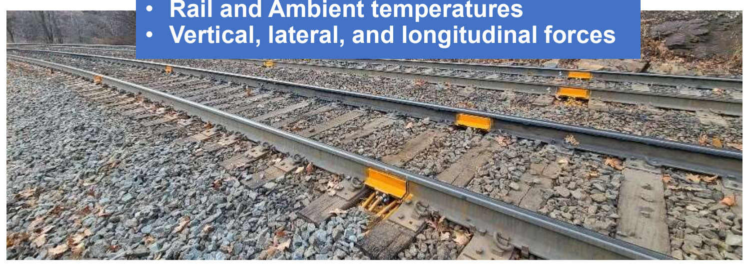
- **Used data from a tie-fastener research study**

Site Details
- **1.8 percent grade**
- **9.25-degree curve**
- **Both dynamic and air braking**





Instrumentation
- **Rail and Ambient temperatures**
- **Vertical, lateral, and longitudinal forces**



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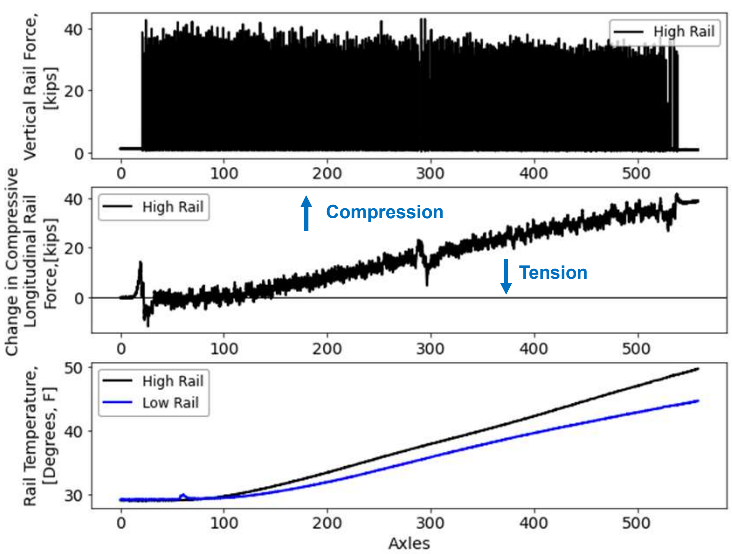
Sample Data



Direction	Measured Trains
Uphill	53
Downhill	72
Total	125

- **Isolate longitudinal rail force components for each train**
  - Rail temperatures
  - Wheel/rail contact
  - Traction
  - Dynamic braking

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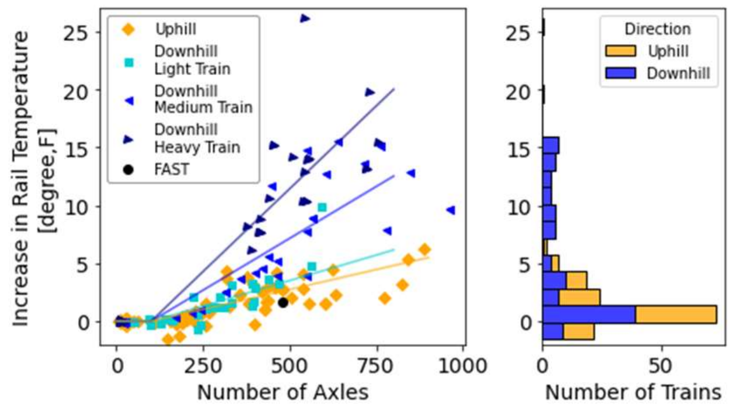
Rail Temperatures from Air Braking

Key Findings

- **Downhill, loaded, braking trains: 15-26°F**
- **Wheel/rail friction: 5°F**
  - Affected by number of axles
- **Air braking: 10 to 20°F**
  - Affected by train weight and number of axles.



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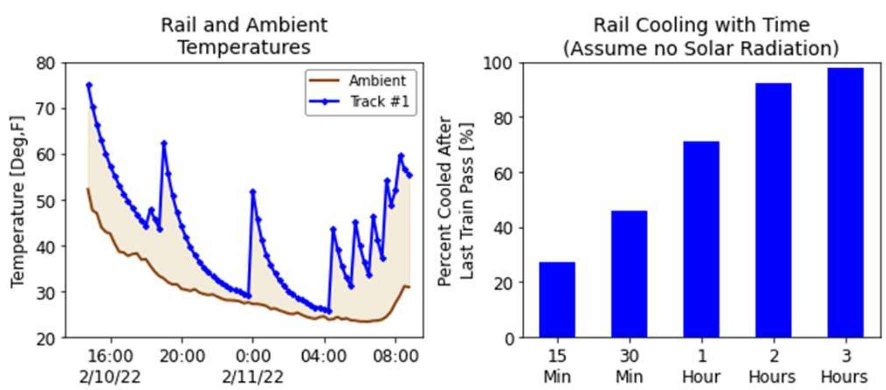
Residual Rail Temperatures



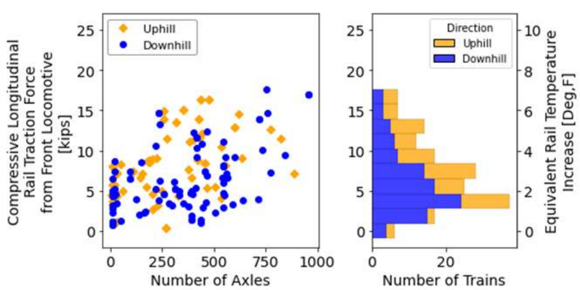
Key Findings

- **Rail temperatures did not always fully cool before next train pass and can accumulate**

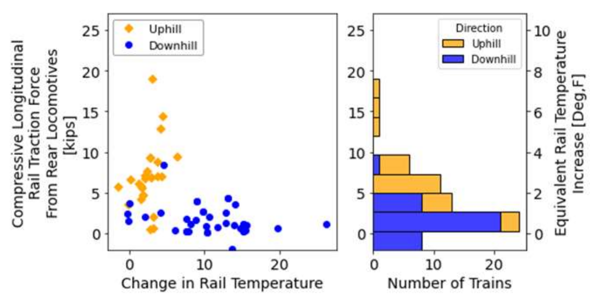
AAR 28TH ANNUAL RESEARCH REVIEW

Mechanical Traction/Braking Forces

Front Locomotives



Rear Locomotives



Key Findings

- **Lead locomotive tends to produce higher forces**
- **Traction forces greater than braking forces in this situation**

AAR 28TH ANNUAL RESEARCH REVIEW

Train Parameters

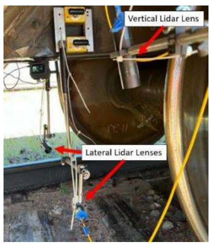
- **Longitudinal rail forces produced by multiple train and non-train factors. Specific magnitudes can vary significantly by location from track and train operation characteristics**
  - Ambient temperature and solar radiation: Largest influence and sunny days can increase rail temperatures by 30°F
  - Wheel-rail friction: High curvature on uphill and downhill trains increased rail temperatures by about 5°F and was dependent on number of axles
  - Air braking: Sustained air braking down high grades increased rail temperatures by about 10 to 20°F and was dependent on number of axle and train weight
  - Traction/braking forces: Mechanical forces up to about 20 kips (7°F equivalent). Braking forces were greater in the front locomotives

AAR 28TH ANNUAL RESEARCH REVIEW

Topic 2: University Programs Topics

- **MxV Rail/AAR partnered with multiple universities to fund fundamental research into track stability and rail neutral temperature (RNT) measurement devices**

Virginia Tech
LIDAR methods



University of Missouri
Electro-magnetic based methods

Mizzou
University of Missouri

University of Pittsburgh
Photographic based methods

University of Pittsburgh

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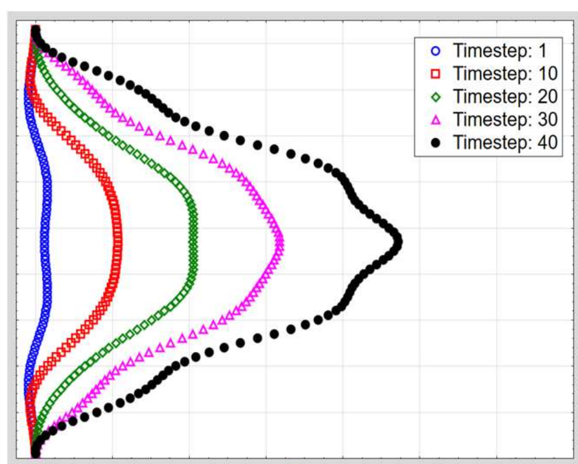
Topic 3: AAR/TAMU Track Buckling Model

- **MxV Rail and Texas A&M University (TAMU) is producing a high-end track buckling finite element method (FEM) model**
- **Status update:**
  - Base model completed



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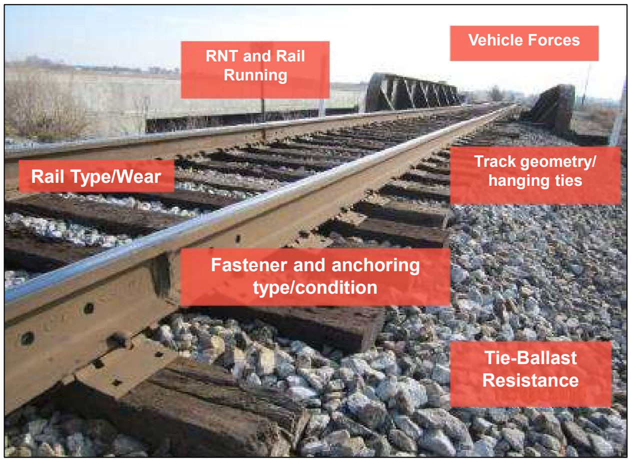
Track Buckling Model – Moving Forward

- **Capabilities**
  - Track structure characteristics
  - Curvature and misalignments
  - Tie liftoff and hanging ties
  - Lateral and longitudinal forces
- **Wide range of outputs:**
  - Help identify high-buckle risk locations
  - Understand how changes in track and operation conditions change overall buckling risk



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Topic 4: Field Track Buckle

- **Produce and monitor a controlled track buckle**
- **Demonstration purposes**
- **Separate important parameters relevant for track buckling**

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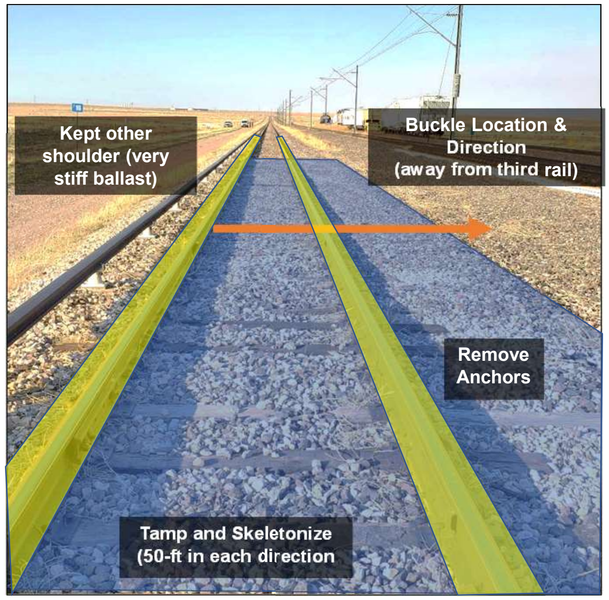
Track Modifications

- **Remove anchors to allow rail movement**
- **Tamped and skeletonized track to weaken tie/ballast resistance**
- **Added over 5 inches of rail to reduce RNT an estimated 50°F (90°F to 40°F)**



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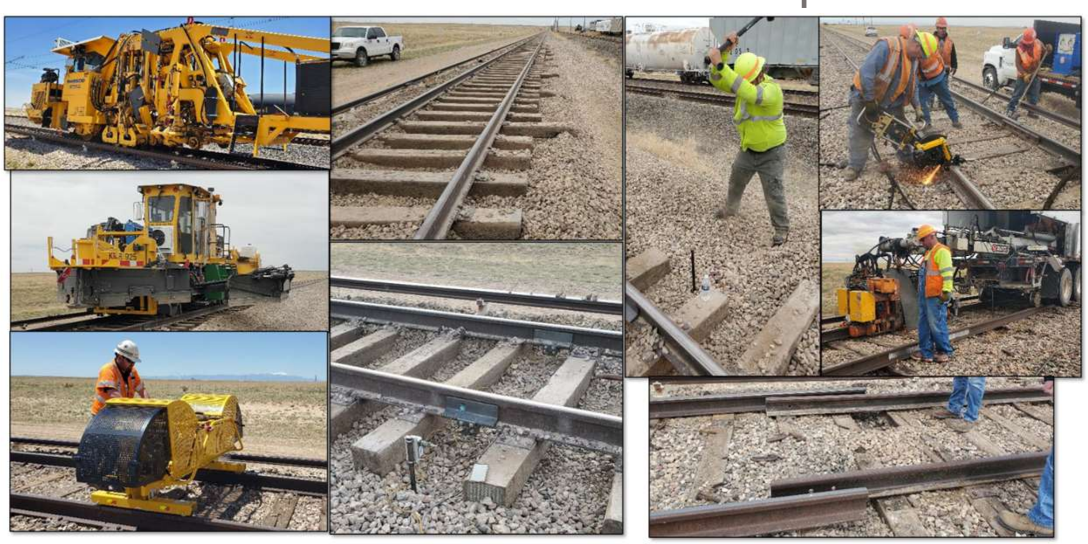
Trackwork and Instrumentation Preparation



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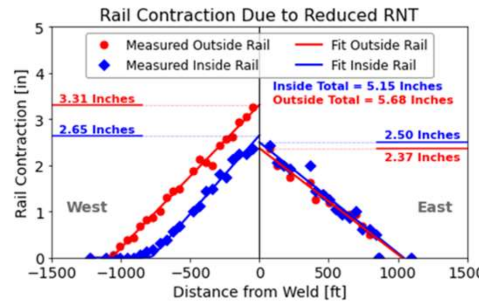
Reduced RNT



Added about 5 inches of rail to reduce RNT to 40 degrees

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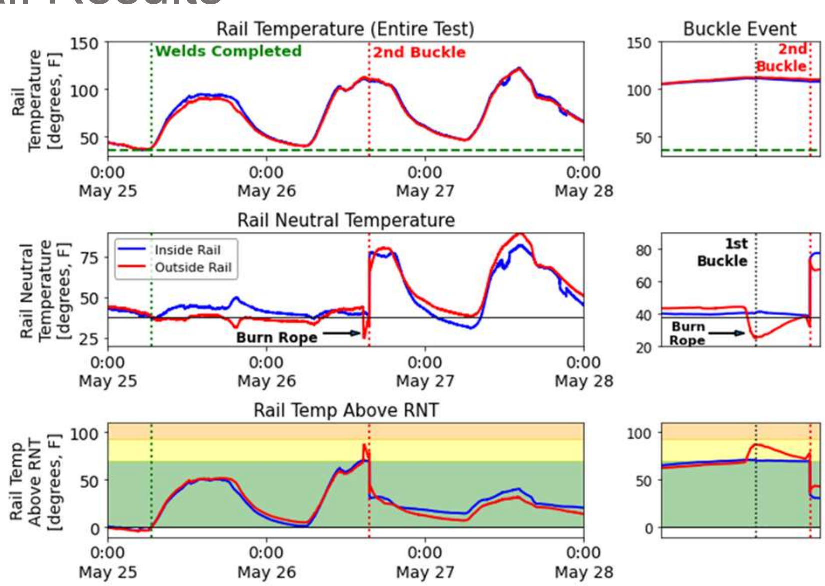
Overall Results



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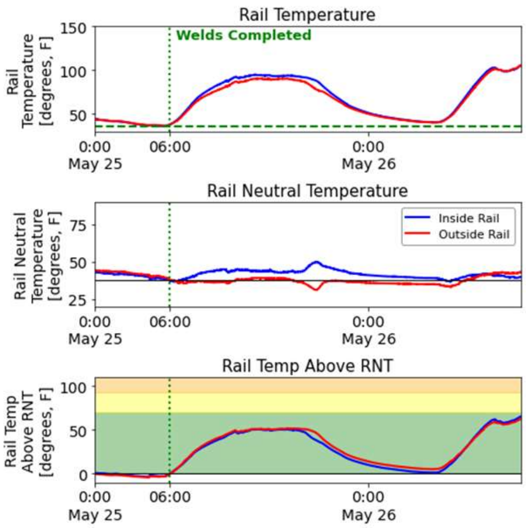
Pre-Buckle



At 70 degrees above RNT, just had wavy rail and about a 1/4-inch kink

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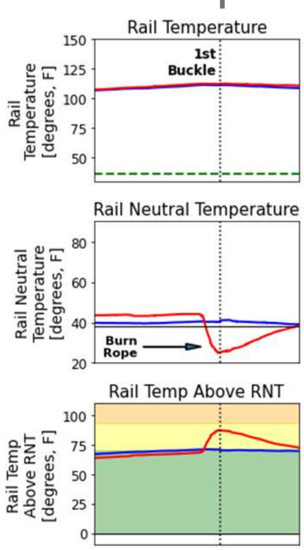
Burn Rope and First Buckle Event



Burn rope caused rail to run and "push" into buckle location. This resulted in a reduction in RNT

About 80 degrees above RNT resulted in small 1 1/4-inch "buckle"

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Second Buckle Event *(Click for video)*

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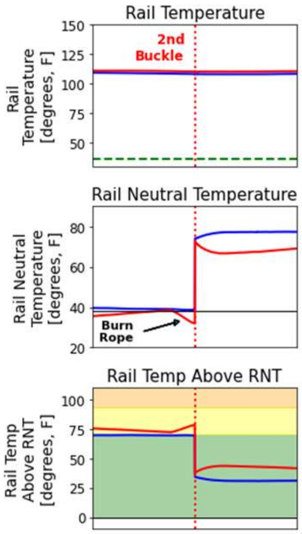
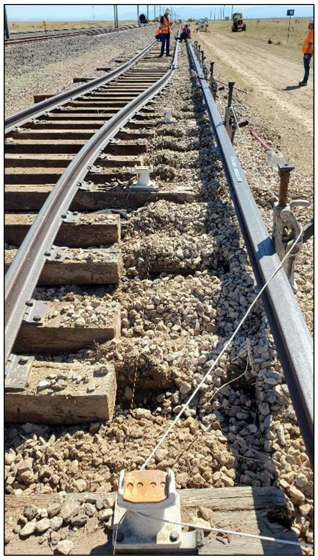
Second Buckle Event



Buckle occurred at 74 degrees above RNT

30-inch buckle

1-inch additional misalignment reduced buckle temp by 6 degrees



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Summary

- **At the revenue service test location, sustained air braking on steep downgrades increased rail temperatures up to 26 degrees, with temperatures accumulating from back-to-back trains**
- **Track buckling model completed by Texas A&M**
- **Produced and monitored track buckle and capable of measuring many important track buckle components**

Acknowledgements

Class 1 Railroads

NS Railway: rail temps

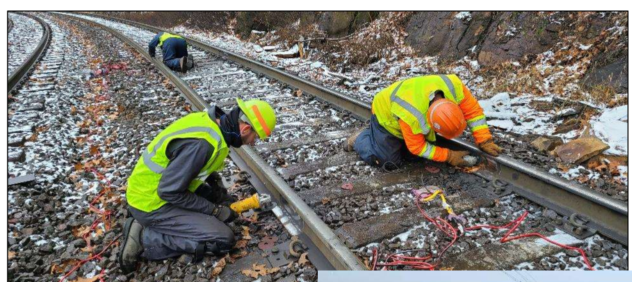
CPKC Railway: Rail temp discussions

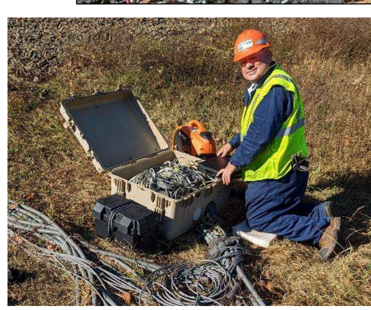
BNSF Railway: Buckle test

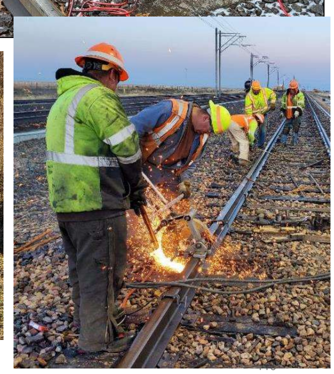
MxV Rail Track, Instrumentation, and Engineering Teams

Kenny Morrison, Dustin Clasby, Chris Johnson, Duane Otter, Yin Gao, Yi Wang, Anish Poudel, Dingqing Li

Texas A&M University







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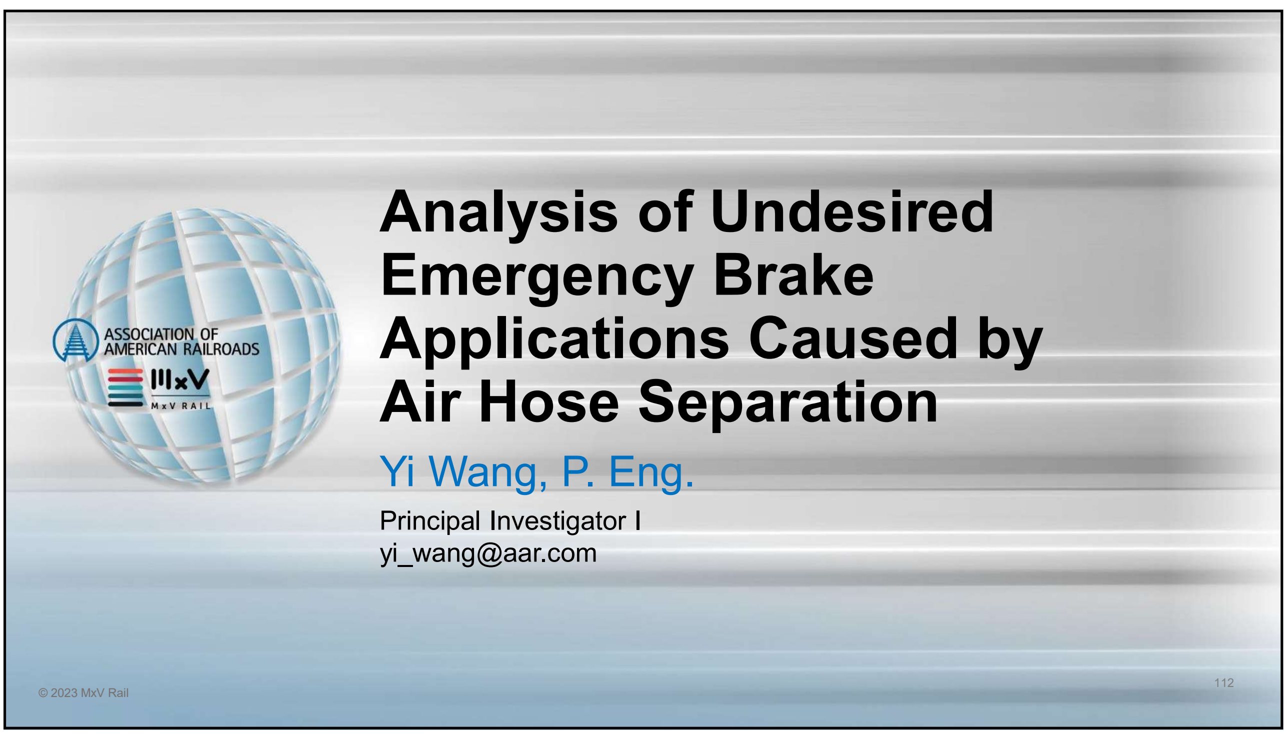

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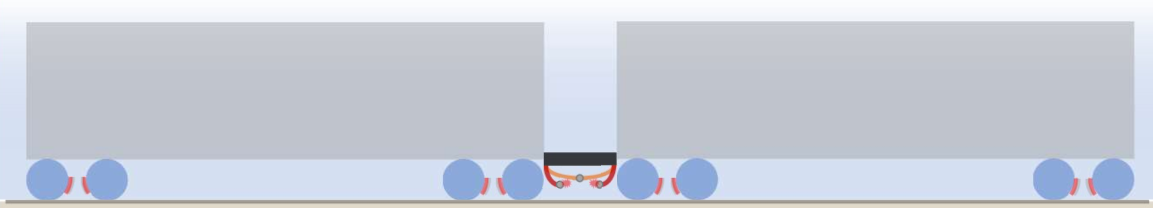
Overview

- **Background**
- **Data and Methodology**
- **Results and Observations**
- **Summary**

AAR 28TH ANNUAL RESEARCH REVIEW

Background

- **Air hose separations (AHS) cause undesired emergency (UDE) applications and significant service interruptions**



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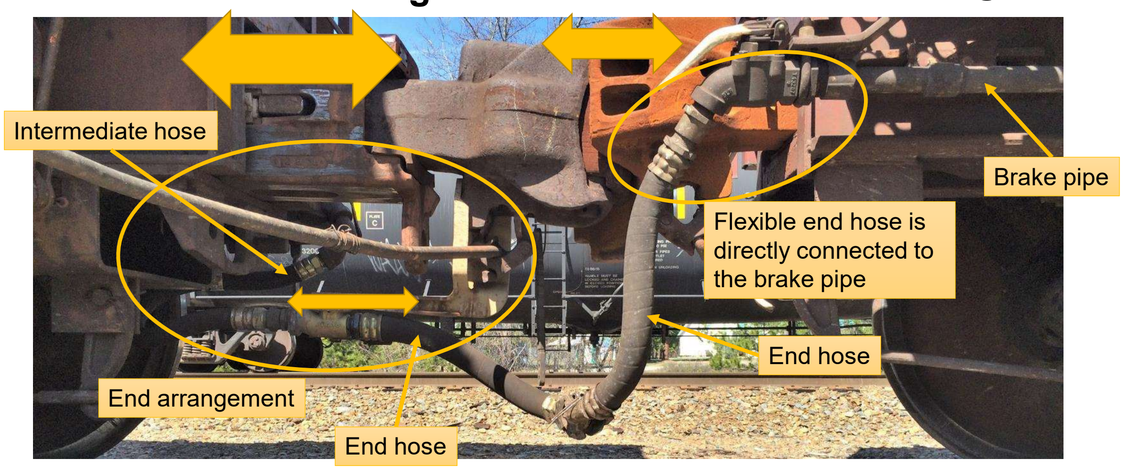
Recap on Draft Systems

End-of-car cushioning **Standard draft gear**



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Studies Involving UDE

Previous studies by MxV Rail:

- AHS due to car pitch and bounce and fouling the gladhands
- UDE with no cause found
- Conditions of the end arrangements under which AHS may occur

This study:

- Operational, track, and equipment data that are related to AHS reported in revenue service

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Service Interruption Data

For this hose-separation study, the following data were collected from a Class 1 partner:

- 95 full-length incident reports
- Event recorder logs
- Locations of fixed object such as bridges, crossings, turnouts, etc.

From a different Class 1 partner:

- A list of AHS events and cars involved

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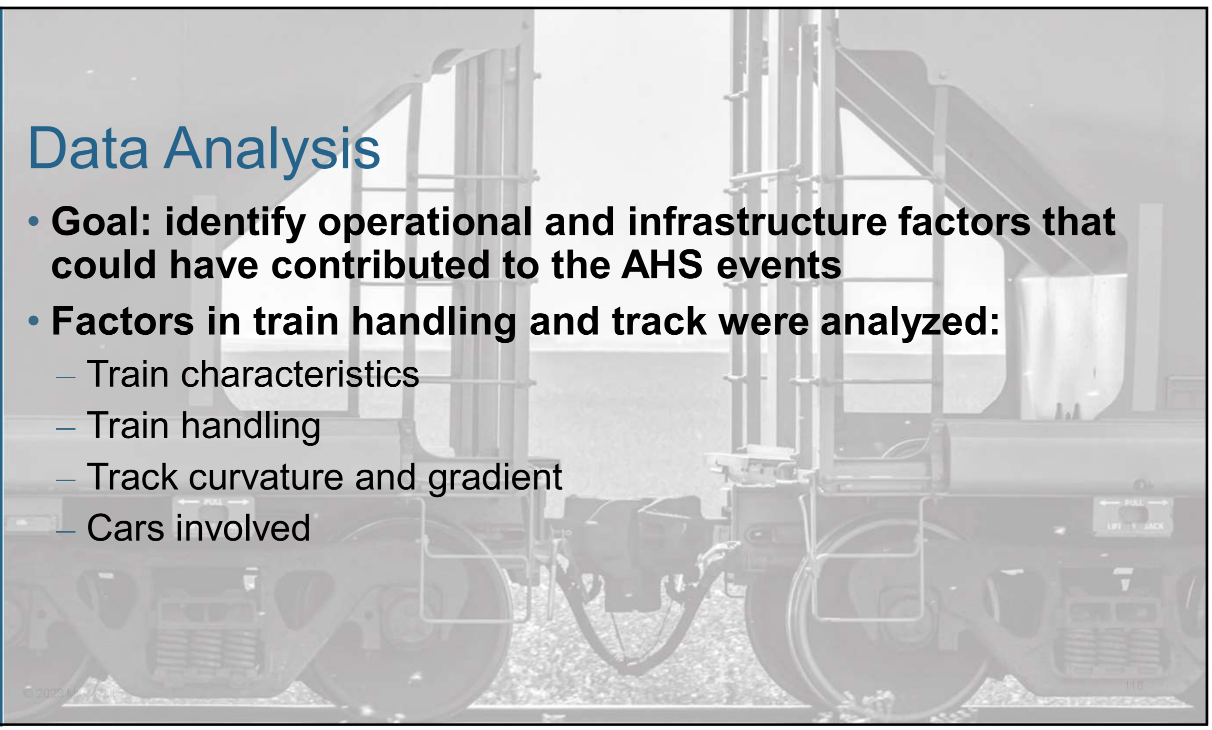

Data Analysis

- **Goal: identify operational and infrastructure factors that could have contributed to the AHS events**
- **Factors in train handling and track were analyzed:**
  - Train characteristics
  - Train handling
  - Track curvature and gradient
  - Cars involved

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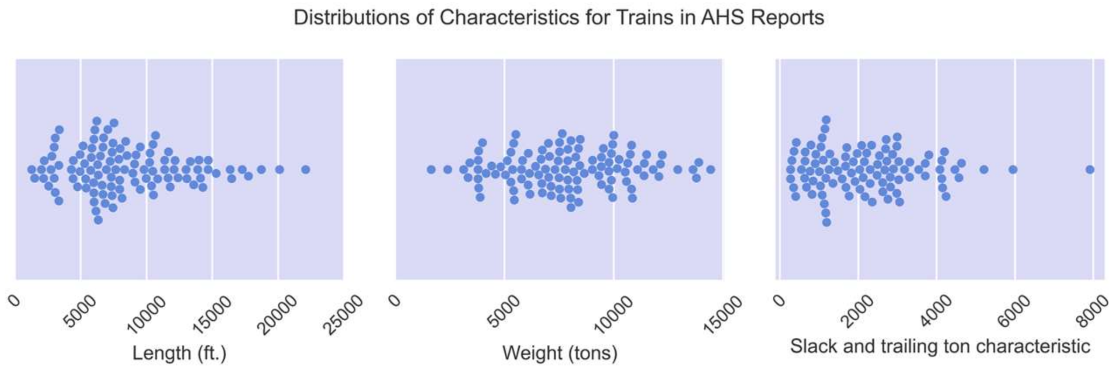
Train Characteristics

Most trains analyzed would be considered "normal"



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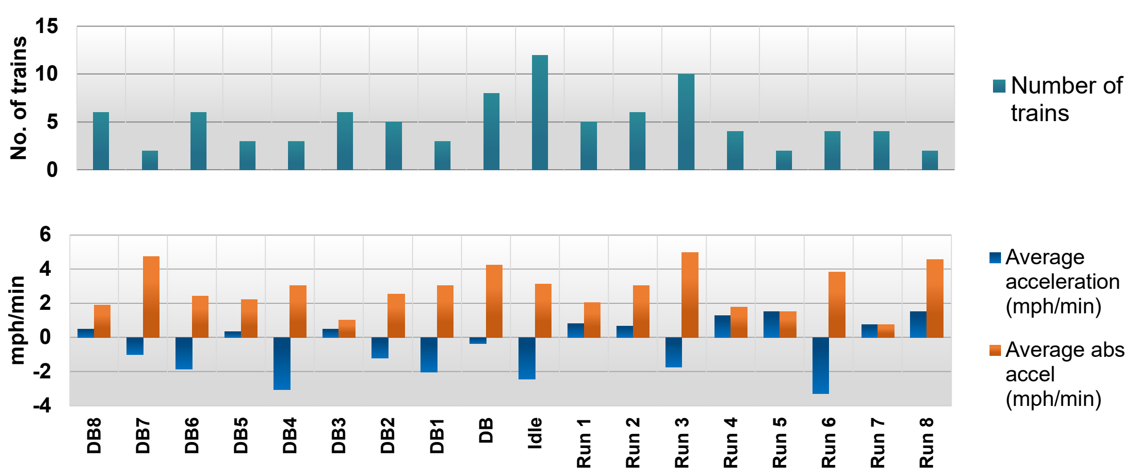
Train Handling:
Throttle Position and Accelerations before UDE



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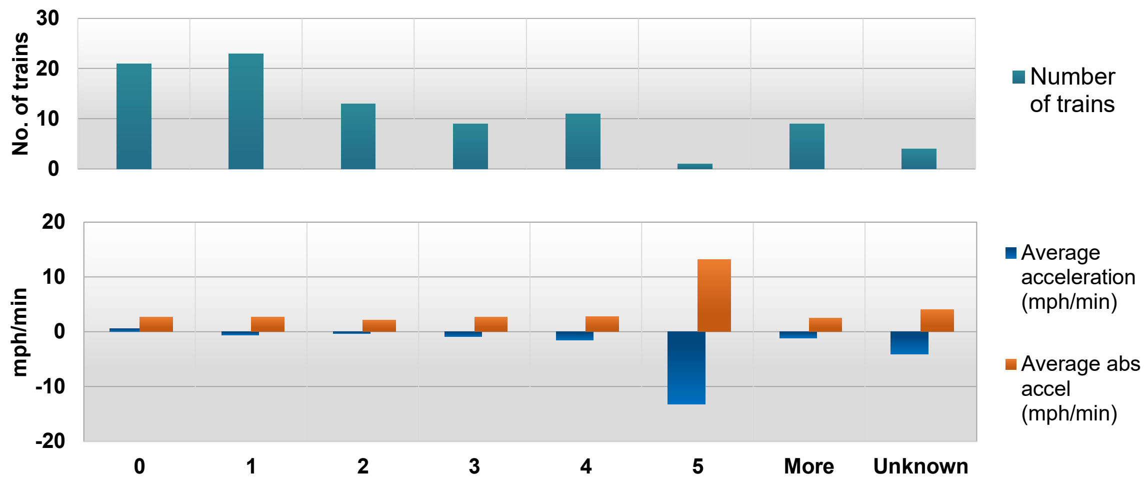
Train Handling:
Number of notch changes and accelerations before UDE



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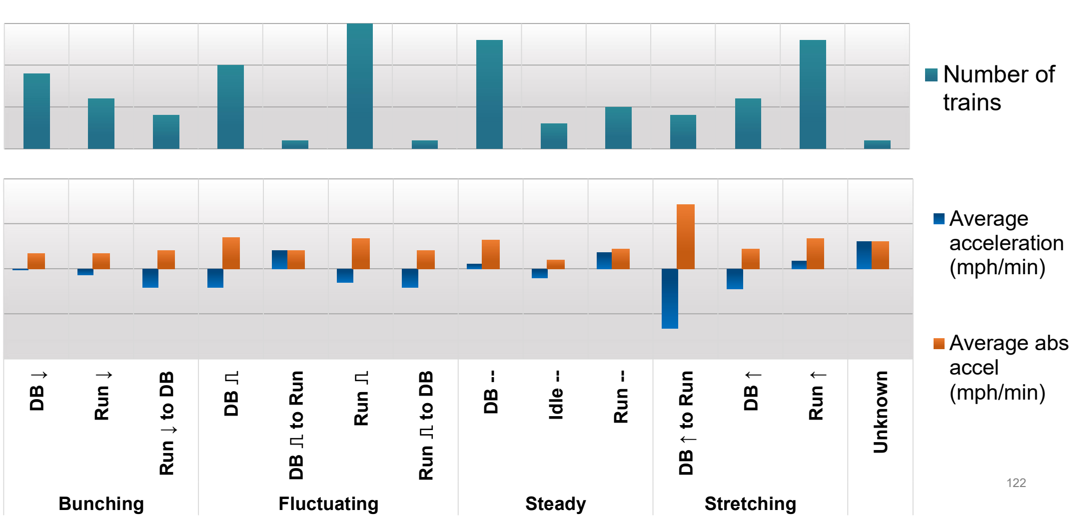
Train Handling:
Throttle/DB trends before UDE



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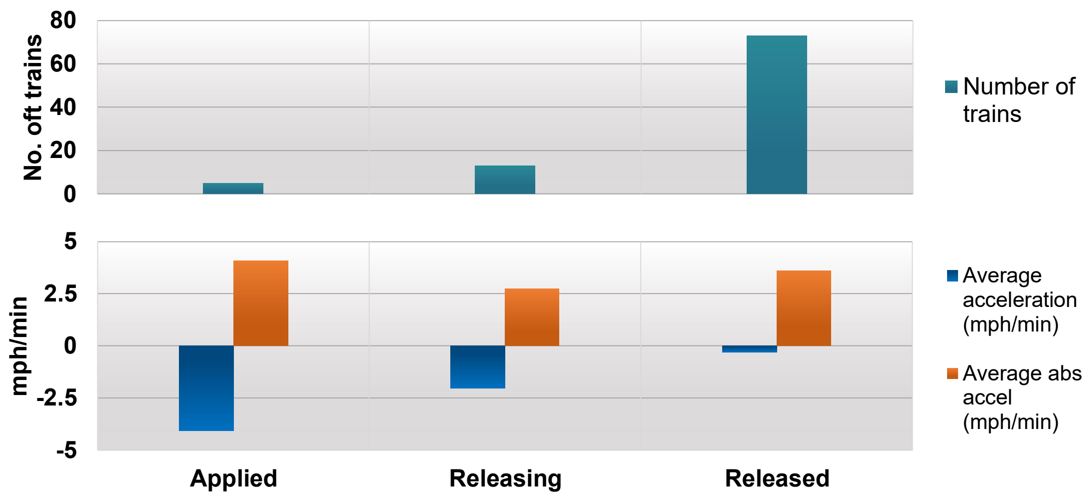
Train Handling:
Airbrake use before UDE



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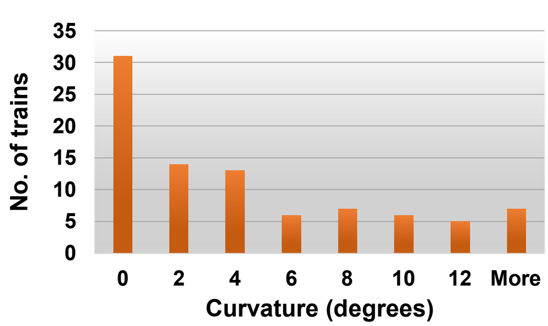
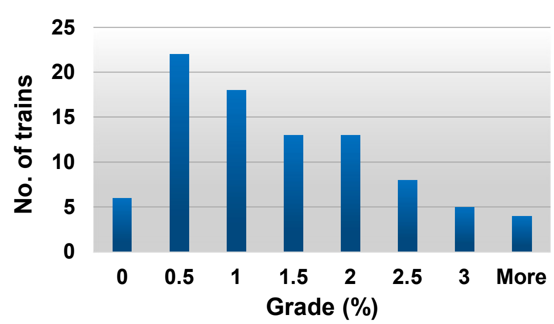
Track Factors

- **Over 90% of trains encountered features that could foul the hoses, no fouling of gladhands reported**
- **Cumulative curvature and gradient changes:**





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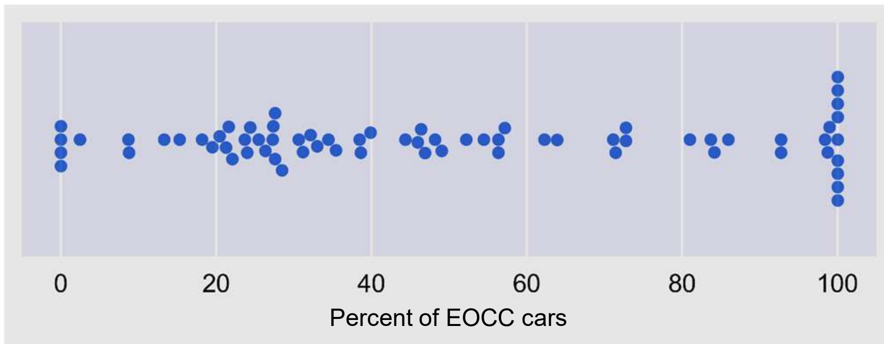
Equipment Factors

- **Majority of trains in the AHS reports have EOCC cars in the consist**



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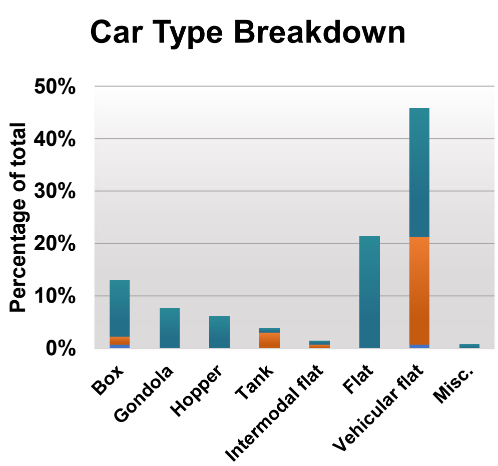
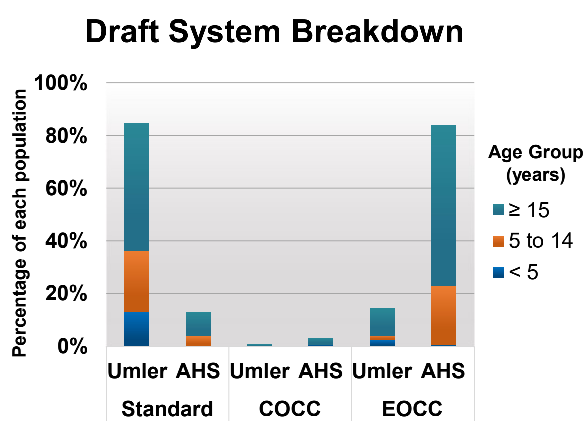
Equipment Factors





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A A R 2 8 T H A N N U A L R E S E A R C H R E V I E W

Equipment Factors

- **Data from a second Class 1 railroad showing AHS and equipment involved showed a similar breakdown**
- **Car age is not indicative of when the end arrangement was last repaired or replaced, but newer cars are more likely to have newer end arrangements both in design and condition**

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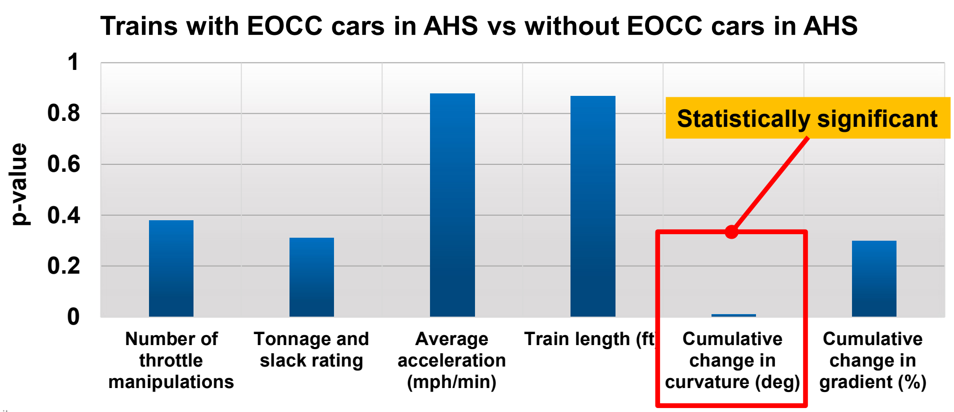
A A R 2 8 T H A N N U A L R E S E A R C H R E V I E W

Additional Analysis based on EOCC

Trains were also separated into two groups and analyzed using a statistical test



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Summary

- **95 AHS events and corresponding data did not show a strong indication that train handling or track features were the cause**
- **EOCC cars represented a large proportion of cars involved and age appeared to be a factor**

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Acknowledgements

Scott Cummings, Walter Rosenberger & Kenny Morrison – MxV Rail

Class 1 Railroad Partners

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Thank you

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Reconditioned Bearing Performance

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Senior Engineer

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ASSOCIATION OF AMERICAN RAILROADS

MxV RAIL

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Overview

- **Project Motivation**
- **Reconditioning Process**
- **NDE Technology for Bearing Inspection**
- **Test Results of Repaired Bearing Cups**
- **Path Forward**
- **Acknowledgements**

AAR 28TH ANNUAL RESEARCH REVIEW

Project Motivation

- **Research concentrated on safety, reliability, and efficiency**
- **Most bearings in revenue service are reconditioned**
- **What methods are available to improve the reconditioning process?**

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Bearing Reconditioning Process

- **Once a bearing is removed from the wheelset, it cannot be re-installed until it goes through the reconditioning process**
- **The bearing is broken down into components, which are cleaned and inspected**
- **Any defects must be repaired, or the components must be scrapped**

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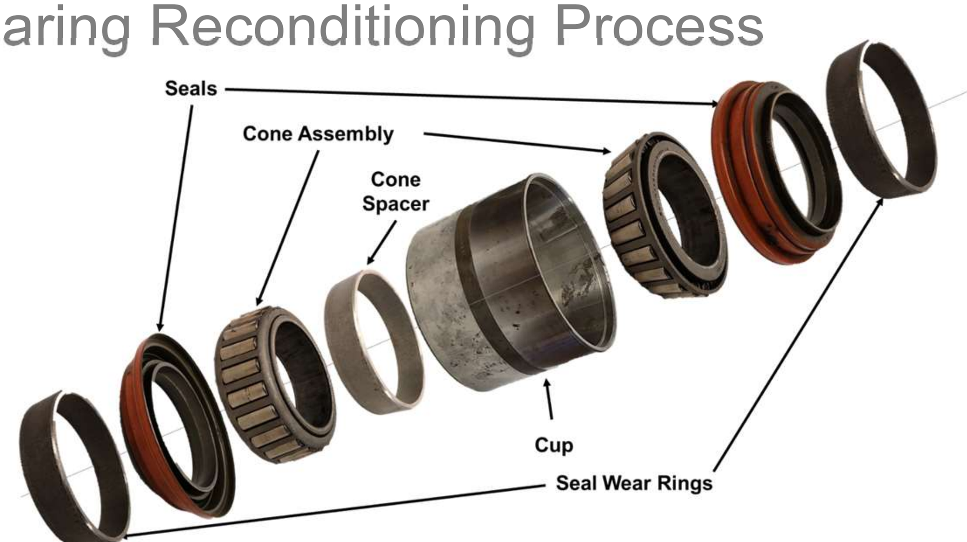
Bearing Reconditioning Process



Disassembled Roller Bearing

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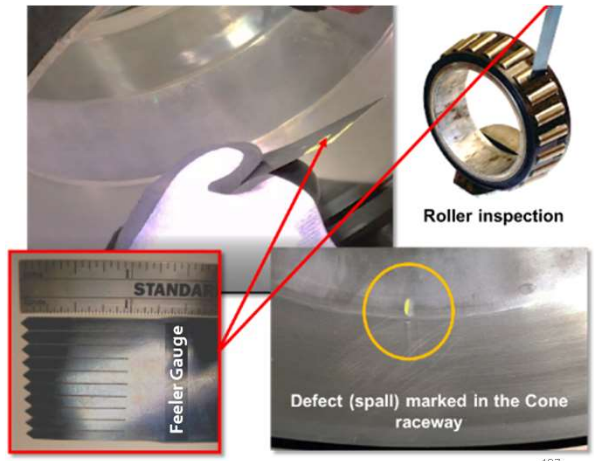
Bearing Reconditioning Process

- **Current inspection practices**
  - Visual inspection of component surfaces
  - Feeler gauge on raceway surfaces
- **Proposed an NDE system to find subsurface defects**

Bearing Inspection Process



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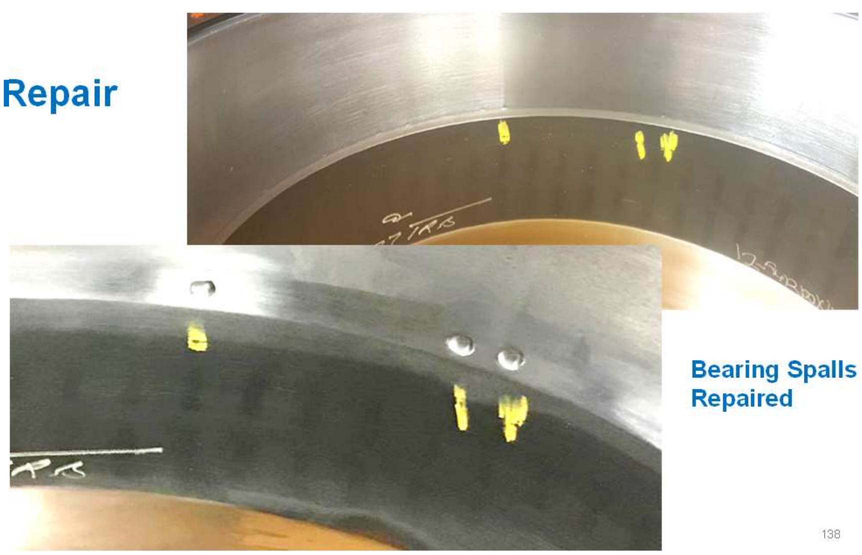
Bearing Reconditioning Process

Before Repair

After Repair



Bearing Spalls Repaired

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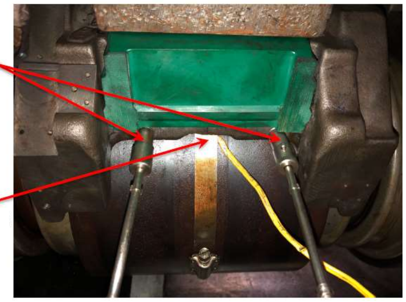
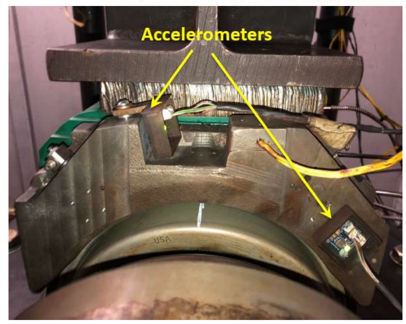
Previous Testing

- **Reconditioning did not negatively impact the bearing performance**
- **Performance of 12 bearings tested before and after reconditioning**
  - Paired test to assess change in performance after repairs
- **Five bearings had slightly lower operating temperatures**
- **Ten bearings had a decrease in vibration levels**
- **Three bearings had slightly higher operating temperatures, but still within normal bounds**

Bearing Monitored During Rig Testing





Bearing Monitored During Rig Testing

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Previous Testing

- **Previous test explored Bearing performance with spall repairs**
- **One of the repairs spalled early into the test**
- **Is there an inspection method that could determine if a repair will spall again?**

Area around repair spalling during test

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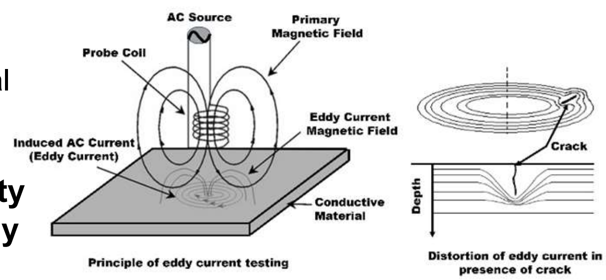
NDE Technology for Bearing Inspection

- **Eddy current testing uses electromagnetic induction principles**
  - Coil is excited with alternating current with frequency between 100 Hz – 10 MHz
  - Frequency based on the test material and depth of defect to be detected
- **Induced current on the material surface interacts with discontinuity in the material, disturbing the eddy current flow**
  - Change in impedance detected by the device

Eddy current inspection principles



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NDE Technology for Bearing Inspection

- **Eddy Current Array (ECA) technology has a wider coverage area than a single coil**
  - Larger surfaces scanned more reliability in less time
- **The *flexible* ECA probes allow complex surface geometries to be scanned, such as axles, wheels, and bearings**

Flexible eddy current array inspection

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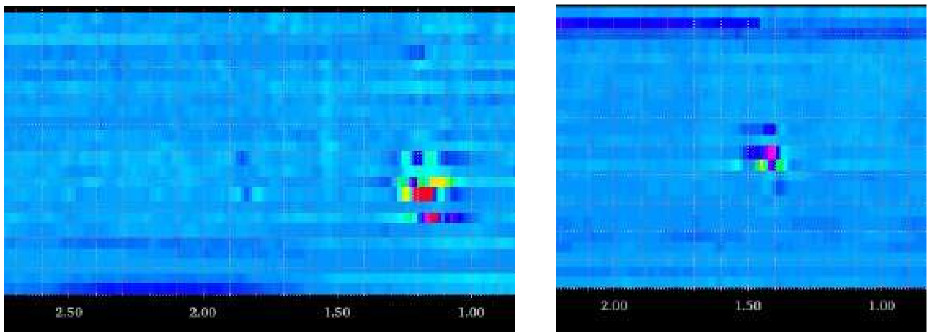
NDE Technology for Bearing Inspection

- **Flexible ECA displays indications as a heat map showing the location of anomalies**



Flexible ECA Indications

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Reconditioned Bearing Rig Test

Bearing Test Rig

- **Scanned 204 bearing cups with repairs on the raceway**
  - 33 showed indications (16%), including 7 cups with indications near the repair
- **Bearings were assembled and installed on four bearing test rig at University of Texas-Rio Grande Valley**
- **Performance was monitored to detect spalling on the raceway**

Bearing Cup Repair Test Method

- **Two sample sets**
- **First, bearing cups had no indications from ECA system**
  - Eight bearing cups
- **Second, bearing cups had indications near repair from ECA**
  - Seven bearing cups
- **Indications from the ECA near a repair may indicate subsurface damage that was not detected during the inspection**
- **Bearing cups with ECA indications may spall before the end of their expected service life**

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Reconditioned Bearing Rig Test

- **Bearings were loaded to about 35,000 pounds**
- **Axle was spun at an equivalent train speed of 85 mph**
- **The tests ran for up to 240,000 simulated miles**
- **Cup was rotated so repair was directly under load**

Bearing raceway spall during test

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Reconditioned Bearing Results

- **Row – Count of bearings that did or did not show indications from the ECA**
- **Column – Count of bearings that did or did not spall during the rig test**
  - Note: One bearing cup had two repairs in the raceway, where one repair had an indication and the other did not
    The repair that did not have an indication spalled

Rig Testing of Scanned Bearings

Bearing Outcomes	Spall During Test	No Spall During Test	Total
ECA Indication	1	6	7
No ECA Indication	1	8	9
Total	2	14	16

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Reconditioned Bearing Results

- **The presence or absence of ECA indication predicted the outcome of spalling during the rig test 56% of the time**
- **False Negative Rate: 50%**
- **False Positive Rate: 43%**

Rig Testing of Scanned Bearings

Bearing Outcomes	Spall During Test	No Spall During Test	Total
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AAR 28TH ANNUAL RESEARCH REVIEW

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AAR 28TH ANNUAL RESEARCH REVIEW

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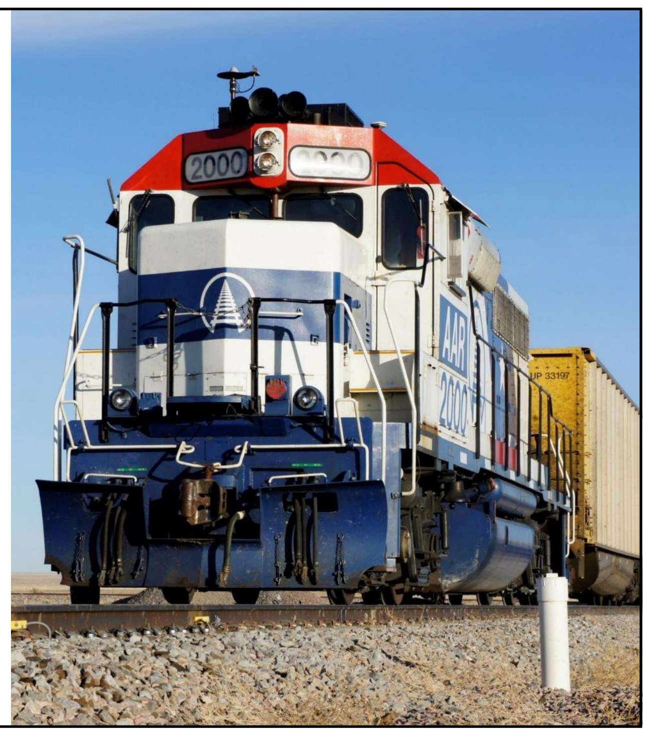
Path Forward

- **Develop understanding of what the ECA scans are physically detecting in the material**
  - Size and depth
- **Understand the difference between the indications that spalled during the rig test and those that did not**



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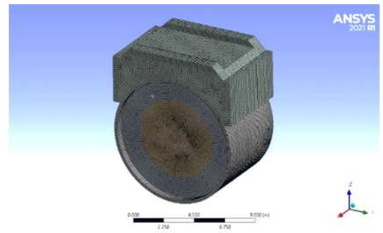
Other Research Avenues

- **Finite element model of roller bearing**
  - Accelerate testing by simulating many different repair possibilities
  - Answer industry questions about repair rules
- **Expand testing to water-etch bearings**



Finite Element Model of Roller Bearing

Water Etch on Bearing Raceway

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Other Research Avenues

Grease Sampling of Roller Bearing

- **Degradation of grease in bearings during periods of inactivity**
  - Understand the characteristics of grease when allowed to settle and not worked
  - Detect fretting wear or contamination of bearings during inactivity

28th Annual
Association of American Railroads
RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS
MxV RAIL

June 26-28, 2023 | Pueblo, CO

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Draft Systems Research

ASSOCIATION OF AMERICAN RAILROADS
MxV RAIL

Adam Klopp
Principal Investigator II – VTI
adam_klopp@aar.com

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Overview

- **Objectives**
- **Background**
- **Impact Testing of Draft Systems**
- **Modeling of Draft Systems**
- **Concluding Remarks**

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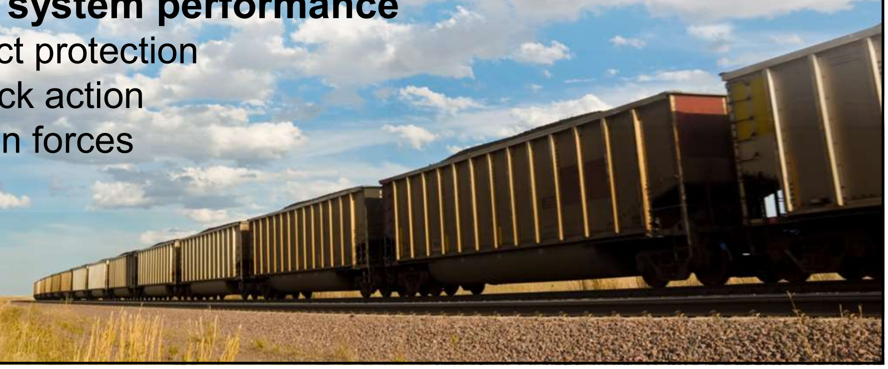
Objectives

- **Reduce service disruptions from:**
  - Component failures
  - Broken knuckles
  - Train separations
- **Improve draft system performance**
  - Provide impact protection
  - Limit train slack action
  - Control in-train forces



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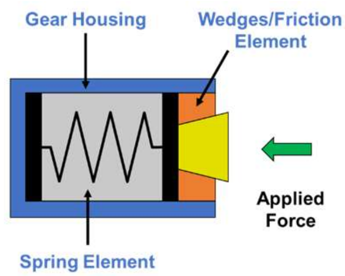
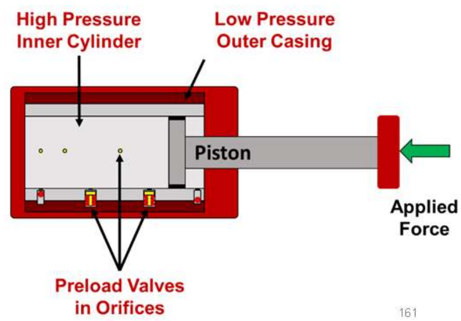
Background

- **Draft systems protect railcars and lading from coupler forces in a train**
  - Limit relative motion
  - Absorb impact energy
- **Common draft systems**
  - Friction draft gears (DG)
    - Short displacement stroke
    - Good control of train slack action
  - End-of-car cushioning (EOCC) units
    - Long displacement stroke
    - Good energy absorption in yard impacts





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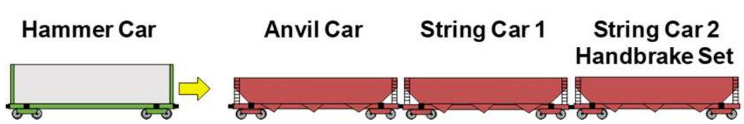
Draft System Evaluations

- **Historically done in North America through car-to-car impact testing or drop hammer tests from AAR's *Manual of Standards and Recommended Practices***
  - Good for evaluating impact protection and energy absorption
  - Not good indicators of in-train performance and slack control



M-921B Impact Performance Test Setup

- **Currently developing a combined testing and simulation methodology to evaluate impact and in-train performance**

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Impact Testing of Draft Systems

- **Impact tests conducted for six systems:**
  1. Friction draft gear
  2. Dual draft gear
  3. Elastomeric friction clutch draft gear
  4. Non-hydraulic long travel unit
  5. Standard 15-inch EOCC unit
  6. 13/2 active draft EOCC unit
- **Impact tests conducted to:**
  - Evaluate impact protection provided by systems, dynamic forces
  - Characterize the systems for use in modeling

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Impact Test Videos *(click for video)*

Video shows impacts at 5 mph, the highest common speed at which all systems were tested

Friction Draft Gear

Dual Draft Gear

Non-hydraulic Long Travel Unit

Elastomeric Friction Clutch Draft Gear

15-inch EOCC Unit

13/2 Active Draft EOCC Unit

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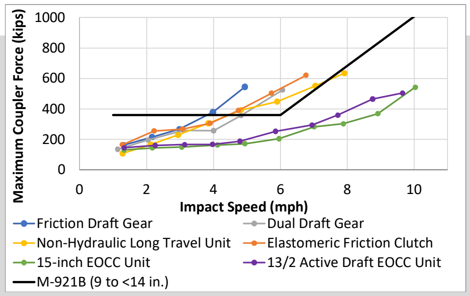
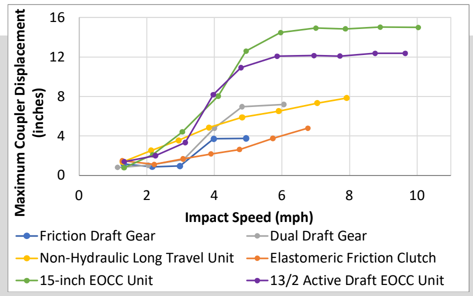
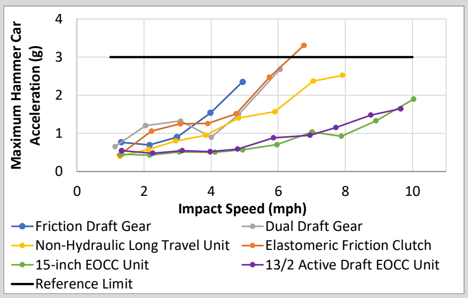
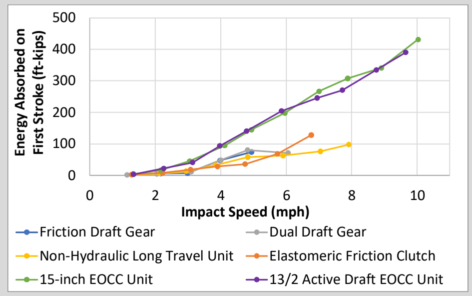
Impact Test Results









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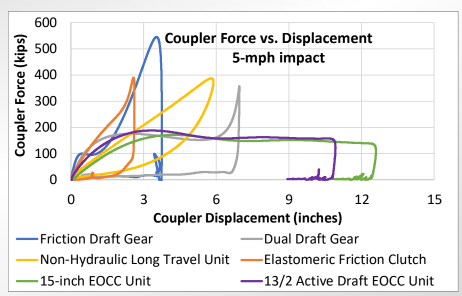
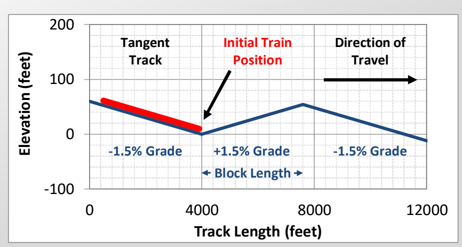
Modeling Draft System Performance

- **End-of-car Energy Management Task Force developing methodology to evaluate draft system performance**
- **Data from impact tests used to:**
  - Characterize draft system performance
  - Develop models of the draft systems
- **Drift simulations**
  - Block of 286,000-pound cars equipped with a single draft system type
  - No locomotives, no brakes
  - Block of cars allowed to “drift” through grade transitions
  - Intended to create slack action and evaluate in-train performance





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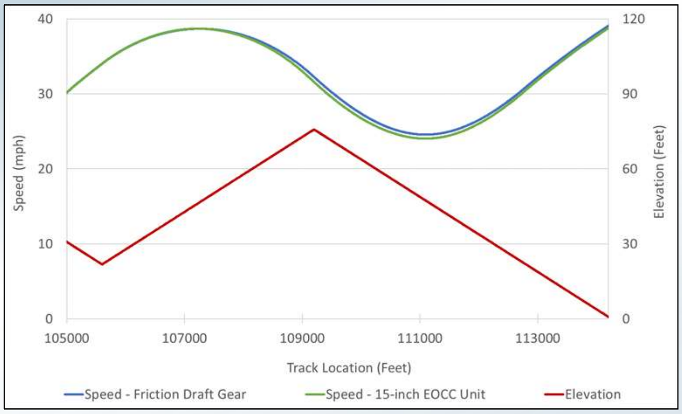
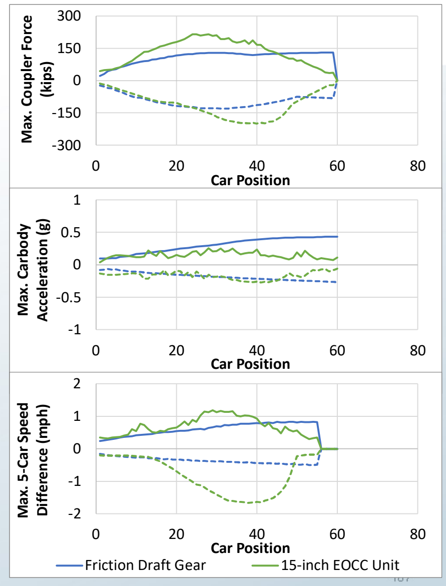
Example Drift Simulation





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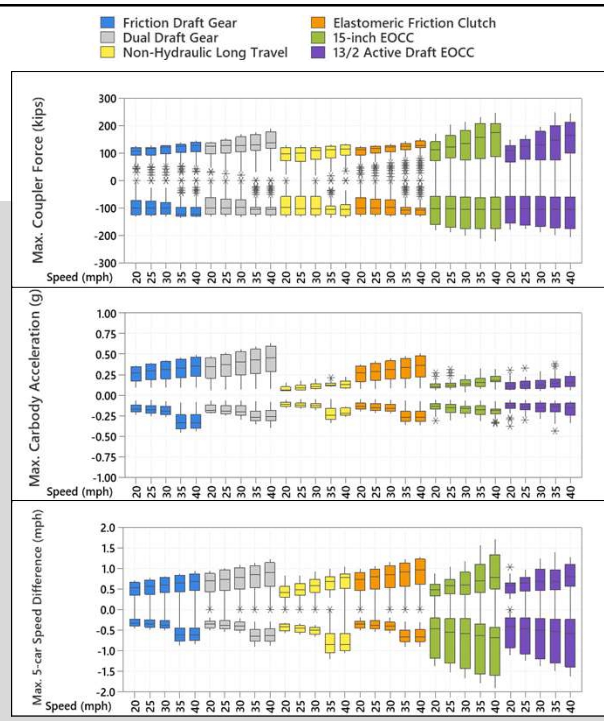
Drift Simulation Results

- **Results show that EOCC units generally provided less train action control**
  - Higher speed differences and forces develop
- **Friction draft gears and alternative units generally provided better train action control**
  - Limited relative motion and forces



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Summary

- **MxV Rail and the EOC Energy Management Task Force are developing a draft system evaluation Recommended Practice**
  - Supplement current impact tests with train action modeling
  - Update draft system evaluations for modern railroad environment
- **Impact tests showed EOCC units provided the most impact protection, while standard DGs provided the least**
- **Drifting simulations showed that standard DGs provided the most slack control, while EOCC units provided the least**
- **Alternative draft systems provided better impact performance than DGs but with a smaller displacement than EOCC units**

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Acknowledgements

TTX Company

End-of-Car Energy Management Task Force

MxV Rail Staff

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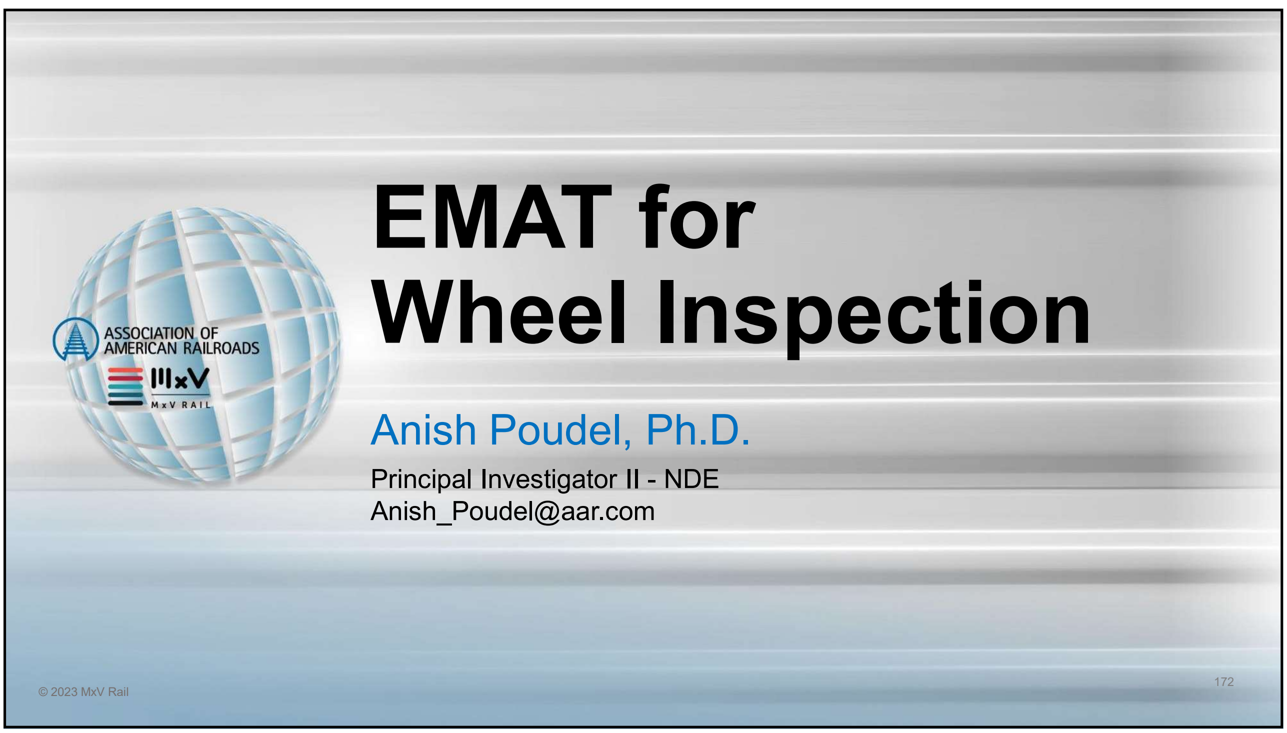

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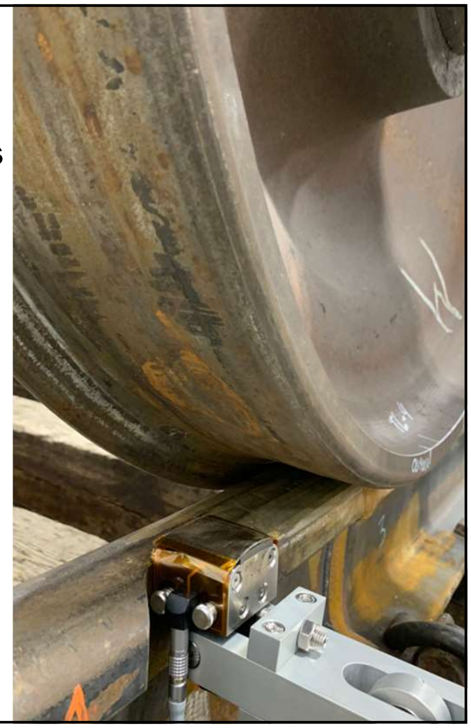
Overview

- **Project Motivation**
- **Wheel Subsurface Fatigue Crack Features**
- **In-Motion Wheel Inspection Challenges**
- **Existing Wheel Inspection Options**
- **Electro-Magnetic Acoustic Transducer (EMAT)**
  - Principles and Prior Work
  - New Method Development
- **Laboratory and Preliminary Field Test Results**
- **Path Forward**
- **Summary**
- **Acknowledgements**



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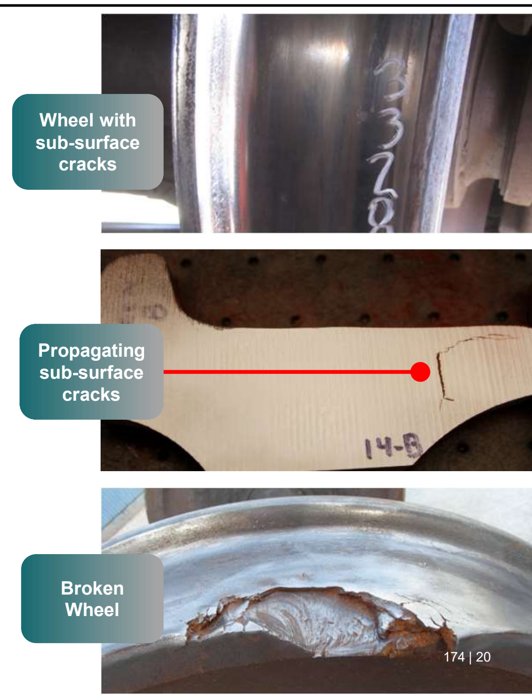
Project Motivation

- **Pursue safe, reliable, efficient train operations without mechanical interruption (origin to destination)**
- **Explore innovative alternative automated inspection systems**
  - Reliable and efficient real-time, in-motion wheel detection systems for autonomous equipment health monitoring
- **Key Objectives**
  - Reduce incidents due to broken wheels
  - Reduce mechanical interruption
  - Increase efficiency of wheel maintenance

DETECTING WHEEL DEFECTS AND FAILURES BEFORE THEY FIND US!



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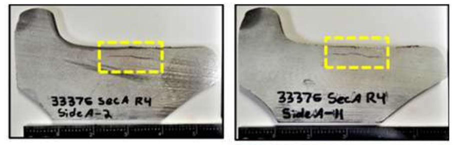
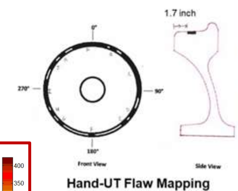
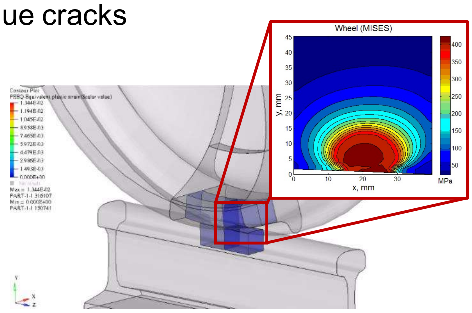
Sub-Surface Fatigue Crack

- **Broken wheels are results of sub-surface fatigue cracks**
  - Result of complex loading mechanisms and maximum shear stresses in the layer just beneath the wheel surface
  - If present, non-metallic inclusions or voids accelerates fatigue cracks







Wheel Rail Contact Stresses

Kiani, M. and Fry, G.T., 2017, "Fatigue Analysis of Railway Wheel Using a Multiaxial Strain-based Critical-plane Index," Fatigue Fract Eng Mater Struct., pp.1–13.

Broken Wheel

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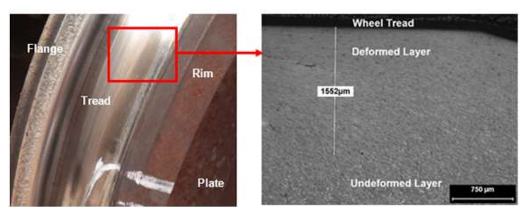
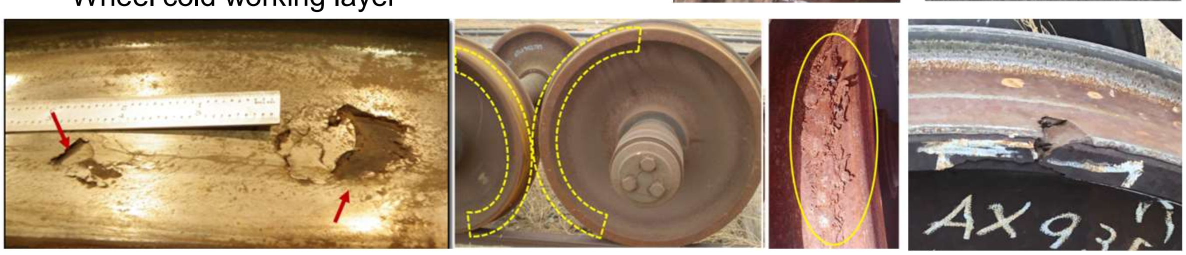
In-Motion Inspection Challenges

- **Common challenges to dynamically inspect railway wheels include:**
  - Spalling, shelling, and/or flaking
  - Differences in wheel rim/flange/tread thickness
  - Tread surface built-up or broken rims
  - Wheel cold working layer





Spalling / Shelling

Rim Thickness

Tread Built-up

Broken Rim

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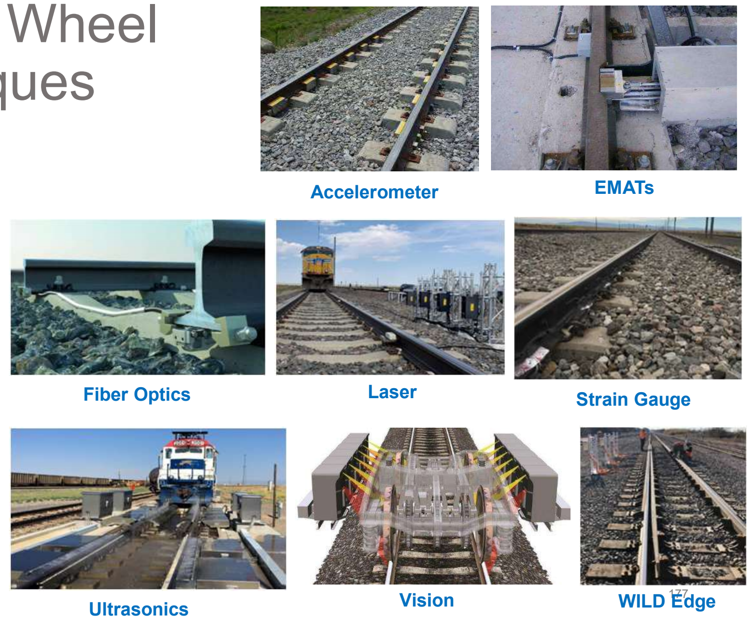
Existing In-Motion Wheel Inspection Techniques

- **Visible damage**
  - Vision
  - Laser
- **Mechanical damage**
  - Fiber optics
  - Accelerometer
  - Strain gauge
- **Internal damage**
  - Ultrasonic testing (UT)
  - EMATs



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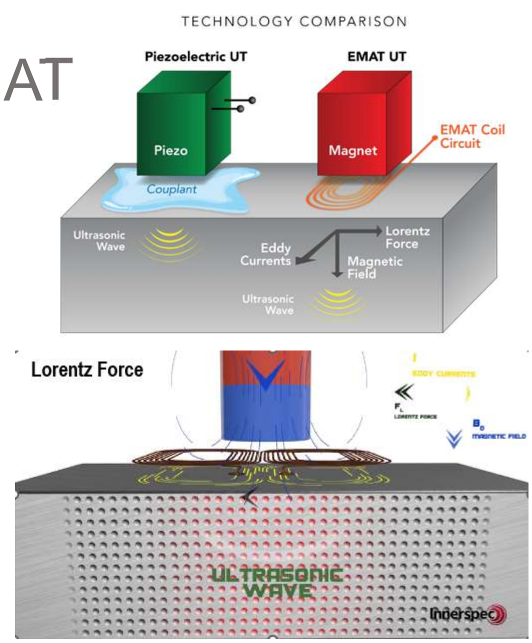
Piezoelectric UT vs. EMAT

- **Piezoelectric UT**
  - Generates ultrasound in a piezoelectric transducer
  - Ultrasound is transmitted (coupled) into the part using a liquid
  - Most common wave modes are “bulk” wave modes including longitudinal (normal beam) and shear vertical (angle beam), not practical for guided waves
- **EMAT UT**
  - Generates ultrasound in the part using electromagnetic induction through two basic mechanisms: Lorentz force and magnetostriction



Video/Photo Courtesy: Innerspec Technologies

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EMAT Prior Work

- **EMAT is not a new method or technique**
- **Pioneering work on EMAT for wheel/rail inspection led by researchers at North American Rockwell Science Center & National Institute of Standards and Technology (NIST) in the 1980s**
- **Later research explored surface waves for wheel inspections using electromagnet in lieu of permanent magnets to improve durability (2000s)**
- **All suffered from successful/reliable field demonstration!**

Photo Courtesy: Quingdao Depot


Photo Courtesy: Mermec Group

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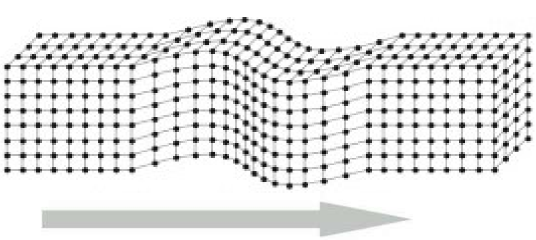
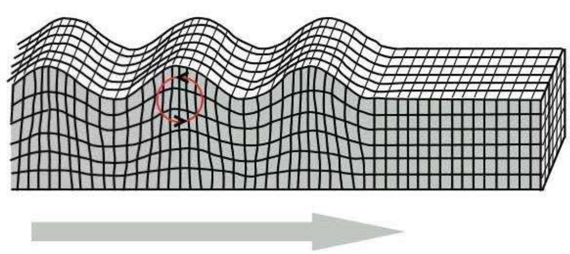
Shear Horizontal (SH) Guided Waves EMAT

- **Our approach is fundamentally different**
  - Using Shear Horizontal (SH) guided wave modes:
    - Particle motion is parallel to surface plane of entry and perpendicular to direction of propagation
    - Penetration depth is equal to one wavelength with a practical range from 1-25mm
    - Not affected by dirt, water, or rolling surface conditions


SH Waves


Surface Waves

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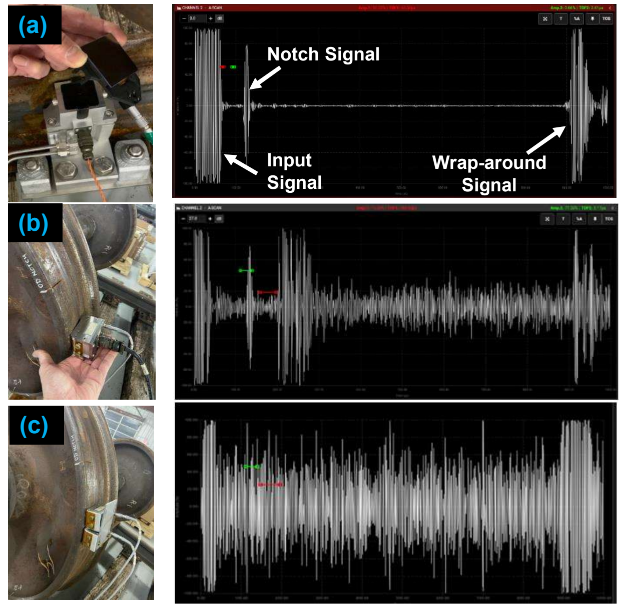
SH Wave EMAT Laboratory Test Results

- **EMAT Approach Comparison**
  - a) Magnetostrictive strip with DC electromagnet
    - 3dB gain to reach 80% flaw response
    - Baseline noise of 2%
    - Signal-to-noise (SNR) ratio: 32dB
    - Defect detectable from 5° to 175° with almost no deterioration of the signal
    - Saturated wraparound signal at 180°
    - Proposed method
  - b) EMAT with pulsed electromagnet (magnetostriction)
    - 27dB gain to reach 80% flaw response
    - Baseline noise of 30%
    - SNR ratio: 8.5dB
    - PPM pitch-catch (Lorentz force)
    - 57dB gain to reach 80% flaw response
    - Poor SNR

Notes:
- Flaw - surface notch 8 in. away from sensor
- No signal averaging required

EMAT Signal Comparisons



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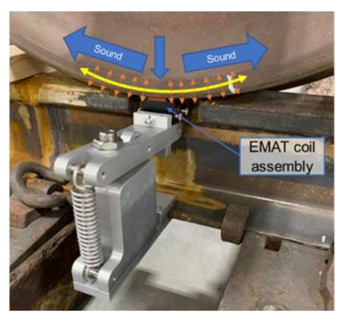
SH Wave EMAT Laboratory Test

- **Pressure-Coupled Magnetostrictive Patch Approach**
  - Magnetostrictive patch is a 0.010” thick Iron-Cobalt (FeCo) alloy that couples with the wheel and protects the EMAT coil underneath
  - Coupling pressure is less than 50 psi with minimal strain on sensor and actuator
  - The transduction process does not require liquids and the sensor can withstand temperatures from -40°C to +200°C
  - Generates >20dB (10x) more signal amplitude than the surface wave EMAT and penetrates deeper in the tread



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Laboratory Testing Demonstration *(Click for video)*

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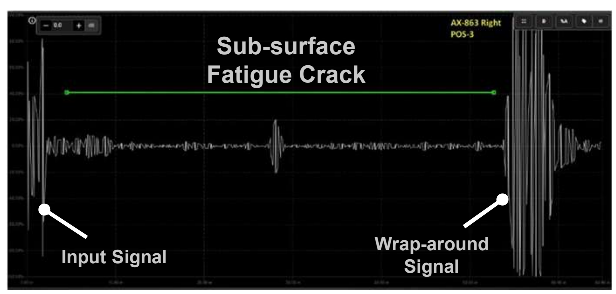
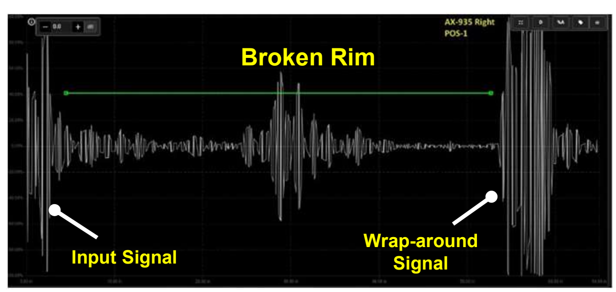
Laboratory Testing Results

- **Five different wheelsets from FAST with machined reflectors, broken wheel, and sub-surface fatigue cracks were tested in 12-foot panelized track**
- **Magnetostrictive path SH wave technique was able to detect all the defects on these wheelsets initially tested**
- **This success paved for the further development of the sensor**





EMAT Signal Amplitudes

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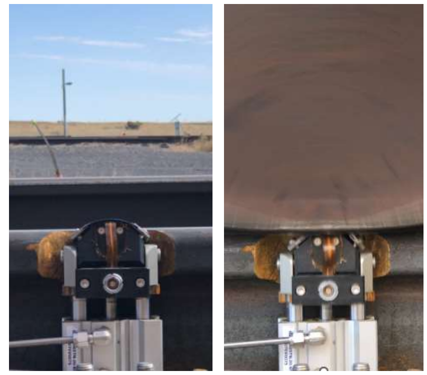
EMAT Sensor Durability Testing

- **The goal is to test the endurance of:**
  - Magnetostrictive strip and coil assembly
  - Coupling mechanism
  - Pneumatic actuator
- **Different versions of the strip with different annealing methods are undergoing testing**
- **One strip version sustained 1 million wheel passes in the rolling load fixture**
- **The coupling mechanism and pneumatic actuator are also holding well**

FAST EMAT sensor testing on a sidetrack



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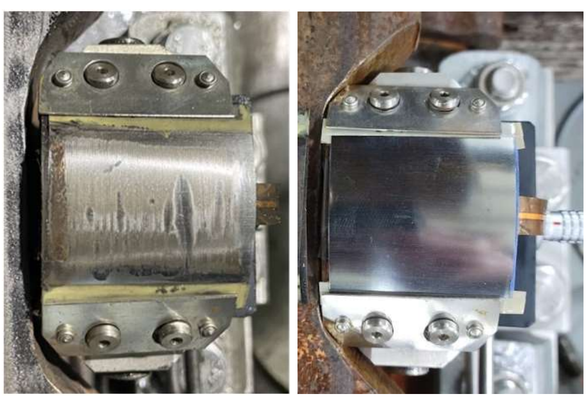
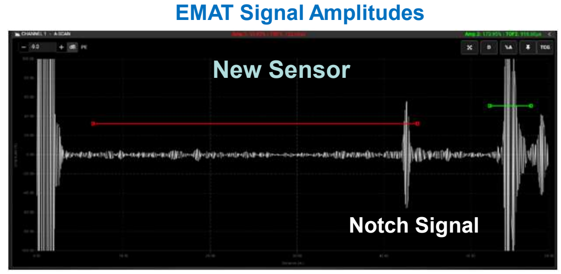
EMAT Sensor Signal Quality

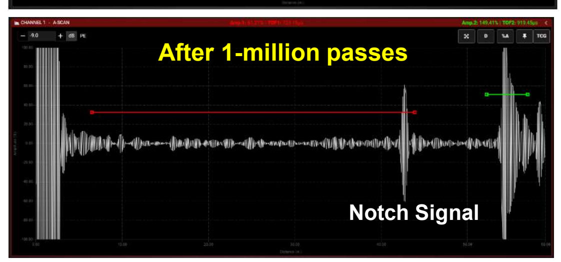
No deterioration in EMAT signal when tested over wheel with artificial notch



After 1 million passes **New**

EMAT Signal Amplitudes





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(Click for video)

The Path Forward

- **Cyclical tests using a rolling load fixture to estimate long-term sensor longevity (ongoing)**
- **Design final version of the sensor and actuator for final field tests**
  - Multi-frequency RF coil for depth discrimination
  - Expected to be finished in Q3 2023
- **Design final instrument for field tests**
  - Four to five sensor heads per side for redundant inspection
  - Ruggedized for field use
  - Field installations and testing starting Q3 2023

Rolling Load Fixture
EMAT Sensor Testing

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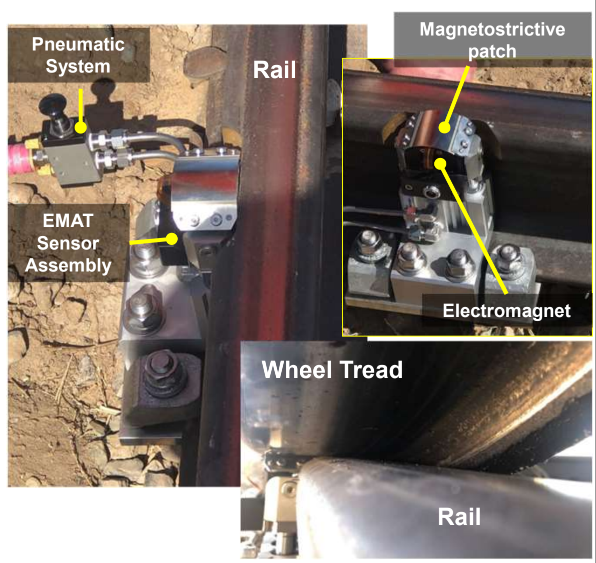
Summary

- **EMAT development – key points**
  - Does not require couplants
  - Withstand temperatures -40° to +200°C
  - Not sensitive to dirt, grease, and other wheel surface conditions
  - Does not require extensive trackwork and structure
  - Good SNR ratio
  - Detects cracks at different depths (1- 25mm)
  - Can achieve higher speeds (30 mph+)



EMAT sensor assembly installed on notch rail track

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A A R 2 8 T H A N N U A L R E S E A R C H R E V I E W

Acknowledgements

MxV Rail Team
Innerspec Team
AAR SRI Program
AAR Research Committee

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Track Inspection Technology

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Principal Investigator I
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Overview

- **Project Objectives**
- **Automated Track Inspection (ATI) Pilot Program**
- **Performance-based Vehicle/Track Interaction (VTI) Monitoring Technology**
- **Summary**
- **Acknowledgements**

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Project Objectives

Track health assessment is fundamental priority for railroads

- **Evaluation of non-traditional track monitoring technologies**
- **Continued improvement of track safety**
- **Optimized resource utilization for maintenance efforts**

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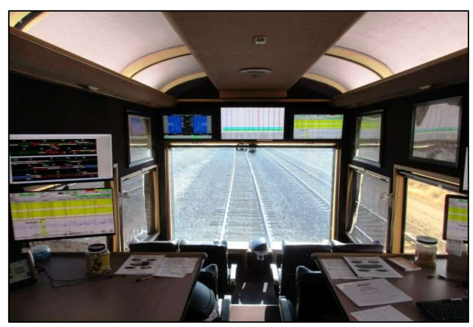
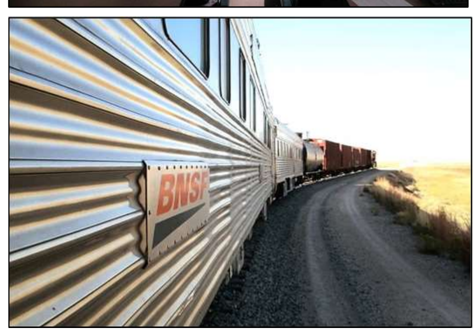
Pilot Test Program

- **Support AAR and Class I railroads in Pilot Testing Programs for Automated Track Inspections (ATI)**
  - Equipped on a moving train uses lasers and cameras to measure track geometry and track components
  - Benefits of improvements in inspection safety and efficiency





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Pilot Test Program

- **Data received from six Class I railroads**
- **Report No. 1**
  - US systemwide mainline track geometry data 2016 – 2017 (pre-pilot testing)
- **Report No. 2**
  - US Pilot corridor track geometry data 2016 – 2017 (pre-pilot testing)
- **Report No. 3**
  - US Pilot corridor track geometry data since pilot test program starts
- **Report No. 4**
  - Visual inspection data for Pilot territory 2016 – 2017 (pre-pilot testing)
  - Visual inspection data for Pilot territory since pilot test program starts
- **Track-Caused Derailments**
- **Track Authorities**
- **Highway Grade Crossing**

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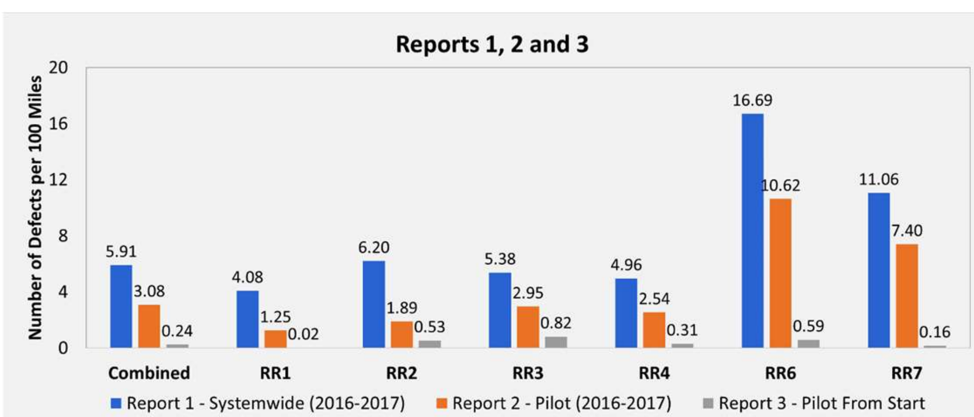
Defects per Inspected 100 Miles

- **Combined and individual railroads – Reports 1, 2 and 3**



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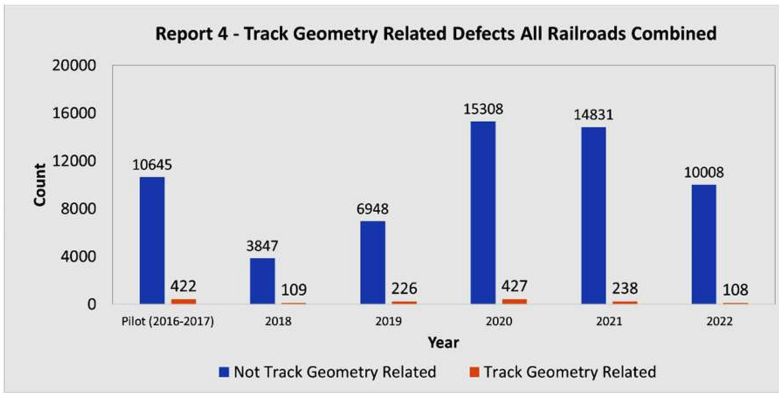
Geometry vs. Non-geometry Defects

- **Combined railroads for visual inspections – Report 4**
  - 60-80 percent non-geometry defects were in turnouts and special trackwork



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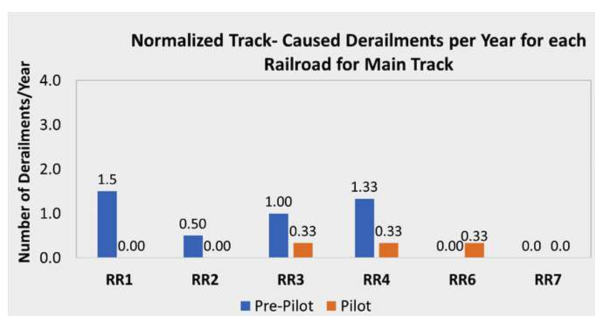
Reportable Track-Caused Derailments

Railroad ID	Reportable Track Caused Derailments	
	Pre-pilot	Pilot Test Period
RR1	3	0
RR2	1	0
RR3	3	1*
RR4	4	1*
RR6	0	1**
RR7	0	0



* Broken rails occurred while visual inspections were still being conducted twice weekly.

** Pilot testing was inactive when derailment occurred.

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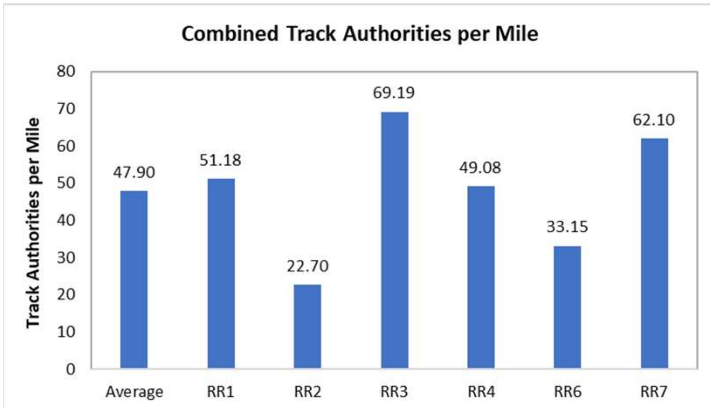
Track Authorities in Pilot Territory

- **Track authorities issued per track mile for each railroad**
  - Improved human safety for inspectors with reduced on-track exposure



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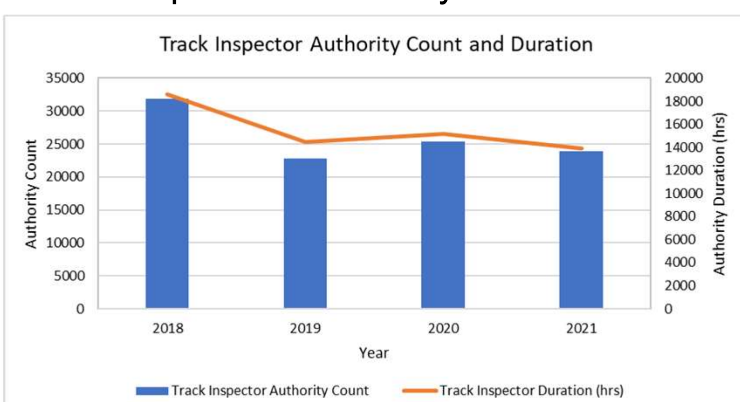
Track Authority Pilot Data – RR3

- **Track Authority hours and count**
  - Reduced visual inspection to weekly in 2019



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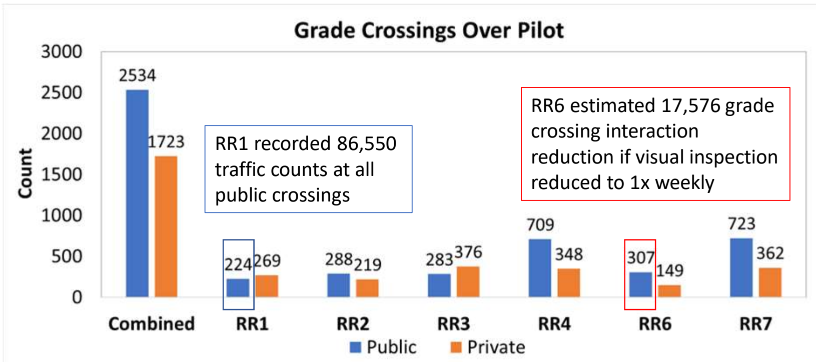
Grade Crossings in Pilot Territory

- **Combined and individual grade crossings**
  – Reduces exposure risks for the inspectors and the public
  – Setting hi-rail vehicle on wrong track



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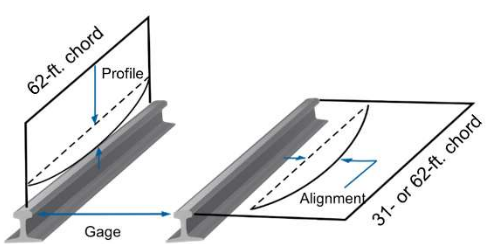
Performance-based VTI Monitoring Technology

- **Track geometry consists of measuring the positioning of railroad track**
- **Vehicle-track interaction (VTI) inspection systems**
  – Measure vehicle dynamics, such as acceleration



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Performance-based VTI Monitoring Technology

- **Instrumented Freight Car**
  - Aims to optimize track maintenance practices
  - Equipped with accelerometers
  - Relates vehicle dynamics to:
    - Track condition
    - Operating speed
  - Continuous data collection
  - Exception reports
  - Runs with FAST train
    - Nightly track health assessment

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Performance-based VTI Monitoring Technology

- **Examination of Track Geometry Measurement Vehicle and Instrumented Freight Car**
  - Six tests at FAST

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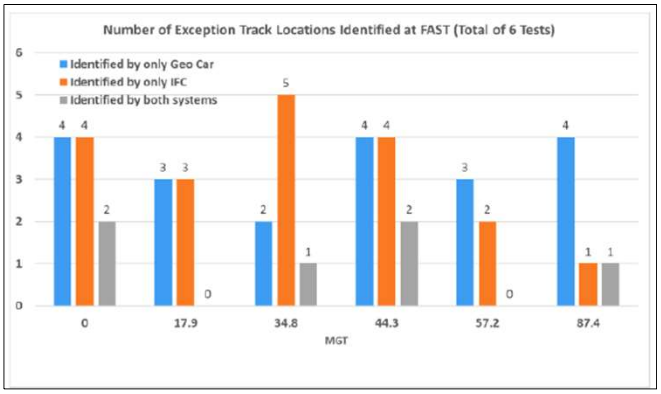
Performance-based VTI Monitoring Technology

- **Exceptions identified by IFC did not always relate to track geometry defects**
- **IFC has the potential to supplement current track geometry measurements to optimize maintenance and improve track safety**



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Summary

- **ATI technologies can improve track safety by inspecting the systemwide track integrity**
  - Inspection frequency and inspection miles increased substantially using ATI technologies. The number of defects per 100 inspected miles in the pilot corridor reduced from 3.08 in the pre-pilot testing period to 0.24 during the pilot testing.
  - No mainline derailments were attributed to ATI-targeted defects while the pilot programs were active.
  - ATI technologies could reduce visual inspection trips, therefore could reduce the exposure risks for the workforce and the public.
- **Visual inspection documented substantially more non-geometry detects than geometry defects. The majority of the non-geometry defects are related to turnouts and special trackwork.**
- **Performance-based inspection technology may supplement the current track geometry measurements to optimize maintenance and improve track safety**

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Acknowledgements

AAR Engineering Policy Committee

Class I Railroads

MxV Rail Data Science Group and Instrumentation Team

Abe Meddah (formerly MxV Rail) and Silvia Galván-Núñez

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Locomotive Undercarriage Thermal Inspection (LUTIS)

Matthew Witte, Ph.D.
Scientist
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Overview

- **Historical Background**
- **The Concept**
- **Development**
- **In-service Testing**
- **Implementation**
  - Successes

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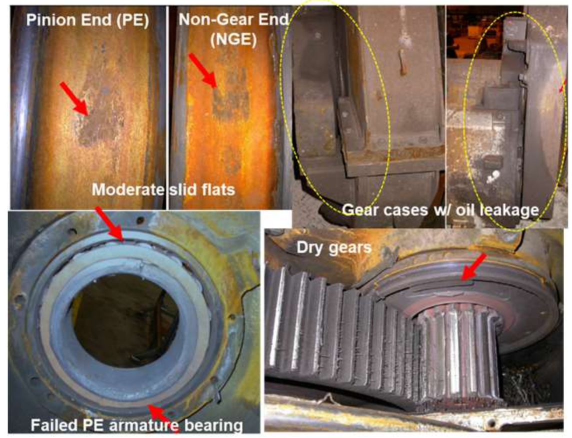
Historical Background

- **Concept proposed by the Research Committee in 2014**
- **High-Load components not reliably monitored**
- **Figure out how to apply thermal scan technology on locomotives**
- **Provide advance warning**
- **Avoid Traction Motor lockup!**



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Thermal Imaging

- **Full-field thermal camera**
  - In-shop study 2015
  - Colors show temperatures
  - Heat map
- **Wheel is yellow (104°F)**
- **Gearbox is green (84°F)**

(Click for video)

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SRI Project Approach

- **Look for applications of interesting technologies**
- **Evaluate performance relative to requirements**
- **Invite the supply community to develop concepts**
- **Two companies accepted**
  - Different approaches
    - Several sensors each aimed at components of interest
      - Monitor the sensor array for high readings
    - Line-scan technology to cover the entire field
      - Image analysis to find hot spots

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Supplier 1 – Concept Development

- **Optimize sensor position**
  - Adjustable rack

- **In-track test system**
  - Fixed thermal sensors on ties

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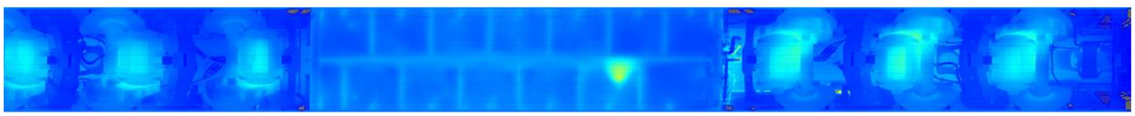
Supplier 2 – Concept Development

- **Line-scan thermal imaging**
  - Whole-field thermal image
- **Camera box mounts on ties**
  - Coincident with optical system



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Validation at FAST

- **Simulated component failure**
  - Detect hot plate under locomotive

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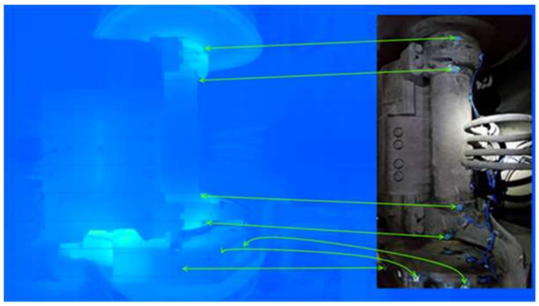
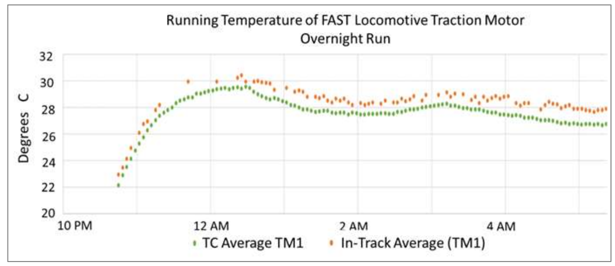
Validation at FAST

- **Thermocouples on Loco**



- **TCs and LUTIS correlate well**



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In-service Evaluation

Class 1 Railroad

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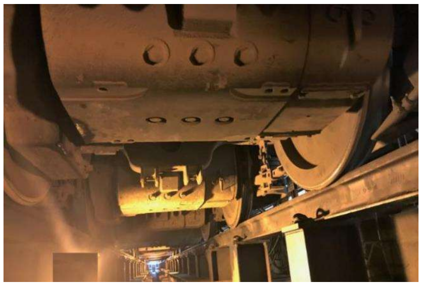
Pathway to Implementation



- **2014–2019: Initial concept testing**
  - Completed evaluation at FAST
  - TD19-013
- **2020–2021: In-service evaluation**
  - Define evaluation criteria
  - Three vendors install on Class 1 (Two completed)
  - Monitor performance
- **2022: Results published**
  - TD22-008 and TD22-009
- **2023: Ongoing implementation**

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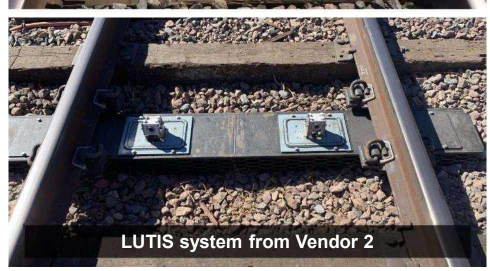
In-Service Evaluation

- **Systems installed Lenwood, CA**
- **Thirteen-month trial**
  - Started early June 2020
  - Concluded late June 2021
  - Instrumented three locomotives
- **Objectives**
  - Document normal range of locomotive component temperatures
  - Validate wayside LUTIS performance
  - Recommend data standards

LUTIS system from Vendor 1



LUTIS system from Vendor 2

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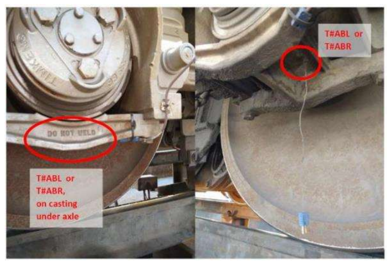
Thermocouple (TC) Placements

T#GC	Located on bottom of **Gear Case** (“GC”), in line w/ axle
T#UBL	Located near **U-Tube** Bearing (“UB”), left/conductor side
T#UBR	Located near U-Tube Bearing (“UB”), right/engineer side
T#MBL	Located near **Motor Bearing** (“MB”), left/conductor side
T#MBR	Located near Motor Bearing (“MB”), right/engineer side
T#ABL	Located under **Axle Bearing** (“AB”), left/conductor side
T#ABR	Located under Axle Bearing (“AB”), right/engineer side
T#MC	Located in center & bottom of **Motor Case** (“MC”)

- **Very rich data set**
  - Warmup profiles
  - Ambient temp extremes
  - High load (grades)
  - Nominal load (flat land)
  - Correlate with LUTIS



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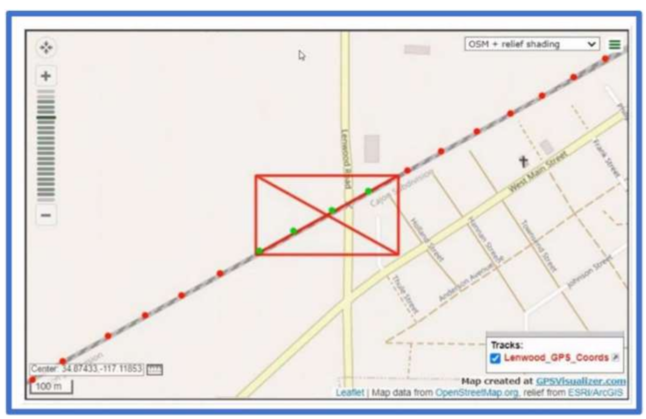
Geo-fencing to Correlate TC and LUTIS

- **Date Range: 6/1/20–6/30/21**
  - Geo-fence
  - Captures data when near LUTIS
- **Three locomotives**
  - GE-DC Motor, C44-9W
    - Total pass recorded: 33
  - EMD-AC Motor, SD70ACe
    - Total pass recorded: 23
  - GE-AC Motor, ES44AC
    - Total pass recorded: 28



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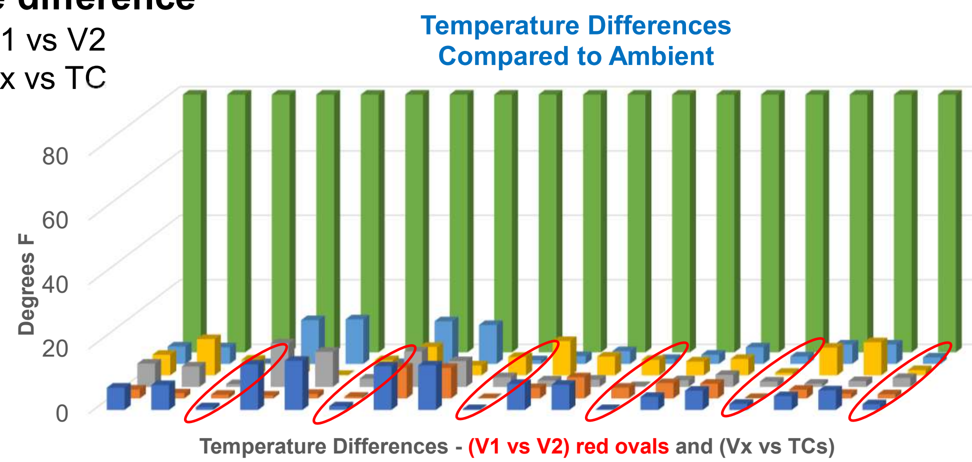
Correlations - LUTIS and TC Measures

- **Average difference**
  - 2 oF V1 vs V2
  - 6 oF Vx vs TC



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In-Service Examples (Reported by Host)

- **More than 120 “events” in the first year**
  - Trace back to “most recent pass”
  - Found indicators in all cases
- **Developing alert strategies**
  - Delta from ambient
  - Component specific
  - Trending
- **Examples follow**

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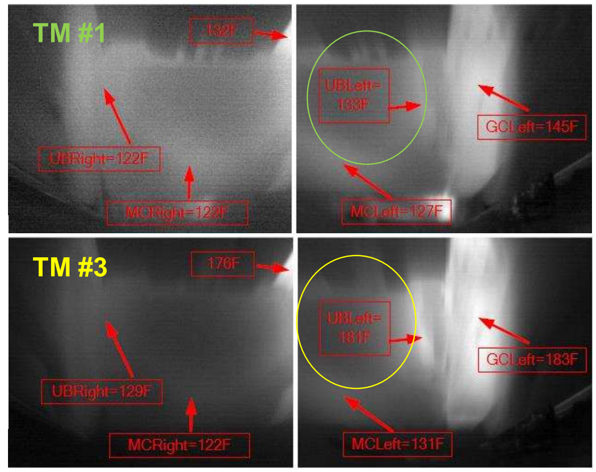
Example Locomotive A – TM 3 Failed

- **Passed detector 1 day prior**
  - No actionable alarms
- **Indicators from both systems**

Vendor # 1

Vendor # 2



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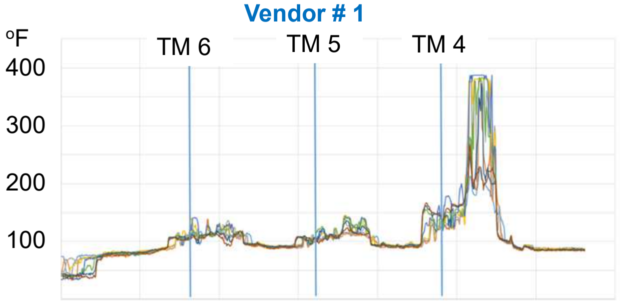
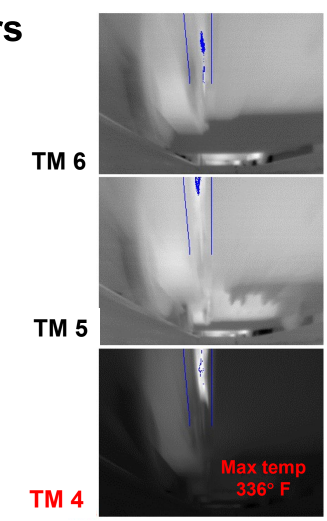
Example Locomotive B – TM 4 Failed

- **No actionable alarms from other detectors**
- **Indicators from both LUTIS systems**

Vendor # 1



Vendor # 2



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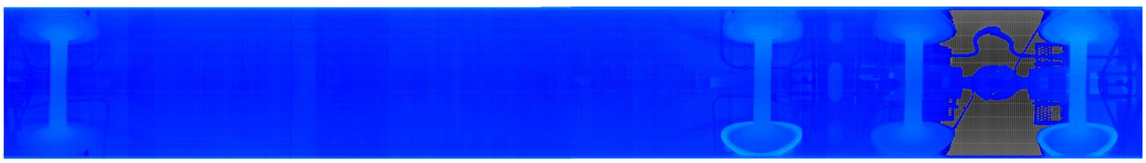
Summary

- **Thermal scanning is effective for monitoring TM health**
  - At least one Class 1 railroad is implementing it in a big way
    - Well received by the host railroad
    - Internal recognitions for implementation
- **Applications beyond locomotive**
  - Wheel temperature image from testing at FAST



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Acknowledgements

Research Committee for funding and support

Mike Iden for the idea

Class-1 Host Hark Braren for championing
the work through to completion

Team MxV Rail
Anish Poudel
Ryan Alishio

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Voestalpine
Progress Rail
Trimble – Beenavision
KLD Labs
Duos Technologies

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Thank you

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Wheel-Rail Profile Design and Maintenance

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Overview

- **Introduction to Project**
- **Asymmetric Hollow Wear**
- **Derailments at Switches**
- **Grinding Template Analysis**
- **Closure**

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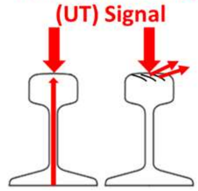
Project Introduction

Rolling contact fatigue (RCF) damage

Ultrasonic Testing (UT) Signal



"Loss of Bottom"

Wheel tread spalling

Rail gage corner shelling

Wheel and rail wear

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Asymmetric Hollow Wear

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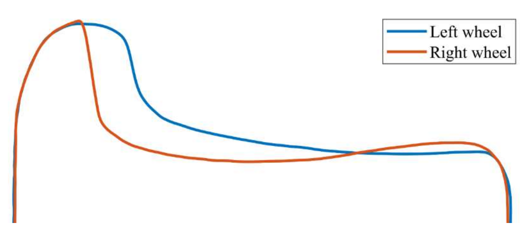
Introduction

- **Asymmetric hollow worn wheels increase:**
  - Rolling contact fatigue (RCF)
  - Turnout damage
  - Lateral forces
  - Component fatigue
- **Infrastructure and car owners benefit from reduced wheel wear**
- **Ongoing effort at MxV Rail to determine root cause of asymmetry**



Example of asymmetric hollow wear

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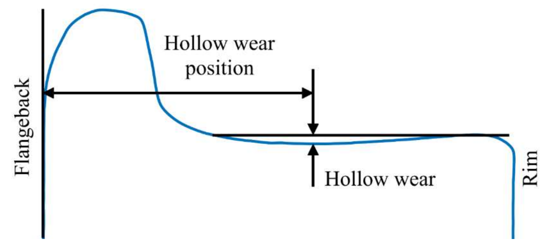
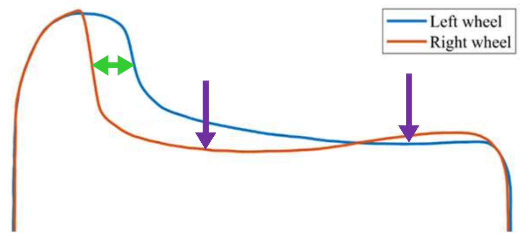
Method

- **Measured data from wayside wheel profile detector (WPD)**
  - ~4 million records including car numbers, truck, axle information
- **Umler® database for railcar type**
- **41,700 manufacturing records of wheel diameters**



Calculation of hollow wear and position



Calculation of hollow wear difference

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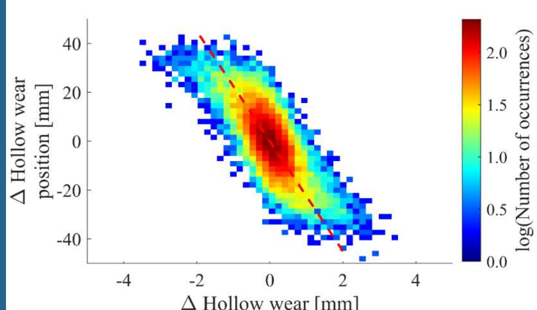
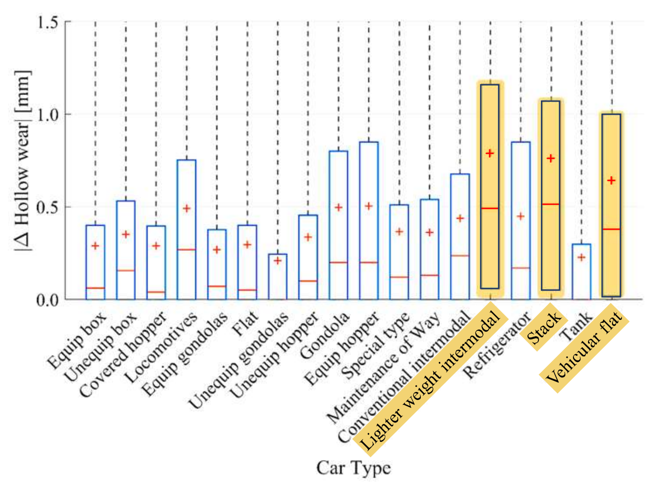
Results



Hollow wear position versus difference in hollow wear



Difference in hollow wear per railcar type

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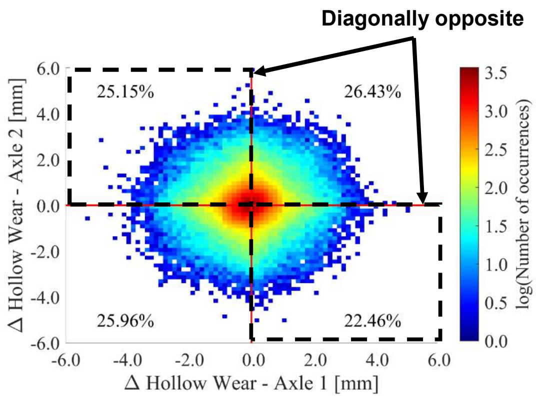
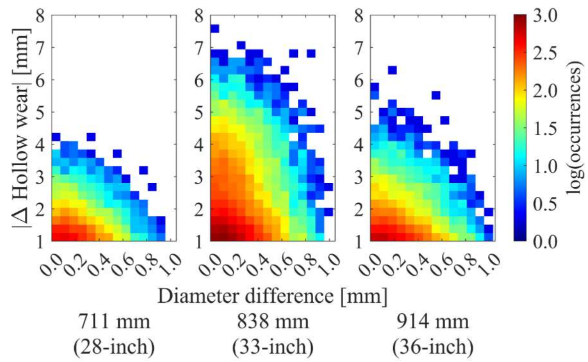
Results



Comparison of hollow wear difference on Axles 1 and 2



Hollow wear difference as a function of initial diameter difference

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Conclusion

- **Hollow wear difference related to difference in hollow wear location**
- **Asymmetric hollow wheel wear**
  - Develops more noticeably on intermodal and vehicular flat railcars
  - Not found on diagonally opposite wheels
  - Is not caused by the initial diameter difference of mate wheels
- **Several root cause hypotheses have been eliminated**
- **Root cause of asymmetric wheel wear remains unidentified**

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Investigation of Derailments at Switches

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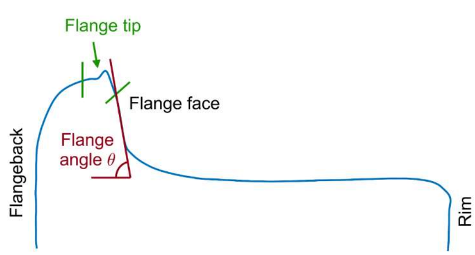
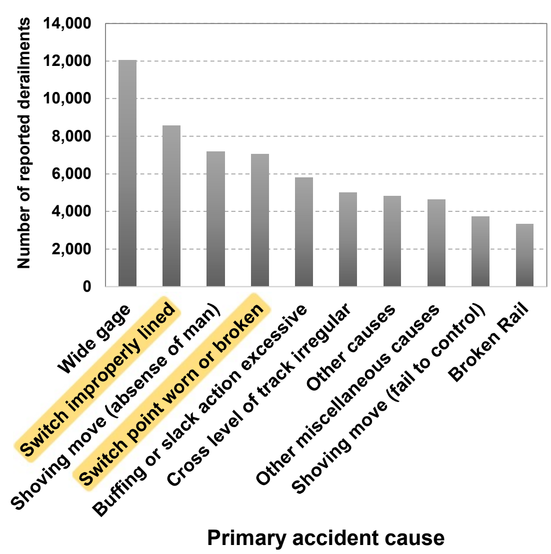
Introduction

- **Turnouts are common and require considerable and expensive maintenance**
- **Study flange tip radius contribution to derailments at switches**



Selected worn wheel terminology with sharp flange and acute flange tip radius



Leading causes of derailments (1975 to 2021)

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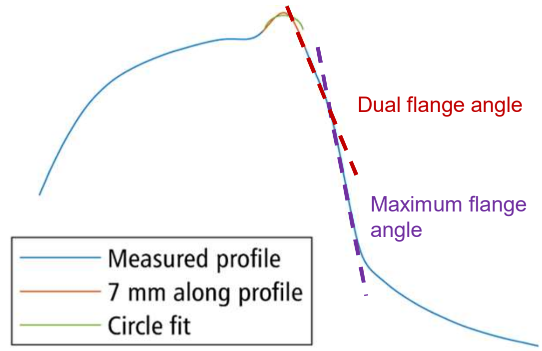
Method

- **320,000 wheel profiles**
- **Minimum flange tip radius**
- **Maximum flange angle**
- **Noted dual flange angle**
- **Identified 9 wheels**
- **NUCARS®* analysis:**
  - Lateral wheelset displacement
  - Angle of attack
- **CAD models of wheel and rail**



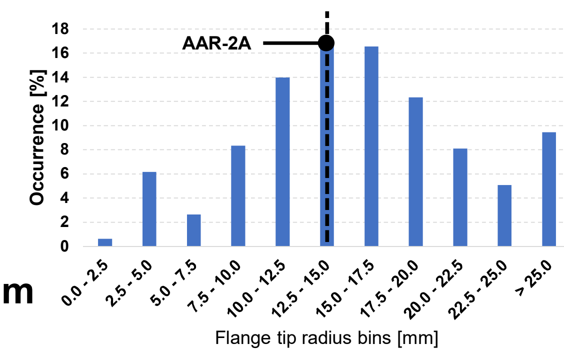
Calculation of minimum flange tip radius and flange angles

3D CAD model of turnout switch and stock rails

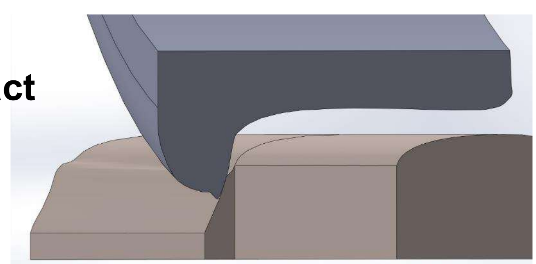
**NUCARS® is a registered trademark of Transportation Technology Center, Inc.*

Results

- **Flange tip radii > AAR-2A as a result of calculation process**
- **6.8% had flange tip radius < 5mm**
- **Wheelsets running with:**
  - Tracking offset
  - Larger angle of attack
- **Flange contact fore of tread contact**
- **Wheels would be guided away**
- **No switch picking was identified**
  - Gap > 3/8 inch



Distribution of calculated flange tip radii



Wheel contacting switch point

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Conclusion

- **Turnouts that are adequately maintained do not pose a derailment risk to severely worn wheels**
- **Wheel profiles with acute flange tip radius could pose an increased derailment risk when:**
  - Switch maintenance and adjustment is poor
  - Switch chipped or broken
  - Potential contact with dual flange angle

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Analysis of Grinding Templates

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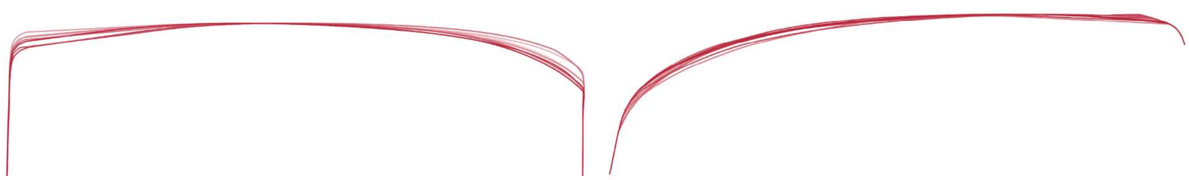
Introduction

- **Wear and RCF performance influenced by transverse rail profile**
- **Railroads develop and optimize their own rail profile grinding templates**
- **AAR-2A wheel profile is the standard wheel profile**
- **While still many worn AAR-1B wheel profiles in service**
- **Assess the performance of railroads rail profile templates**



Low Rail Templates **High Rail Templates**

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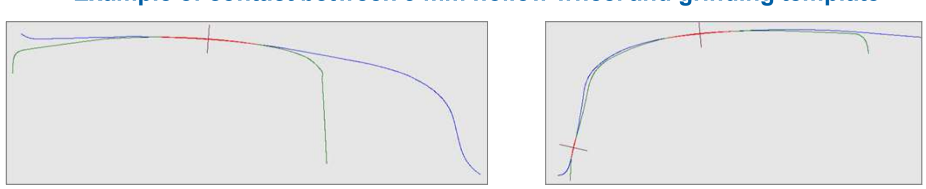
Method

- **NUCARS® simulations**
  - Loaded grain hopper car at 286,000 pounds
  - Qualified M-976 trucks in a new condition
  - Measured AAR-1B wheel profiles representing 0, 1, 2, 3, & 4 mm hollow wear
  - Three curvatures 3, 6, and 9 degrees
  - Superelevation resulting in a balance speed near 25 mph
  - Used narrow, nominal and wide gauge

Example of contact between 3 mm hollow wheel and grinding template



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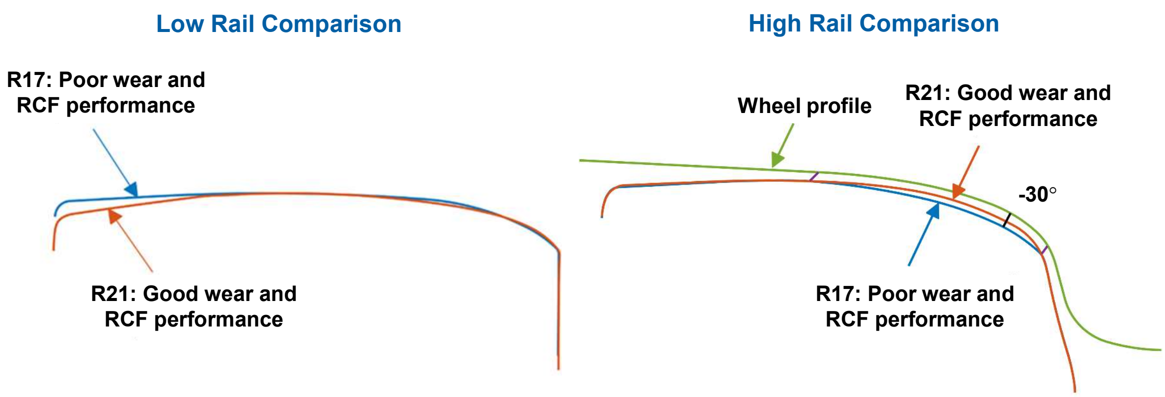
Results



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AAR 28TH ANNUAL RESEARCH REVIEW

Summary, Conclusions & Future Work

- **Asymmetric hollow wear**
  - Many hypotheses were investigated and disproven
  - Root cause is still unidentified
  - Root cause analysis is ongoing
- **The contribution of wheel profiles in derailments at switches**
  - Turnouts that are adequately maintained do not prose a derailment risk to severely worn wheels
  - Gapping of more than 3/8 of an inch increased risk of derailment
  - Not all combinations of wheel and rail wear were studied

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AAR 28TH ANNUAL RESEARCH REVIEW

Summary, Conclusions and Future Work

- **Grinding templates**
  - Rail profile templates have an influence on the wear and RCF performance
  - Better wear and RCF performance for high rail profiles with:
    - Crown radius between 6 and 8 inches
    - No relief of the gage shoulder
  - Better wear and RCF performance of low rail profiles with:
    - Crown radius below 10 inches
    - Relief on the field side

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Acknowledgements

Colleagues and contributors including

Scott Cummings

Kenny Morrison

Arun Wickramasuriya

Andrew DeKruif

Alexander Keylin

Rolling Stock and RCF TAGs

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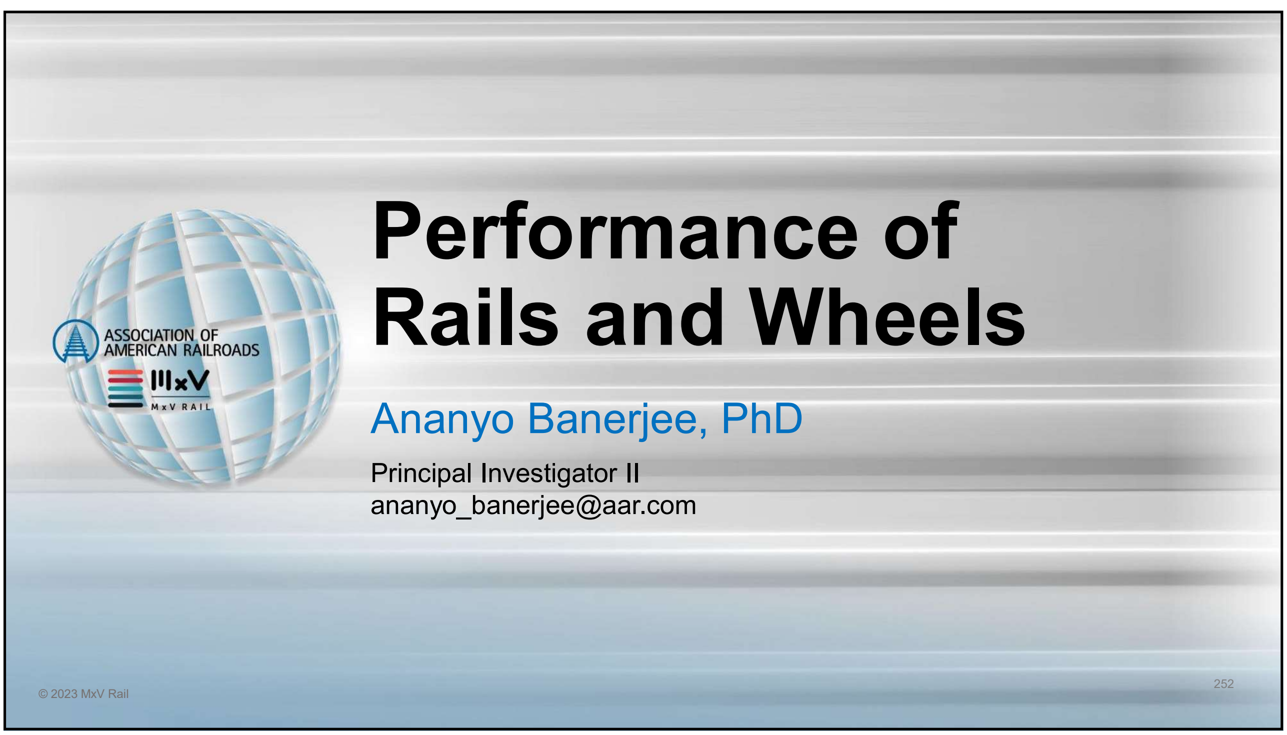

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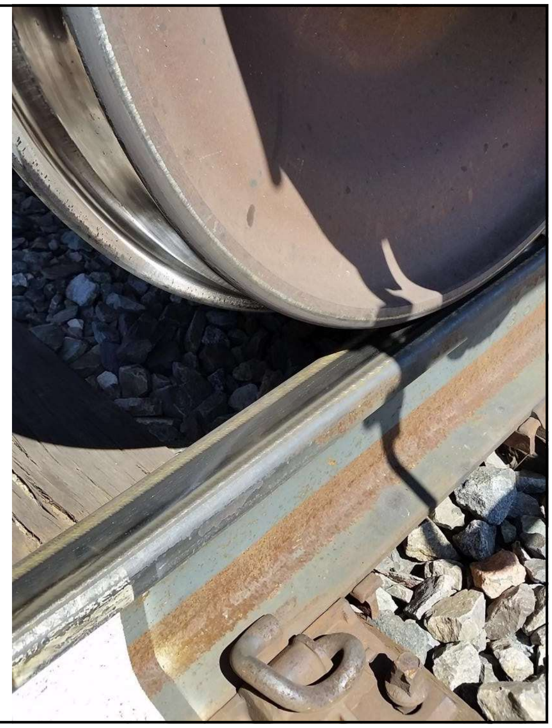
AAR 28TH ANNUAL RESEARCH REVIEW

Overview

- **Objectives**
- **Rail Testing at FAST**
  - High Strength (HS) Rails
    - High rail and low rail wear
    - Rolling contact fatigue (RCF) analysis
    - Residual stress estimation
- **Wheel Testing at FAST**
- **Wheel-Rail Contact Tests Outside of FAST**
- **Conclusions**
- **Future Work**



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AAR 28TH ANNUAL RESEARCH REVIEW

Objectives

- **Rail and wheel performance and integrity**
  - Define the properties that dictate wear and rolling contact fatigue (RCF)
  - Improving rail and wheel life with better wear resistance
    - FAST, revenue service
  - Improving weld longevity between dissimilar rails
  - Understanding response to fatigue defects
    - Rails – shells, transverse defects, split heads
    - Wheels – vertical split rims (VSRs), sub-surface fatigue cracks

Transverse defect in rail

Fatigue defect in wheel tread

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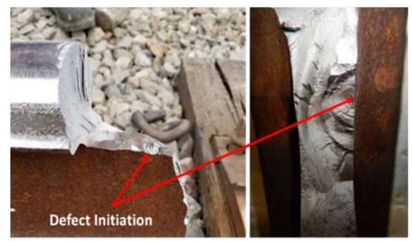
AAR 28TH ANNUAL RESEARCH REVIEW

HS Rail Test

- **Test started in 2018 and concluded in 2022**
  - High and low rails on a 1,000-foot-long (304.8m), 5-degree reverse curve with no direct lubrication
    - Eight rail types from eight different manufacturers
  - One electric flash butt weld break at 210 MGT; no rail defects detected

TEST PARTICIPANTS
Arcelor-Mittal (Cleveland Cliffs)
British Steel Hayange (Saarstahl)
EVRAZ Rocky Mountain Steel
JFE Steel
Panzhihua Angang
Nippon Steel
Steel Dynamics, Inc
Voestalpine Schienen



EFB weld failure at 210 MGT

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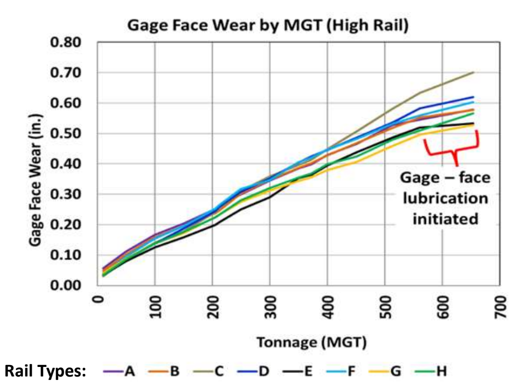
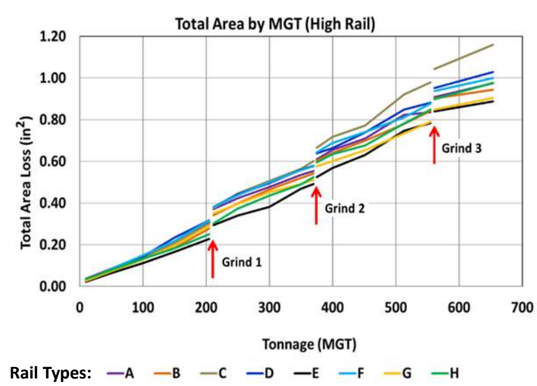
High Rail Wear (2018-2022 Test)

- **Head area loss dominated by gage wear**
- **Gage wear was slow between 561 and 654 MGT because of gage face lubrication**





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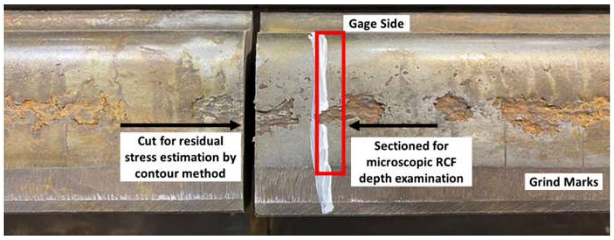
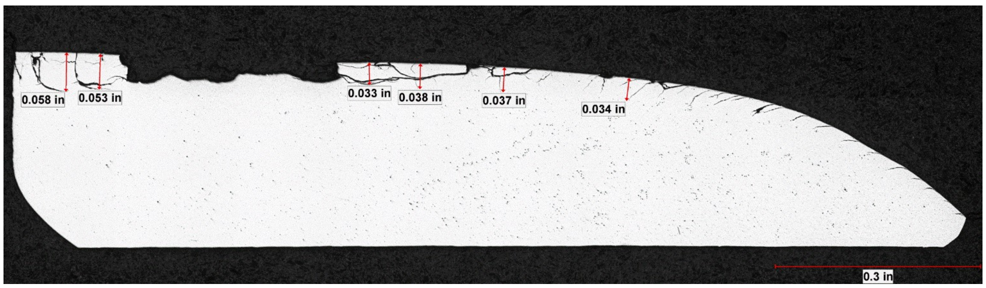
RCF Depth Examination



- **Rails with the worst RCF cut from track**
  - Tested for residual strains
  - Adjacent location with spalls analyzed for RCF depth estimation



RCF depth with spalls on top of rail surface in rail type B

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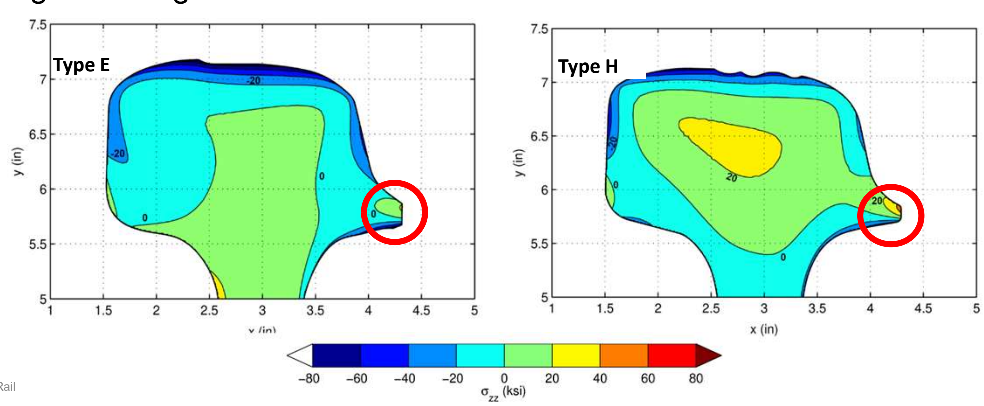
Residual Stress Estimation

- **Tests conducted on samples with severe RCF**
- **Contour method used with finite element analysis (FEA)**
  - Lip formed on bottom of gage shows high tensile stresses that can lead to fatigue damage



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Metal Flow at Bottom of Gage Face

- **Gage wear and metal flow increases with tonnage**
  - Plastic deformation and wear causes metal lip at bottom of gage
  - Subsequent removal by grinding is required to prevent wheel damage

Wheel damage caused by metal lip

Switch grinder removing metal lip

FAST

Bottom of gage lip breaking off

Revenue Service

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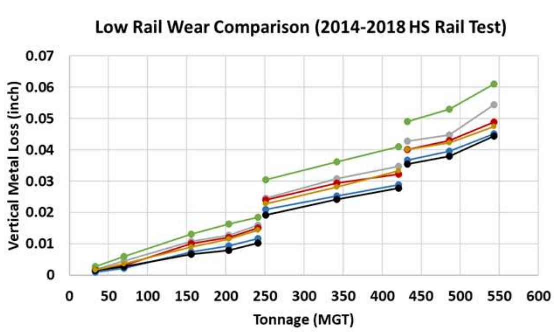
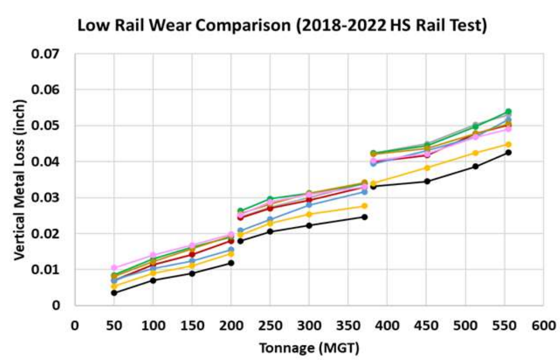
Low Rail Wear

- **Comparison between 2014 and 2018 HS rail tests**
  - Vertical wear dominates rail wear; gap between data indicates metal loss due to grinding (Rail types A-F were different for both tests)





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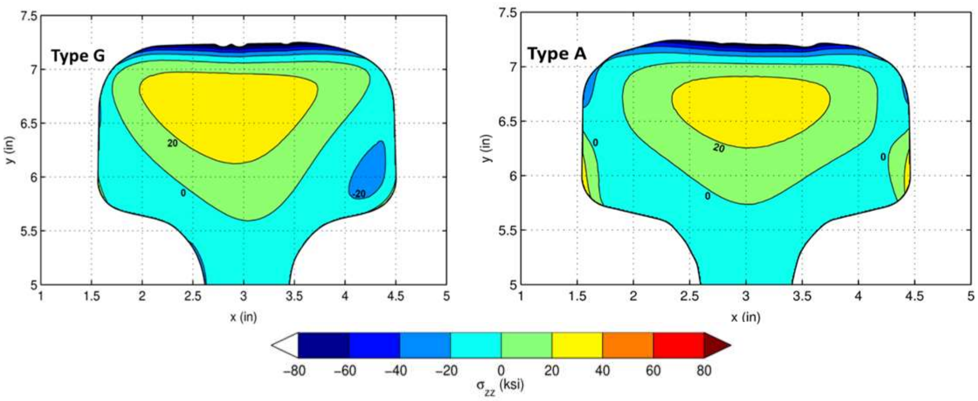
Residual Stress- Low Rail (2018-2022 Test)

- **As compressive stresses become high on top of rail surface and sub-surface, inside of rail head becomes more tensile**
  - Gage and field side of few rail types with insignificant wear show presence of tensile stresses



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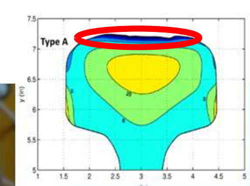
Low Rail RCF



RCF observed on top of rail

- Grinding concentrated on top of rail surface and up to gage corner and field corner to maintain profile shape

Severe RCF with spalls at end of test (654 MGT) on top of rail surface in type A low rail

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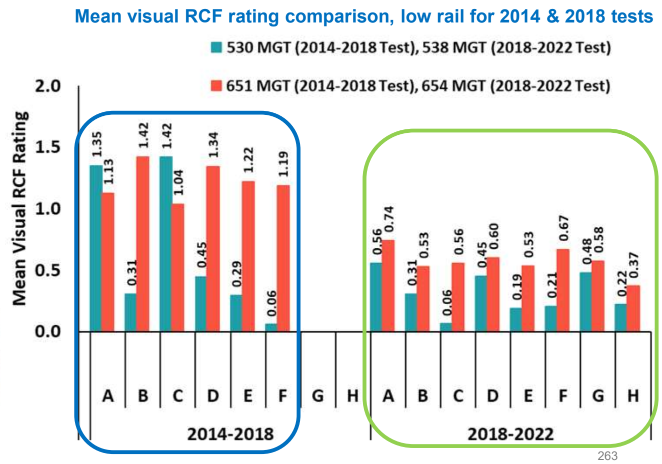
Low Rail RCF Observations

- **RCF visual ratings conducted for both 2014 and 2018 tests**
  - Plot shows combined effects of wear and grinding
    - Grinding done at 557 MGT for 2018 test with six passes on low rail
    - Grinding specifically done on low rail of 2014- test with 18 passes at 590 MGT
    - 2018- test showed improved RCF conditions

Mild: 1 Heavy: 2 Severe: 3



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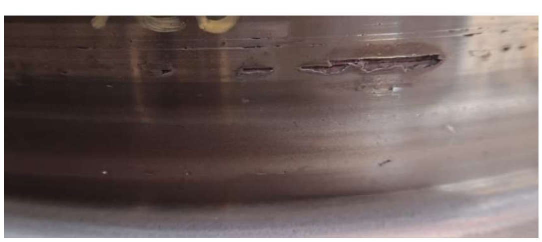
High Performance Wheel Testing

- **Current test is High Performance Wheel Test 2 (HPW2)**
  - Fourteen types of wheels provided by 11 manufacturers
  - Phase I: Laboratory testing
    - Mechanical, chemical, and metallurgical properties
  - Phase II: On-track testing under controlled conditions
    - Wheelsets running under 10 similar cars on FAST train consist
  - Phase III: Revenue service test



Discontinuous pitting/spalling in wheel

Continuous spalling in wheel

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HPW2 Results – On-Track Testing

- **Nine wheelsets out of 50 removed by end of 2021**
  - Wheelsets experience 70% curving on FAST loop; more aggressive environment compared to revenue service
- **Remaining wheelsets till 2022: Mean 96,500 miles**
  - No defects detected through FAST 2022 operations

Type	Removal Cause	Mileage at Removal (approximate)
3	Subsurface fatigue cracks (detected by ultrasonic NDE scans)	15,500
5		17,300
5		28,900
5		31,800
7		25,300
7		48,900
13		22,700
12	**Shattered rim**	63,700
12	**Wear reached limit**	87,900

Shattered rim

Subsurface fatigue cracks

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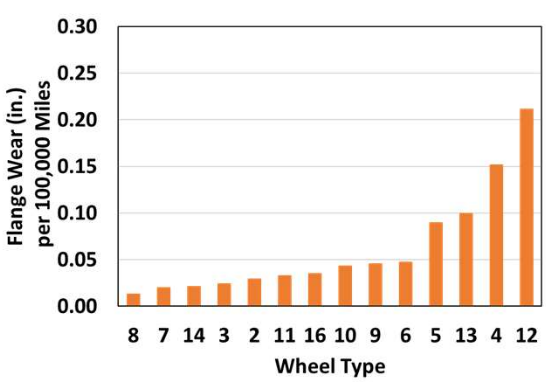
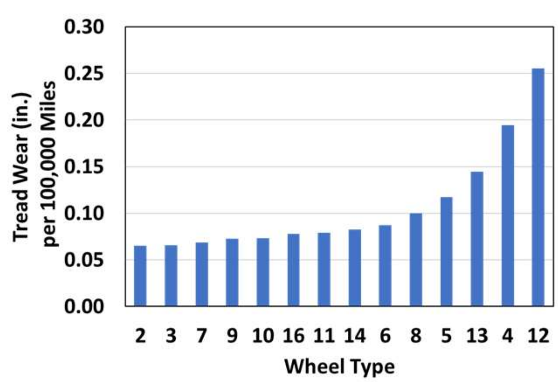
HPW2 Wear Results – FAST

- **Significant differences in tread and flange wear between wheel types**





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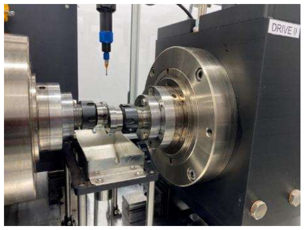
Rolling Contact Tests Outside FAST



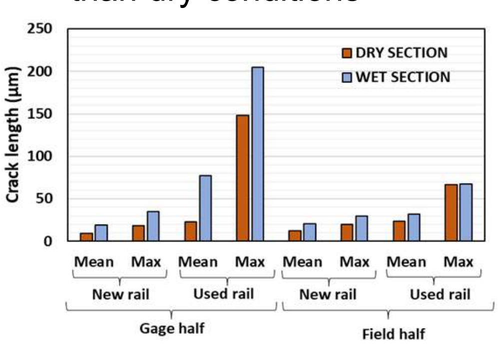
Twin Disc Tribometer (since 2022)

RCFS (since 2016)

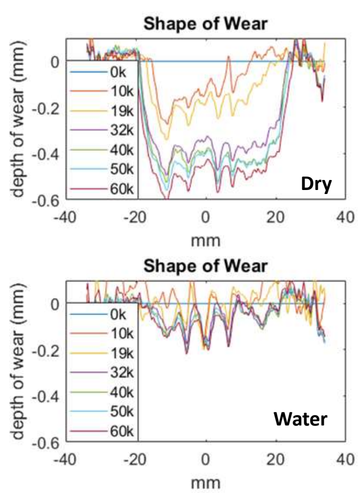
- **Tests conducted to understand wear and RCF under controlled conditions (lubrication, load ratios, angle of attack)**
  - Rolling Contact Fatigue Simulator (RCFS)
    - Provides insight to full-scale wheel/rail wear and RCF initiation
  - Twin Disc Tribometer
    - Disc-on-disc tests evaluating wear for various wheel and rail materials

RCFS

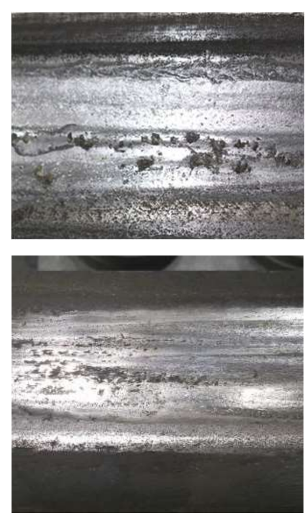
- **Effects of lubricating media including water**
  - Water causes less wear but more surface damage than dry conditions



Comparison of crack lengths



Comparison of rail wear



Pitting on wheel tread (top) and rail surface (bottom) due to water

AAR 28TH ANNUAL RESEARCH REVIEW

Summary

- **Rail and Wheel Performances**
  - 2018 test concluded with no internal defects detected on high or low rail
    - Residual stress estimation shows tensile stresses in defect-prone areas
    - Metal flow and gage wear formed lip on bottom of gage face that needed removal to prevent wheel damage
    - Low rail RCF less severe during 2018 test compared to 2014 test
  - FAST test continues to show differences in wear between different wheel types
    - Shattered rim and sub-surface fatigue may dictate wheel life
  - Wheel-rail contact tests outside FAST continue to provide insight on wear and RCF

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Future Work

- **New HS rail test; starting in 2023 at new FAST**
- **Continue Intermediate Strength (IS) rail test at new FAST; test has accumulated 282 MGT through 2022**
- **HPW2 test to continue at FAST and in revenue service**

Continuing 2021 IS Rail Participants
EVRAZ Rocky Mountain Steel (IS rail)
Steel Dynamics, Inc. (IS rail)
Třinecké železárny (IS rail)
Standard Strength Rail (US Manufacturer)

New 2023 HS Rail Test Participants
Cleveland Cliffs
Saarstahl
EVRAZ Rocky Mountain Steel
JFE Steel
Nippon Steel
Voestalpine Schienen

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Acknowledgements

- **Kerry Jones, MxV Rail (SRI Wheel Performance Project)**
- **MxV Rail NDE-Metallurgy and RCFS teams**
- **Rail and Wheel Manufacturers**
- **Hill Engineering**
- **MxV Rail FAST track crew and Instrumentation staff**

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Thank you

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Vehicle-Track Interaction Research

Walter Rosenberger, PE

Scientist

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AAR 28TH ANNUAL RESEARCH REVIEW

Overview

- **Vehicle Track Interaction (VTI)**
  - Rigid body response to track input
  - Conicity
  - Truck hunting
- **Track Conditions at Truck Hunting Detectors**
- **Findings**

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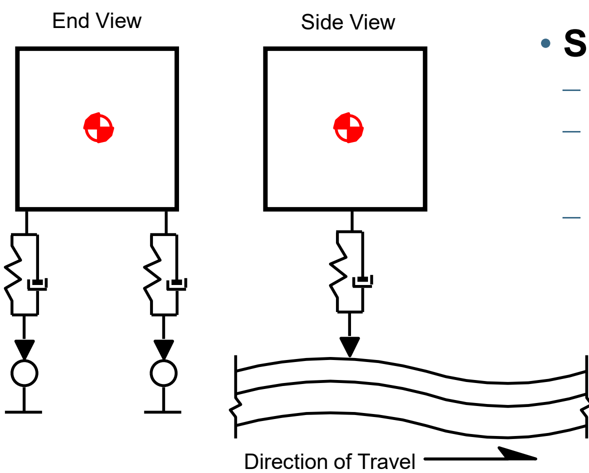
AAR 28TH ANNUAL RESEARCH REVIEW

Vehicle Track Interaction



- **Single degree-of-freedom system**
  - Track structure is the input function
  - Vehicle characteristics represented by the mass
  - Track and vehicle share the connection
    - Stiffness and damping characteristics
      - Rail/ties/ballast
      - Truck suspensions: adapter pads, springs, wedges, side bearings, etc.

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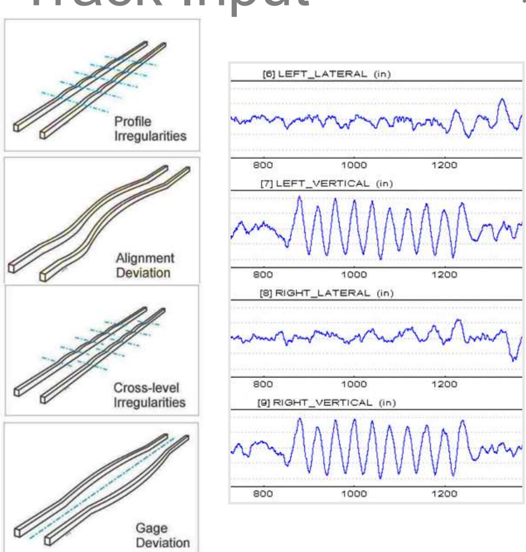
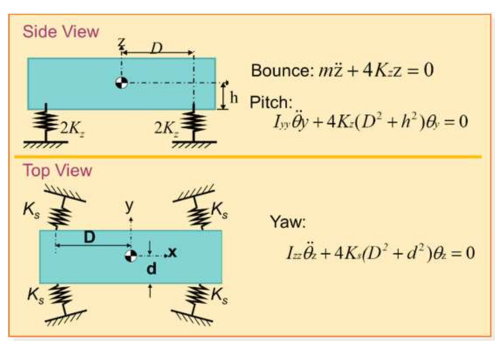
Track Input ⇒ Vehicle Response





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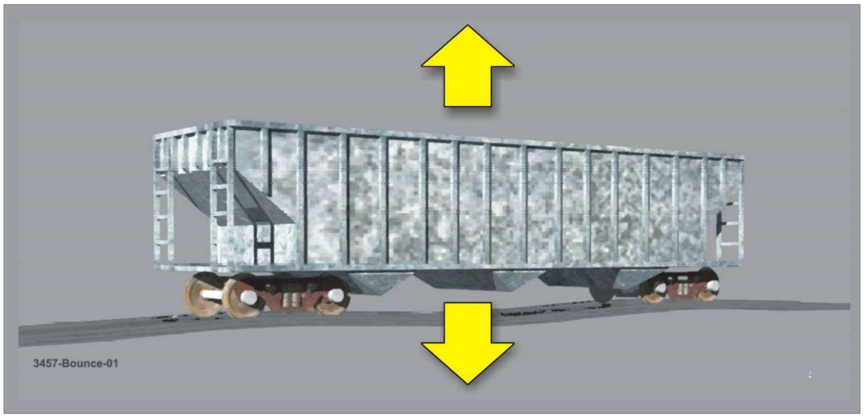
Vehicle Track Interaction – Bounce Mode

Wavelength of several parallel dips matching the truck center spacing excites the bounce mode



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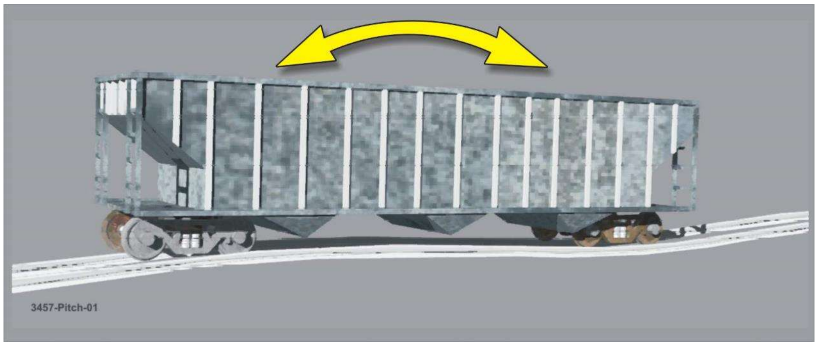
Vehicle Track Interaction – Pitch Mode

Wavelength of several parallel dips longer or shorter than the truck center spacing excites the pitch mode



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Vehicle Track Interaction – Roll Mode

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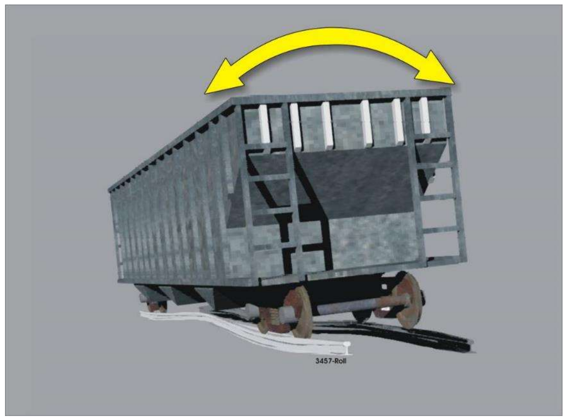
Wavelength of several offset dips matching the truck center spacing excites the roll mode



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Vehicle Track Interaction – Twist & Roll

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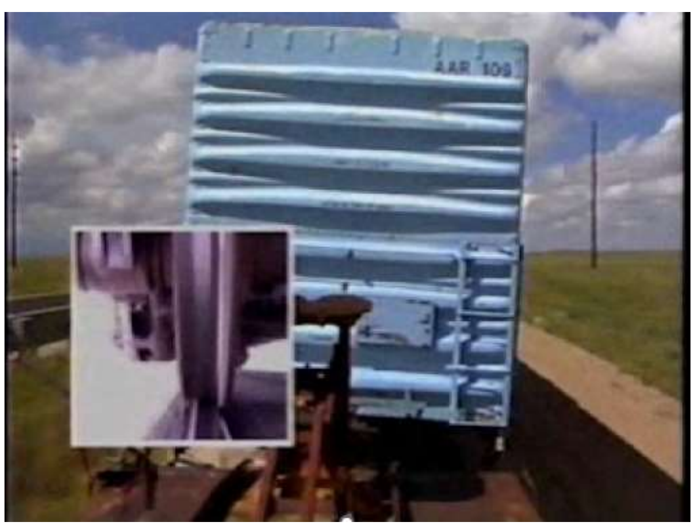
(Click for video)



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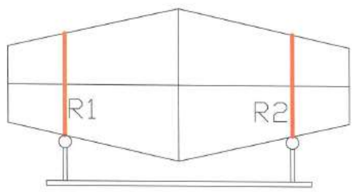
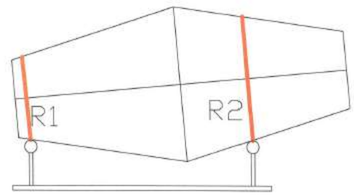
Vehicle Track Interaction – Conicity

Simplified wheelset on tangent



Rolling radius R1 equals radius R2, wheel will roll in a straight line. Rolling-Radius-Difference (RRD) =0

Simplified wheelset in curve



Rolling radius R1 does not equals radius R2, wheel rolls in a curve to the left . Rolling-Radius-Difference (RRD) ≠0

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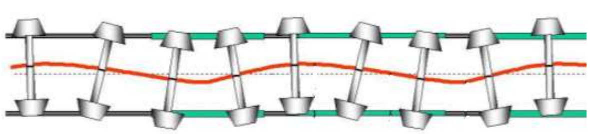
(Click for video)

What is (Truck) Hunting?

- **Physics of conicity give rise to instability at speed**
- **Hunting defined by AAR *MSRP*, M-1001 Chapter 11**
- **Lateral carbody oscillation, 0.13 g standard deviation or 1.5 g peak-to-peak**



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Truck Hunting Detectors (THDs)

- **THDs look for hunting driven by *vehicle characteristics***
- **Track characteristics at the THD**
  - Minimal input
  - Consistency
- **Goal: Let the vehicle performance "speak for itself"**

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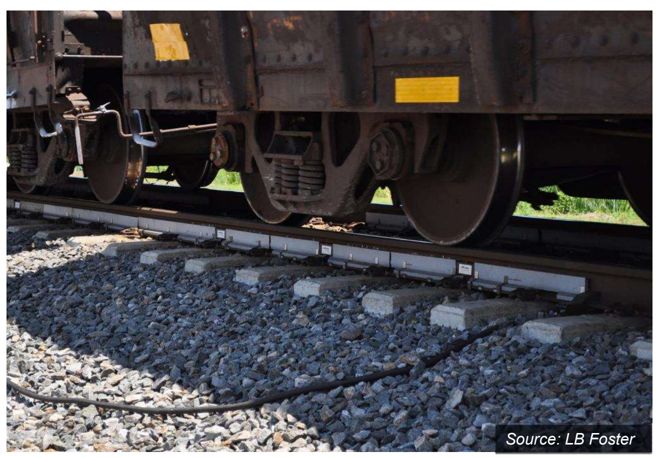
Example of what a THD site looks like

- **Usually, better quality than surrounding class track**
- **Concrete ties**
- **Asphalt underlayment**
- **Tangent, with long tangent approaches**
- **Track speed >45 mph**



WILD site with lateral force (THD) sensors

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NUCARS® Simulations

- **Empty covered hopper**
- **Conventional three-piece trucks in nominal condition**
- **New AAR-2A wide flange wheel profiles**
- **Single-layer (conventional) "beam on elastic foundation" track model**
- **Rail – 136RE with 10-inch crown radius, 1:40 cant**

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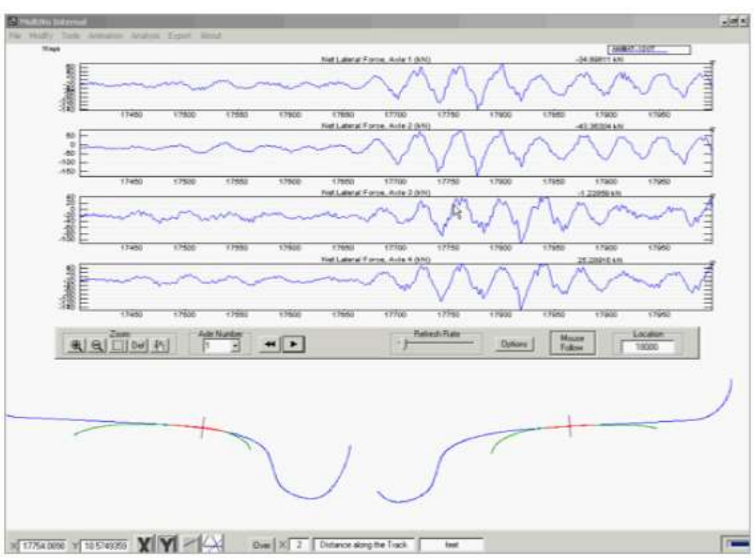
NUCARS® Simulations



Example of NUCARS® hunting simulation

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Track Factors that Matter

- **Track geometry extremes**
  – Pure, perfect tangent
  – Measured open track
- **Gage**
  – Tight engages high conicity
  – Open engages less conicity, but allows more lateral displacement
- **Track modulus**
  – Higher is "harder," lower is "softer"

Input parameter	Variation
Track geometry	• Theoretical Chapter 11 input • Measured hunting zone
Gage	• 56.25 inches • 56.5 inches • 56.75 inches • 57 inches
Track modulus	• Minimum typical • Nominal typical • Maximum typical
Rail profiles	• Theoretical 136RE-10 1:40 • Moderately worn measured
Friction coefficients	• 0.5 gage face and top of rail • 0.2 gage face, 0.5 top of rail • 0.2 gage face, 0.35 top of rail
Vehicle speed	• 50 miles per hour • 70 miles per hour

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Track Factors that Matter

- **Rail profiles**
  – Prominent gage corner engages high conicity
  – Worn gage corner less sensitive
- **Wheel/rail friction**
  – Dry develops more W/R forces
  – Gage face only – intermediate
  – Gage face + top of rail friction modifier
- **Speed**
  – Stability is speed-dependent
  – Used as a witness check of results

Input parameter	Variation
Track geometry	• Theoretical Chapter 11 input • Measured hunting zone
Gage	• 56.25 inches • 56.5 inches • 56.75 inches • 57 inches
Track modulus	• Minimum typical • Nominal typical • Maximum typical
Rail profiles	• Theoretical 136RE-10 1:40 • Moderately worn measured
Friction coefficients	• 0.5 gage face and top of rail • 0.2 gage face, 0.5 top of rail • 0.2 gage face, 0.35 top of rail
Vehicle speed	• 50 miles per hour • 70 miles per hour

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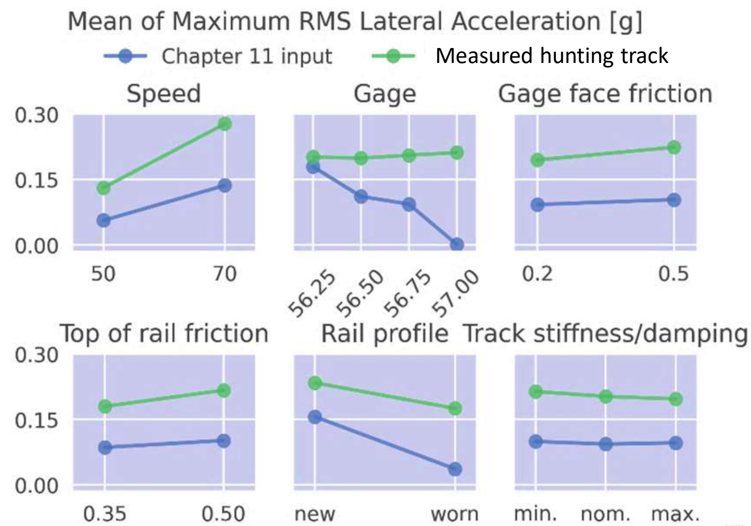
Main Effects Plot of Results - Averages

- **Speed**
- **Gage***
- **Rail profile**

***The hunting zone never allows oscillations to "die out"**



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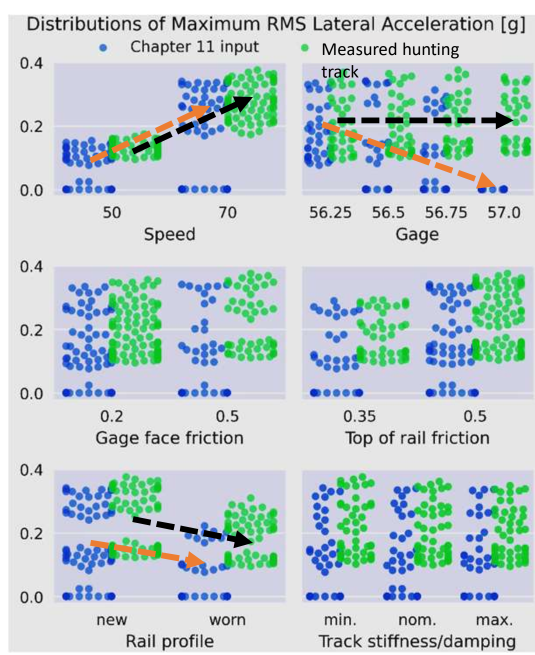
Results Details

- **Distribution plots**
  - Maps out the variation in responses, while keeping one factor constant
- **Less definitive than Main Effects plot**
- **Shows how variability affects the results**



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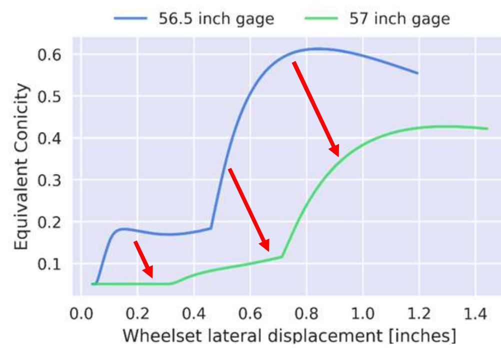
Top Factors Involve Conicity

Worn ***rail profile*** has less conicity for small wheelset lateral movements

Wide ***gage*** has much less conicity for all wheelset movements



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Summary

- **Suggested best practices for THD track maintenance:**
  - Maintain standard gage
  - Grind regularly to maintain the gage corner*

Measuring gage

Grinding rail

*Consistent with findings from *Wheel Rail Profile Design & Maintenance* SRI

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Acknowledgements

Michael Craft, MxV Rail, provided data and input concerning THD sites

Yi Wang, MxV Rail, performed NUCARS® simulations and analysis of results

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