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29TH ANNUAL Association of American Railroads RESEARCH REVIEW

APRIL 23-25, 2024 | Pueblo, CO

29TH ANNUAL Association of American Railroads RESEARCH REVIEW

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Click titles to jump to presentation

Wednesday, April 24, 2024 – Presentations of AAR Strategic Research Initiatives

AAR Annual Research Review | Pueblo Convention Center

PLENARY SESSION 1:

Safety Briefing/Greeting	**Scott Cummings** AVP Research & Innovation, MxV Rail
Welcome	**Heather Graham** Mayor of Pueblo
Keynote: Tools of the Trade	**Ed Boyle** VP Engineering, Norfolk Southern
Rail Coalition for Advancing Safety Technology (RCAST)	**Jamie Williams** Chief Mechanical Officer, Norfolk Southern
Strategic Research Initiatives (SRI) Program Overview	**Scott Cummings** MxV Rail
Facility for Accelerated Service Testing (FAST®)	**Christopher Johnson** Scientist, MxV Rail

NORFOLK SOUTHERN

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Tools of the Trade

April 24, 2024

Ed Boyle

Vice President - Engineering

2023 NS Engineering Year in Review

00:16.35

MW&S

NORFOLK SOUTHERN

ENGINEERING

PM B&S

2024

D&C EP&T

ONE TEAM

C&S

TOOLS OF THE TRADE


HARSCO


DL&W
NORFOLK SOUTHERN
NS 99


MK VI

NORFOLK SOUTHERN ENGINEERING

MW&S · B&S · EP&T · C&S · D&C · PM

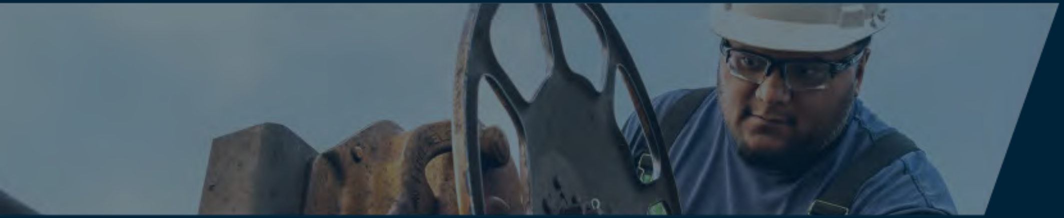
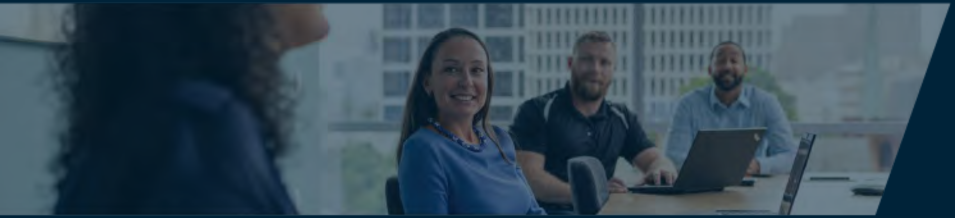
2024

ONE TEAM

NS ENGINEERING DEPARTMENT MISSION

Provide a safe, fast and reliable infrastructure network at the lowest possible cost.

WIN THE DAY!

Thank You

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RCAST

Rail Coalition for Advanced Safety Technology

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Rail Coalition of Advanced Safety Technology (RCAST)

Introduction

- RCAST is a coalition of rail stakeholders who are committed to safety.

- RCAST information sharing sessions show how technology continues to evolve and should not be restricted.
  - Initial meeting held in Washington, DC, April 17, 2024
  - RCAST is not a silo approach, limited to freight car inspection

- Technology continues to advance changes in railcar maintenance.
  - Dynamic testing of air brakes
  - AI driven technology provides insight into managing exceptions
  - §20303 Safety Appliance Act and the future of Digital Inspection

- Advancing lessons learned through combination rules.
  - WILD (wheel impacts), WPD (wheel profile)
  - HBD, ABD (bearings)

RCAST

Machine Vision

- Consistent and precise condition monitoring in different operating environments.
    - Any time of day in all conditions 24/7/365
- Captures, measures, and analyzes cars in their natural dynamic state
    - Driving deeper understanding of behavior (buff vs draft)
- Allows inspectors to view the alert prior to physically inspecting / repairing the equipment.
    - Tiered Approach
        - Derailment prevention
        - Maintenance scheduling

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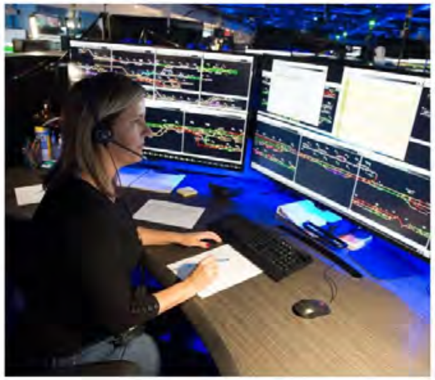
RCAST

- **Vision**
  - Educate stakeholders on advanced wayside technology
    - Collaborate on the future of dynamic train inspection
    - Forecast freight car repair process
  - Facilitate Discussion and Feedback

Hardware
Machine Vision Camera Portals

Software
AI Algorithms & Automated Notifications
Near real-time "at the edge"



People
Response Protocol

RCAST

Car Inspector's Perspective

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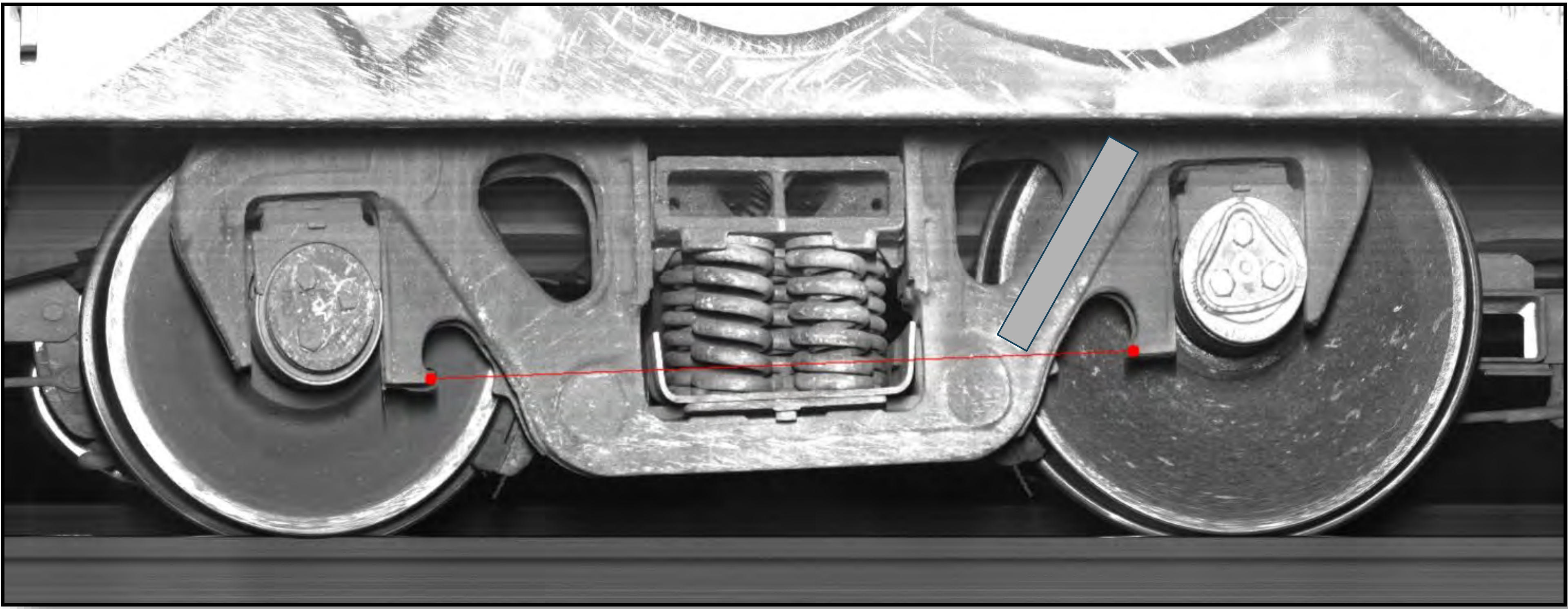
RCAST

Machine Vision Perspective



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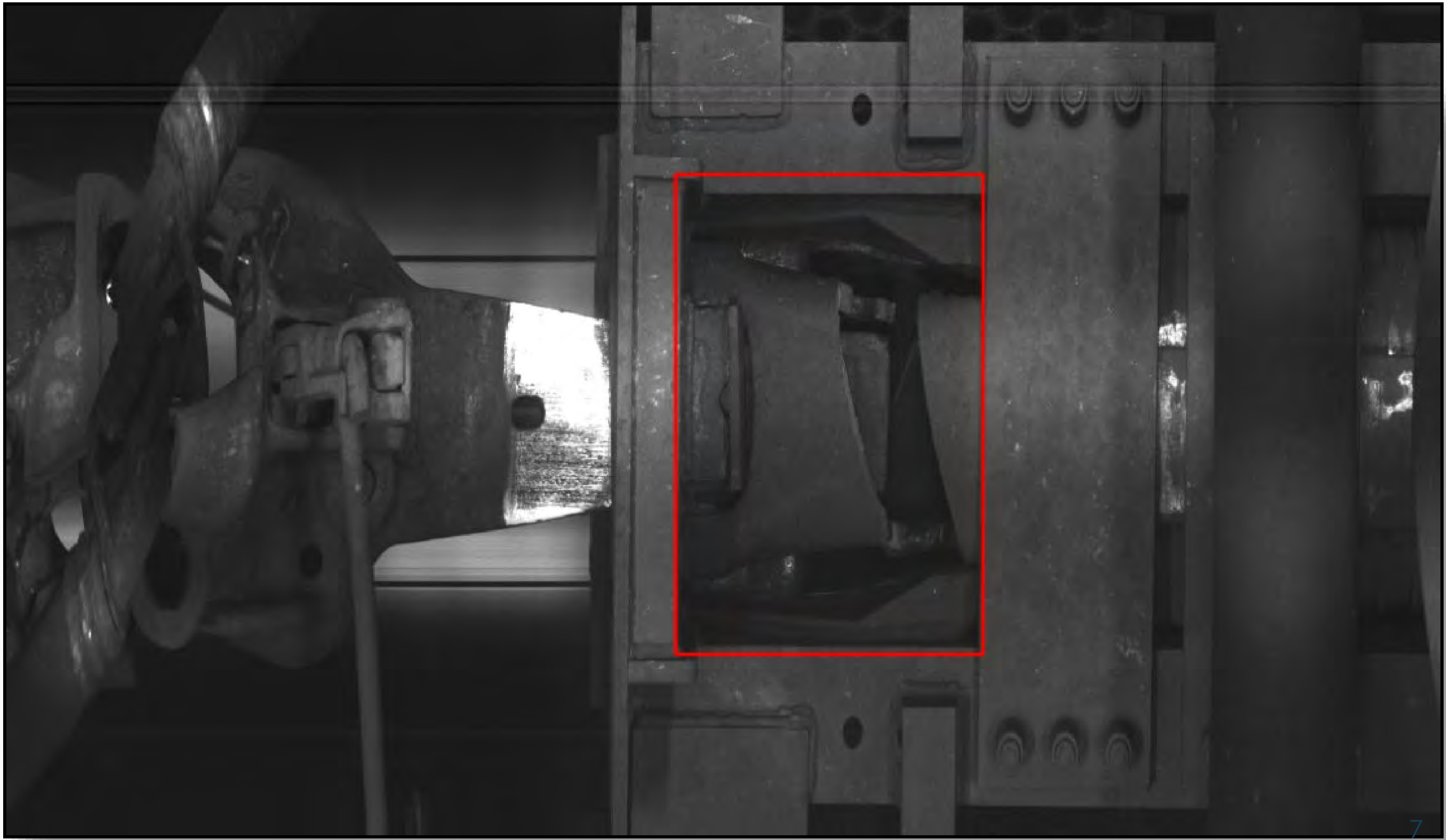
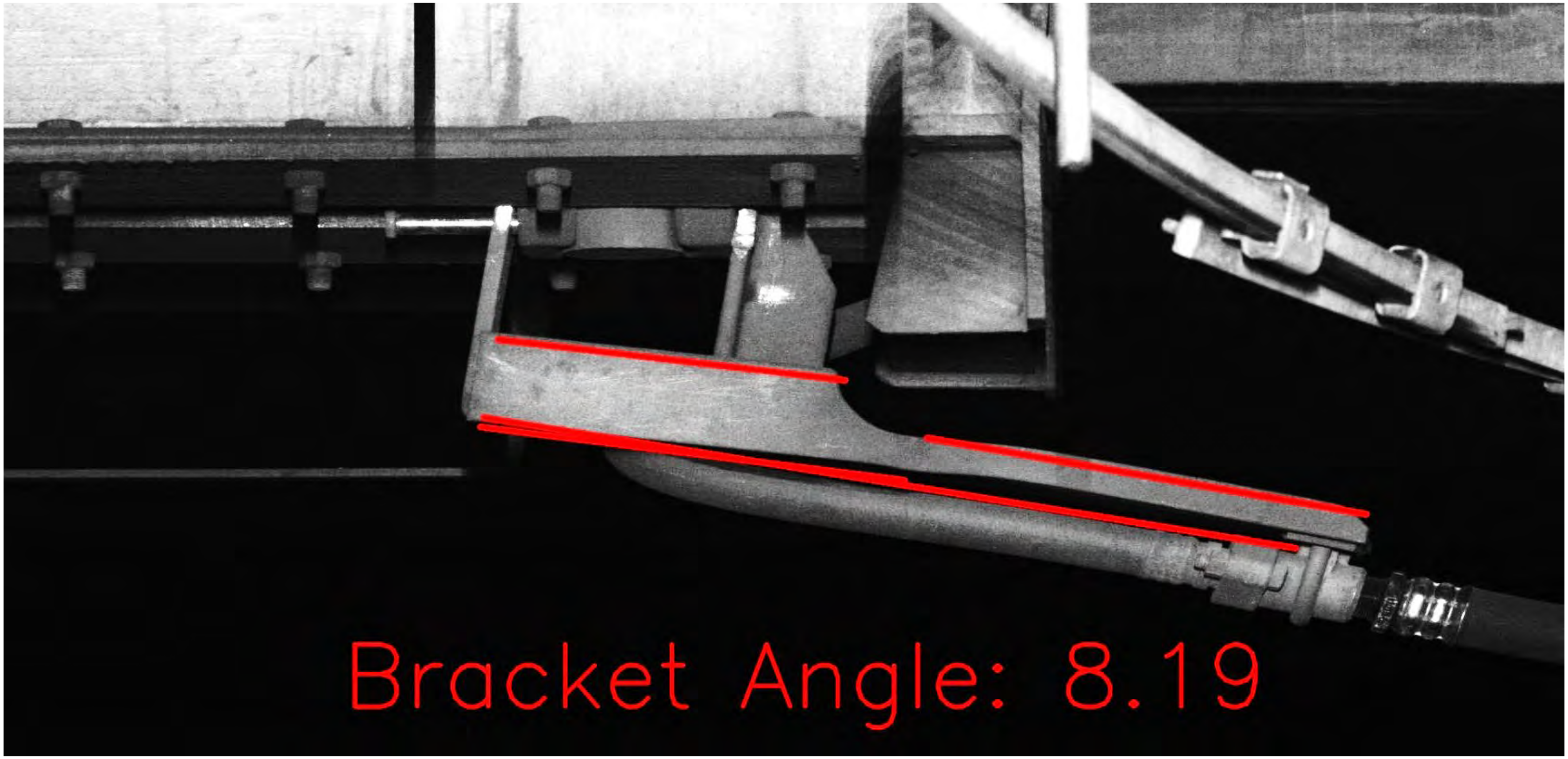
Machine Vision Perspective



RCAST

Machine Vision Perspective

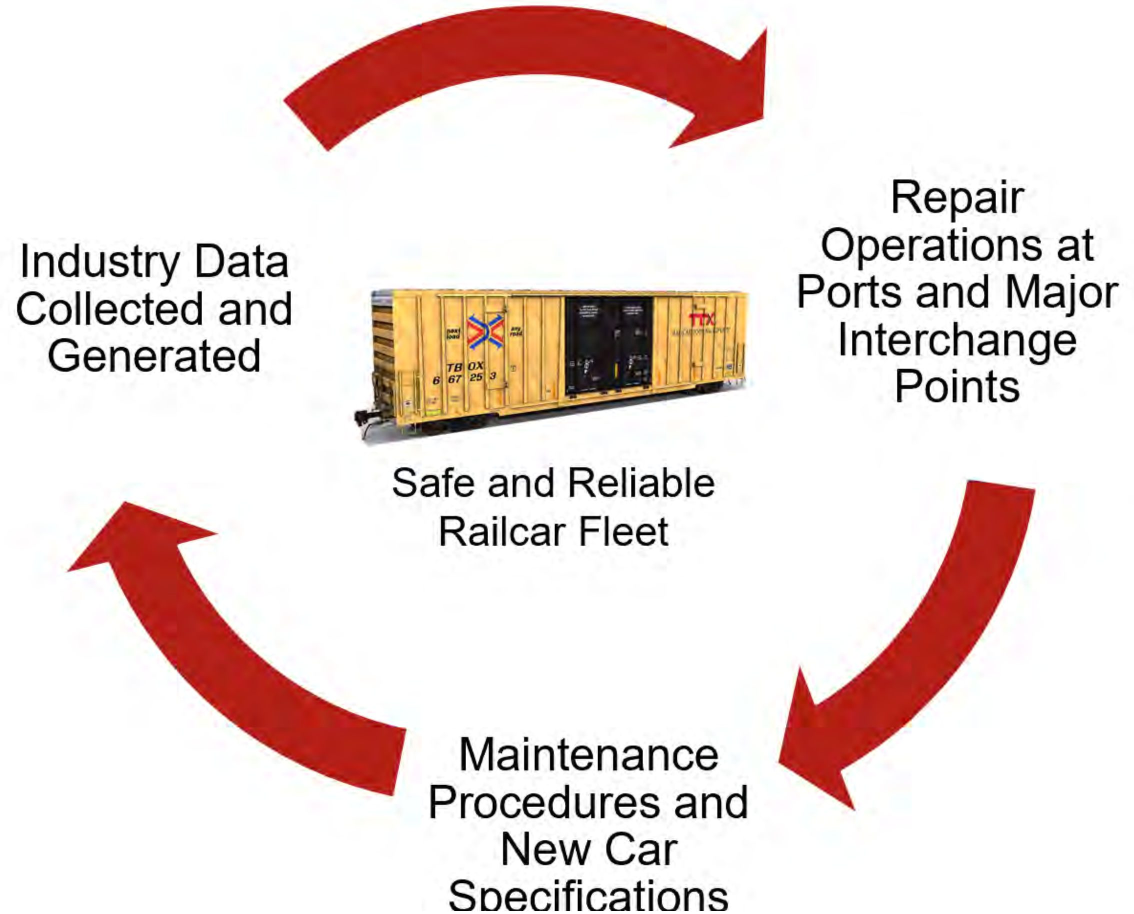


RCAST

Customer Focused

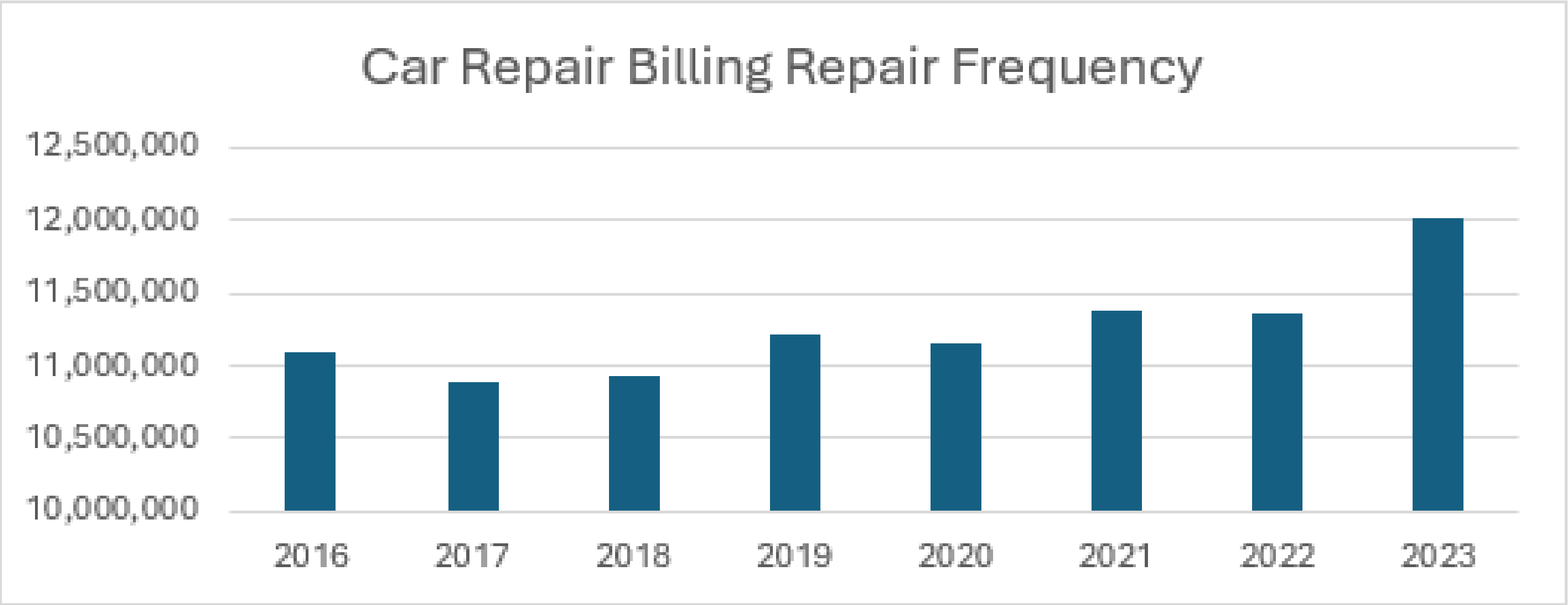
- Dynamic condition
- Open Top Load securement can change enroute

Stakeholder Benefits



RCAST

Car Repairs as Technology Increases



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RCAST

What does rail need to advance?

- Collaboration amongst the stakeholders to advance technology.
- Innovation is dependent on stakeholder collaboration (rulemaking & railroad investments).
- Having the capability to advance and deploy technology is good for all stakeholders.
- Proceeding in a way that is mindful of the impacts that regulations can have on innovation.

Conclusion

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Overview of AAR Strategic Research Initiatives

Scott Cummings

AVP Research & Innovation

Overview

- **Strategic Research Initiatives (SRI) – Vision & Mission**
- **Background/How it works**
- **Industry interaction in the work scope cycle**
- **Implementation pathways**
- **Sampling of research work**

General SRI Information

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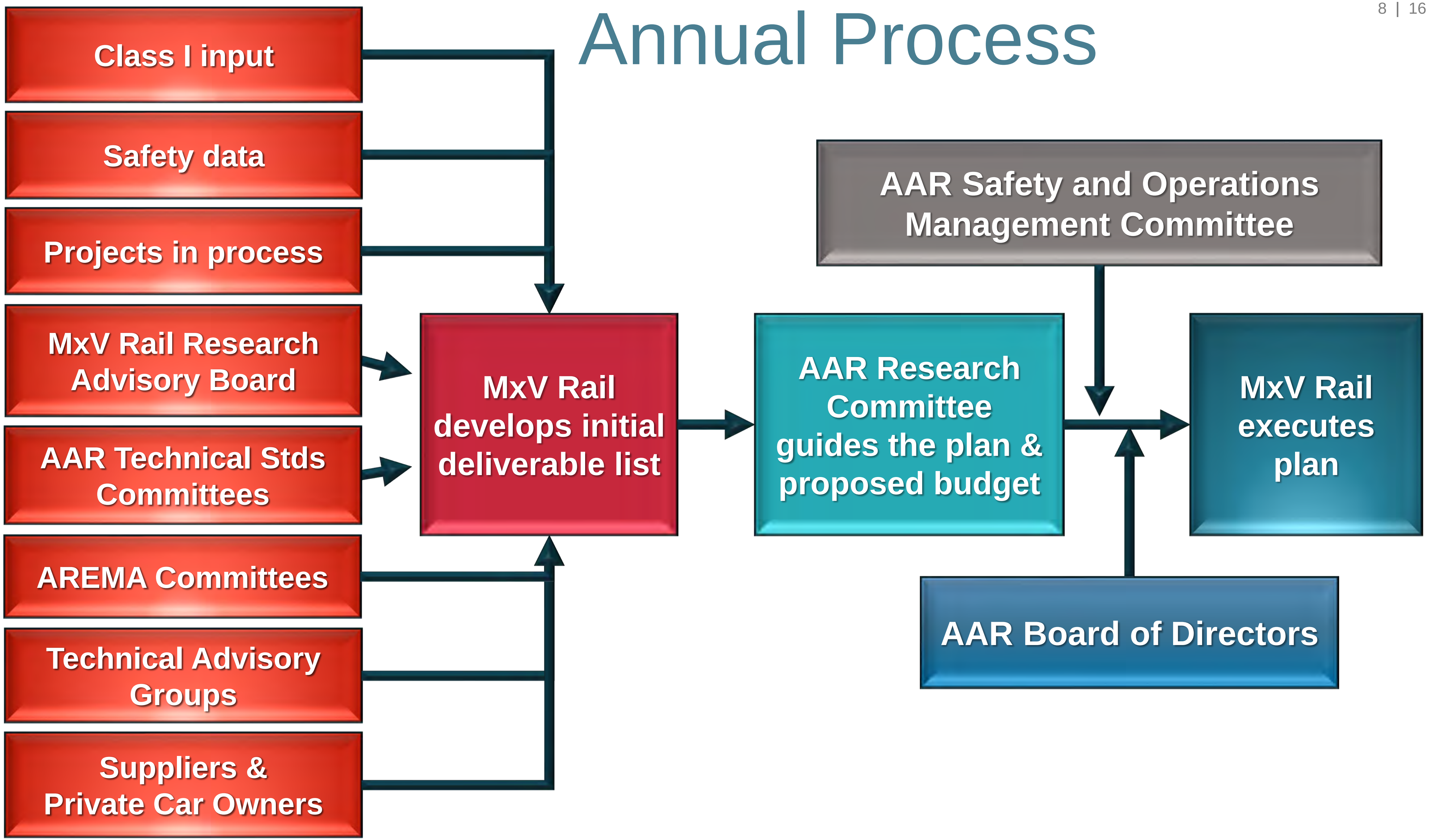
SRI Vision and Mission

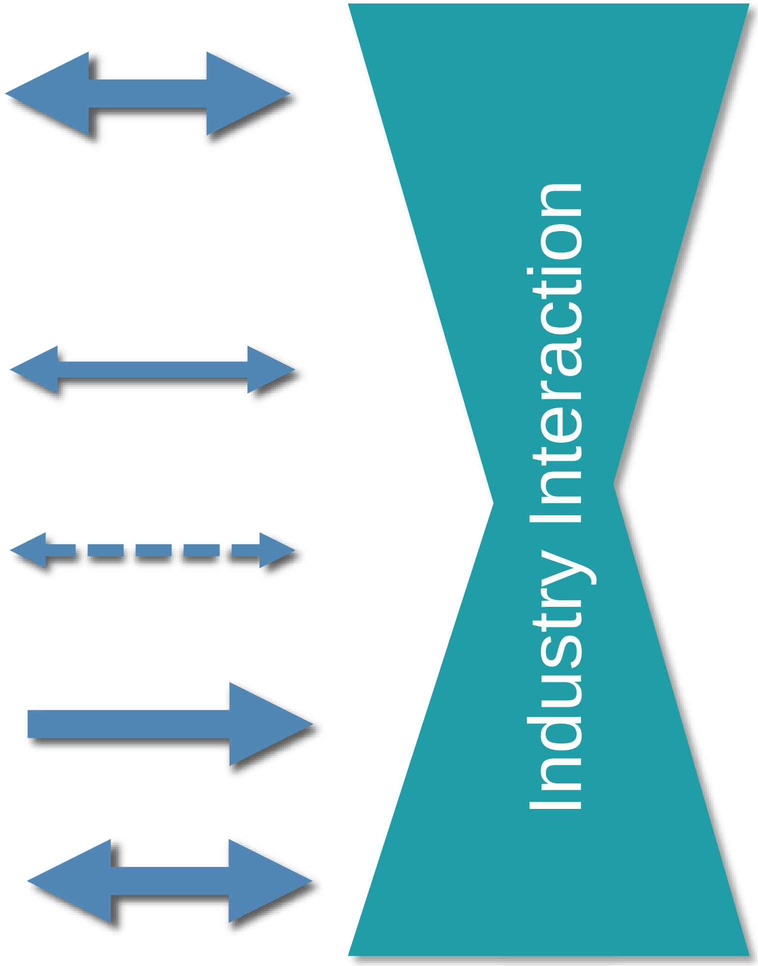
- **Vision: Build exemplary teams and tools to empower science-based solutions for railway industry challenges**
- **Mission: Promote advancements in railway safety, reliability, and efficiency**
  - Demonstrate understanding of root causes
  - Identify & evaluate technologies
  - Support implementation
  - Communicate findings

Annual Process



SRI Work Scope Cycle

1. **MxV Rail becomes aware of an idea, question, challenge, technology or product**
2. **MxV Rail develops an evaluation plan**
3. **MxV Rail conducts the evaluation**
4. **MxV Rail communicates the findings**
5. **Determination of next step(s)**



Implementation Pathways

Most SRI work fits one of four categories:

1. Providing information to support informed policy-making
2. Product, service, and operating practice evaluations

1 & 2:
Information for decisions

3. Technological investigations

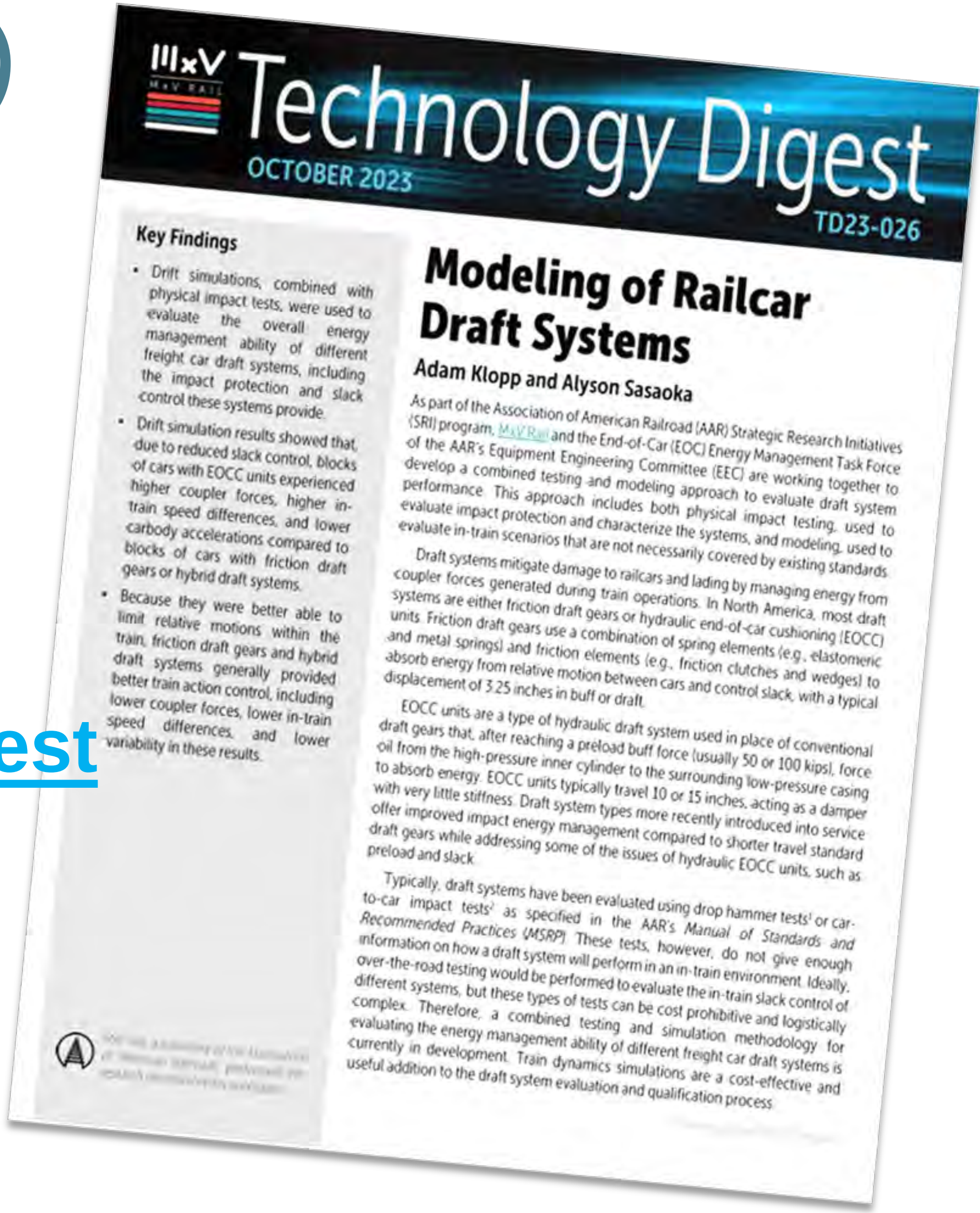
3: “Will this work?”

4. Root cause investigations / improved scientific understanding

4. “Why does this happen?”

Technology Digests (TDs)

- **Four-page research summaries**
- **Now available: Free, searchable internet download capability**
- **Averaging 170 downloads/month**
- **www.mxvrail.com/technology-digest**



MxV RAIL Technology Digest

OCTOBER 2023

TD23-026

Modeling of Railcar Draft Systems

Adam Klopp and Alyson Sasaoka

Key Findings

- Drift simulations, combined with physical impact tests, were used to evaluate the overall energy management ability of different freight car draft systems, including the impact protection and slack control these systems provide.
- Drift simulation results showed that, due to reduced slack control, blocks of cars with EOCC units experienced higher coupler forces, higher in-train speed differences, and lower carbody accelerations compared to blocks of cars with friction draft gears or hybrid draft systems.
- Because they were better able to limit relative motions within the train, friction draft gears and hybrid draft systems generally provided better train action control, including lower coupler forces, lower in-train speed differences, and lower variability in these results.

As part of the Association of American Railroad (AAR) Strategic Research Initiatives (SRI) program, MxV Rail and the End-of-Car (EOC) Energy Management Task Force of the AAR's Equipment Engineering Committee (EEC) are working together to develop a combined testing and modeling approach to evaluate draft system performance. This approach includes both physical impact testing, used to evaluate impact protection and characterize the systems, and modeling, used to evaluate in-train scenarios that are not necessarily covered by existing standards.

Draft systems mitigate damage to railcars and lading by managing energy from coupler forces generated during train operations. In North America, most draft systems are either friction draft gears or hydraulic end-of-car cushioning (EOCC) units. Friction draft gears use a combination of spring elements (e.g., elastomeric and metal springs) and friction elements (e.g., friction clutches and wedges) to absorb energy from relative motion between cars and control slack, with a typical displacement of 3.25 inches in buff or draft.

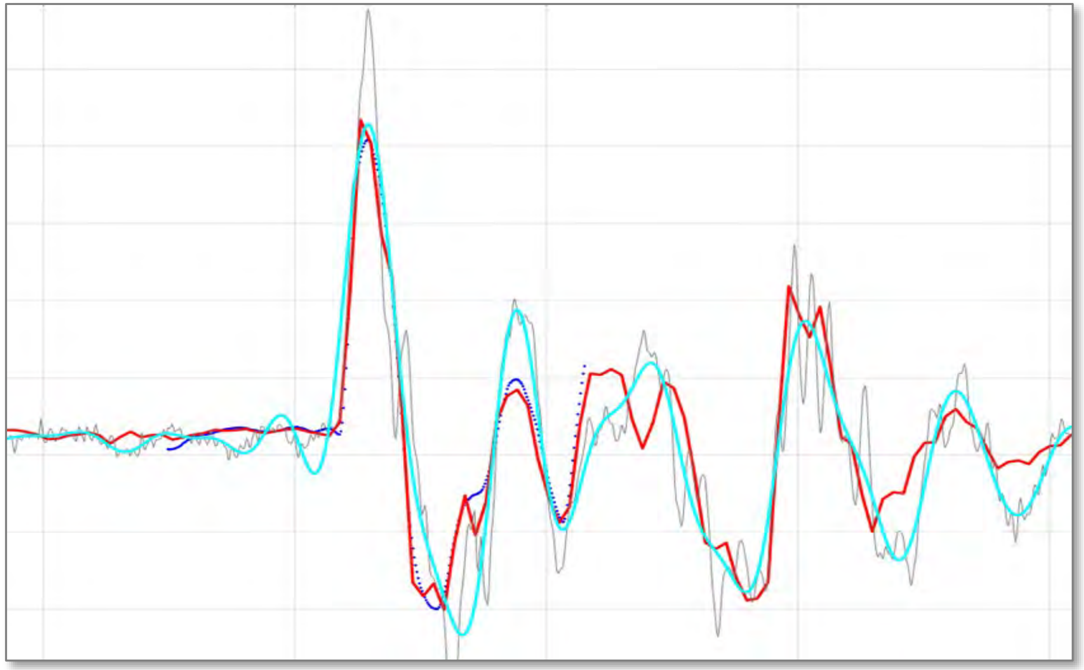
EOCC units are a type of hydraulic draft system used in place of conventional draft gears that, after reaching a preload buff force (usually 50 or 100 kips), force oil from the high-pressure inner cylinder to the surrounding low-pressure casing to absorb energy. EOCC units typically travel 10 or 15 inches, acting as a damper with very little stiffness. Draft system types more recently introduced into service offer improved impact energy management compared to shorter travel standard draft gears while addressing some of the issues of hydraulic EOCC units, such as preload and slack.

Typically, draft systems have been evaluated using drop hammer tests[1] or car-to-car impact tests[2] as specified in the AAR's *Manual of Standards and Recommended Practices* (MSRP). These tests, however, do not give enough information on how a draft system will perform in an in-train environment. Ideally, over-the-road testing would be performed to evaluate the in-train slack control of different systems, but these types of tests can be cost prohibitive and logistically complex. Therefore, a combined testing and simulation methodology for evaluating the energy management ability of different freight car draft systems is currently in development. Train dynamics simulations are a cost-effective and useful addition to the draft system evaluation and qualification process.

Sample Research

Mechanical Technical Sessions

- **Draft Systems Research**
- **Bearing Research**
- **EMAT Wheel Inspection Update**
- **Air Brake Research**
- **Wheel Research**
- **Measuring Wheel Impact Loads**

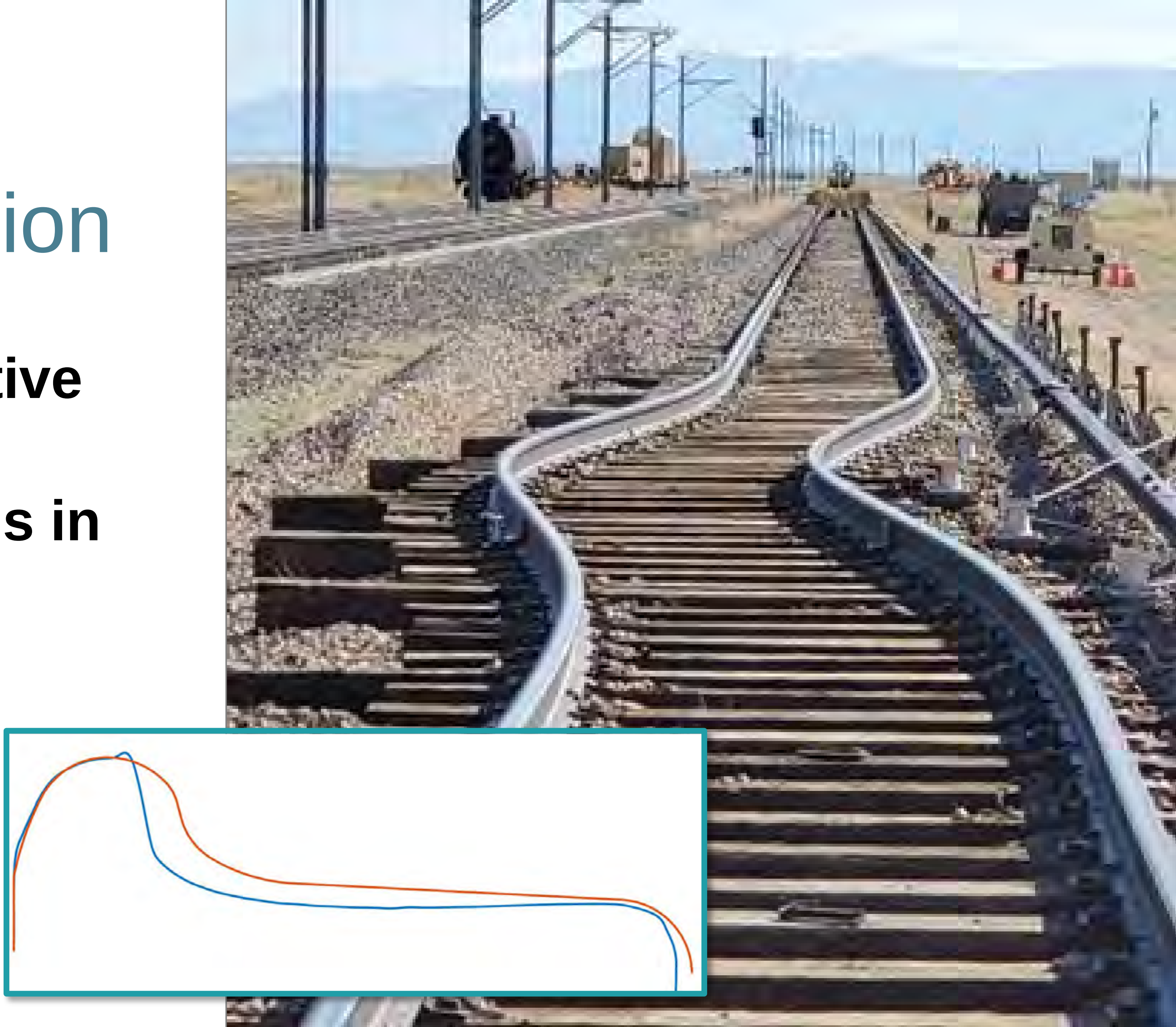


Infrastructure Technical Sessions

- **Evaluation of Rail and Weld Integrity**
- **Crosstie and Fasteners**
- **Bridge Research**
- **Revenue Service Testing**
- **Ballast and Subgrade Research**
- **Rail Inspection**

Afternoon Plenary Session

- **Lifecycle and Evolution of Positive Train Control**
- **Speed Restrictions in Hot Weather**
- **Wheel and Rail Profile Research**



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Acknowledgements

- AAR Research Committee
- MxV Rail Research Advisory Board
- Technical Advisory Groups
- MxV Rail Team

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Facility for Accelerated Service Testing (FAST®)

Chris Johnson

Scientist

What is FAST?

- **Facility for Accelerated Service Testing**
- **2.8-mile loop**
- **18,000-ton train**
- **140 MGT (21,000+ miles) Annual accumulation**
- **31+ tests**

2 9 T H A A R R E S E A R C H R E V I E W

FAST Objectives

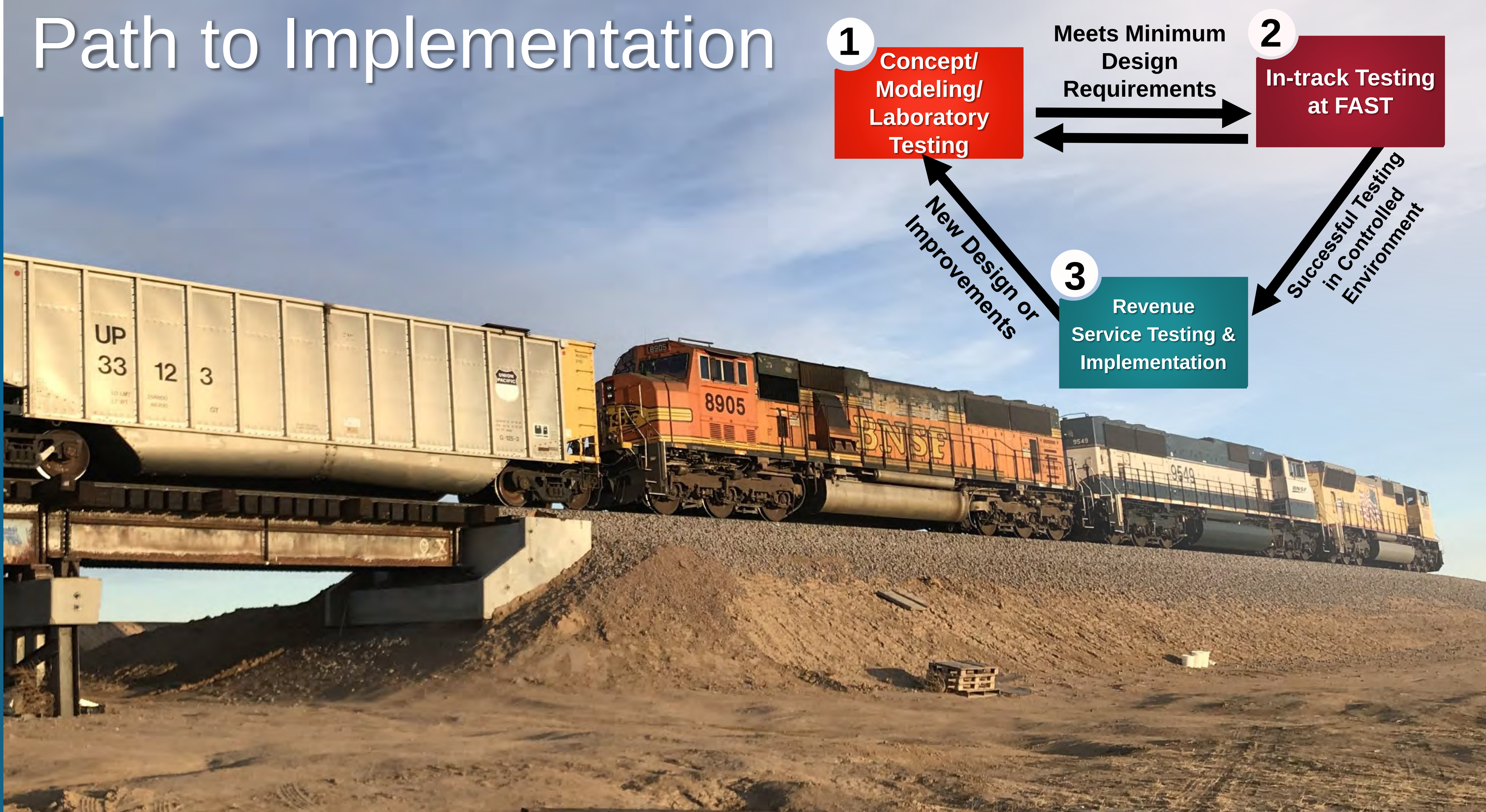
- **Increase the understanding of the effects of high tonnage and heavy axle loads on:**
  - Accelerated track degradation
  - Mitigation strategies

FAST Objectives

- **Rapid tonnage accumulation in a controlled environment**
- **Well-planned and executed evaluations**
- **Valuable information**
  - Root causes
  - Mitigations of problems
  - Quantified component performance




Path to Implementation



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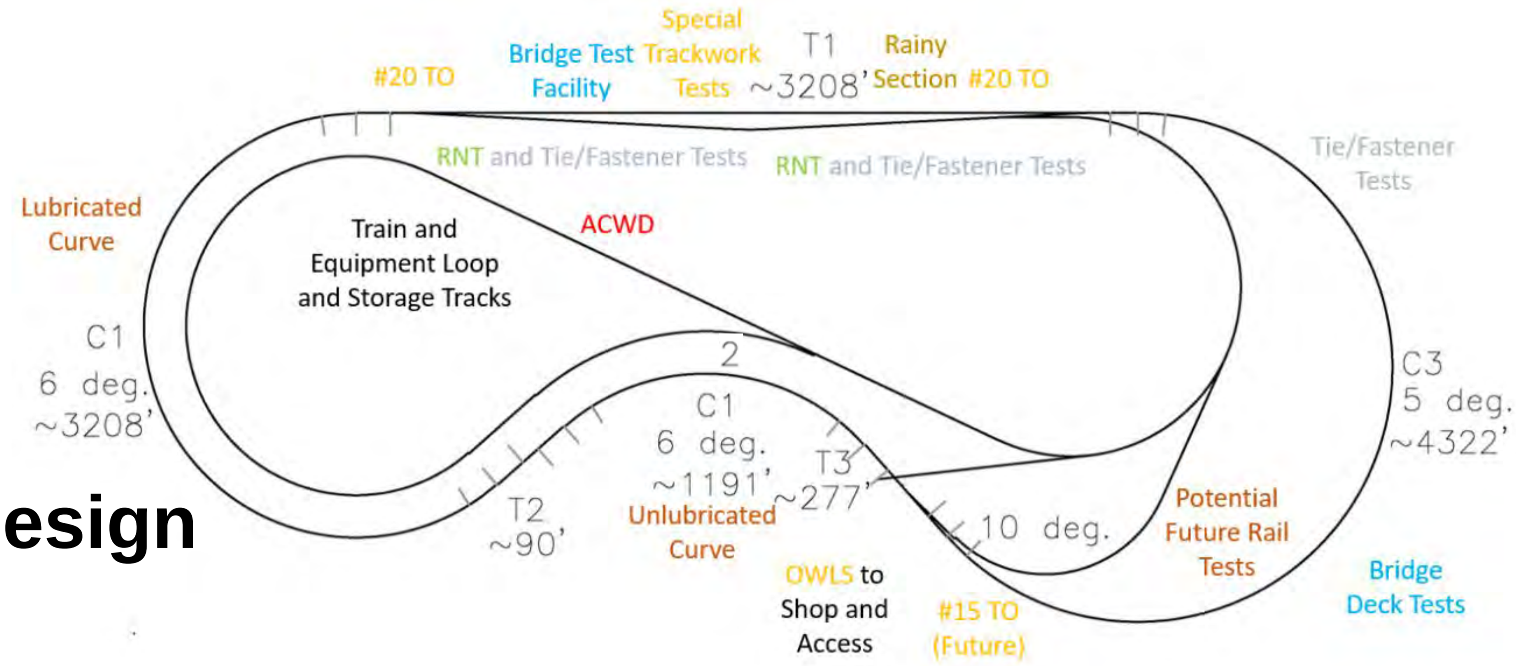
A New FAST

- **New FAST track required for 2023 operations**
- **Outreach to stakeholders**
  - Current and former FAST team membe
    - Operations
    - Track maintenance
    - Instrumentation
    - Engineering
  - Railroad advisors
  - Supplier stakeholders
- **Initial Concepts and design**

Initial FAST Concept



Construction

- **Construction began February 2023**
- **Track construction began June 2023**
- **Substantial completion November 2023**

Construction

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Support Systems and Tests

- **Commercial Systems**
  - AEI
  - HBD, HWD and DED
  - Lubricators (GF and TOR)
  - Rail flaw inspection truck
  - Track geometry
- **Custom In-house Systems**
  - TPD and RNT monitoring
  - Broken rail detection
  - Rail movement
  - Rail temperature
- **Many tests installed with new track construction**
  - Minimize rework
  - Avoid re-spiking new track

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Data FIRST

- **“FAST Internal Records for Statistics and Testing”**
  - In-house infrastructure and operations management tool
    - Modeled after similar RR system capabilities
    - Designed for unique FAST requirements
  - Track and test inventory to tie level accuracy
  - Paper forms replaced with electronic forms
- **Improved**
  - Tracking of test data
  - Insight into operations
  - Test scheduling
  - Maintenance tracking

FIRST Tests and Measurements Screen Example

Tests & Measurements

Create New

Test ID	Test Name	Test Type	Test Leader	MGT to Next Measurement	Rail Side	Start Section	Start Subsection	Start Tie	End Section	End Subsection	End Tie	Test Start Date	Test End Date	Modified By	Modified Date	Test Status
1039	HPW3	SRI	Kerry Jones		N/A	1	1	1	19	1	124	9/1/2024		Kerry Jones	2/2/2024	Proposed
1038	Rail Cut and Deanchor Test	SRI	Stephen Wilk		Outside Rail	1	5	1	1	8	1	1/15/2024		Stephen Wilk	1/29/2024	Proposed
1037	WRI Rail Measurements	SRI	Ulrich Spangenberg	39.98	N/A	1	1	1	19	1	124	2/19/2024	2/22/2024	Christopher Johnson	1/30/2024	Active
1036	Wheel measurement	SRI	Ulrich Spangenberg	53.41	N/A	1	1	1	1	1	1	2/5/2024	2/7/2024	Christopher Johnson	1/30/2024	Active
1035	HS (Premium) Rail Wear Test	SRI	Ananyo Banerjee	-15.28	N/A	9	1	24	9	6	37	11/29/2023	12/31/2027	Christopher Johnson	1/30/2024	Active

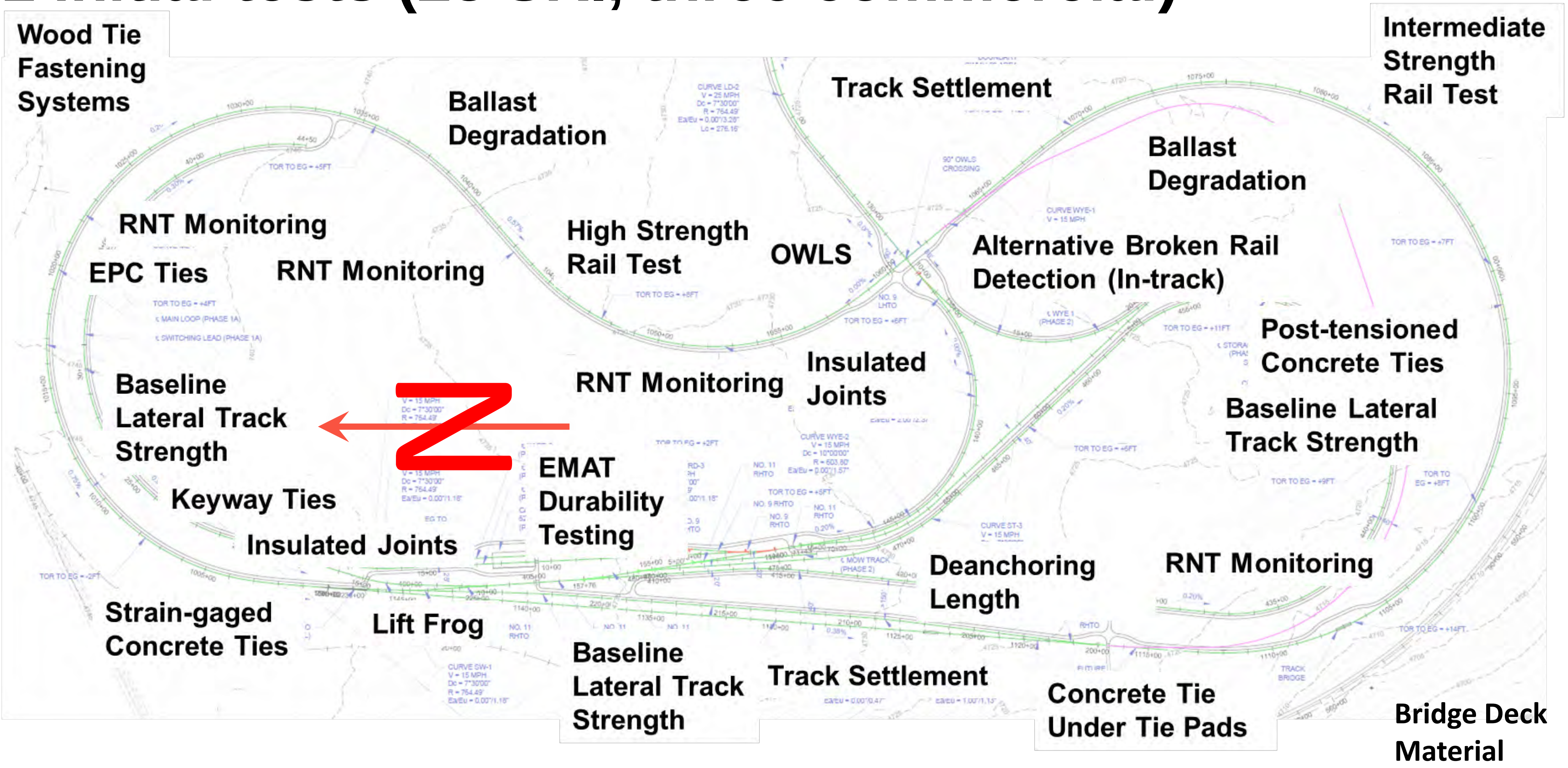
Operations

- **Construction complete November 2023**
- **First tonnage November 20, 2023**
- **First night operations December 11, 2023**
- **Regular operations January 22, 2024 (140 MGT Goal)**

Testing

Testing Overview

- **31 initial tests (28 SRI, three commercial)**



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Rail and Welds

- **2023 High Strength Rail Test**
  – 1,117’ 6-degree unlubricated reverse curve
  – Six suppliers, seven rail types

High Rail																											
40'	OJ7	NH1	JF1	OA7	EA1	VU1	CC1	JE1	SM1	JF2	EA2	OV7	NH2	CC2	SM2	VU2	ON7	JE2	JF3	CC3	EA3	NH3	SM3	JE3	VU3	OB7	40'
Low Rail																											
40'	VU7	NH4	JF4	CC7	EA4	VU4	CC4	JE4	SM4	JF5	EA5	VU8	NH5	CC5	SM5	VU5	CC8	JE5	JF6	CC6	EA6	NH6	SM6	JE6	VU6	VU9	40'

- **2021 Intermediate Strength Rail Test**
  – Moved from previous location
  – 282 MGT from prior test
  – ~760’ 5-degree lubricated curve

Special Trackwork

- **One-way Low Speed (OWLS) diamond**
  - Operations on both routes
  - Longer ramps for testing higher speeds
  - Grooves in rails from initial access
  - IWS testing planned
- **#11 Lift Frog**
  - Main access to loop
- **Insulated Joints**
  - Testing IJs associated with BRD system
  - Slotting required in first 20 MGT
- **Future bypass will add two #20 turnouts**

Ties and Fasteners

- **Multiple test zones**
- **Concrete ties**
  - Post-tensioned
  - Intermixed with timber ties
  - Instrumented ties
  - Under tie pads
- **Timber ties**
  - Elastic fasteners
  - Curve blocks
- **Composite ties**

Substructure

- **Initial baseline measurements**
  - GPR
  - Commercial ground characterization
- **Post construction settlement**
- **Post tamping consolidation**
  - 0, 0.01, 0.03, 0.05 and 0.10 MGT
- **Long-term subgrade monitoring**

Track Stability

- **RNT changes over time**
  - Curves, tangent, fixed structure
- **Deanchoring length for welding**
- **Changes in track lateral resistance**
- **Curve breathing and longitudinal rail movement**

Bridges

- **Two-span, 62-foot-long DPG**
  - Concrete substructure
  - 5-degree curve
  - 4-inch superelevation
- **Bridge deck testing**
  - Open deck
    - Tapered glulam ties
    - Bridge deck anchoring
    - Reused tie life evaluation
- **Planned new design steel span**

Mechanical and Inspection

- **Mechanical tests**
  - High performance wheels
  - Constant contact side bearings
- **Inspection systems**
  - EMFI RCF measurement
  - EMAT wheel inspection testing
  - HBD data trending
  - Broken rail detection
    - In-track and car mounted

Conclusions

- **New FAST loop is operational**
  - Designed for the needs of today’s railroad industry
  - Growing list of tests
  - Improved measurement and data
- **Proof testing**
  - Heavy train loading
  - High-level of control
- **Improve component performance**
- **Reduce risk**

Acknowledgements

- FAST Operating, Maintenance, Instrumentation and Engineering teams
- Railroad and supplier support

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Wednesday, April 24, 2024 – Presentations of AAR Strategic Research Initiatives

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PLENARY SESSION 2:

Communications and Train Control

Alejandro Gonzalez-Ruiz
Principal Systems Engineer II, MxV Rail

Speed Restrictions in Hot Weather

Stephen Wilk, Principal Investigator II
Walter Rosenberger, Scientist, MxV Rail

Wheel and Rail Profile Research

Ulrich Spangenberg
Principal Investigator II, MxV Rail

PLENARY SESSION 3:

Closure and Information for Track Walk & Tour

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Communications & Train Control – Lifecycle and Evolution of Positive Train Control

Alejandro Gonzalez-Ruiz, Ph.D.
Principal Systems Engineer II

Overview

- **Introduction:**
  - – Need for and methods of train control
- **Positive Train Control (PTC)**
  - – Basics, evolution, and interoperability
- **PTC Interoperable Lifecycle Management (ILM)**
  - – Need and key elements
- **PTC Look-Ahead**
  - – New technologies and PTC as an enabler

Why Train Control?

- **Safety**
  - Maintain safe separation between trains
  - Avoid derailments due to speeding, rail stressed
    by speeding, or broken rails
  - Provide for safety of track maintenance forces
- **Performance**
  - Maximize capacity
  - Maximize average train speed
  - Minimize deviance from plan

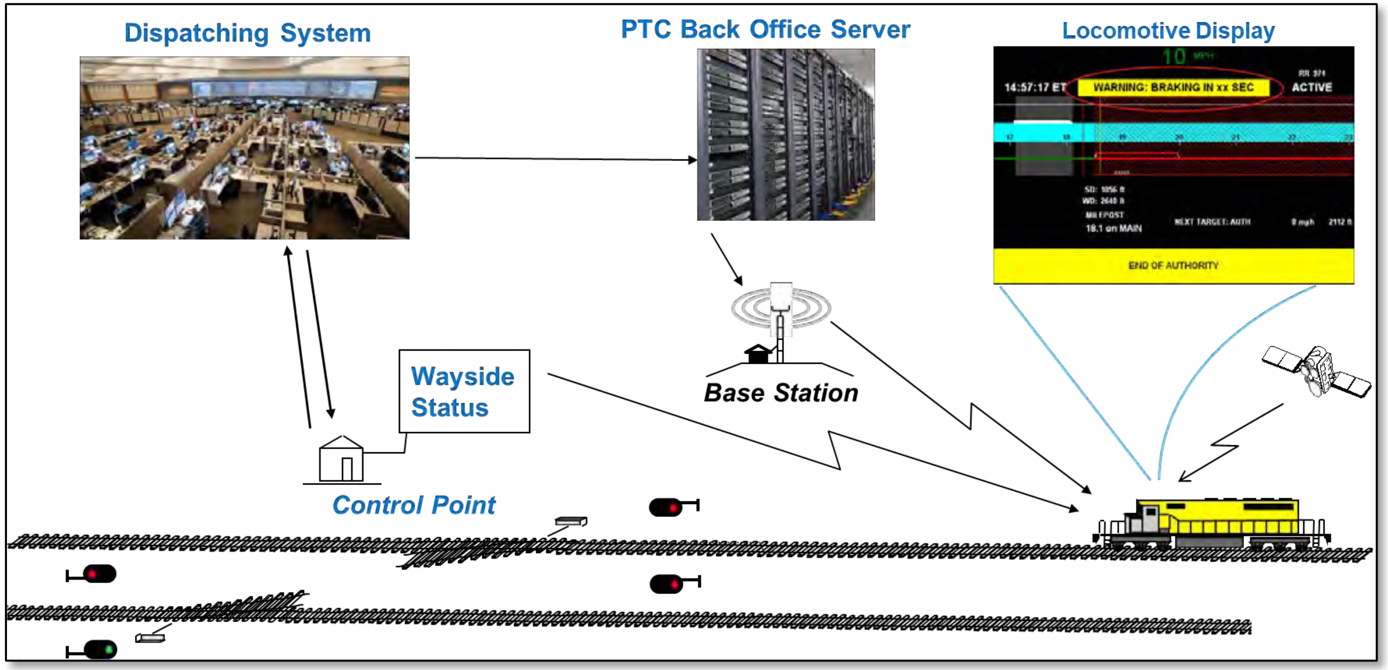
Methods of Train Control

- **Form-based, e.g., Track Warrant Control (TWC)**
- **Automatic Block Signal (ABS) / Current of Traffic**
- **Traffic Control, e.g., Centralized Traffic Control (CTC)**

Positive Train Control (PTC) is an overlay system that enforces the rules imposed by the underlying method of train control

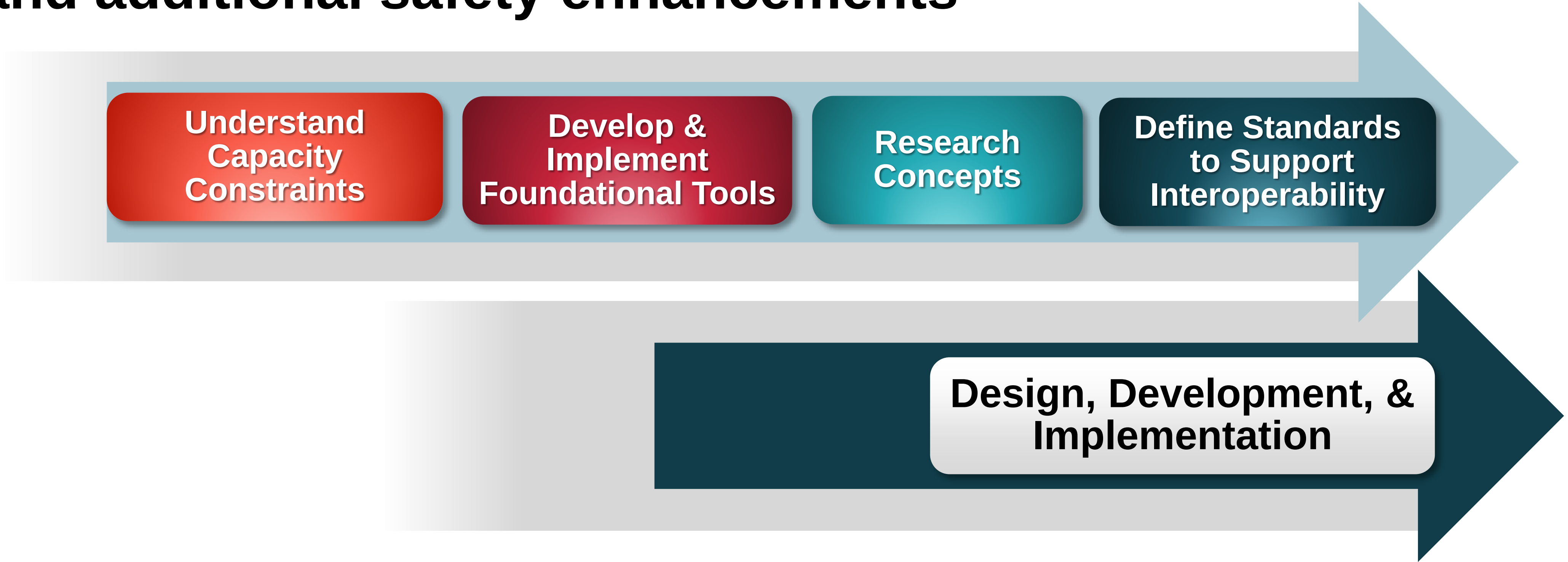
PTC Basics

- **Positive Train Control (PTC): A system designed to improve safety by monitoring train movements and enforcing limits to prevent violations**
- **Specifically, PTC is designed to prevent:**
  - Train-to-train collisions
  - Over-speed derailments
  - Incursions into established work zone limits
  - Movement of a train through a switch left in the wrong position



PTC – Evolution

- **Now that the initial mandate for PTC has been met, the railroad industry is looking at its evolution**
- **PTC is a key enabler for multiple new technologies**
- **Railroads can leverage their investment in PTC for operational and additional safety enhancements**



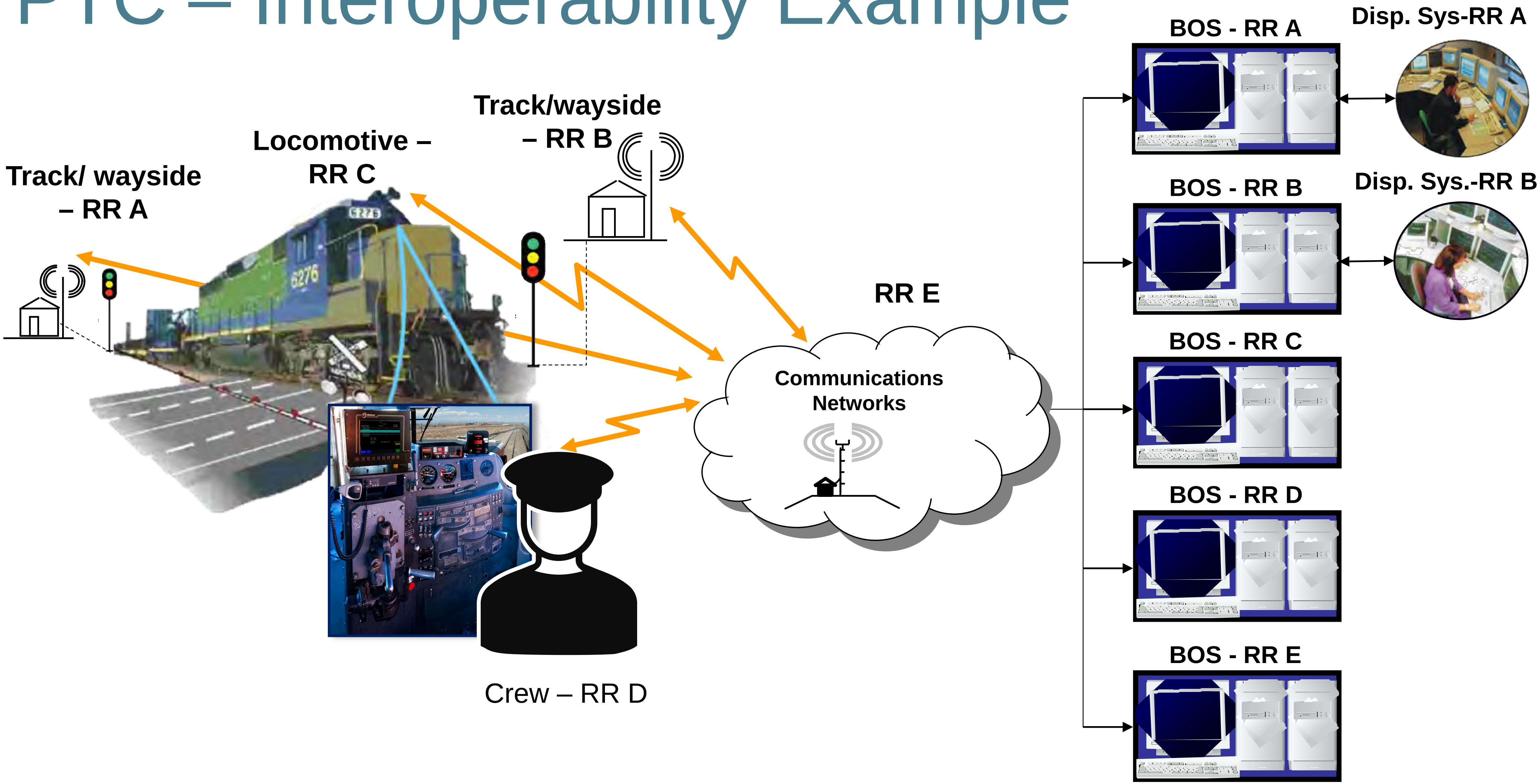
PTC - Interoperability

- **Interoperability is a key requirement of PTC**
- **Trains must be able to traverse from territory operated by one railroad to territory operated by another at track speed without losing PTC functionality or safety**
- **Over 200 Host-Tenant Relationships to date****

An industry-wide interoperability strategy is critical to successful PTC implementation.

**Source: FRA PTC implementation progress graphic, December 29, 2020

PTC – Interoperability Example



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The Need for PTC Interoperable Lifecycle Management (ILM)

Systems Engineering and Requirements Management

Safety and Reliability Engineering

Interoperable Configuration and Change Management

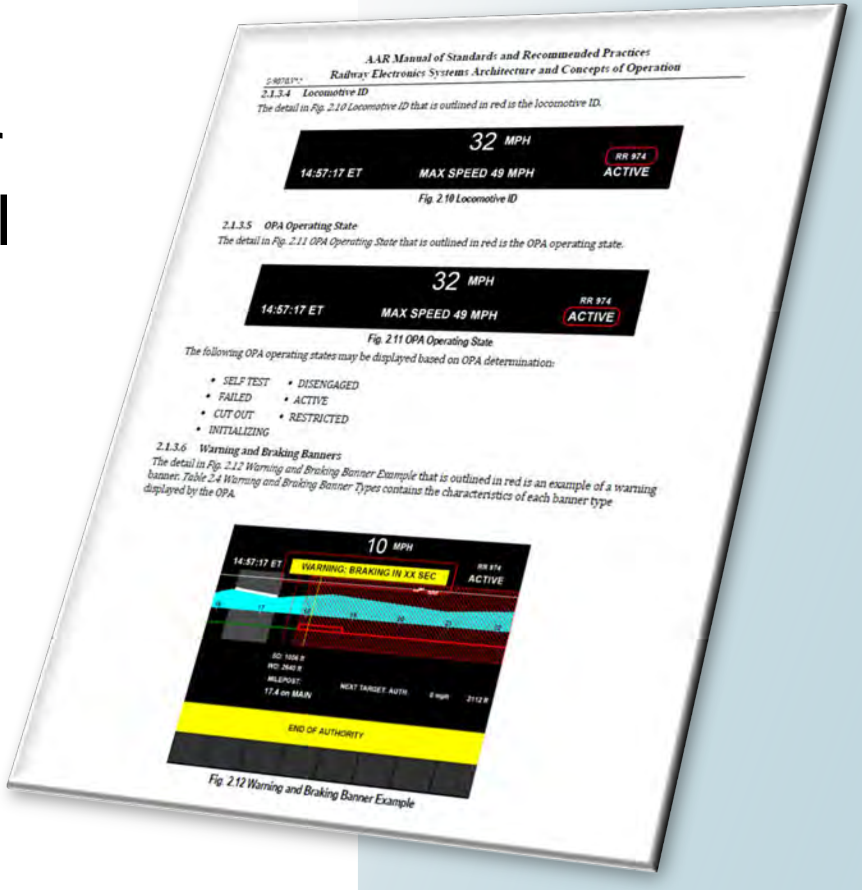
Interoperable System Release Management

Program Management and Governance

- **Systems with multiple segments, suppliers, components, operating rules, shared assets, etc.**
- **Complexity in number of Interoperable Configuration Items and continuous rapid rate of change**
- **Requires close coordination to support ongoing interoperability**

ILM Program – Key Elements

- **Systems Engineering and Requirements Management:**
  - Standards and processes
    - Onboard PTC Application, HMI and other key PTC Standards and Interface Control Documents (ICDs)
  - Processes and teams to handle, prioritize, and engineer system enhancements
  - Software tools to manage and trace standards and safety analyses


AAR Manual of Standards and Recommended Practices
Railway Electronics Systems Architecture and Concepts of Operation

2.1.3.4 Locomotive ID

The detail in Fig. 2.10 Locomotive ID that is outlined in red is the locomotive ID.

Fig. 2.10 Locomotive ID

2.1.3.5 OPA Operating State

The detail in Fig. 2.11 OPA Operating State that is outlined in red is the OPA operating state.

Fig. 2.11 OPA Operating State

The following OPA operating states may be displayed based on OPA determination:

- SELF TEST
- FAILED
- CUT OUT
- INITIALIZING
- DISENGAGED
- ACTIVE
- RESTRICTED

2.1.3.6 Warning and Braking Banners

The detail in Fig. 2.12 Warning and Braking Banner Example that is outlined in red is an example of a warning banner. Table 2.4 Warning and Braking Banner Types contains the characteristics of each banner type displayed by the OPA.

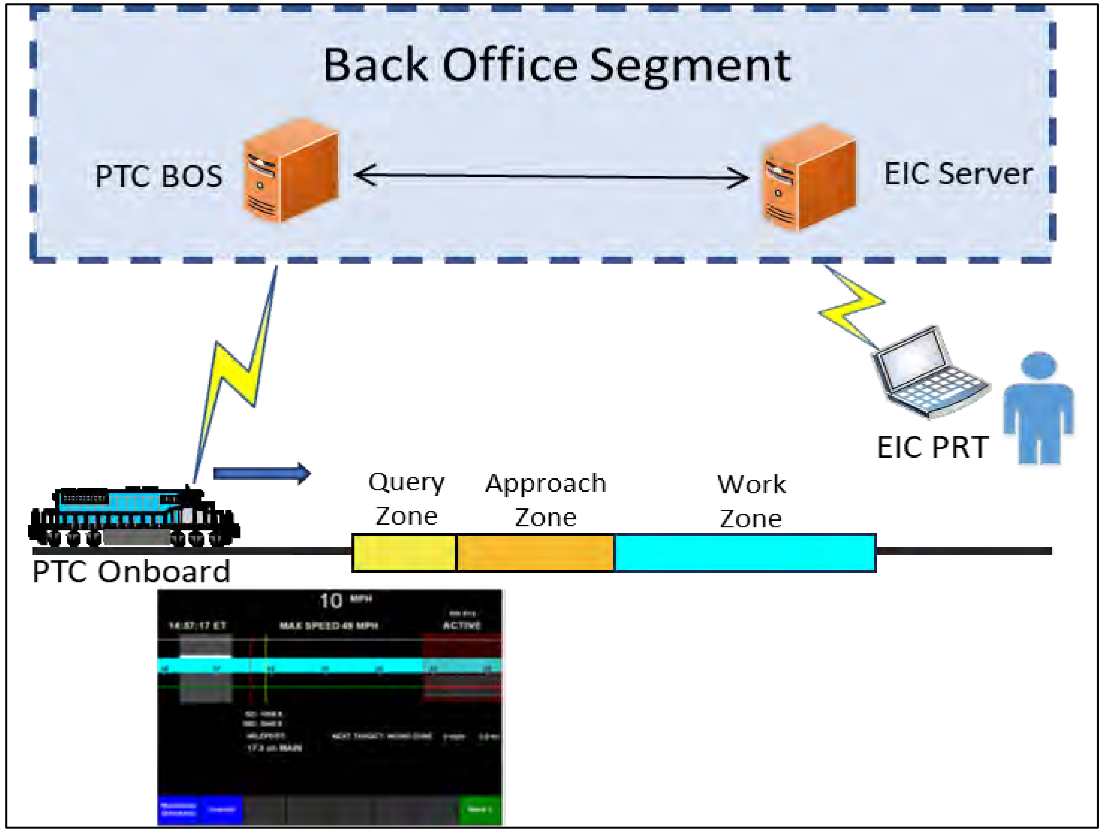
Fig 2.12 Warning and Braking Banner Example

ILM Program – Key Elements

- **Safety Engineering**
  – Establishing and managing system-level safety analysis
- **Interoperable Configuration, Change, and Release Management**
  – Establishing a process to request, analyze, and approve interoperable deployment changes
- **Program Management and Governance**
  – Management of teams defining critical aspects of interoperable technology

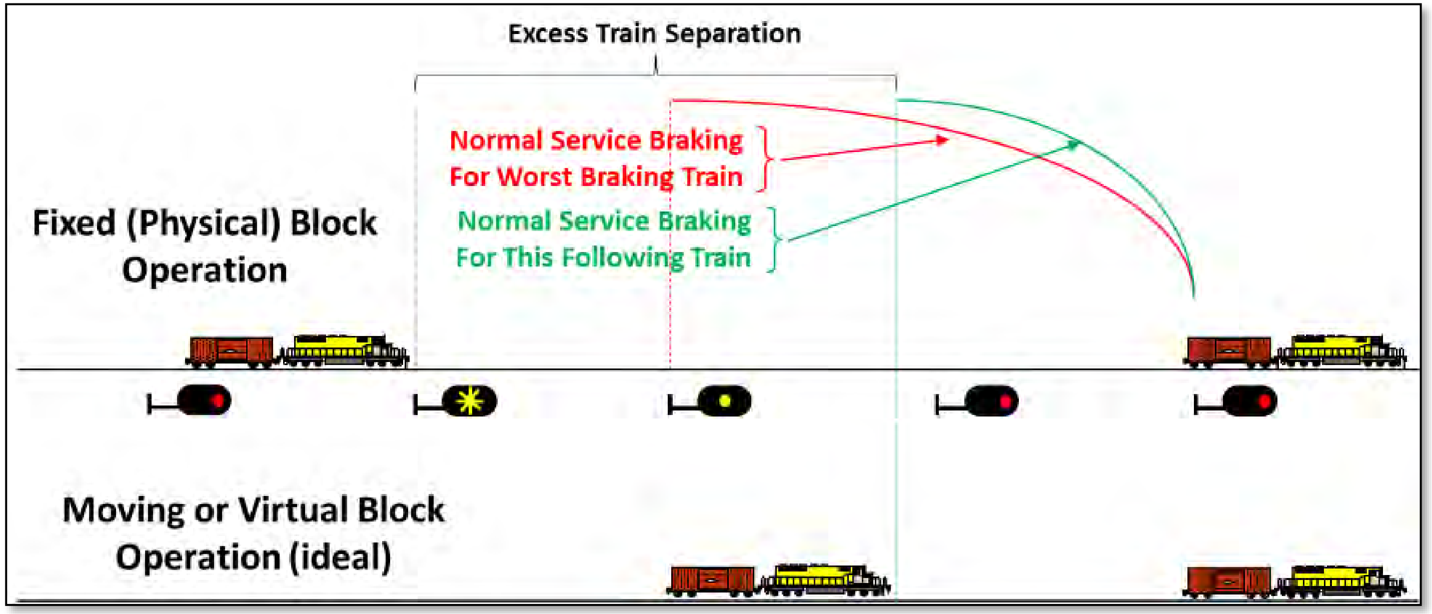
PTC – New Technologies

- **Engineering changes to PTC for technologies that will provide safety or operational benefit**
- **Key focus areas:**
  - Employee-in-Charge Portable Remote Terminal (EIC-PRT)
  - High precision Head-of-Train Location
  - End-of-Train Location
  - Automatic Track Selection
  - PTC Security Architecture 2 (PSA-2)
  - Restricted State Improvements
  - PTC enforcement of Wayside Detector Alarms
  - Equipment Ahead of Controlling Locomotive



PTC as Key Enabler of Future Technologies

- **Future technologies enabled by PTC:**
  - Train Control Technology Roadmap
    - Provides for incremental benefits with a path to High Automation
    - Enables advancement of independent technologies as a system of systems
  - Higher reliability/ Capacity train control
    - Enhanced Overlay PTC
    - Quasi-Moving Block
    - Full Moving Block



29TH AAR RESEARCH REVIEW

Summary

- **PTC is the foundation of several technologies that will provide safety and operational benefits to the railroad industry**
- **PTC requires close coordination between stakeholders and an ILM program**
- **MxV Rail and the railroad Industry have established foundational processes and tools for ILM**

With ILM in place, the railroad industry has the cornerstone to advance the strategic train control objectives of the future.

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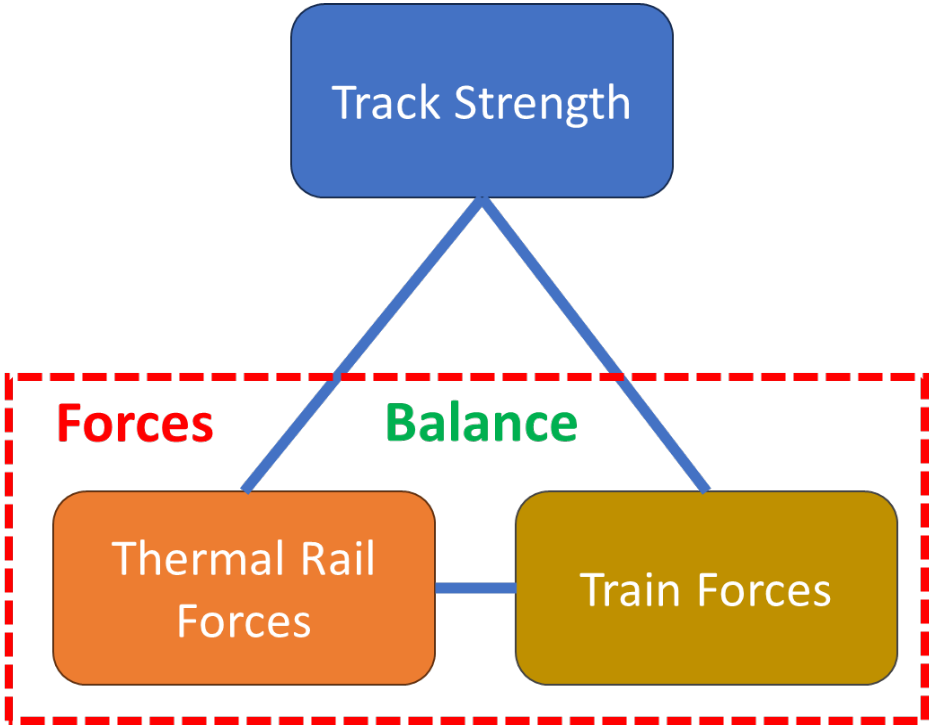
Speed Restrictions in Hot Weather

Stephen Wilk, Ph.D. – Principal Investigator II
Walter Rosenberger, PE – Scientist

Speed Restriction Work

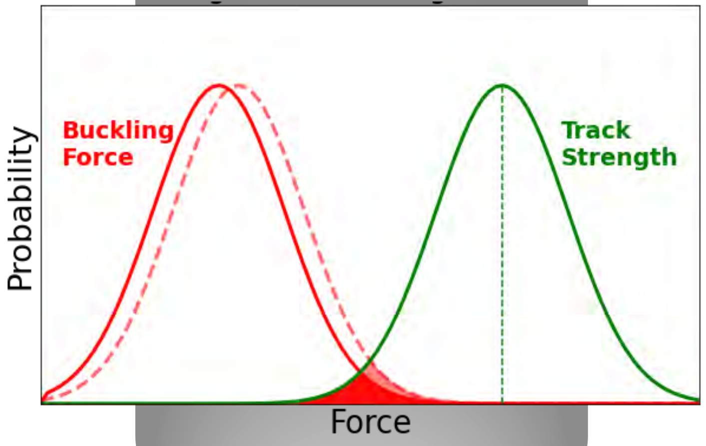
- **Expansion of “Track Buckling Prevention SRI” with emphasis on vehicle influences during hot weather events**
- **Important questions:**
  - What vehicle forces can produce track misalignments during heat events?
  - How can we improve safety against misalignments while also maintaining train velocity?



Outline

29TH AAR RESEARCH REVIEW

1 Background & Concepts



2 Vehicle Forces

3 Track Strength

Speed Restrictions

- **Reduced train velocity in situations of higher risk**
  - Heat events
  - Post-ballast maintenance

Lateral Misalignment

Photo by Brad Kerchoff

Dual Purpose

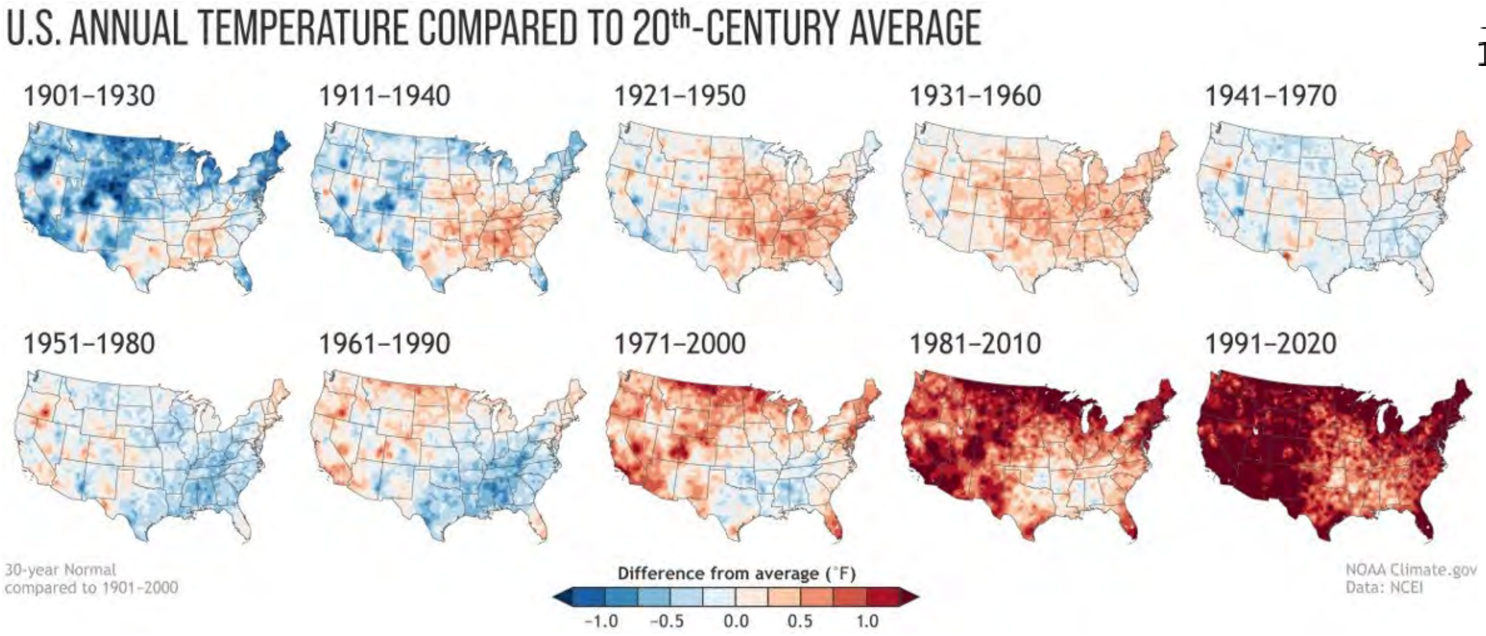
- **Reduce chance of producing misalignments by reducing train forces**
- **Reduce consequences of passing over an existing misalignment**

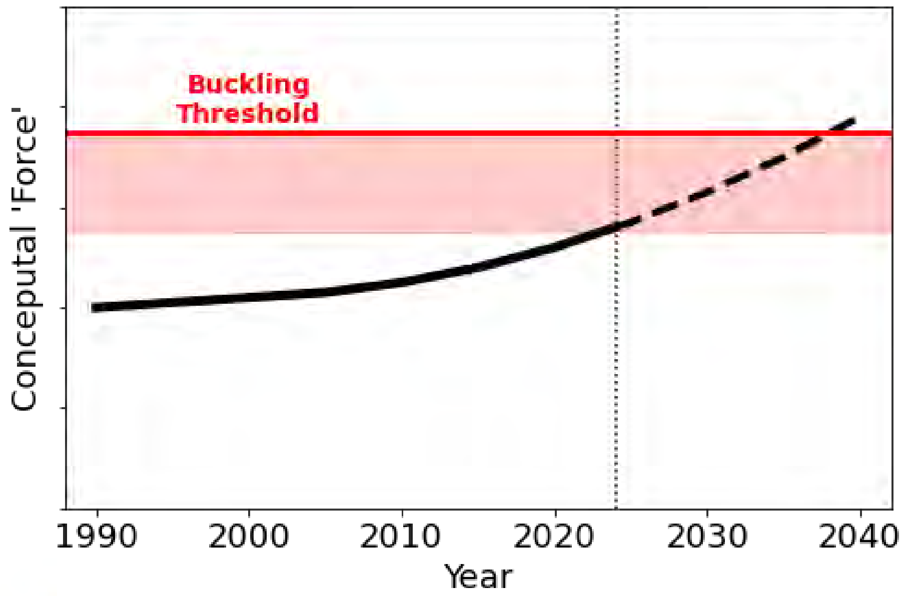
Important Questions

- **Does all track need to be treated the same?**
- **Do all vehicles need to be treated the same?**
- **Can we identify situations where high vehicle forces are likely?**

Changing Environment

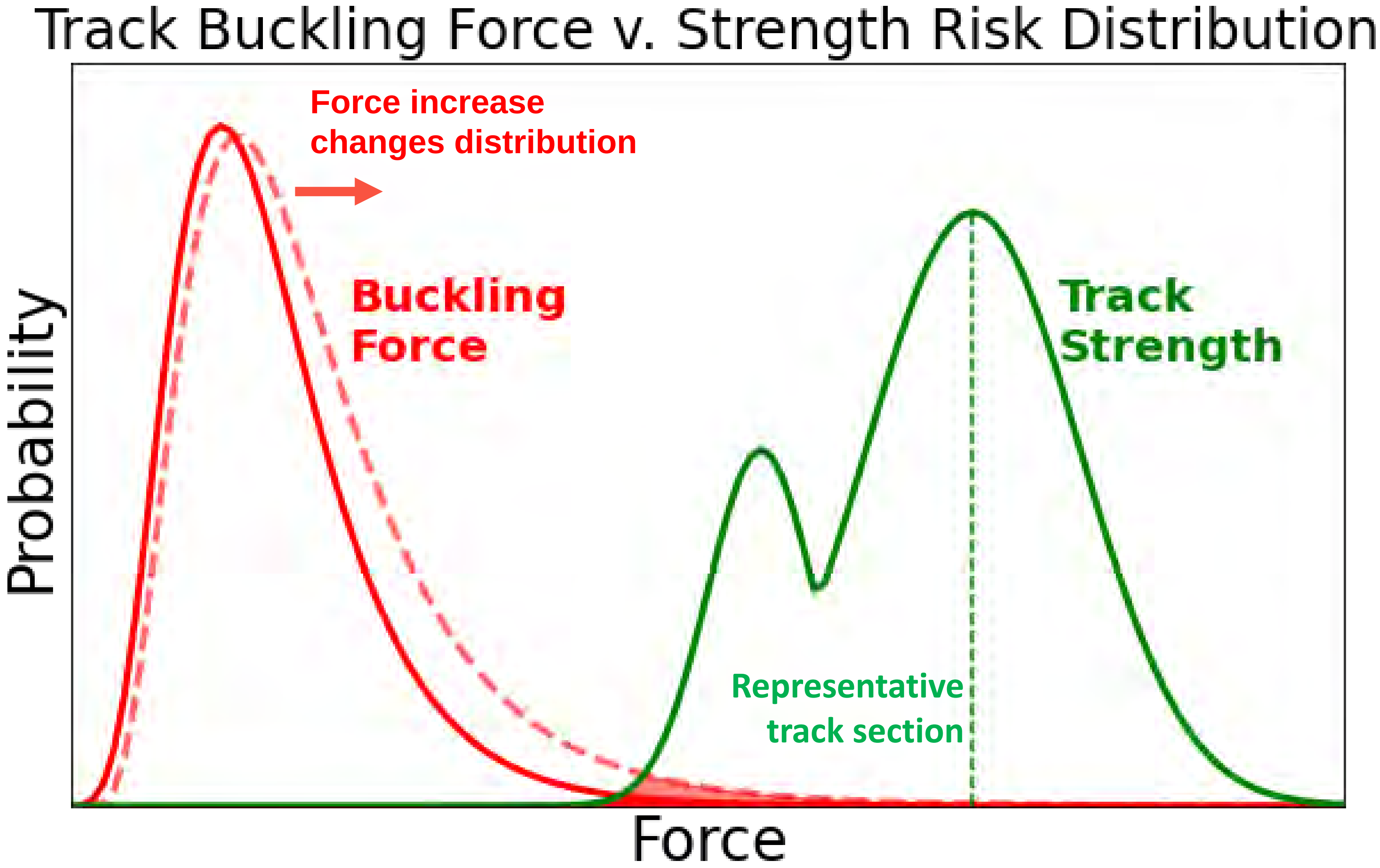
- **Severe hot weather is becoming more common and is forecasted to continue**





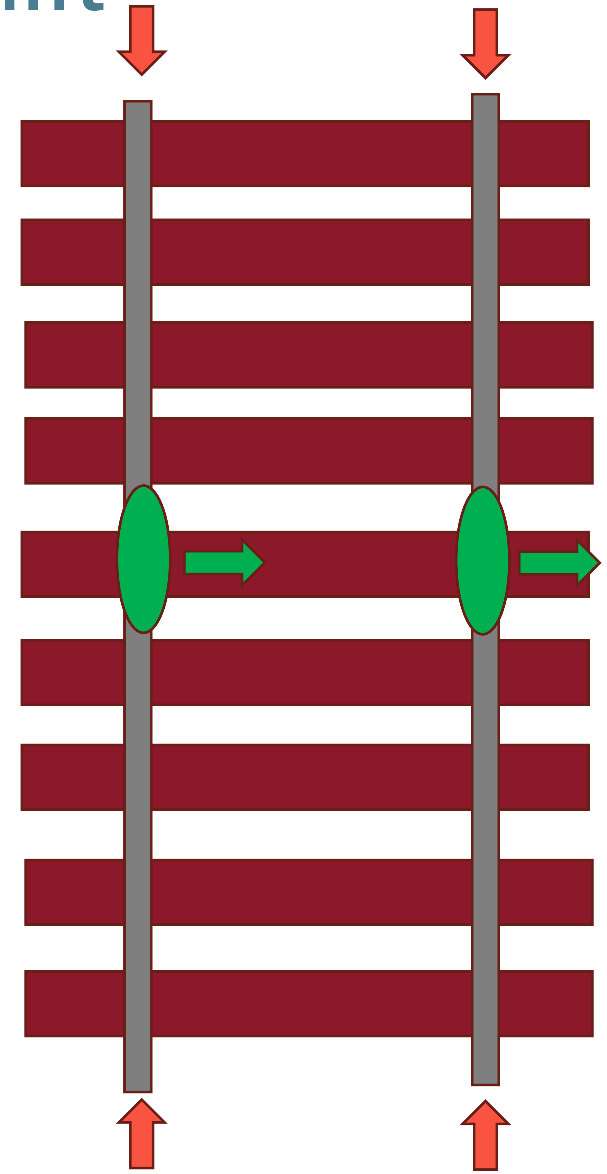
- **Will policies developed decades ago be appropriate in the future?**
- **Data-backed decisions**

Force and Strength Distributions



Track Buckling and Track Panel Shift

- **Different misalignment mechanisms:**
  - **Track Buckling:** Driven by the buildup of compressive longitudinal rail forces
  - **Track Panel Shift:** Driven by the lateral train forces



Key Concepts

- **Lateral misalignments may occur from one or some combination of both mechanisms**
- **Both mechanisms can occur progressively or from a single instance.**
- **Different frameworks are used for track buckles and track panel shift to relate forces and strengths**

29TH AAR RESEARCH REVIEW

Track Buckles

Track Buckle from 2022 MxV Rail/BNSF Test

Increased Forces

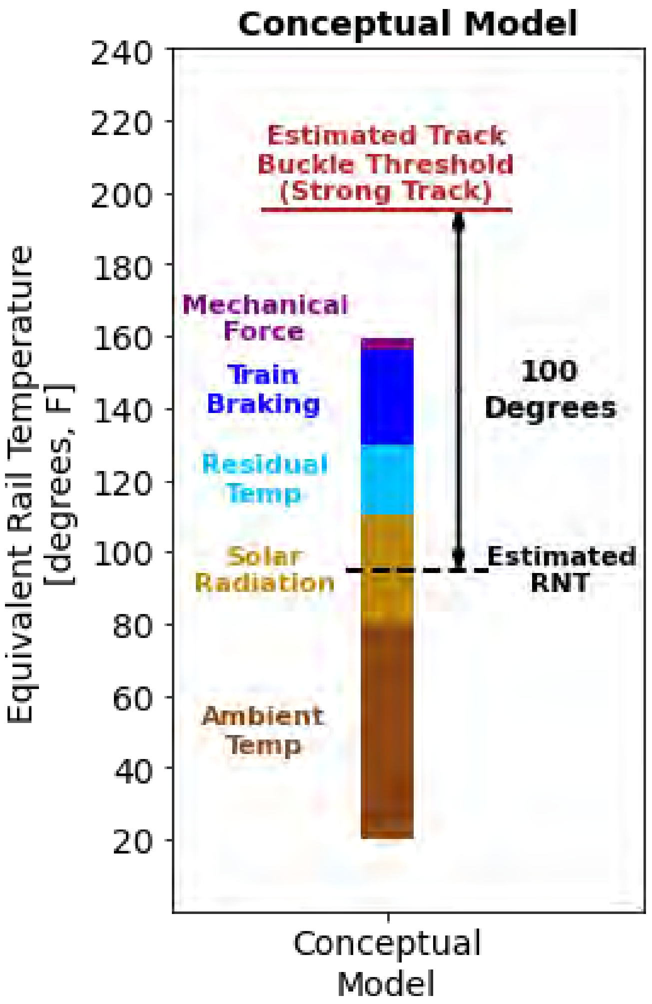
- Rail temperature above RNT (ambient and solar radiation)
- Rail temperature increases from vehicles
- Braking/traction forces

Reduced Strength

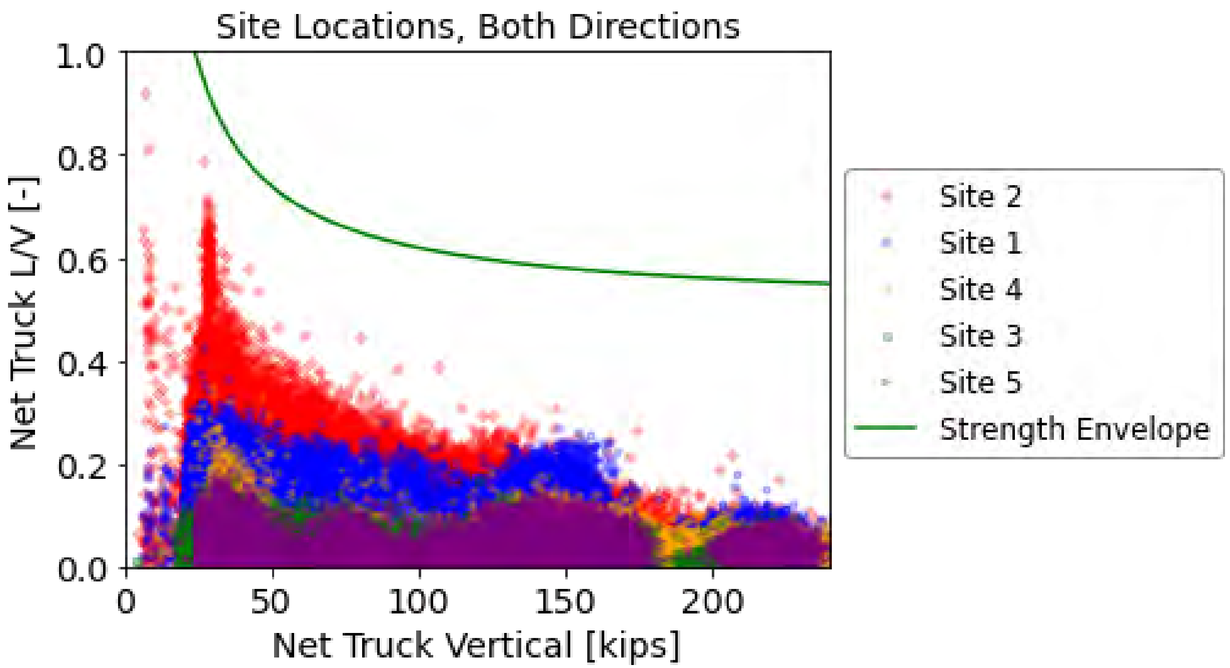
- Track uplift from vehicles
- Misalignments
- Variety of other track conditions

Tools

- Measurements
- Track Buckle Models (AAR/TAMU Model)



Track Panel Shift



Increased Forces

- Variety of vehicle causes

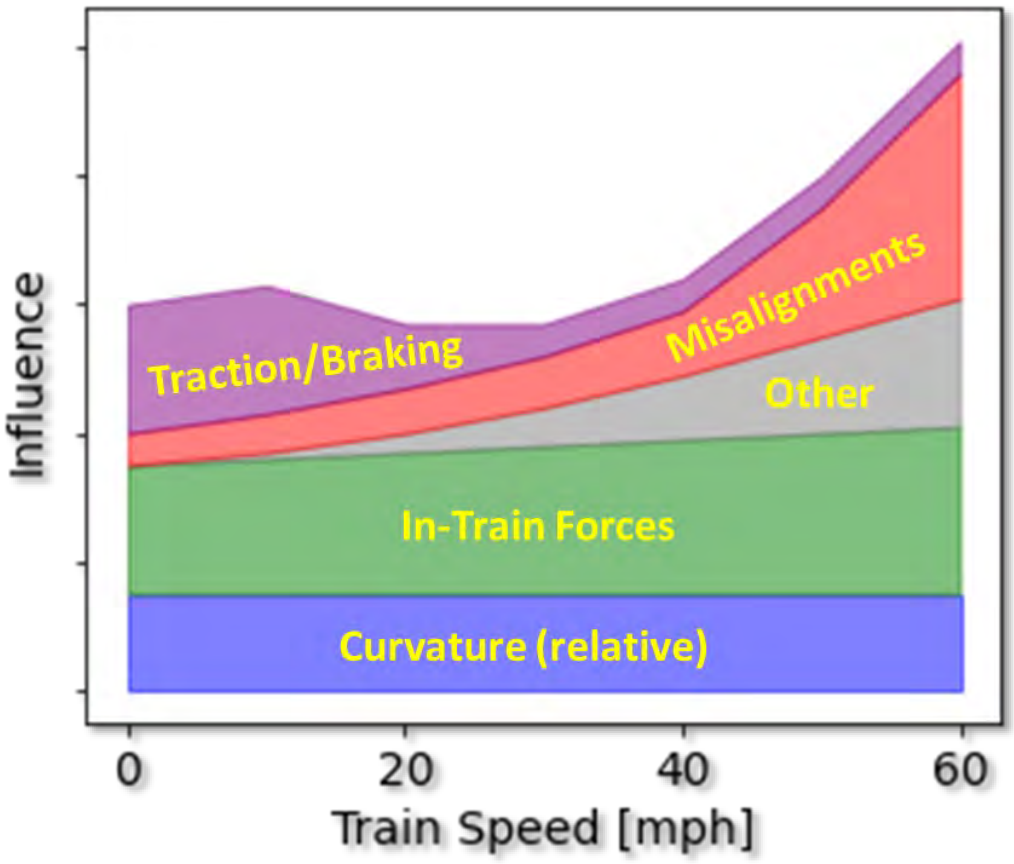
Track Panel Shift on Class 1 Railroad

Reduce Strength

- Similar track strength characteristics as track buckling
- Hotter temperatures suspected to reduce strength

Vehicle Speed Dependencies

- **Vehicle speed dependencies are based on the cause of lateral force**
  - Different track locations will have different combinations of possible forces
- **A policy focusing on one of the forces may not protect the track if another force is actually driving the buckle**



Vehicle Forcing Factors

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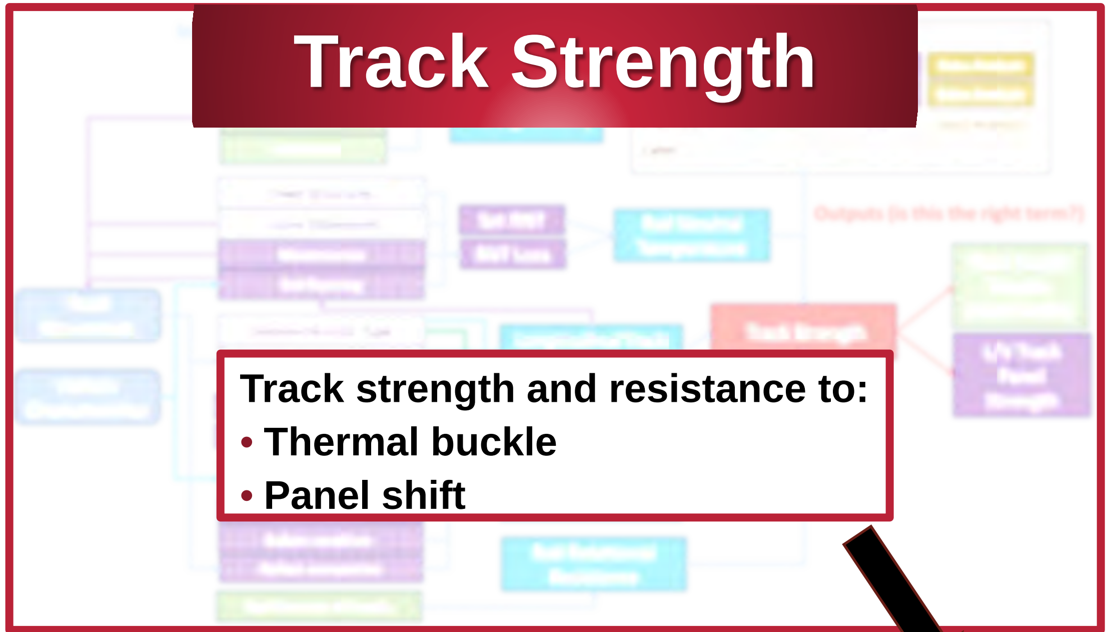
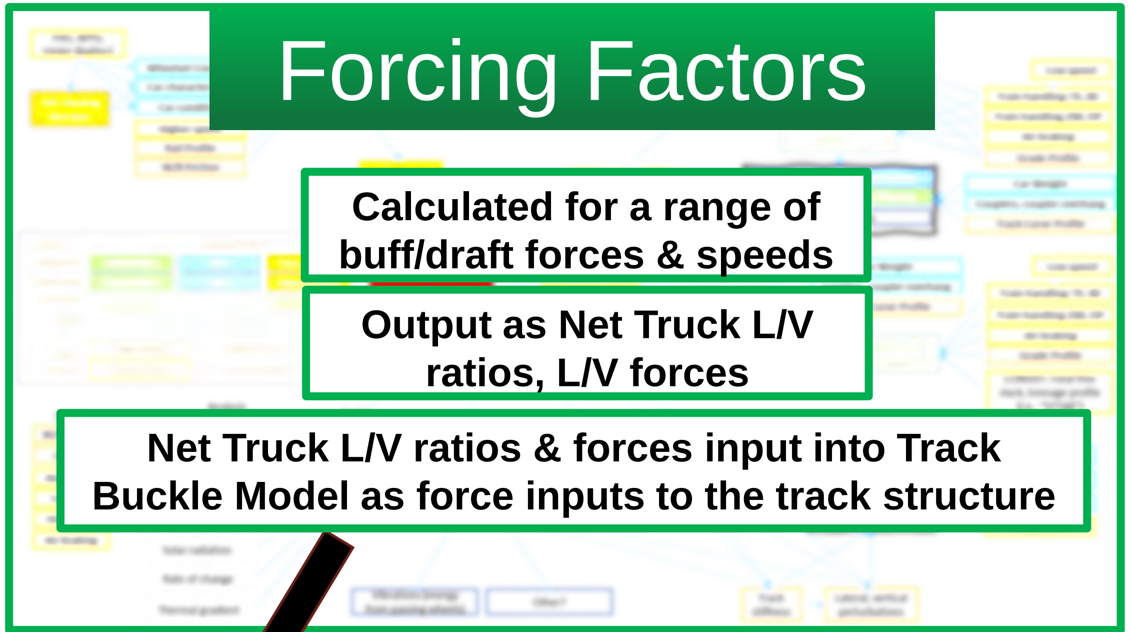
Conceptual Model & Roadmaps

Track Strength



Track strength and resistance to:
- Thermal buckle
- Panel shift

Forcing Factors



Calculated for a range of buff/draft forces & speeds

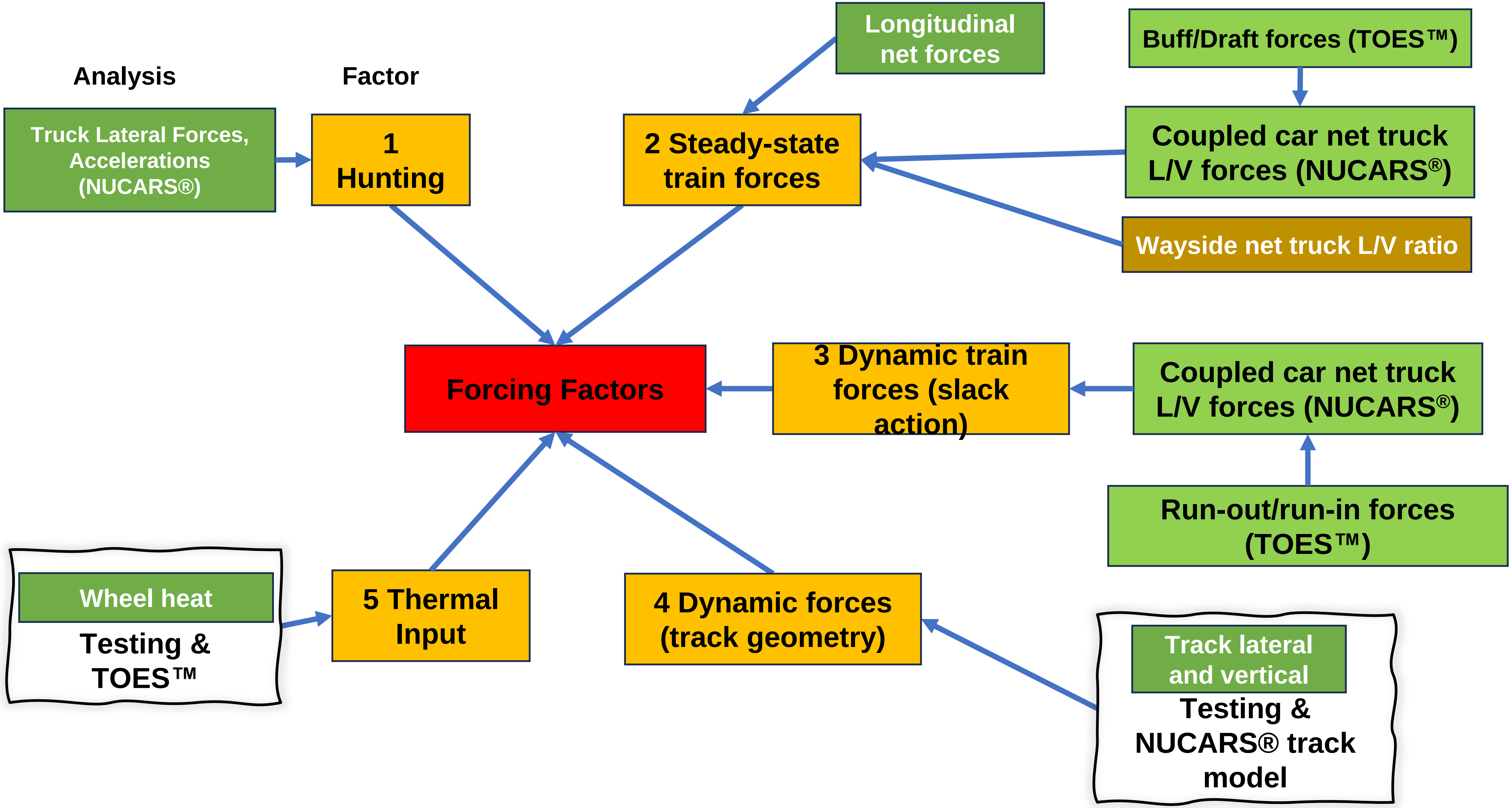
Output as Net Truck L/V ratios, L/V forces

Net Truck L/V ratios & forces input into Track Buckle Model as force inputs to the track structure

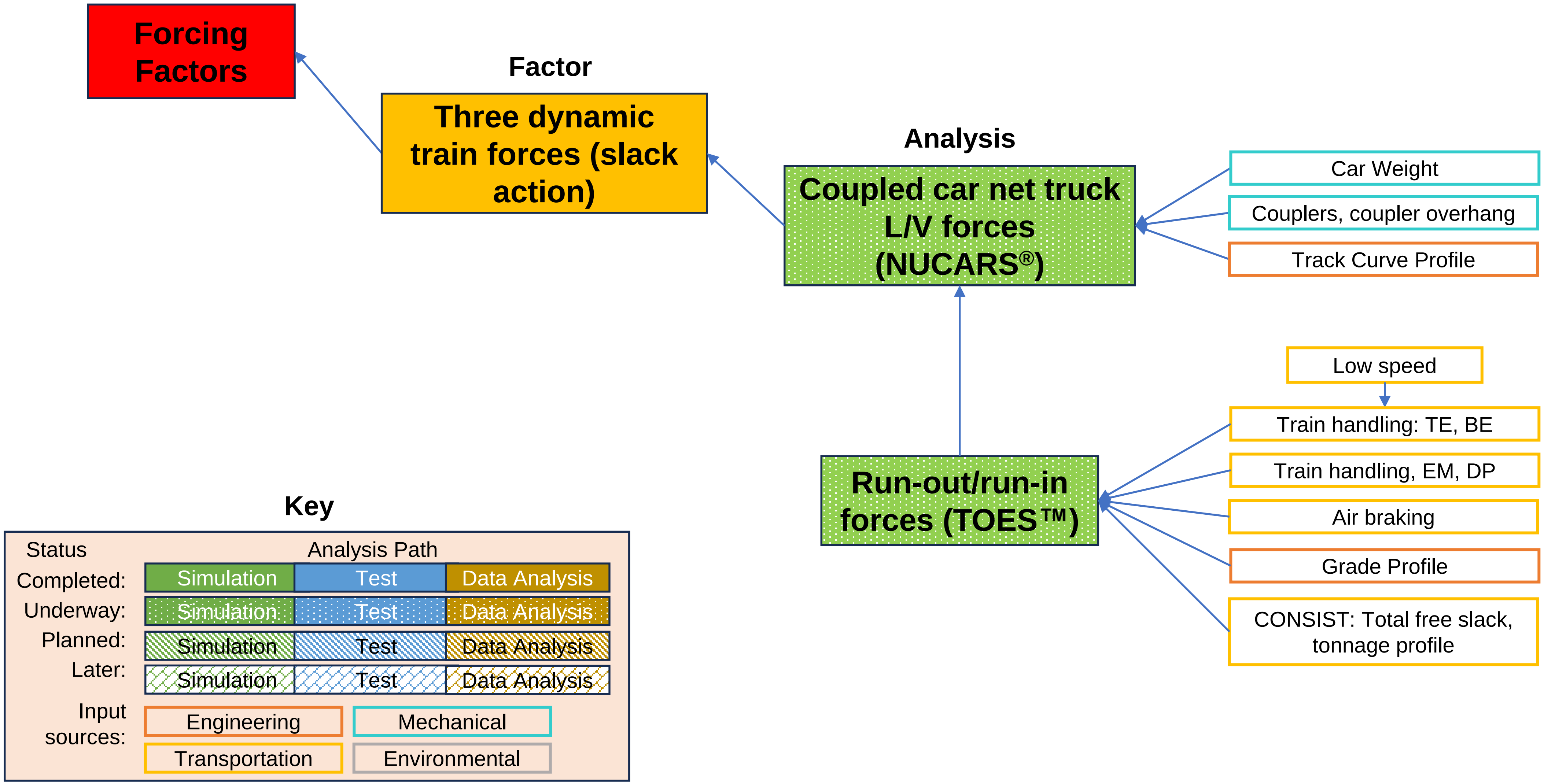
Track Buckle Model

Iteratively run the Track Buckle Model:	With a range of track strength factors:	With a range of forcing factor inputs:
	• RNT • Track geometry • Tie-ballast interface • Rail, fastener rotational resistances • Longitudinal track stiffness	• Range of buff, draft forces • Range of train speeds • Wheel-rail thermal input

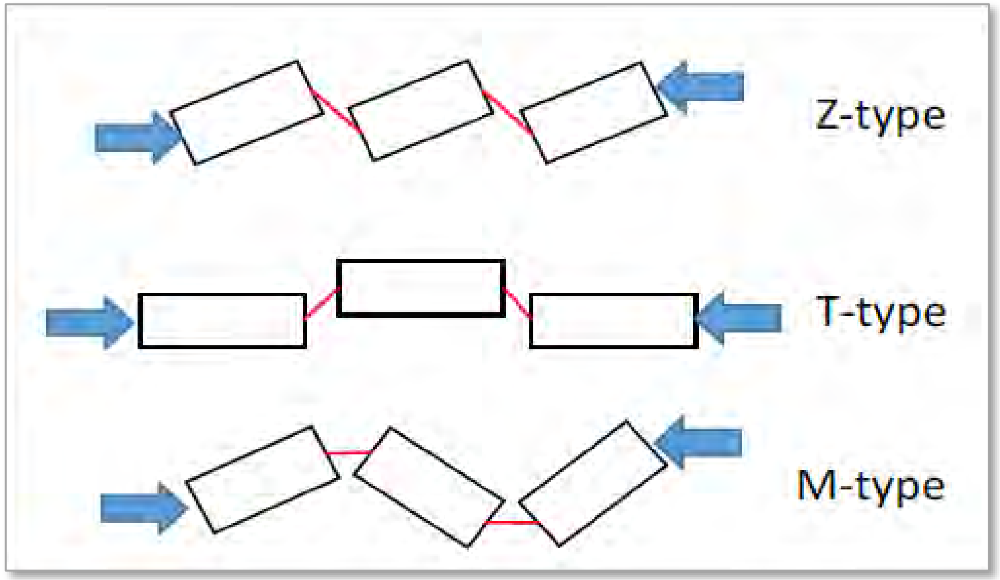
Forcing Factors Roadmap (simplified)



Forcing Factors – example roadmap



Example: In-Train Force Effects



- **Typically, buff force is the problem**
- **Static forces**
  - Tractive, dynamic braking effort
- **Dynamic forces**
  - Slack run-in
- **Car weight, car geometry, coupler length**

Track Strength

29TH AAR RESEARCH REVIEW

Track Strength Parameters

- **Rail in compression is a column with complex bracing**
- **Track buckle strength parameters**
  - Ballast resistance
  - Tie/ballast interface strength
    - Vehicle loading and uplift
  - Fastener rotational resistance
  - Anchoring and longitudinal resistance
  - Geometry

Summary

A Heat Restriction on Track is:

- **An ambient conditions problem**
- **A track strength problem**
- **A train effects problem**
- **Corrective measures require understanding the roles of all three aspects.**

Acknowledgements

- AAR "Speed Restriction" Technical Advisory Group (TAG)
- MxV Rail engineers
  - Scott Cummings, Alyson Sasaoka, Adam Klopp, Duane Otter, Kenny Morrison, and Matt DeGeorge

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Wheel/Rail Profile Design & Maintenance

Ulrich Spangenberg, Ph.D.
Principal Investigator II

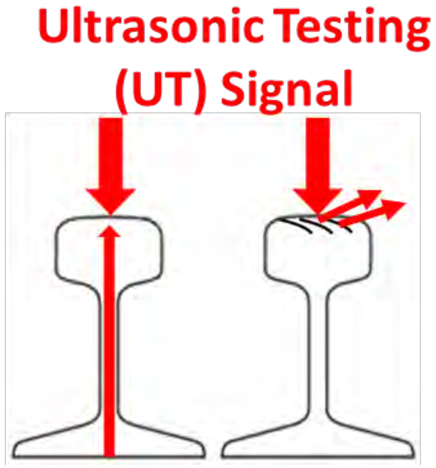
Overview

- **Introduction & background**
- **Asymmetric hollow wear**
  - Single wheelset change out
  - Deteriorating constant contact side bearings (CCSBs)

Project Background

- **Single greatest material costs is related to wheels & rails.[1]**
- **Predict and reduce wear and rolling contact fatigue (RCF) defects to extend service lives of components**

Rolling contact fatigue (RCF)



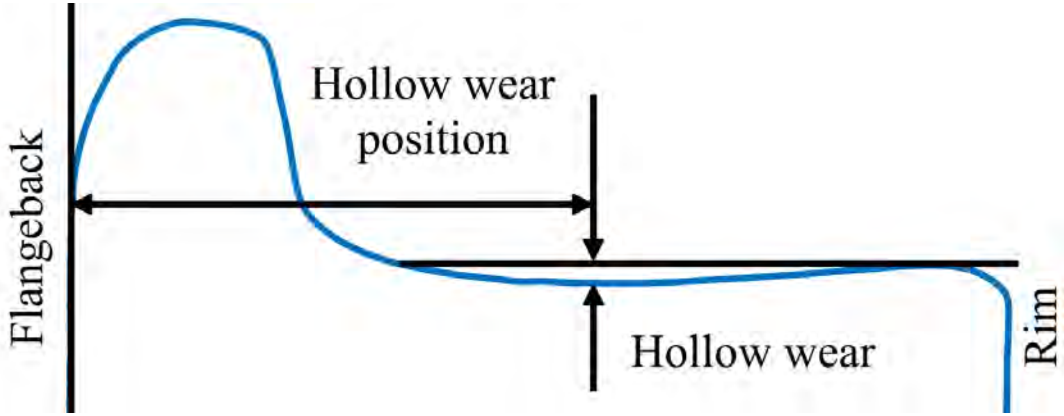
"Loss of Bottom"

Wheel hollow wear

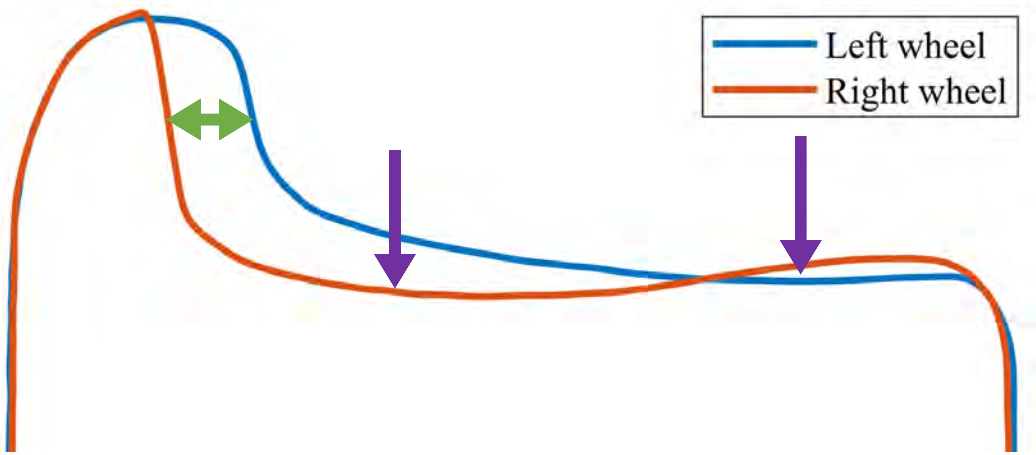
1. International Heavy Haul Association (IHHA), "Guidelines to Best Practices for Heavy Haul Railway Operations: Management of the wheel and rail interface", International Heavy Haul Association, Virginia Beach, 2015.

Introduction to Asymmetric Hollow Wear

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



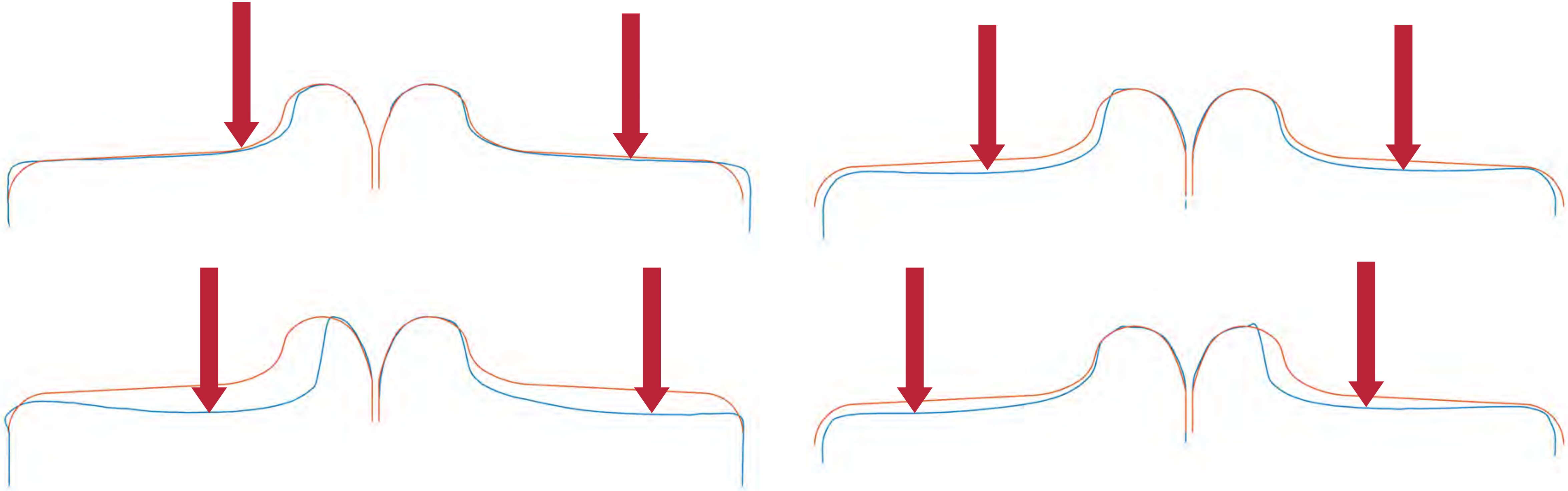
Calculation of hollow wear and position



Example of asymmetric hollow wear

Introduction to Asymmetric Hollow Wear

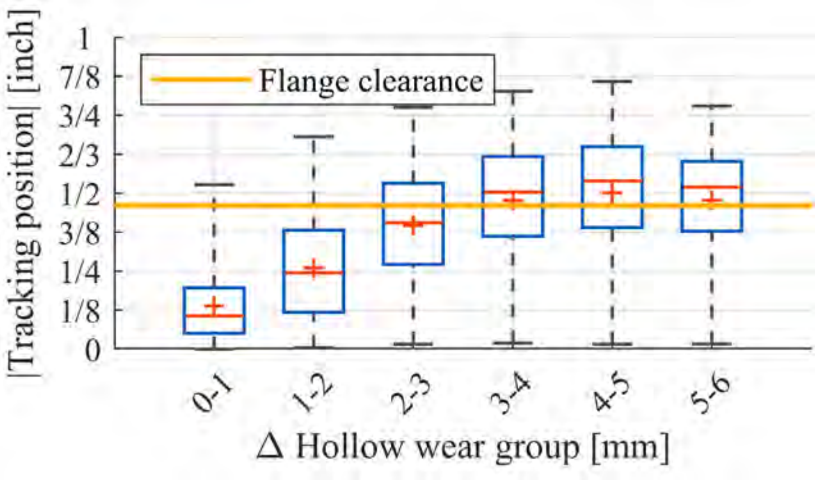
- **Examples of asymmetric wheel hollow wear in a truck**

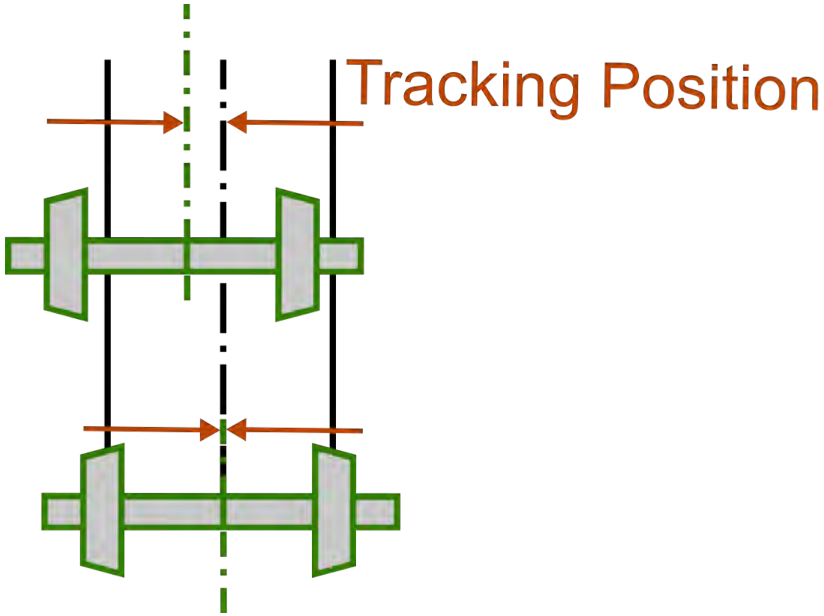


Slight asymmetry on the same side **Slight asymmetry on opposite side**

Introduction to Asymmetric Hollow Wear

- **Asymmetric hollow wear definition from previous work**

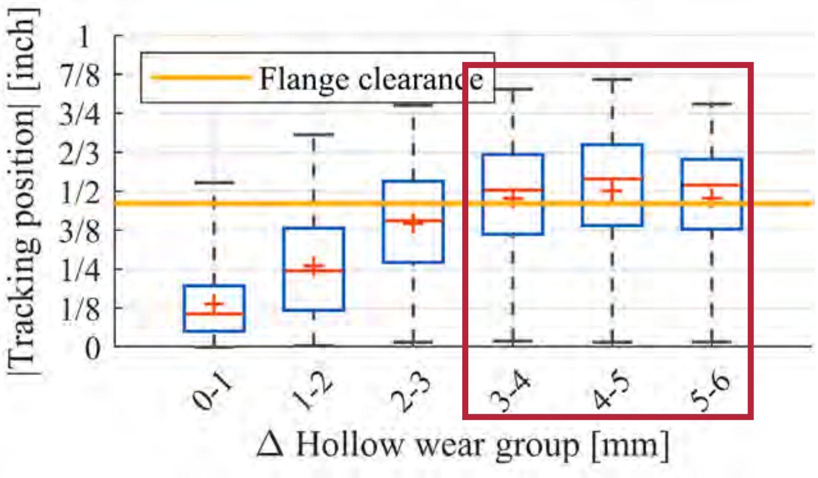


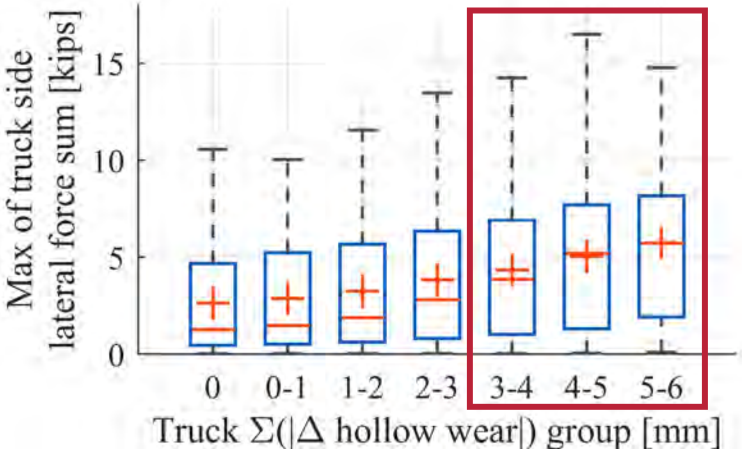


Definition of tracking position

Introduction to Asymmetric Hollow Wear

- **Asymmetric hollow wear definition from previous work**



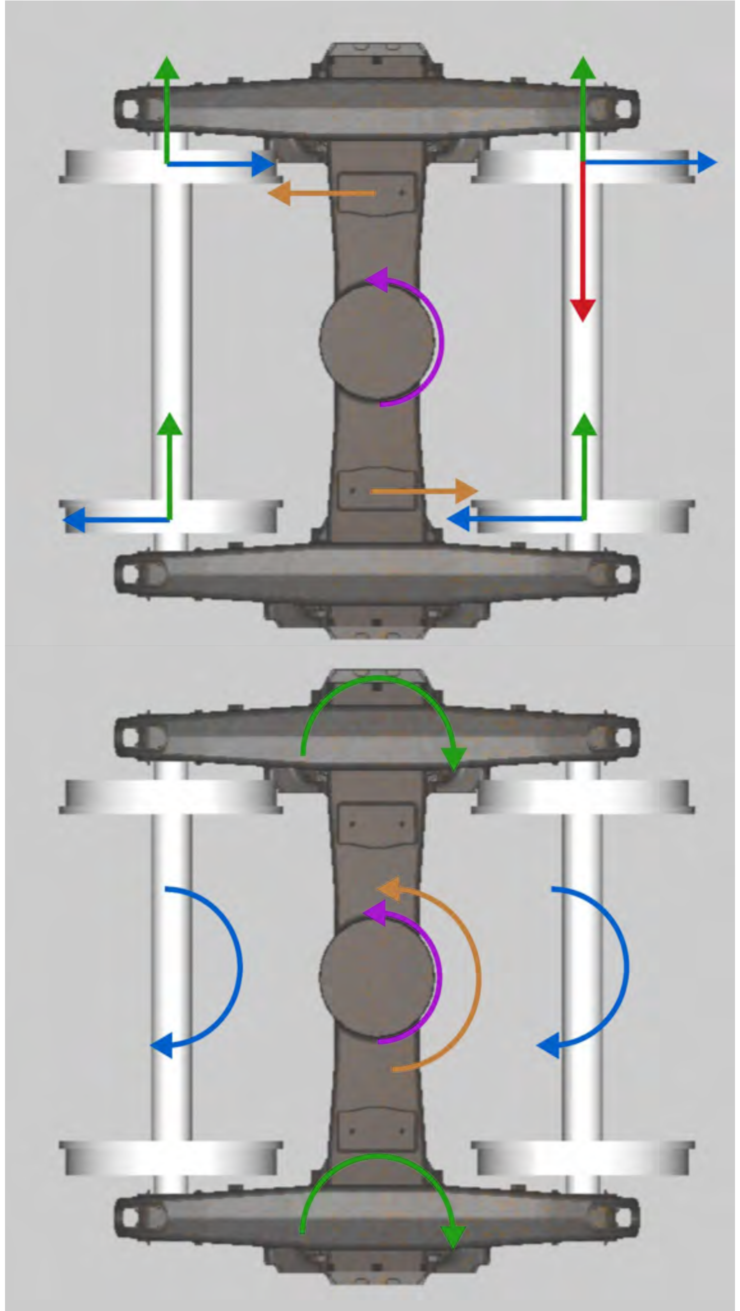


- **Lateral offset and lateral force increase above 3 mm of asymmetric hollow wear**

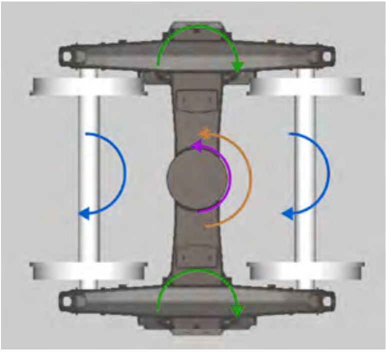
Wear parameter	≥ 1 mm [%]	≥ 2 mm [%]	≥ 3 mm [%]
Hollow wear	22.0	6.8	1.9
Asymmetric hollow wear	12.7	3.1	0.6

Truck Steering and Forces

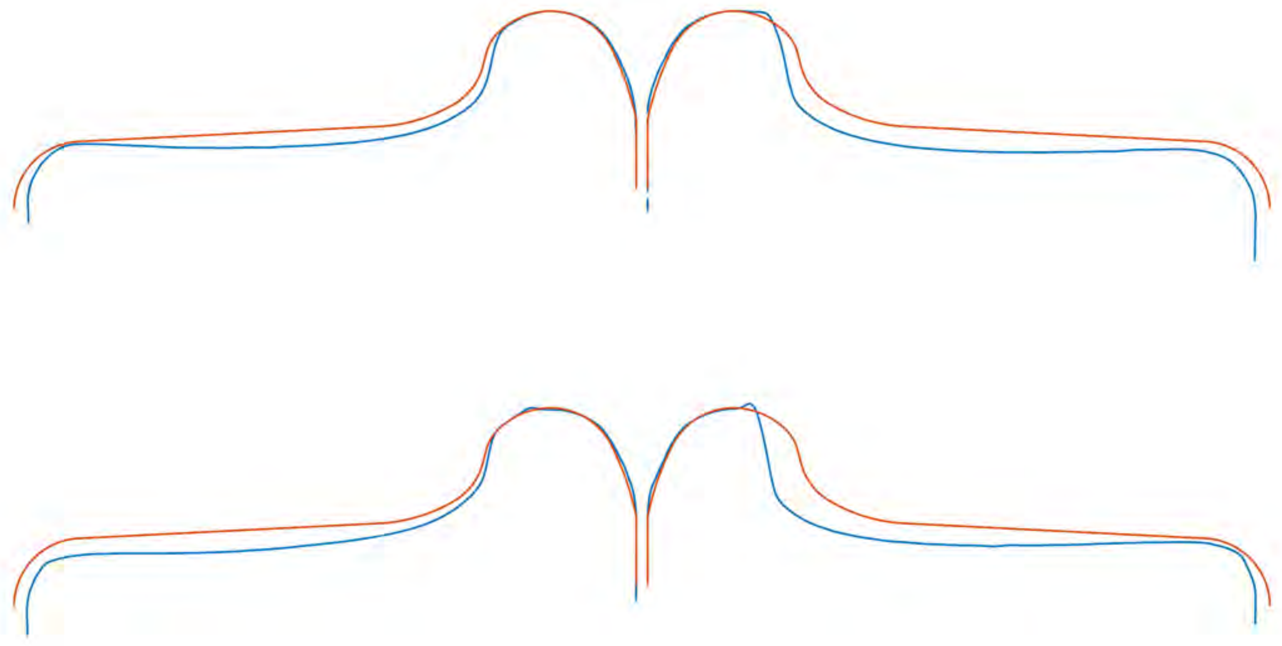
- **Where do the forces that cause wheel wear come from?**
- **Forces in a truck are caused by steering of the wheelset forces and reactions by center bowl and side bearings**
- **Steady state curving: Center Bowl Moment + Side Bearing moment = Warp Moment + Steering Moment**
- **Imbalance of the forces or moments may cause asymmetric wheel wear**



Asymmetric Hollow Wear

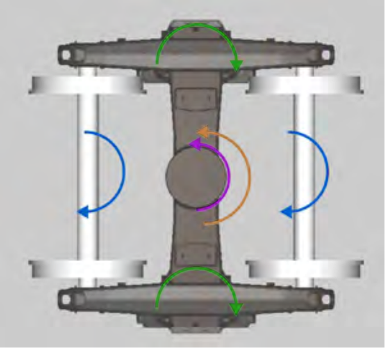


- **Single wheelset change out – Steering moment**
  - Hypothesis of single wheelset change out driving asymmetric wear on the same side.

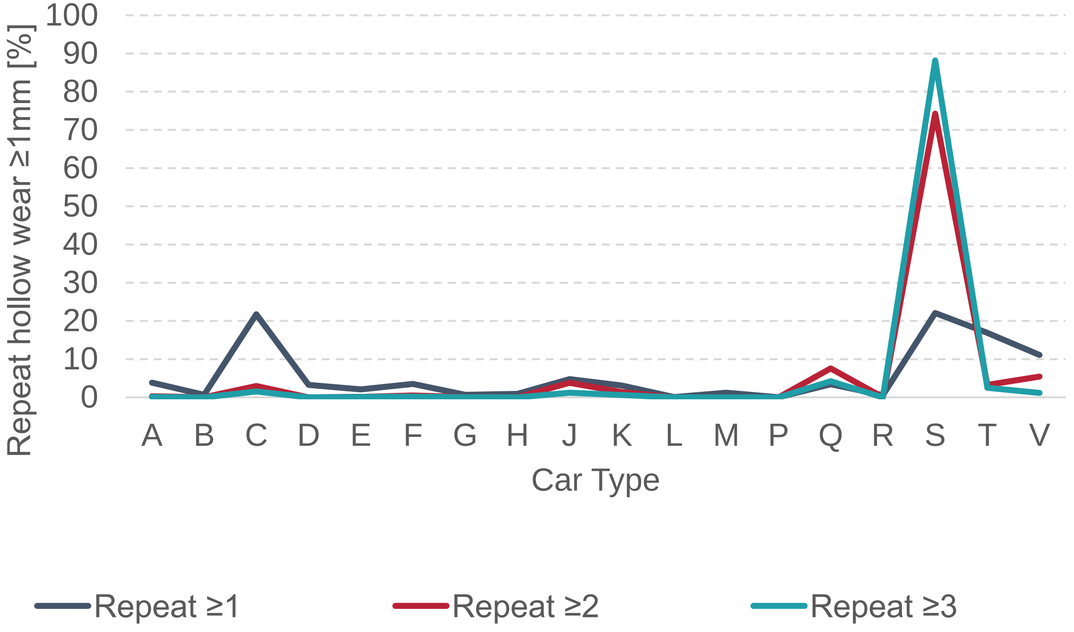


Single wheelset changeout and asymmetry on the same side

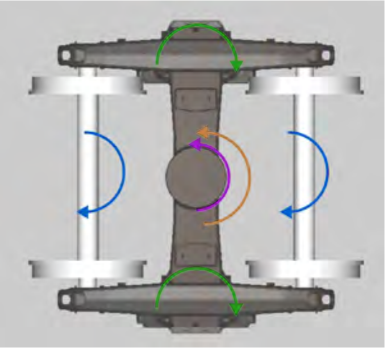
Asymmetric Hollow Wear



- **Single wheelset change out – Steering moment**
  - Cars with two repeat occurrences were analyzed
  - Repeats on Q (intermodal), S (stack cars) and V (vehicular flats)



Asymmetric Hollow Wear



- **Single wheelset change out – Steering moment**
  - Repeat on right minus repeat on left
  - Trucks on intermodals show repeat with consistent bias
  - Data from three years of trucks with single wheelset change out

	Car Type		
Axle #	**Intermodals**	**Stack cars**	**Vehicular flats**
1	-29.00	-3.15	-8.17
2	-5.26	26.87	8.09
3	16.03	-16.52	-11.44
4	24.01	4.76	16.76
5	-11.85	-9.41	
6	-1.21	9.77	
7	-21.85	-7.21	
8	-5.68	7.75	
9	-25.83	-9.99	
10	-10.18	18.05	
11	12.78	-25.71	
12	37.50	7.94	

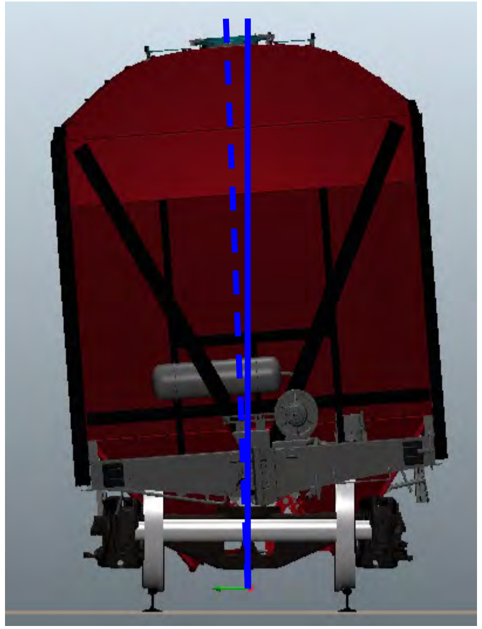
*Negative is left bias, positive is right bias

Row Labels	Count	Percent
Diagonal	36	38.7%
Inconclusive	19	20.4%
Same Side	38	40.9%
Grand Total	93	

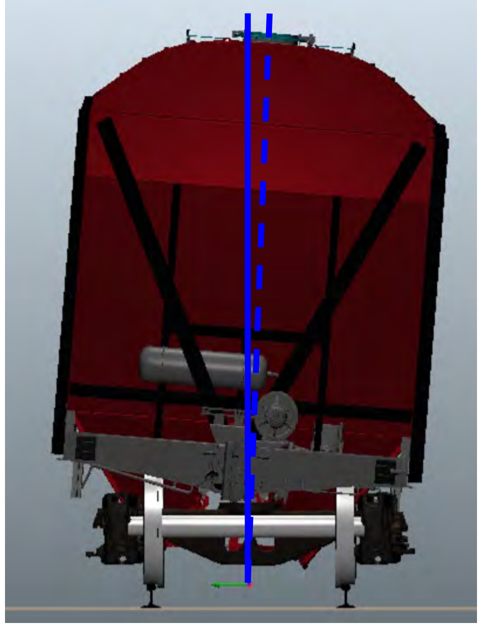
29TH AAR RESEARCH REVIEW

Truck Steering and Forces

- **Side Bearing moment changes:**
- **NUCARS®* analysis with constant curving around 6-degree curve, 5-inch superelevation and 60 mph**
- **CCSB stiffness vary with left = 0.75×right**
  - Carbody lean changes relative to nominal:
    - From -1.4 to -1.7 degrees in right-hand curve
    - From 1.4 to 1.1 degrees in left-hand curve



Right-hand curve

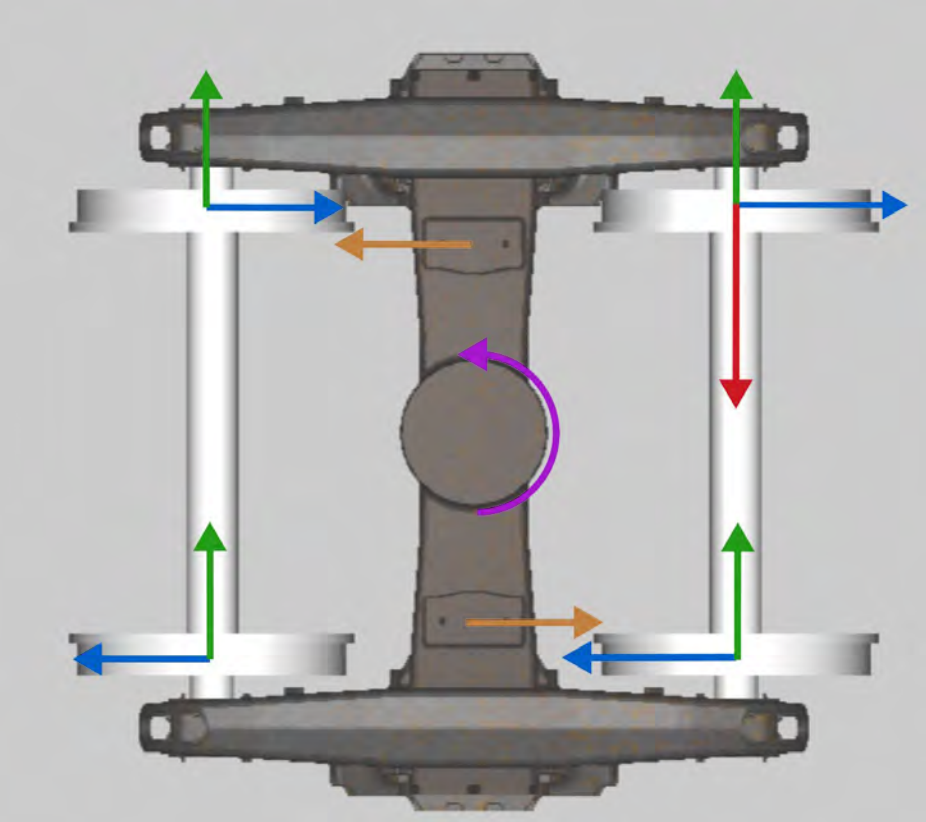


Left-hand curve

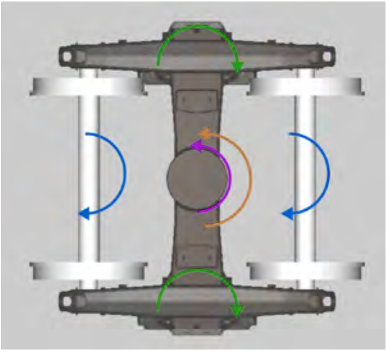
*NUCARS® is a registered trademark of the Transportation Technology Center, Inc. (MxV Rail)

Truck Steering and Forces

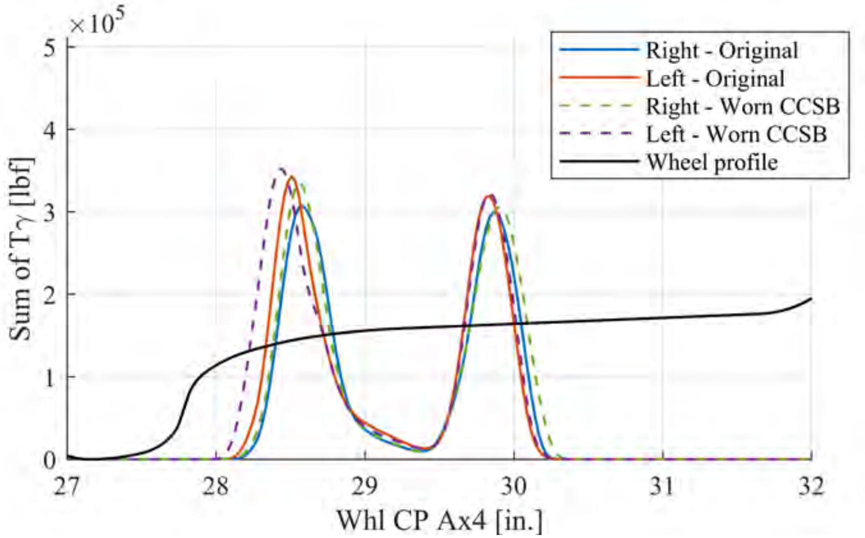
- **Side Bearing moment changes:**
  - Moment change during curving:
    - From 17,200 lb-ft to 12,900 lb-ft in right-hand curve
    - From -17,500 lb-ft to -16,600 lb-ft in left-hand curve
  - Most significant change in right-hand curve:
    - Lateral forces increased by 5.5%
    - Longitudinal forces increased by 28%



Asymmetric Hollow Wear

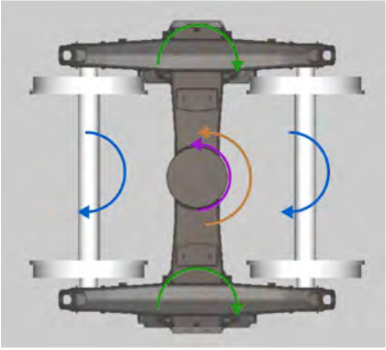


- **Worn constant contact side bearings (CCSB) – Side bearing moment**
  - NUCARS modeling analysis with five semi-permanently coupled intermodal cars with articulated trucks
  - Track with 1-, 2- and 3-degree curves
  - 1- to 3-inch cant deficiency in curves
  - CCSB stiffness and damping reduced to 75% of original values



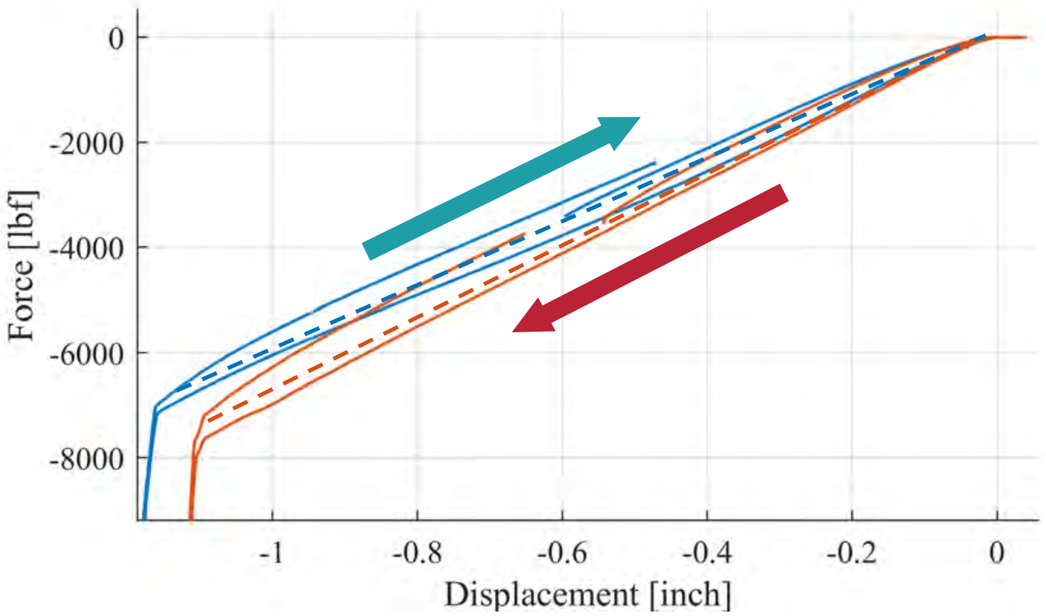
- **Preliminary results show degraded CCSBs influences asymmetric wheel wear**

Asymmetric Hollow Wear



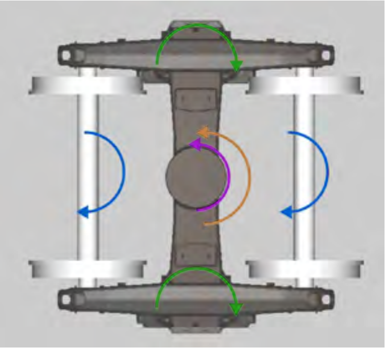
- **Worn CCSBs – Side bearing moment**
  - Characterization show maximum of 12% difference in CCSB stiffness, influencing turning resistance

Test Setup

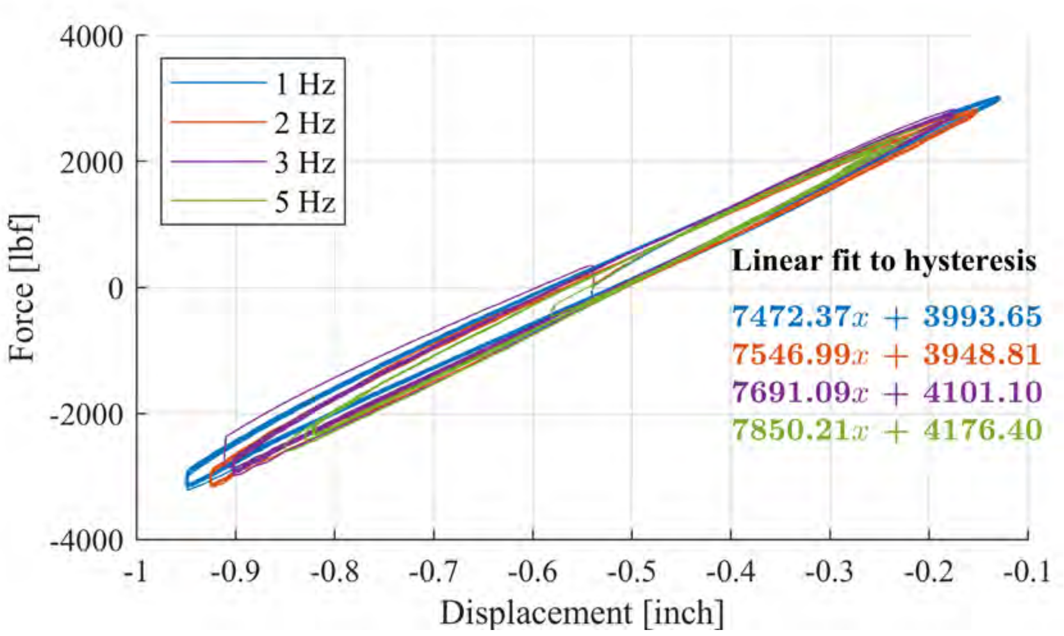


Hysteresis comparisons

Asymmetric Hollow Wear

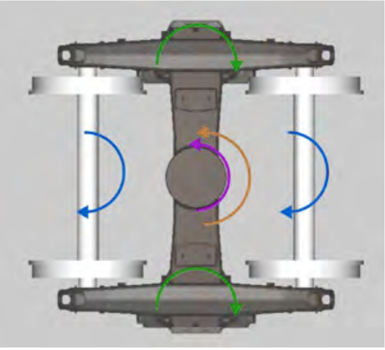


- **Worn CCSBs – Side bearing moment**
  - Frequency of excitation stiffens CCSB characteristic increasing modeling complexity

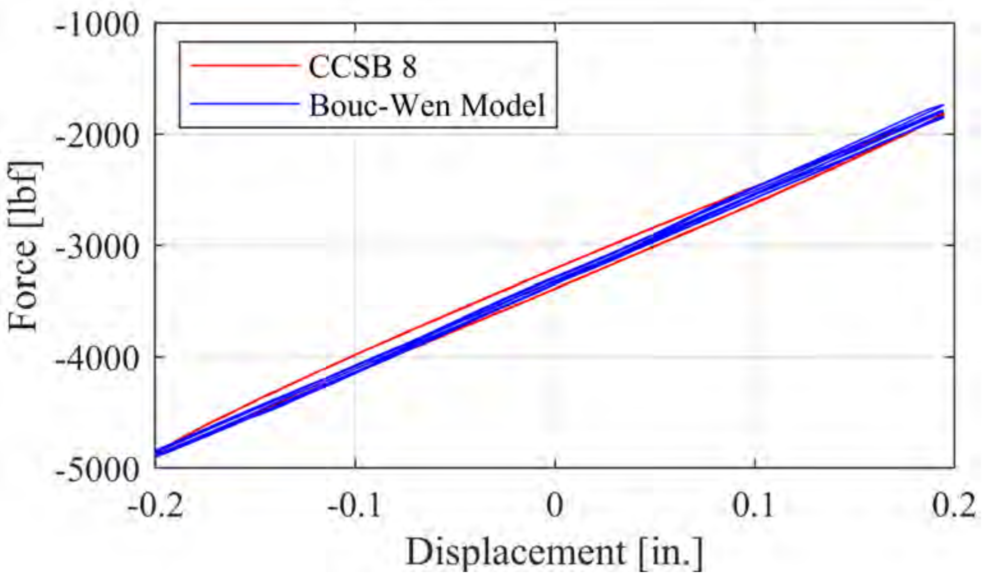


Hysteresis comparisons

Asymmetric Hollow Wear

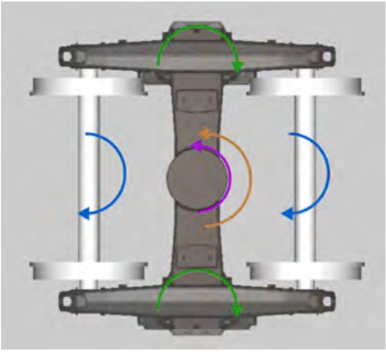


- **Worn CCSBs – Side bearing moment**
  - Complexity in establishing a NUCARS model representing CCSB characteristic
  - Different models to represent behavior

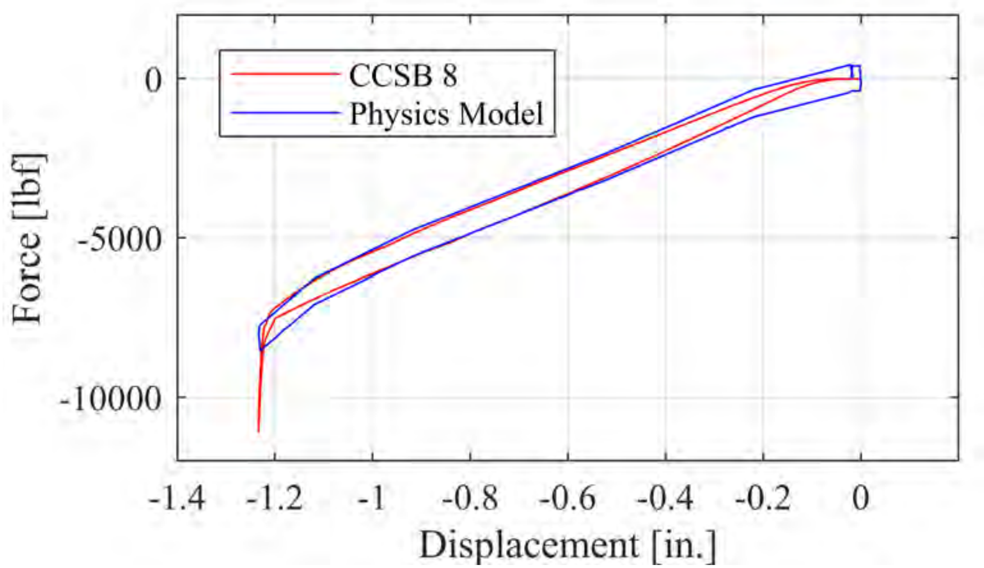


Bouc-Wen hysteresis model

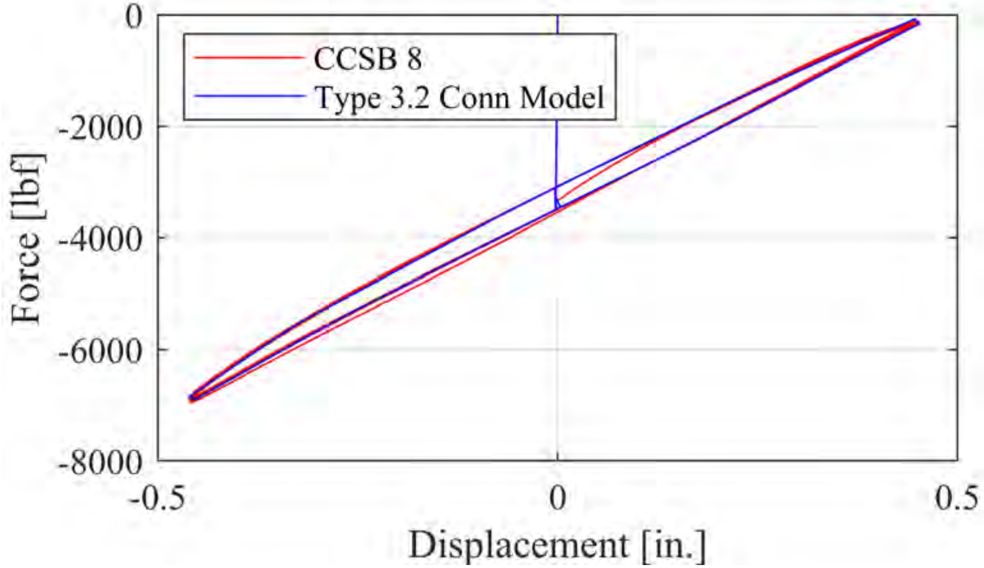
Asymmetric Hollow Wear



- **Worn CCSBs – Side bearing moment**
  - Different models to represent behavior



Physics based polymer model



NUCARS® non-physics model

Summary and Future Work

- **Wheel asymmetry on the same side of the truck unaffected by single wheelset changeout**
- **Accurate CCSB model is imperative to researching curving behavior once CCSBs have degraded**
  - Non-physics-based model likely candidate

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Acknowledgements

- MxV Rail:
  - Kenny Morrison
  - Dennis Rule
  - Alyson Sasaoka
  - Russell Walker
- TTX Company
  - Sawan Dumbre

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29TH ANNUAL Association of American Railroads RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS

MxV RAIL

Wednesday, April 24, 2024 –Technical Sessions – Infrastructure

INFRASTRUCTURE 1:

Evaluation of Rail and Weld Integrity — **Ananyo Banerjee, Ph.D.**, Principal Investigator II, MxV Rail

Crosstie and Fastener Research — **Yin Gao, Ph.D.**, Principal Investigator I, MxV Rail

Bridge Research — **Christopher Johnson**, Scientist, MxV Rail

INFRASTRUCTURE 2:

Revenue Service Testing — **Duane Otter, Ph.D.**, Scientist, MxV Rail

Ballast and Subgrade Research — **Stephen Wilk, Ph.D.**, Principal Investigator I, MxV Rail

Machine Learning Approach to Ultrasonic A-Scans for Rail Flaw Detection — **Anish Poudel, Ph.D.**, Principal Investigator II, MxV Rail

Evaluation of Rail and Weld Integrity

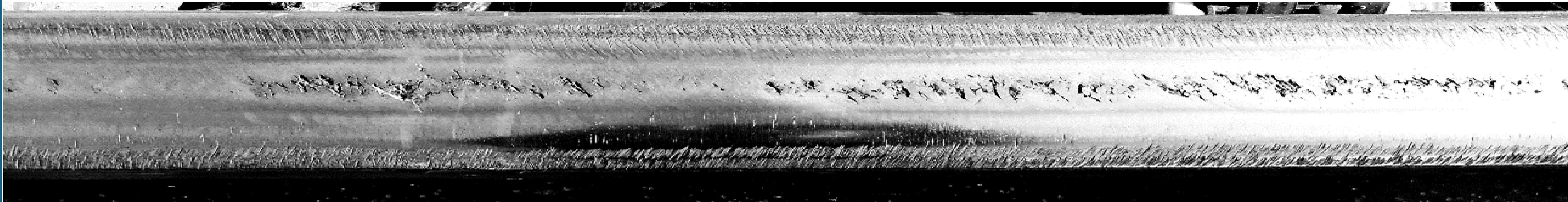
Ananyo Banerjee, Ph.D.
Principal Investigator II

Overview

- **Objectives**
- **Rail Integrity**
  - Final results from cold weather rail test
  - Analysis of transverse defect growth in rails tested for fatigue
- **Analysis of Vertical Electric Flash Butt (EFB) Weld Failures**
- **Rail Test Installation at New Facility for Accelerated Service Testing (FAST®)**
- **Conclusions**

Objectives

- **Rail and weld integrity evaluation**
  – Rails
    - Evaluation of wear and fatigue of latest high strength (HS) and intermediate strength (IS) rails
    - How defects grow and how stress conditions affect defect growth rates
    - How to mitigate Rolling Contact Fatigue (RCF) with effective grinding and better track geometry control
  – Welds
    - How are weld defects related to metallurgy and other conditions?
- **Goal: Extend rail & weld longevity and reduce track outages**



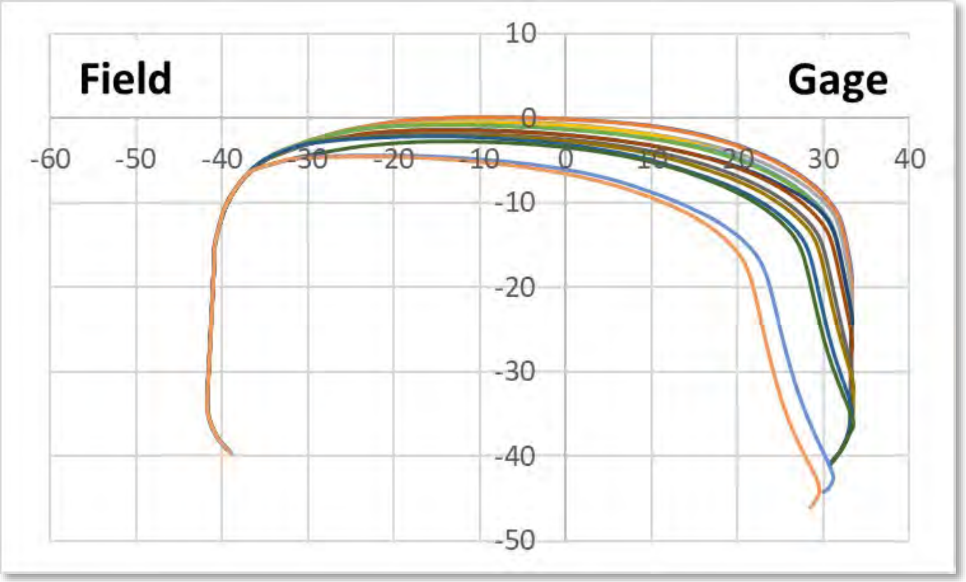
2014–2022 Rail Test at CN*

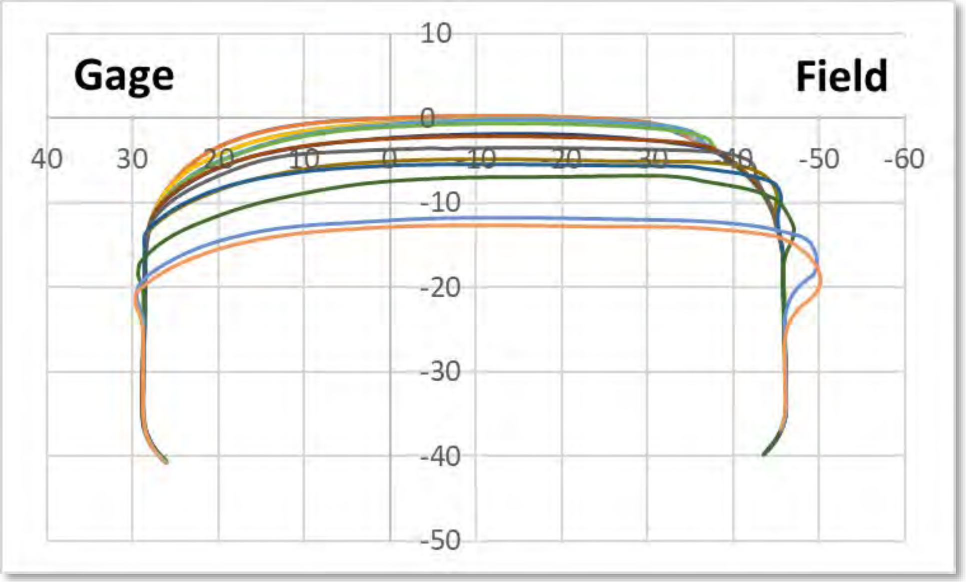
- **Test characteristics**
  - Effects of cold weather on rail performance
  - Test lasted for 361 MGT over 8.5 years
  - Seven rail types, five participants:
    voestalpine (Austria), JFE (Japan) – two types, NIPPON (Japan) – two types, Arcelor Mittal (USA), British Steel (UK, France)
  - 1,000-foot, 5-degree curve on Redditt Subdivision
    - Concrete ties with elastic fasteners
    - Test curve has preventative grinding and gage face (GF) lubrication on high rail
    - Mixed freight and intermodal traffic

**Technology Digest* TD23-028, November 2023

Wear Performance of HS Rails

- **High and low rail profiles**
  - Low rail experienced significant vertical loss with metal flow on field and gage corners
    - Test ended as metal lips interfered with the profilometer measurements
  - High rail showed gage wear primarily

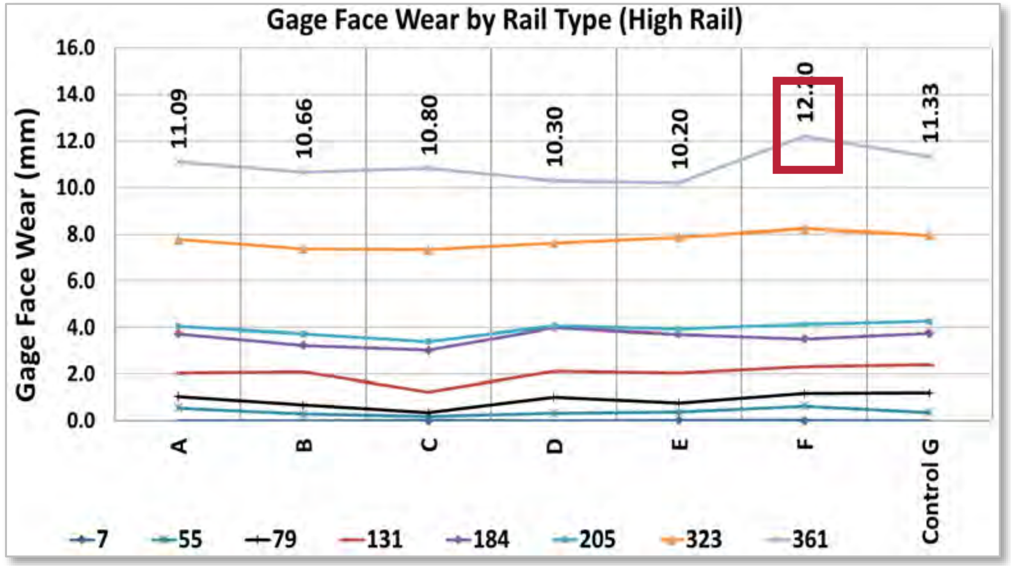




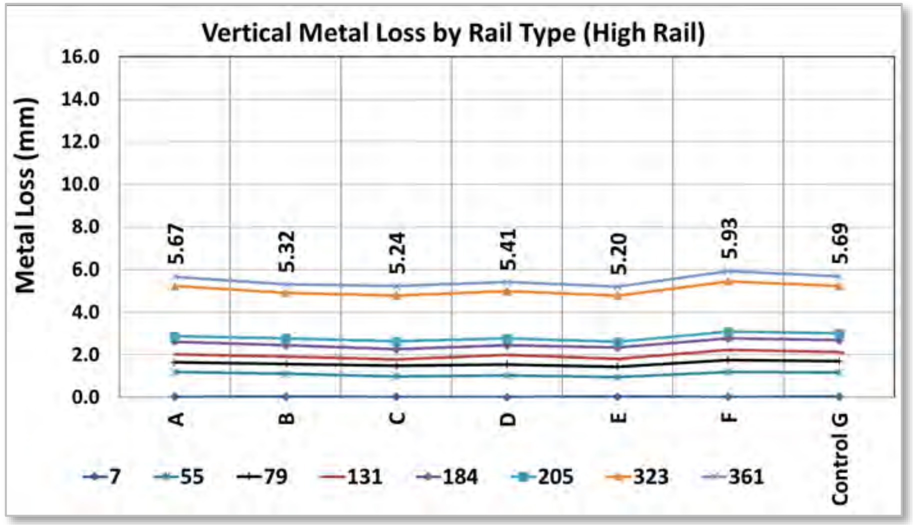
High rail profiles (left) and low rail profiles (right) in mm

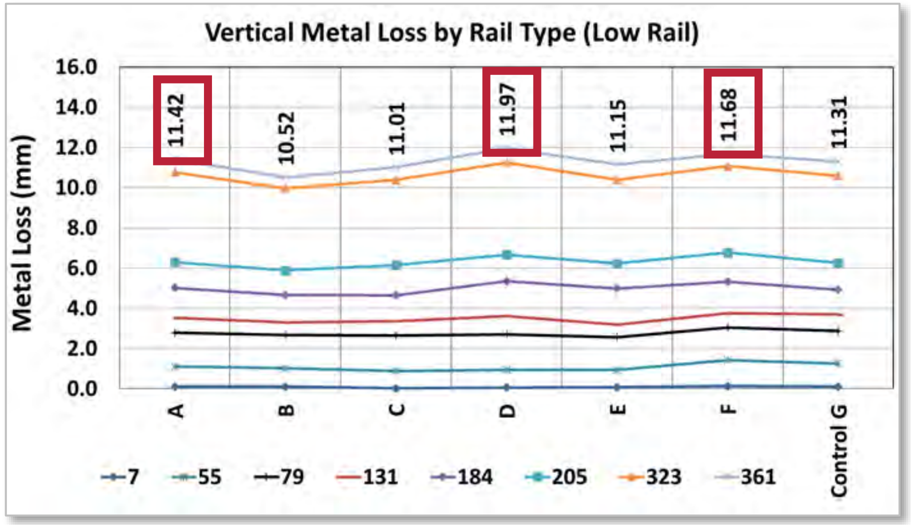
Wear Performance of HS Rails

- **Gage wear and vertical metal loss**
  – Gage wear unaffected by grinding
  – Vertical loss includes grinding loss
    - Statistically significant differences among rail types in low rail



High rail gage face wear for all seven rail types



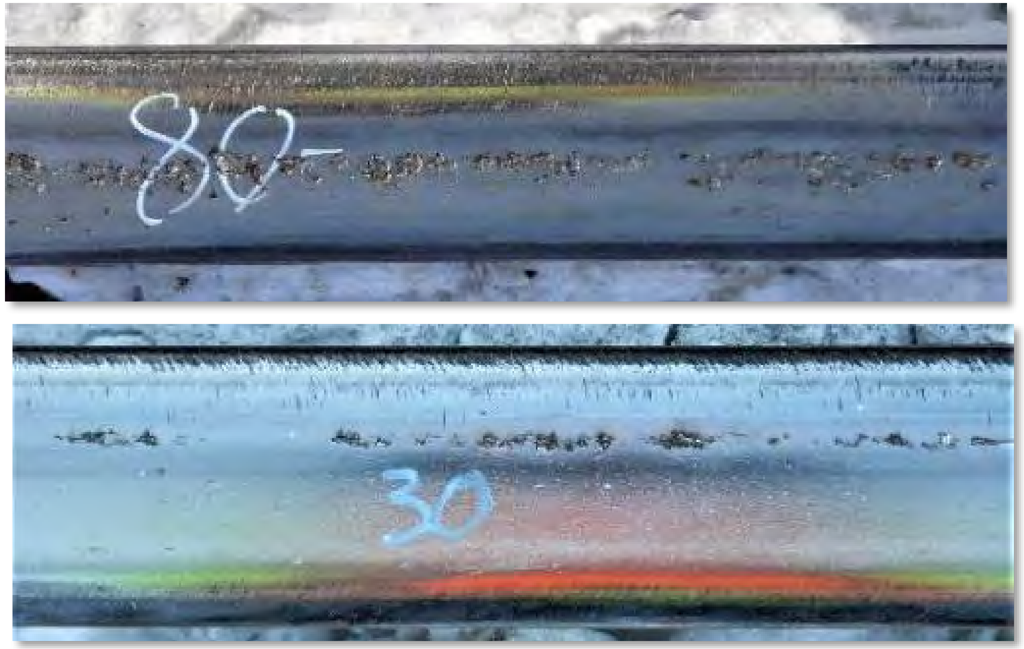


Vertical metal loss for high rail (above) and low rail profiles (below)

Defects Observed in CN Rail Test

- **No internal defects observed in head or base of any rails**
  - RCF observed in both high & low rails
  - RCF on low rail caused by false flange contact
- **Welds continue to be weak links between rails**
  - Four EFB weld removals on low rail; few replacement thermites had defects
  - No weld removals on the high rail

Batter of weld on low rail prior to removal



Spalling observed on high rail (above) and low rail (below)

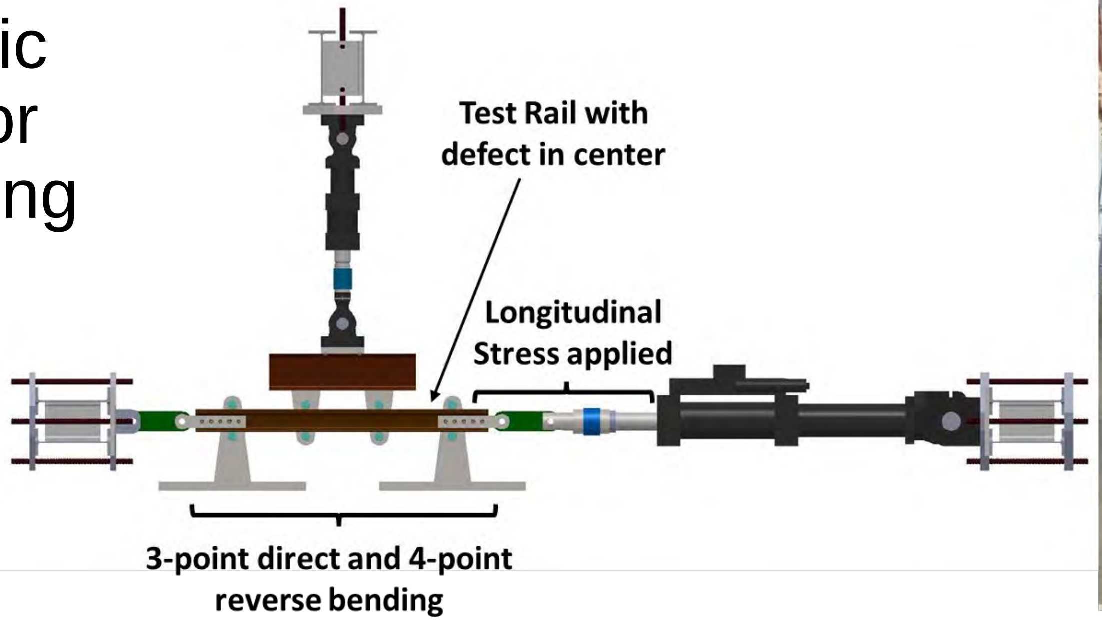
Fatigue Testing of Rails with Defects

Testing with Texas A&M University

- Simulated wheel loads applied with longitudinal stress
- Phased array ultrasonic testing (PAUT) used for defect growth monitoring

Rail is subjected to alternate bending moments

Schematic test fixture



Actual fixture

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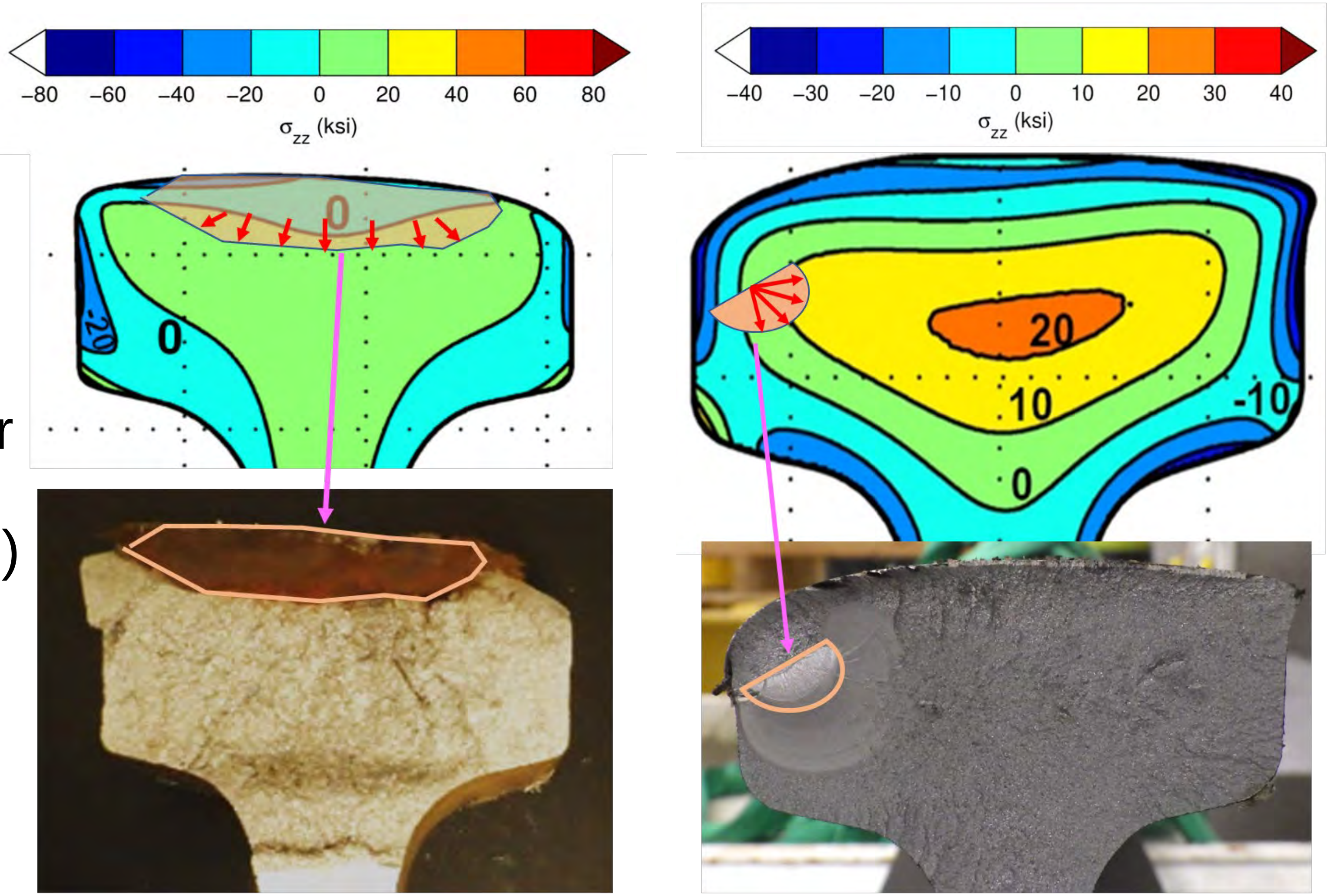
Defect Growth and Residual Stresses*

- **Transverse defects grow toward tensile stresses**
  - Fractured rail sent for residual stress analysis; performed using contour method with finite element modeling (FEM)
  - Defect location and fracture mapped onto FEM plot



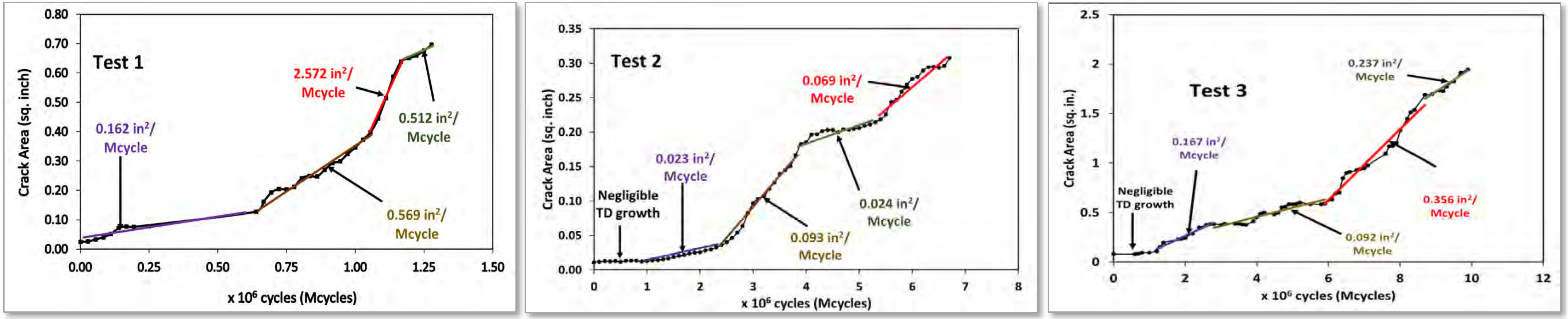
Residual stress plots (top) for defects after fracture (bottom).
Scales show tensile (positive) and compressive (negative) stresses

* *Technology Digest* TD23-013, July 2023

Defect Growth Rates are Variable

- **Residual stresses affect defect growth rates**
  - Defect growth rates deviate from fracture mechanics predictions due to complex distribution of residual stresses

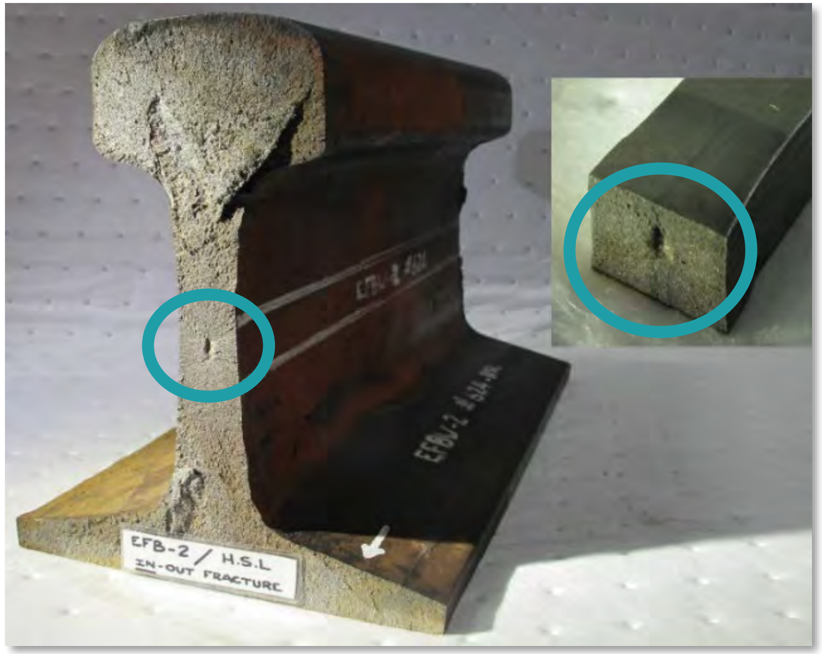
Variation in crack growth rates observed in Tests 1, 2, and 3



Vertical failures in EFB Welds*

- **Three EFB weld failures observed at <2 MGT on MxV Rail's High Speed Loop (HSL)**
  - All failures had identical convex-concave features on the web
    - One half had convex protrusion while other half had concave depression

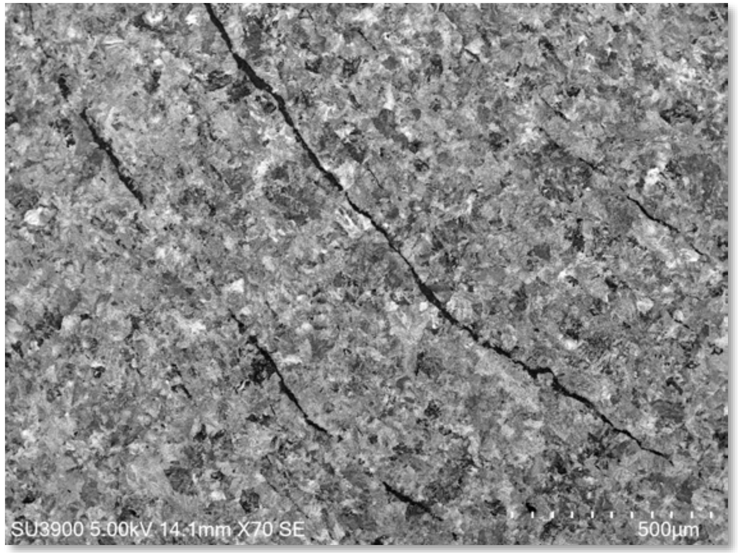
Convex-concave features showing fracture origin of EFB vertical failures



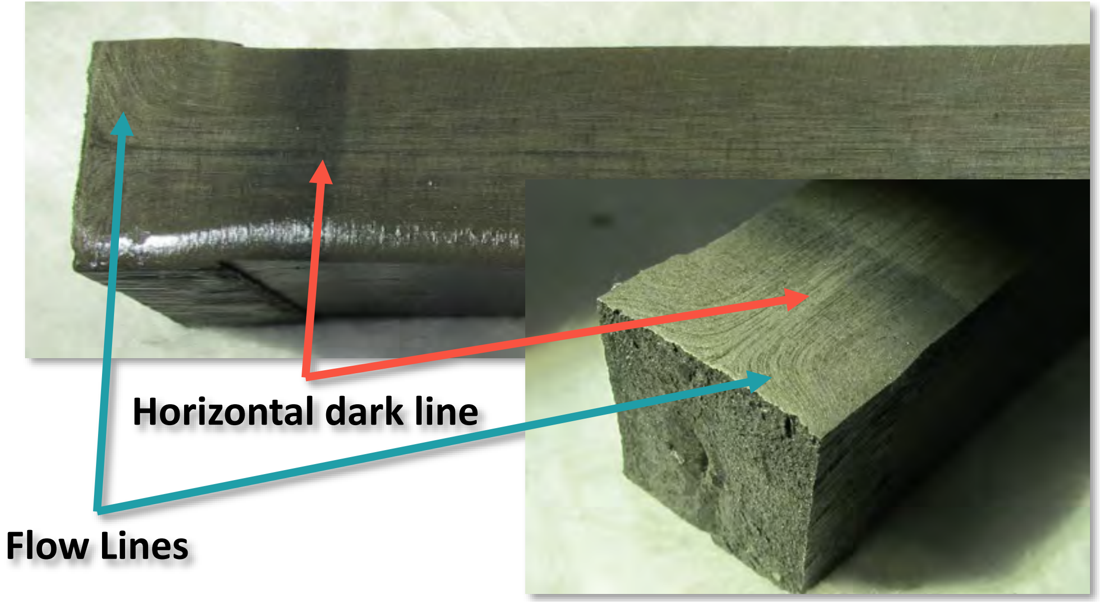
* *Technology Digest* TD24-004, April 2024

Investigation of Features

- **Macro-etching revealed flow lines and alloy segregation**
  - Horizontal dark line at the fracture surface
    - Alloy segregation along the web
    - Manganese Sulphide (MnS) inclusions along central lines, extending into parent rails
  - Flow lines above and below the fracture initiation point
    - Untempered brittle martensite observed along flow lines and inclusions



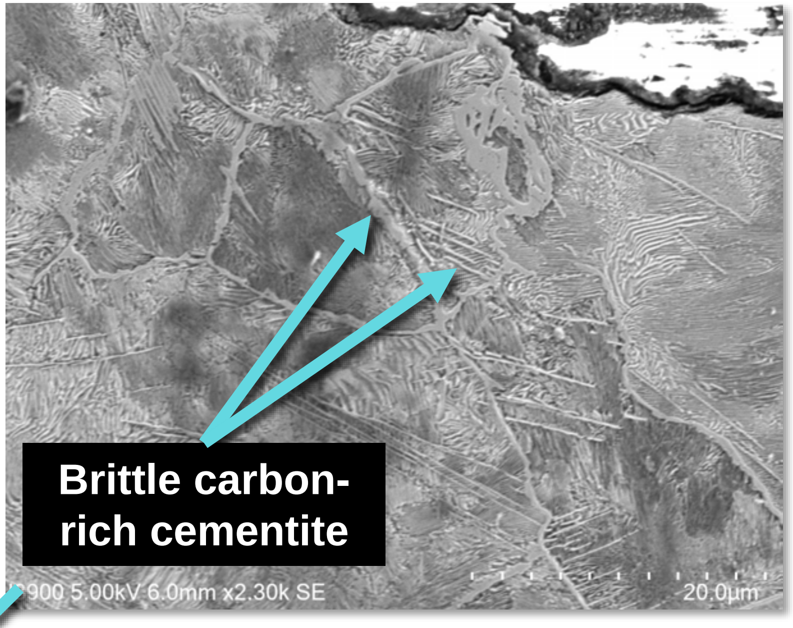
Untempered Martensite (observed along flow lines)

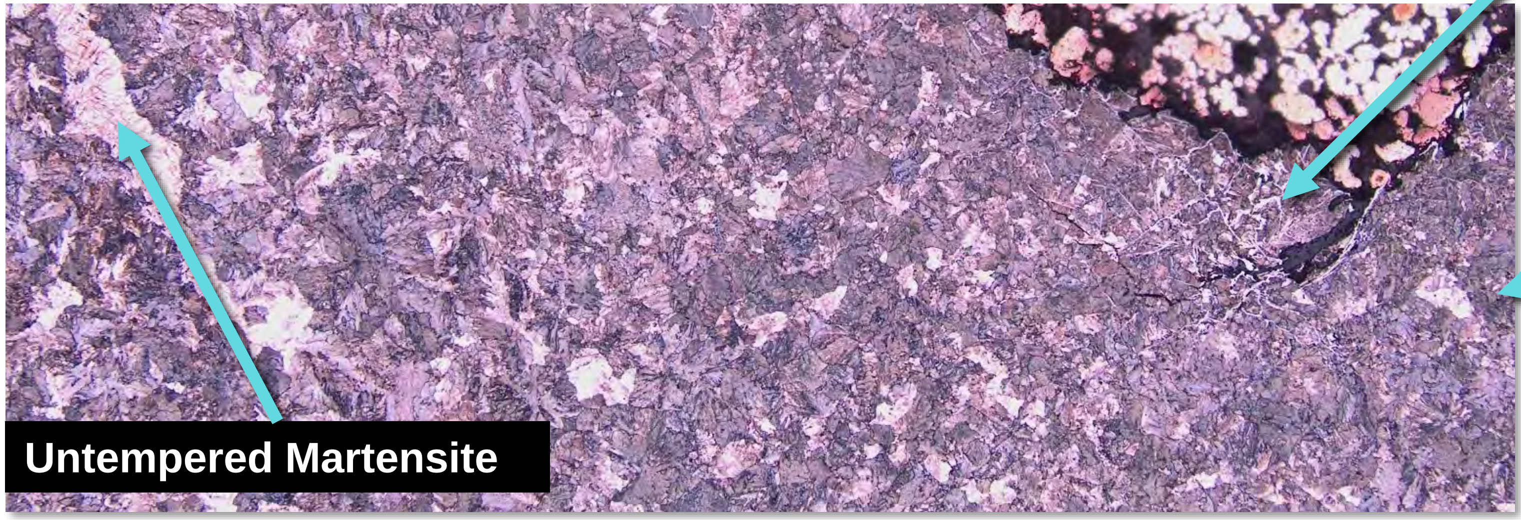


Macro-Etch examination of horizontal bars extracted from failed welds

Microscopic Investigation

- **Excess heat input caused localized liquification and rapid solidification during welding**
  - Brittle carbon-rich cementite (white) observed at failure origin
    - Some carbon segregation observed along web
    - Carbon content higher in web than head or base





Center of concave region, showing network of brittle cementite at fracture origin

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Rail Test Installations at FAST®

- **Welding and installation of new 2023 HS rails and IS rails, which accumulated 282 MGT in 2021–2022**
  - External welding contractor onsite for welding rails
- **HS rail properties analyzed***

Rail welding at FAST by external contractor

FAST New HS Rail Test Participants
Cleveland Cliffs (USA)
Saarstahl (France)
EVRAZ Rocky Mountain Steel (USA)
JFE Steel: 2 Types (Japan)
Nippon Steel (Japan)
voestalpine Schienen (Austria)

**Technology Digest* TD24-001, March 2024

29TH AAR RESEARCH REVIEW

Conclusions

- **Rail and weld integrity analysis**
  - 2014–2022 CN rail test concluded at 361 MGT
    - No internal defects in rails; four EFB weld failures in the low rail
    - Low rail had significant vertical wear with plastic metal flow on both field and gage corners
  - Rail fatigue testing under simulated loads
    - Defects tend to grow towards tensile stress zones
    - Defect growth rates change due to complex distribution of residual stresses
  - Analysis of EFB vertical failures on HSL
    - Convex protrusion and concave depression at the web are identical in all failures
    - Excessive heat input caused liquification and formation of carbon-rich brittle cementite at the fracture origin

Acknowledgements

- Rail manufacturers
- Hill Engineering
- Texas A&M University
- MxV Rail Non-Destructive Examination (NDE)-Metallurgy team, FAST track crew, Data Science and Instrumentation staff
- AAR’s Strategic Research Initiatives Program

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Crosstie and Fastener Research

Yin Gao, Ph.D.
Principal Investigator I

Overview

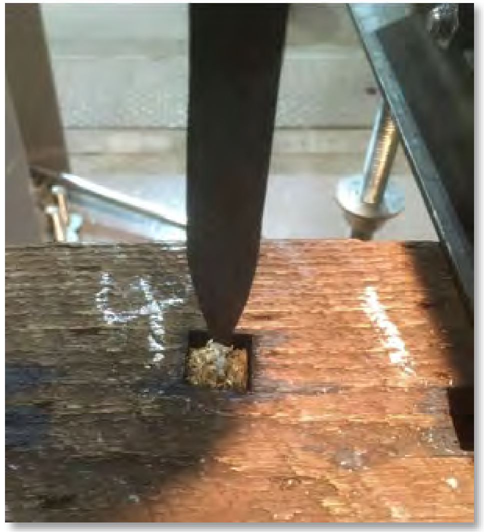
- **Objectives**
- **Tie Plugging Materials – Laboratory Test**
- **Spike Breakage Study**
- **Wood Tie Life Study**
- **Strain-gaged Concrete Ties**
- **New Tie and Fastener Tests at FAST®**
- **Summary**

Objectives

- **Evaluate performance of new and existing tie and fastener designs**
- **Improve understanding of tie and fastener failure mechanisms for best practices in maintenance and inspection**

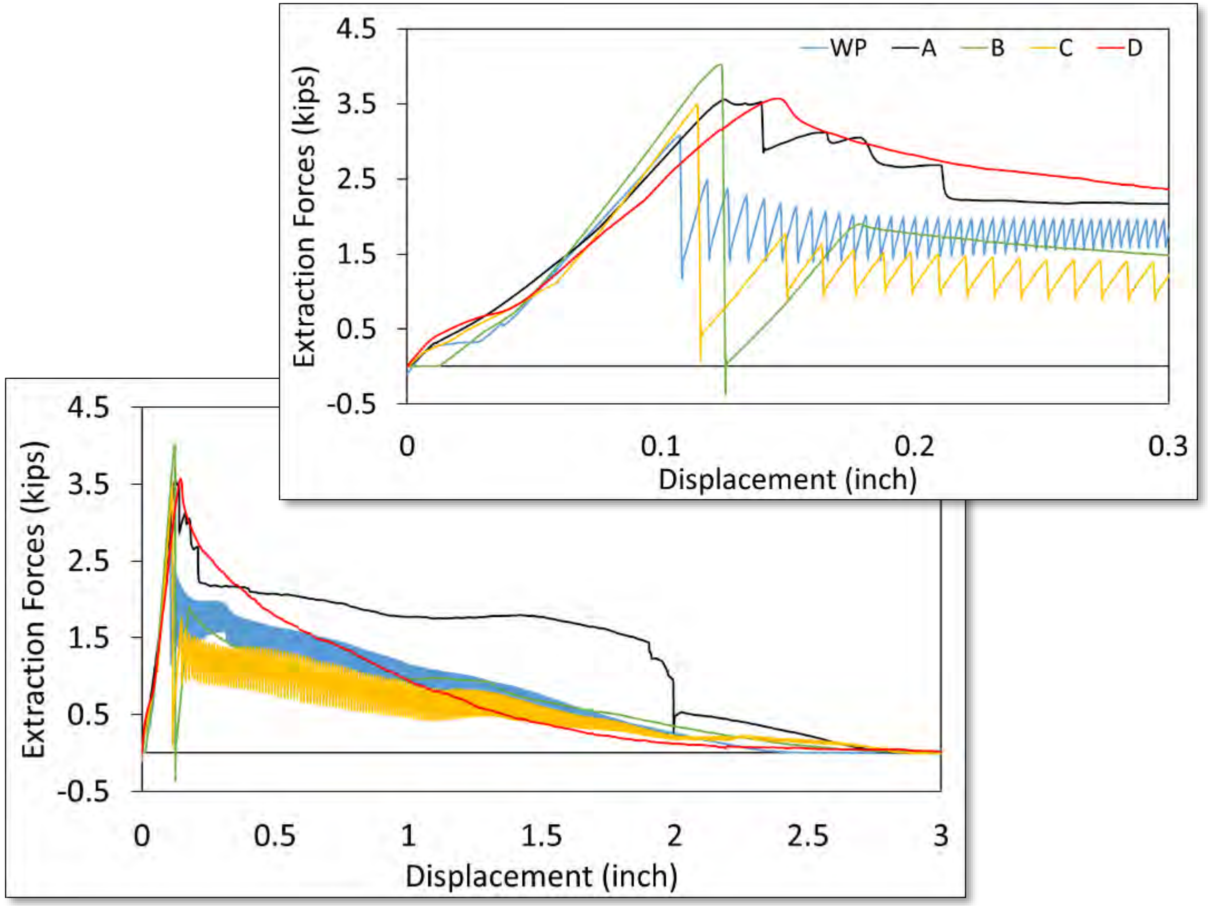
Tie Plugging Materials – Laboratory Test

- **Laboratory spike pullout tests**
  - Prepare a square hole 3/4-in. larger than the spike cross-section size
  - Five tie plugging materials
    - Three liquid/foam-based (A, B, C)
    - Powder-based (D)
    - Wood plug (conventional way)
  - Wet and dry conditions of spike hole
  - Two different cure times

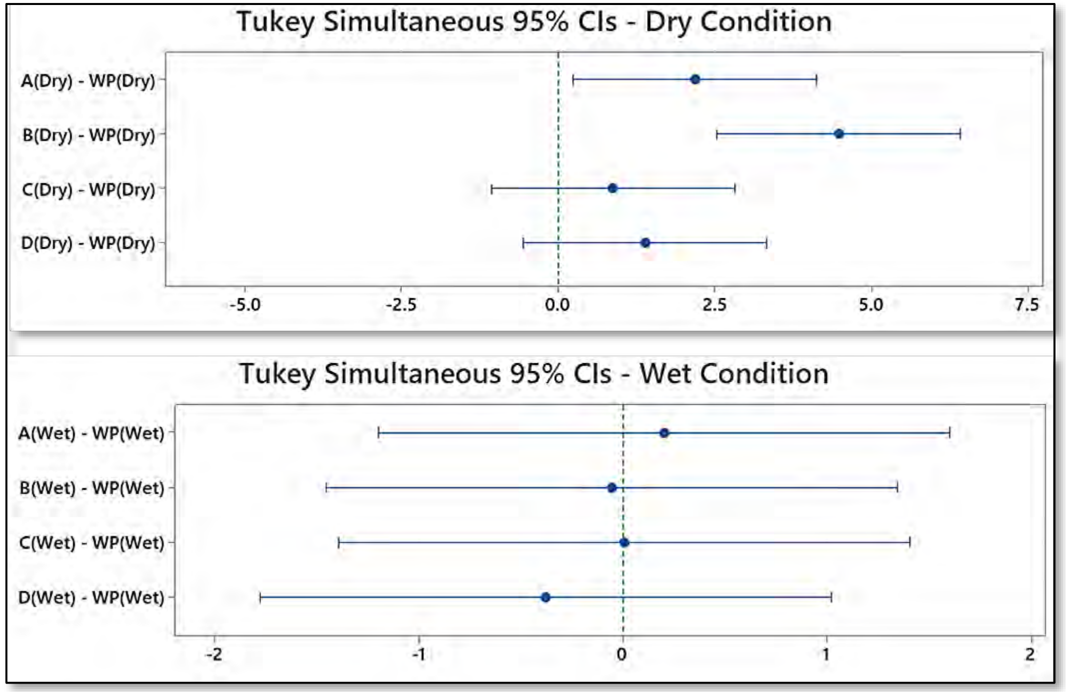


Tie Plugging Materials – Laboratory Test

- **Characterization of pullout force-displacement curve**



- **Statistical Analysis (peak force)**
  - Comparison to wood plugs
  - Wet and dry conditions
  - Plugging material cure time



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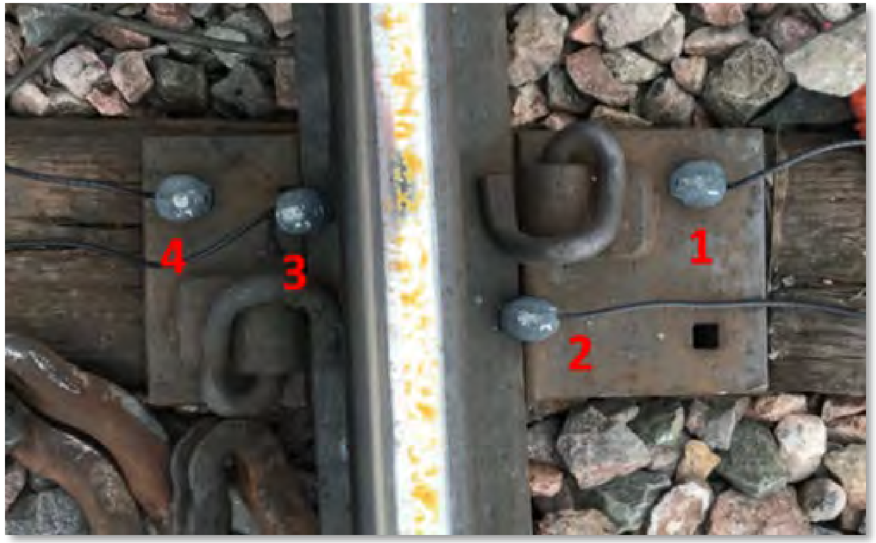
Tie Plugging Materials – Laboratory Test

- **Takeaways**
  - All tested materials met American Railway Engineering and Maintenance-of-Way Association (AREMA) recommendations
  - Liquid/foam and powder materials had pullout forces greater than or equal to the wood plug forces
  - Average pullout forces decreased in wet conditions compared to dry conditions
  - Less cure time did not show a significant difference in the pullout forces for liquid materials
  - *Technology Digest* TD22-014

Spike Breakage Study

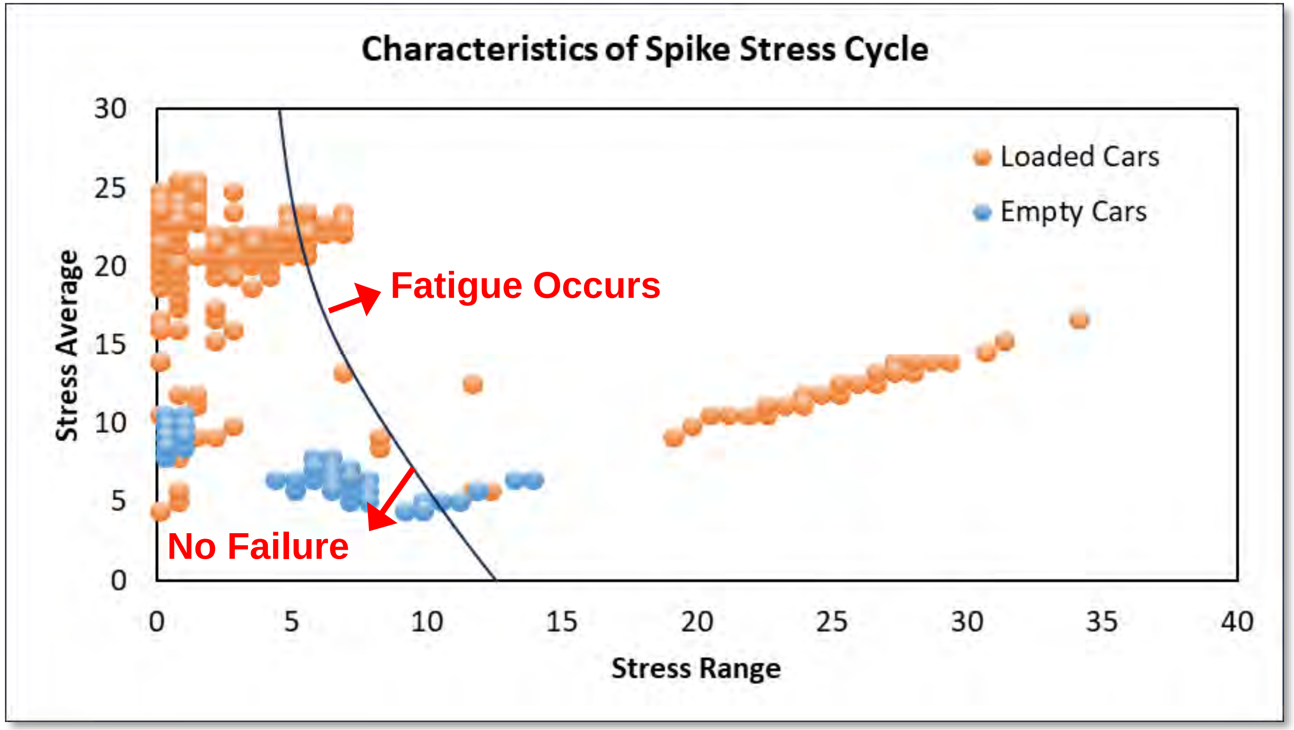


- **In-situ testing at Facility for Accelerated Service Testing (FAST®) and Horseshoe Curve on Norfolk Southern (NS)**
  - Installation of rail circuits, thermocouples
  - Instrumented spikes used for capturing spike bending strains
  - Different operating conditions, fastener types, train types, speeds, etc.

FAST® is a registered trademark of Transportation Technology Center, Inc. (dba MxV Rail)

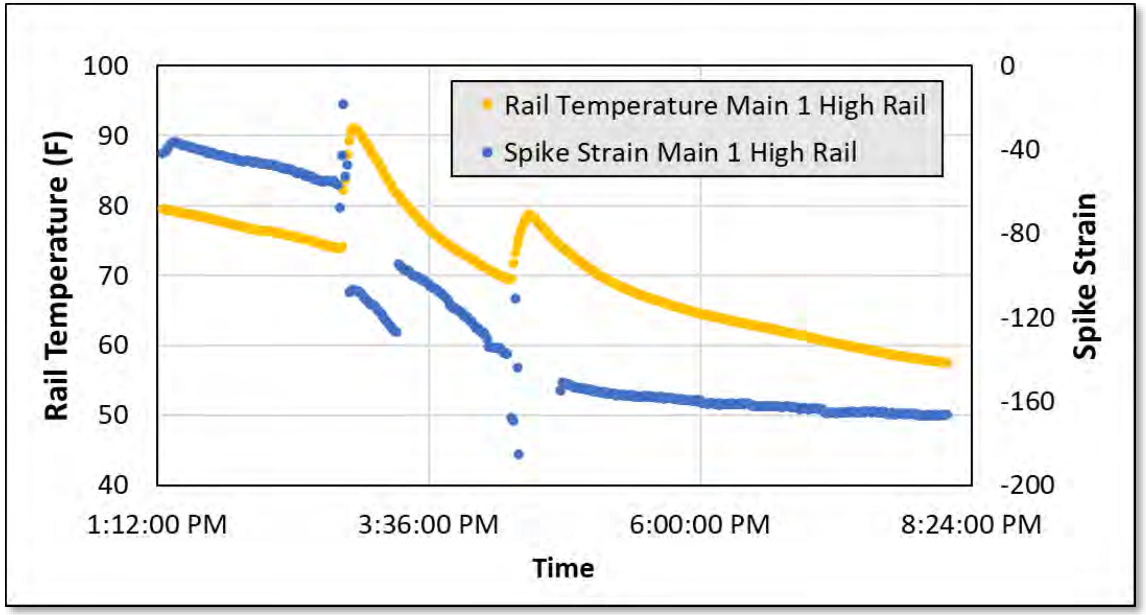
Spike Breakage Study

- **Fatigue analysis using the collected data**
  - Loaded cars may fatigue spikes to failures as soon as 65 MGT
  - Using curve block plates and anchors can extend spike service life



Spike Breakage Study

- **Temperature effect on spike loading environment**
  - 120 microstrain change in the longitudinal direction under 20°F rail temperature change
  - Not enough to break a spike but can be significant when large temperature swing occurs, roughly 10-40 percent added on top of train-induced spike load
  - Does not occur on every spike
    - May be dependent on spike/plate contact
  - *Technology Digest* TD23-025



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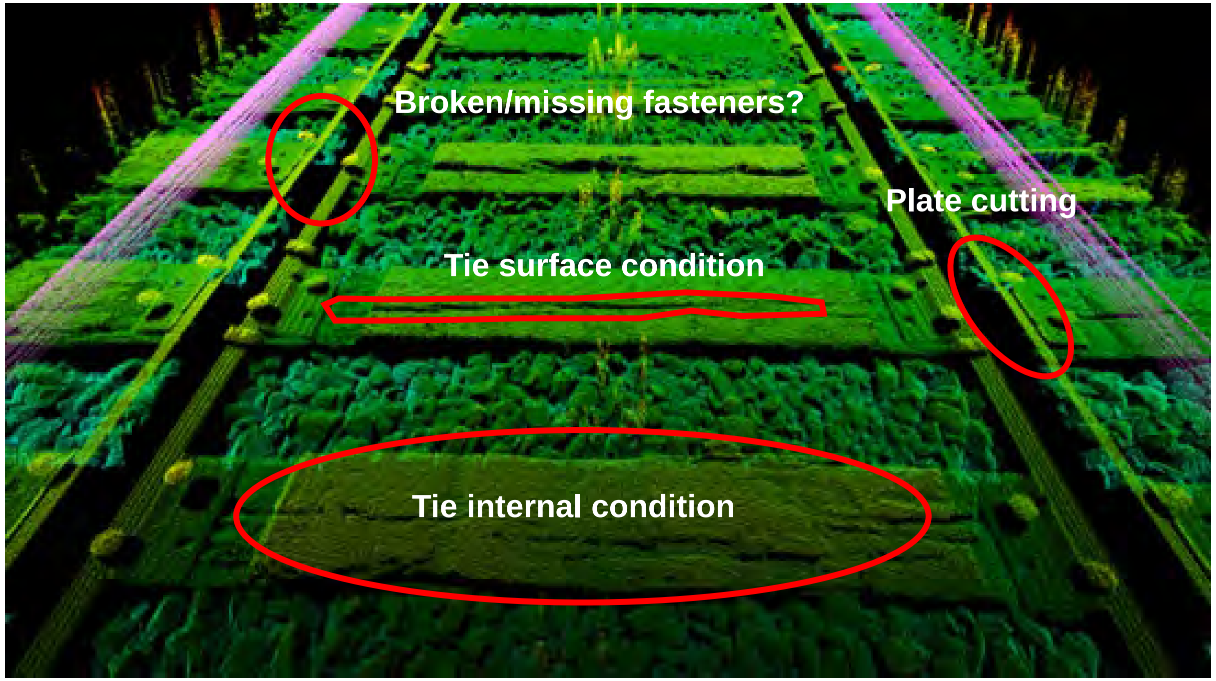
Wood Tie Life Study

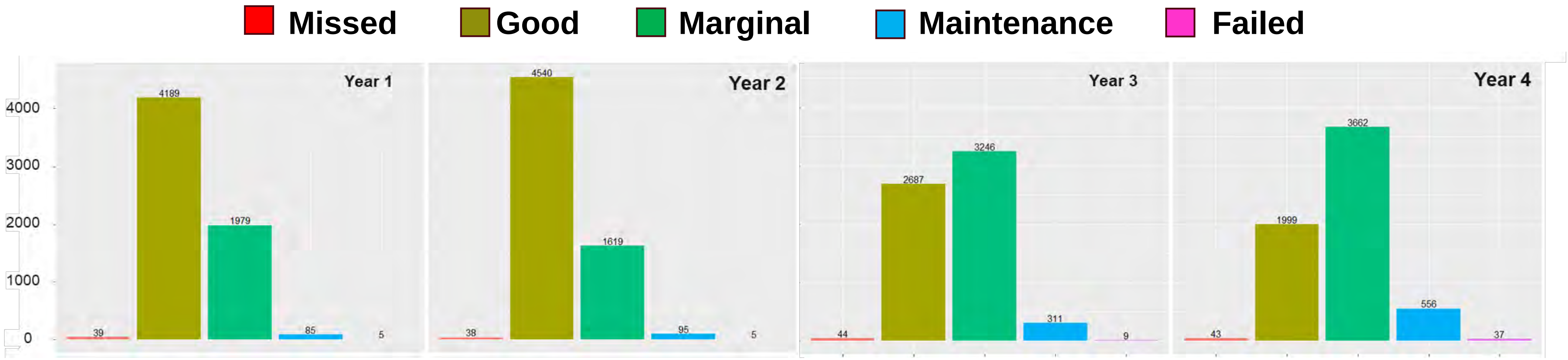
- **Wood tie life prediction based on tie conditions using tie rating scores from machine vision technology**
  - BNSF's scanned data at ten subdivisions

Tie Category	Tie Score
Good ties	1.0-1.9
Marginal ties	2.0-2.9
Maintenance ties	3.0-3.9
Failed ties	4.0



Wood Tie Life Study

- **Example Subdivision – A four-year shift in distribution**
  - The machine system captured the condition degradation over time
  - Rate of change enables wood tie prediction



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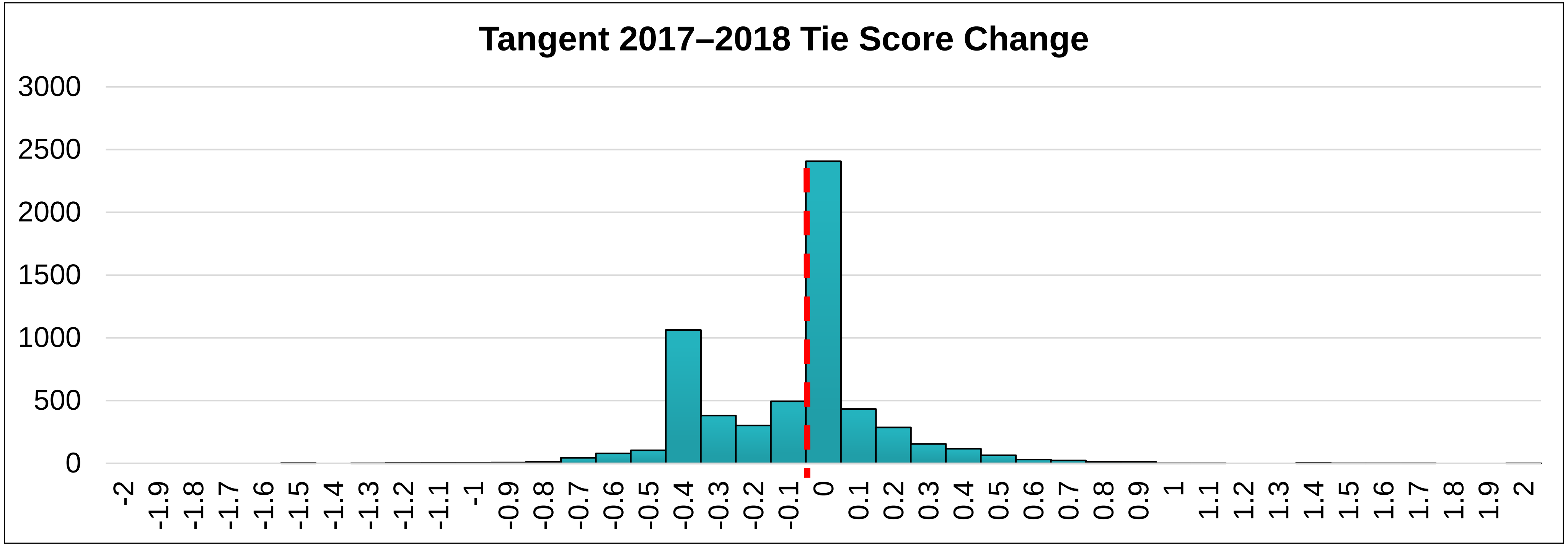
Wood Tie Life Study

- **Need a long period to predict tie condition change**
  - Over 40% of the individual tie scores decreased year over year on one example subdivision



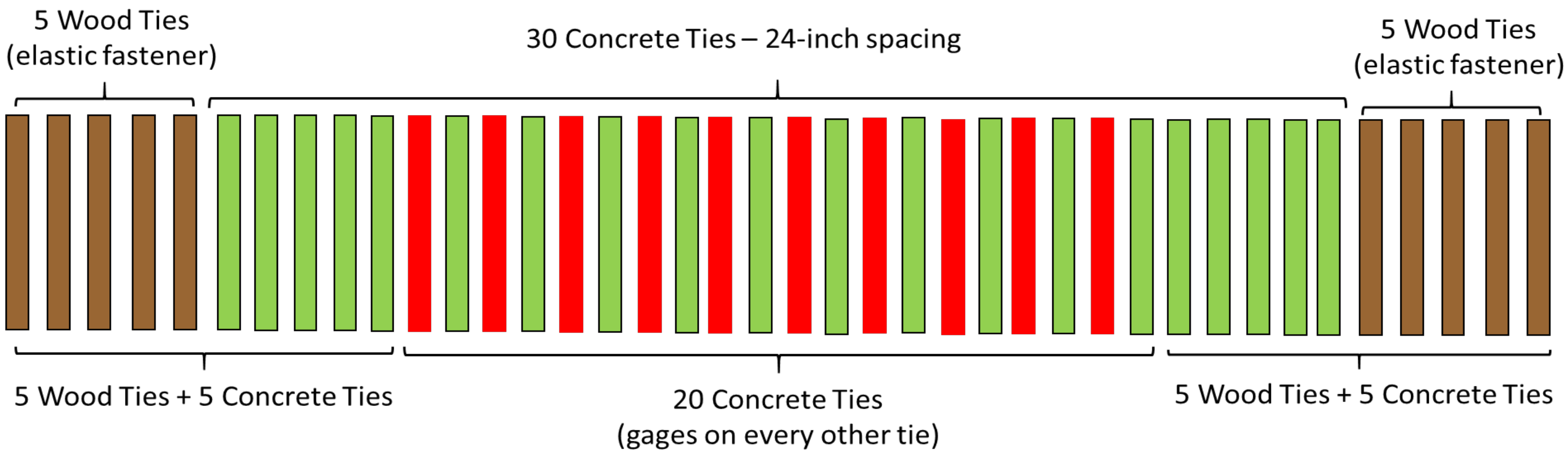
Wood Tie Life Study

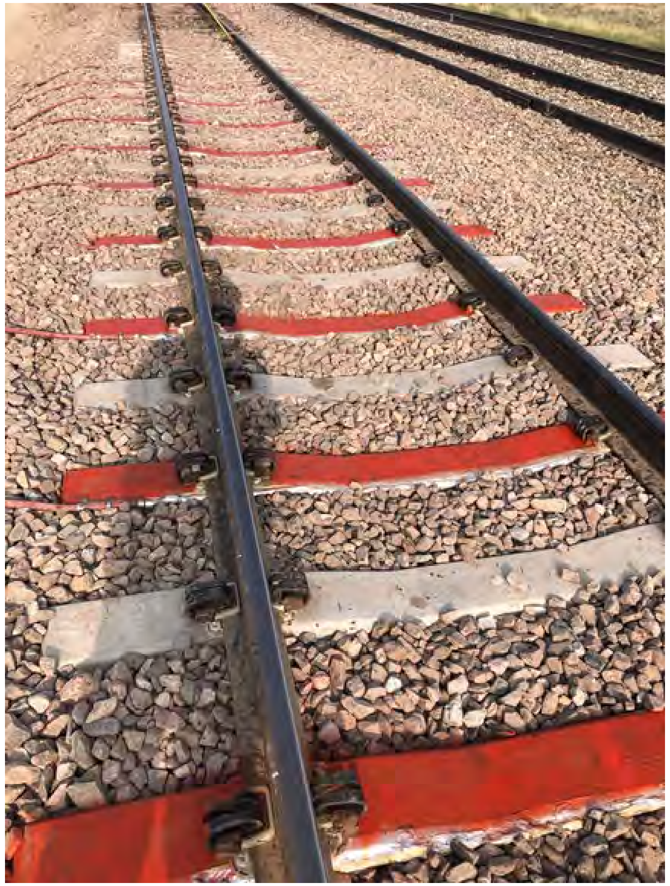
- **Tie life prediction program initiated in 2016**
  - Year-over-year prediction has significant variability
    - Short time span: Limited diversity of inspection data

Subdivision	Decay zone	Annual tonnage (MGT)	Predicted tie life (Year)	Current Life of Ties Being Used by the Railroad (Year)
A	Low	57	27.0	40
B	Severe	55	14.1	19
C	Moderate	47	41.3	31
D	Medium	104	31.9	27
E	Low	79	34.6	30
F	Moderate	61	16.1	28
G	Medium	32	19.0	28

Strain-Gauged Concrete Ties

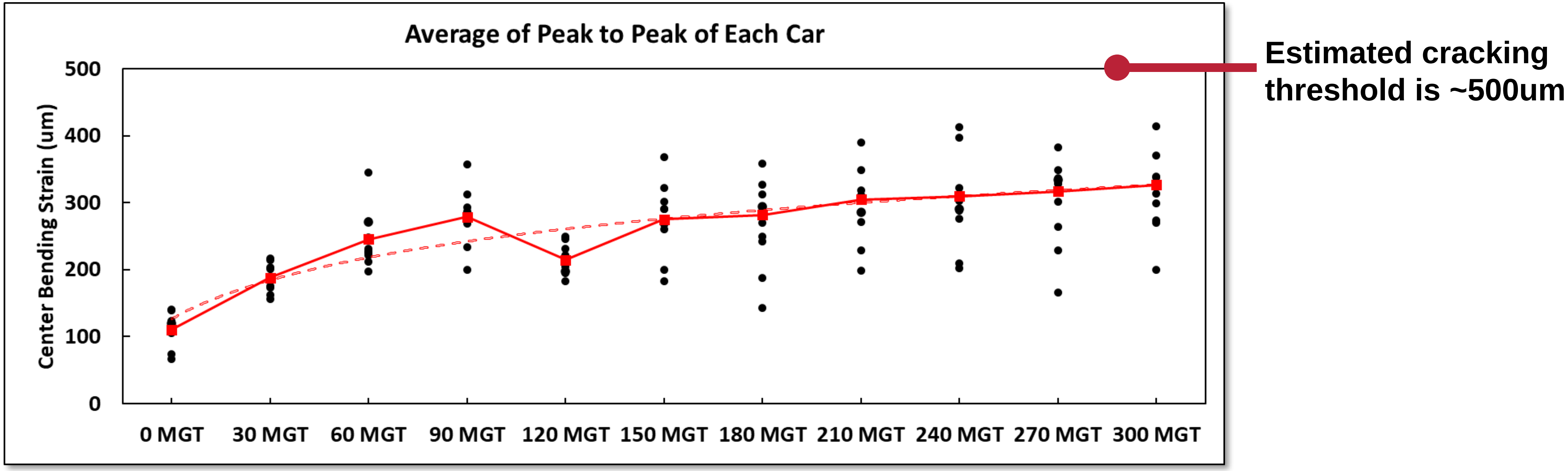
- **Test instrumentation and setup**
  - Calibration of strain-gaged ties
  - Monitor the development of center-binding condition





Strain Gauged Concrete Ties

- **327 MGT since August 2020**
  - Strain gauge measurement taken every 30 MGT
  - Center strain gauge to indicate the center binding condition
  - No concrete tie cracking was found during the testing period



New Test Installation

- **Concrete tie tests**
  - Strain-gaged concrete ties
  - Post-tension concrete ties
  - Concrete ties designed to be interspersed with wood ties
    - Various configurations
  - **Under tie pad (UTP) concrete ties**
    - Consecutive zones and interspersed zones with non-UTP concrete ties
    - Curve and tangent

New Test Installation

- **Wood Tie Fastening Systems**
  - Various systems suggested by railroads
  - New types of rail anchors and screw spikes
- **Engineered Polymer Composite Tie**
  - New-tie and old-tie zones
  - Consecutive tie test zones
  - Wood ties interspersed throughout test zones

Wood Tie Fastening Systems
14″ Curve block plates
16″ Curve block plates
16″ Rolled plates using cut spikes
16″ Elastic fastener plates using cut spikes
16″ Elastic fastener plates using cut spikes with anchors
18″ Elastic fastener plates using cut spikes
18″ Elastic fastener plates using cut spikes and anchors
18″ Elastic fastener plates using cut spikes and newly designed anchors
18″ Elastic fastener plates using screw spikes
18″ Elastic fastener plates using newly designed screw spikes
18″ Elastic fastener plates using screw spikes with anchor

Summary

- **Tie plugging materials tested showed equal or better performance than wood plugs. Wet conditions could decrease the pullout forces but reducing cure time would not.**
- **Rail temperature swing could increase spike load by 10–40 percent.**
- **Wood tie life predicted by machine vision technology showed a reasonable trend. More scanned data could improve the consistency and accuracy of tie life prediction.**
- **New ties and fasteners have been installed at FAST and are now being tested.**

Acknowledgements

- **Tie and fastener manufacturers**
- **Class I railroads and Tie TAG**
- **RJ Corman for installation**
- **MxV Rail**
  - Instrumentation team
  - Track team
  - Engineering Team

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Bridge Research

Chris Johnson
Scientist

Overview

- **Bridge Research Objectives**
  - Develop, evaluate, and implement
    - New bridge design and maintenance strategies
    - Best practices for bridge fitness for service assessments
  - Evaluate legacy bridge designs
- **Bridge Deck Test Facility**
- **Member Level Redundancy**

Bridge Deck Test Facility

Bridge Deck Test Facility

- **First bridge built at new FAST® Loop**
- **Two-span, 62-foot-long DPG spans**
  - One span level, one span superelevated
- **5-degree curve, 4-in. superelevation**

Bridge Deck Test Facility

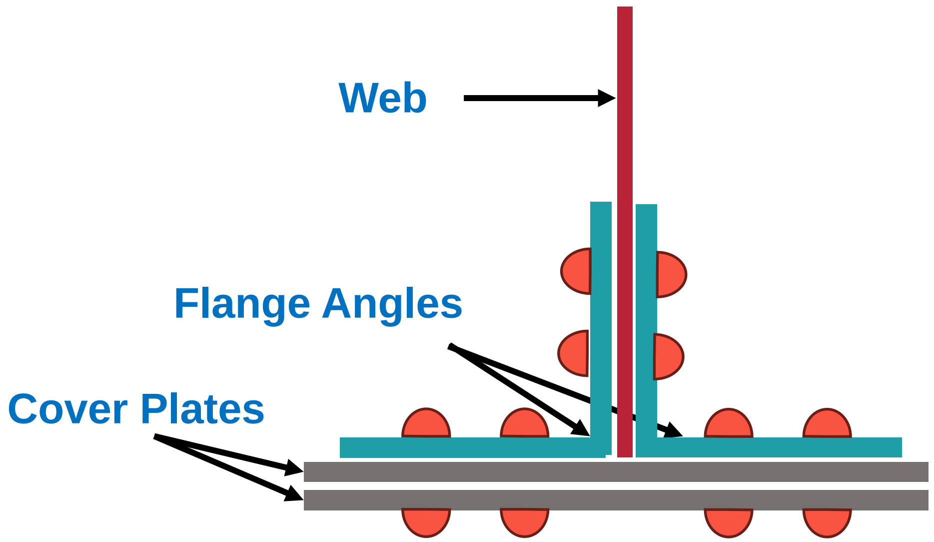
Bridge Deck Test Facility

- **Tapered glulam tie test**
  - Span moved from old site
  - 620+ MGT on ties
- **Other tie materials**
  - Glulam
  - Solid-sawn
  - New and previously used ties
- **Deck anchors**

Member Level Redundancy (MLR)

What is MLR?

- **The concept that the presence of multiple cover plates, as well as flange angles, provides a level of redundancy within a built-up steel girder bridge tension member**
- **If a single component develops a crack, there will be redistribution of stresses into other components of the built-up member**



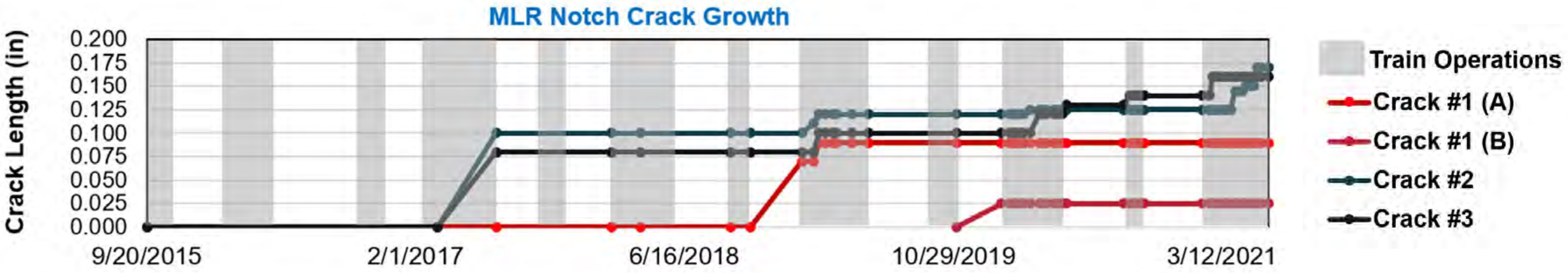
Objectives

Original testing of this span at FAST had three objectives:

1. Determine crack growth rate
   - Provides information regarding appropriate inspection intervals.
2. Determine critical crack length at which fracture might occur
3. Determine whether:
   - Fracture propagates to additional components of the built-up girder.
   - The number of additional cycles required to do so.

FAST Testing

- **1904 design for Canadian Pacific Railway**
  - Originally 33 ft. long, shortened to 32 ft. for FAST testing
  - E-54 rating, FAST train loading E-72
  - Three notches cut in outside girder bottom flange cover plate
  - FAST tonnage:
    - 990 MGT (6.26 million cycles) on span
    - 875 MGT (5.54 million cycles) with notches
  - Minimal crack growth from notch tips



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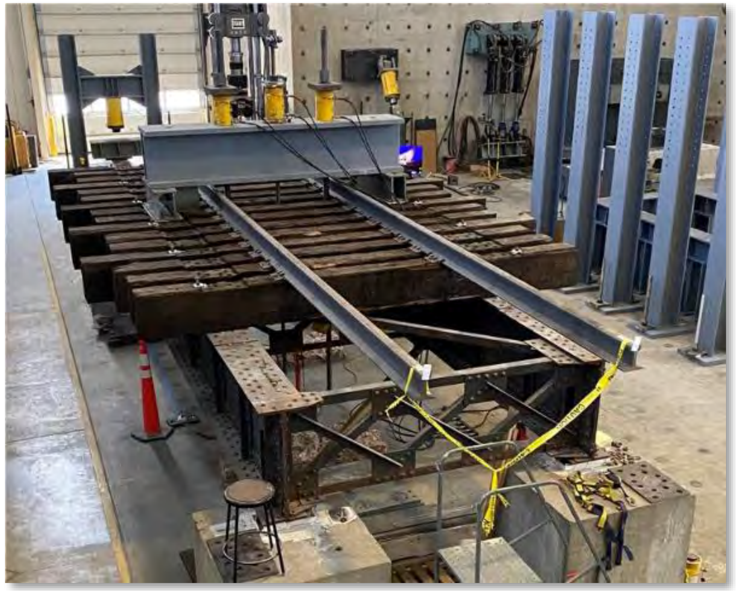
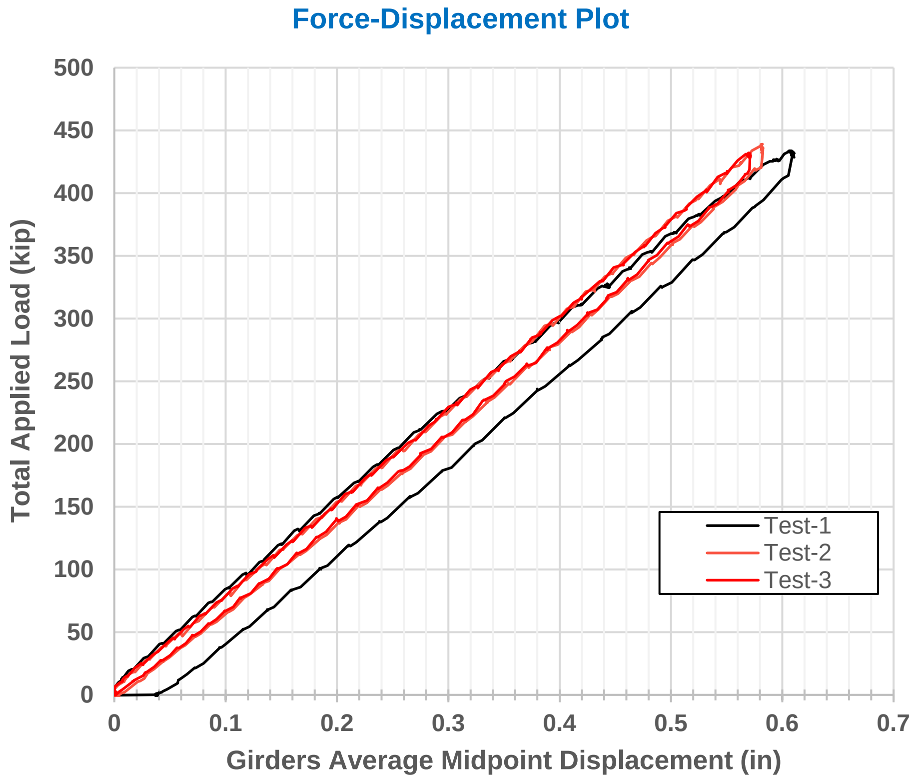
Cold Temperature Test

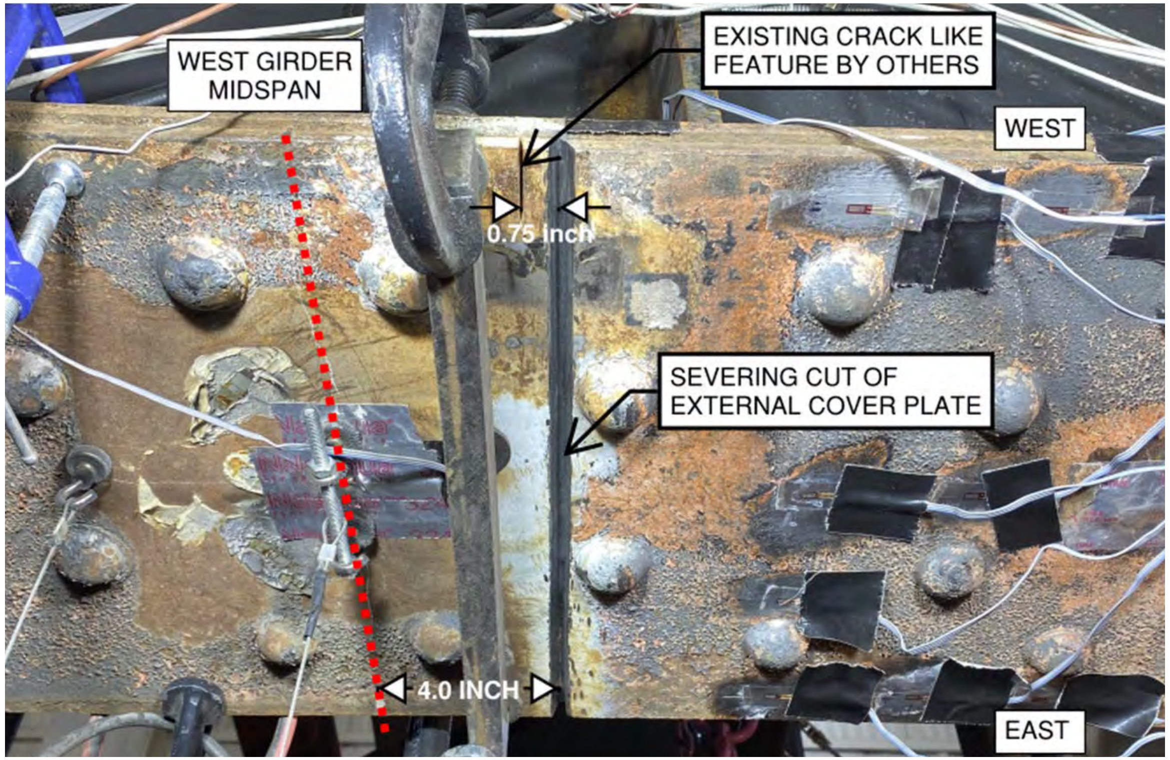
- **Attempt to force fracture**
- **Bottom flange section cooled to -60°F**
  - Increase brittleness
- **Loaded to 433 kips**

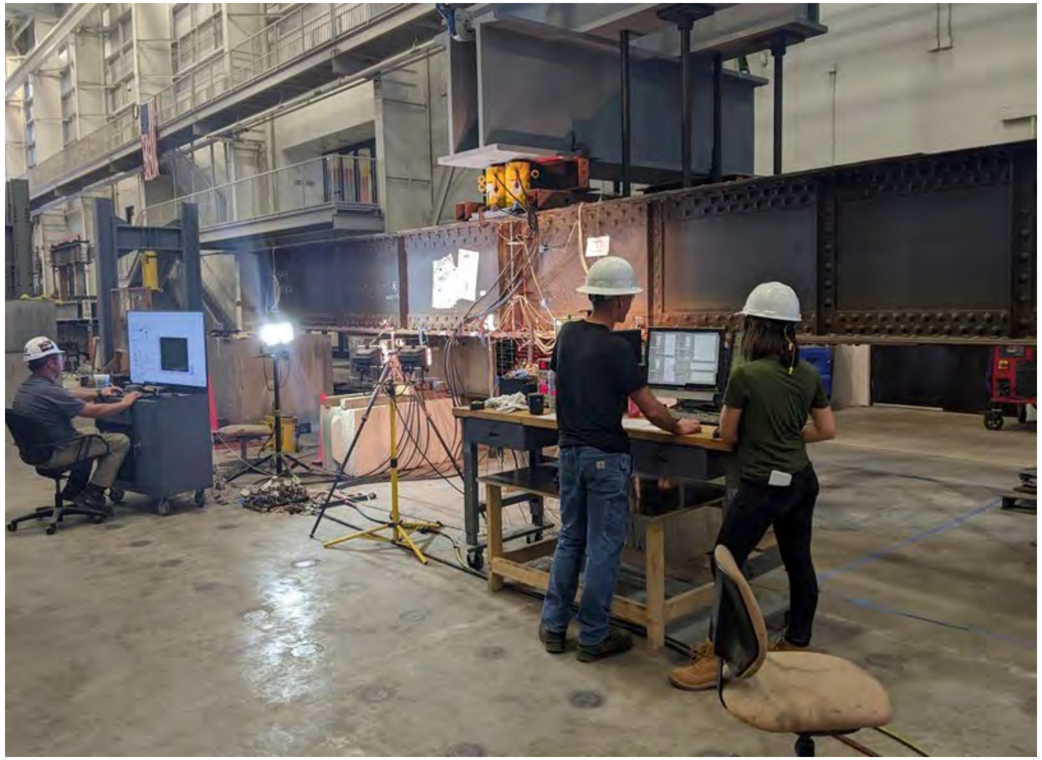




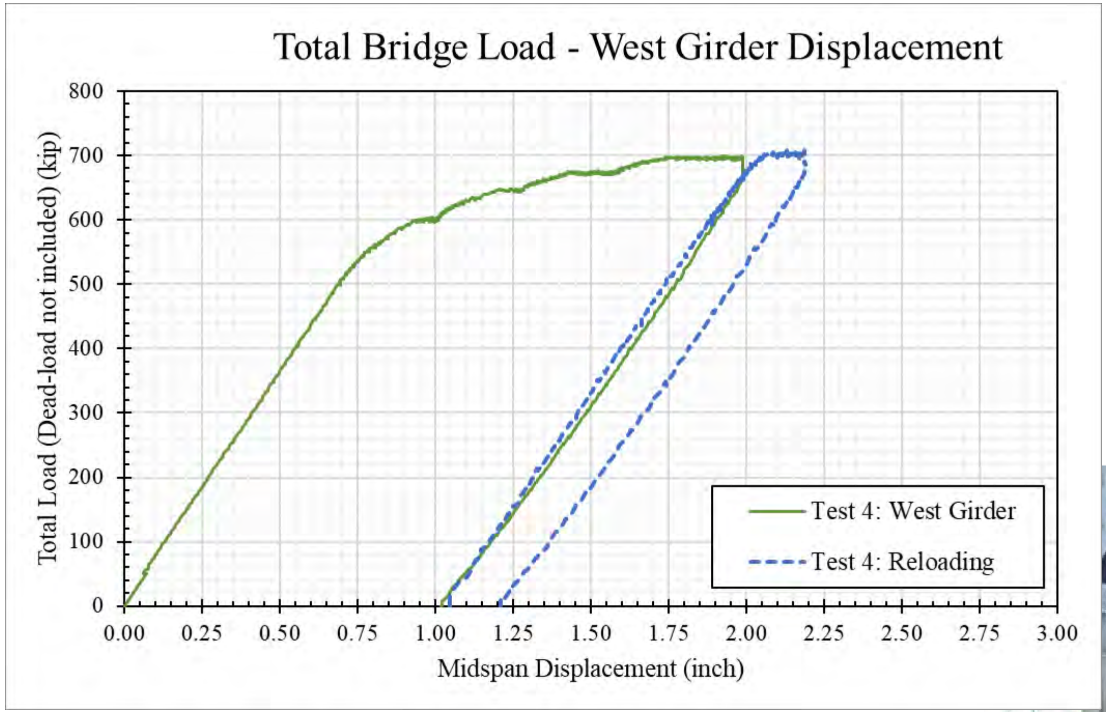
Ultimate Strength Loading Test

- **Bottom cover plate of tension flange cut completely near midspan**
  – Additional strain gages in tension area and on each tension component
- **Loading increased and applied directly to top of girders**

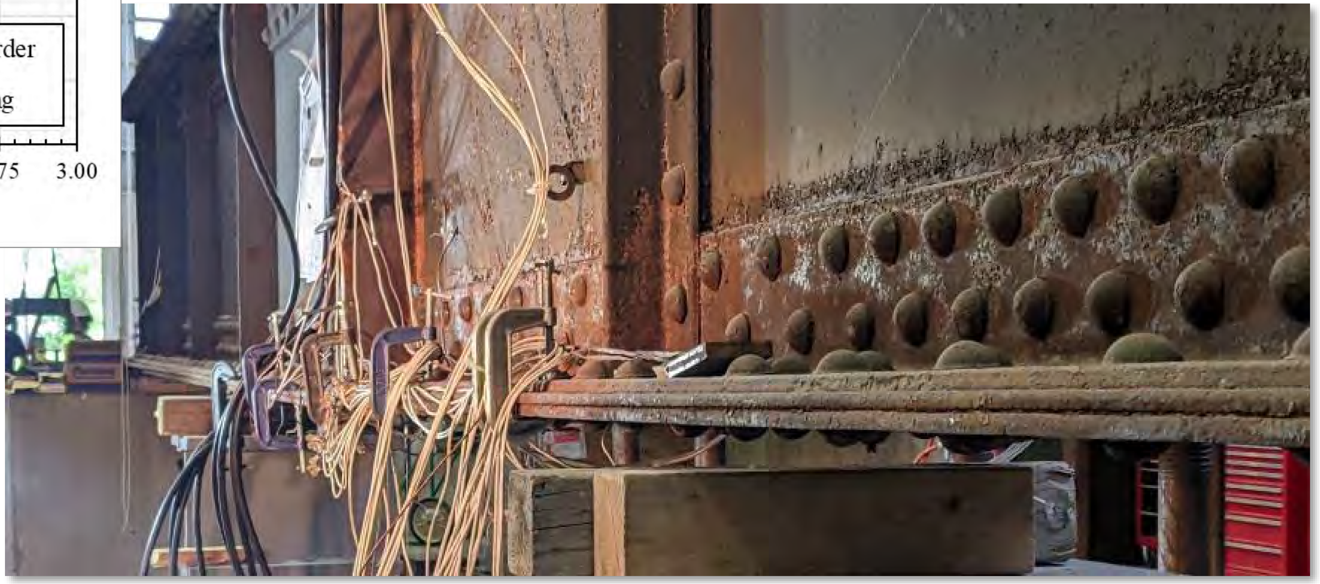




Ultimate Strength Loading Test

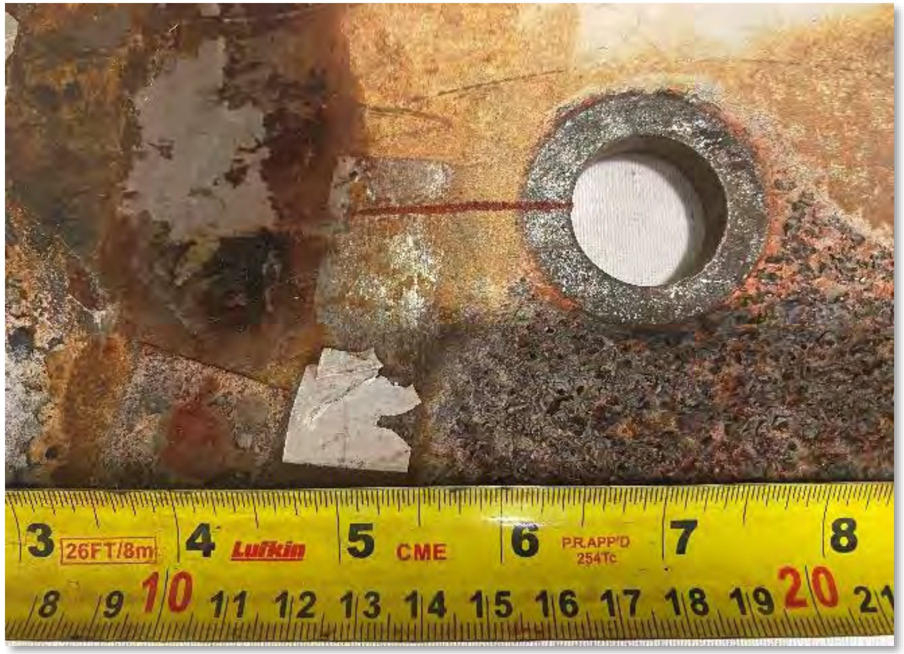


- **No fracture**
  - Linear behavior to >500 kips
  - Ductile yielding to 700 kips
  - Strain hardening to ~700 kips



Post Test Destructive Evaluation

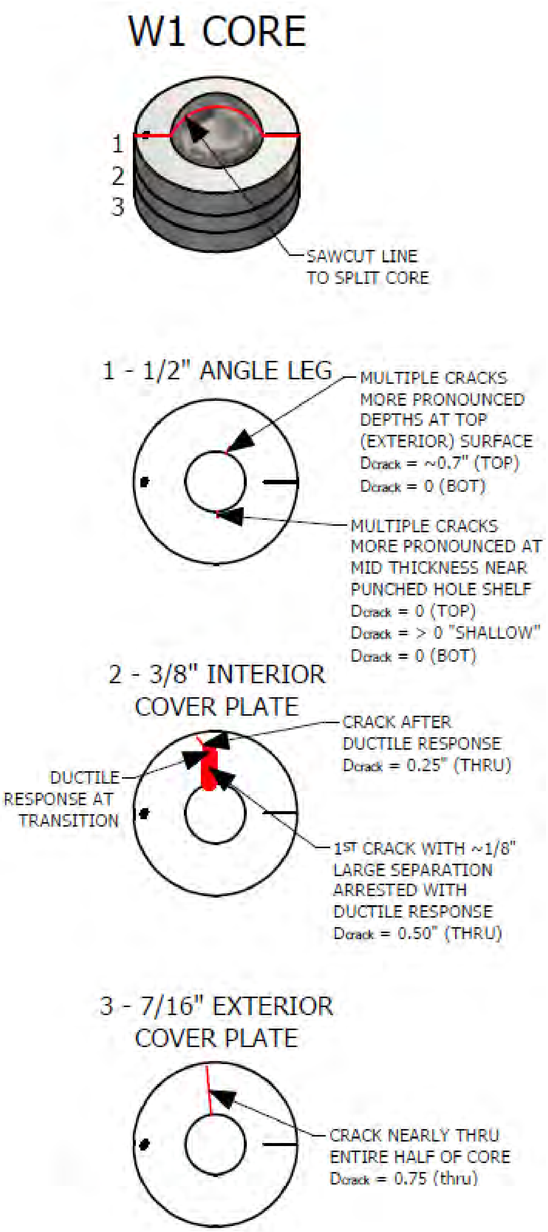
- **Previous calculations predicted fatigue life of span had been exceeded**
- **Look for cracks after ultimate strength test**
  - Cracks in plate visible after cleaning and magnetic particle inspection
  - Rivet removals
  - Twelve cores around rivet locations
  - Cover plate section removed



29TH AAR RESEARCH REVIEW

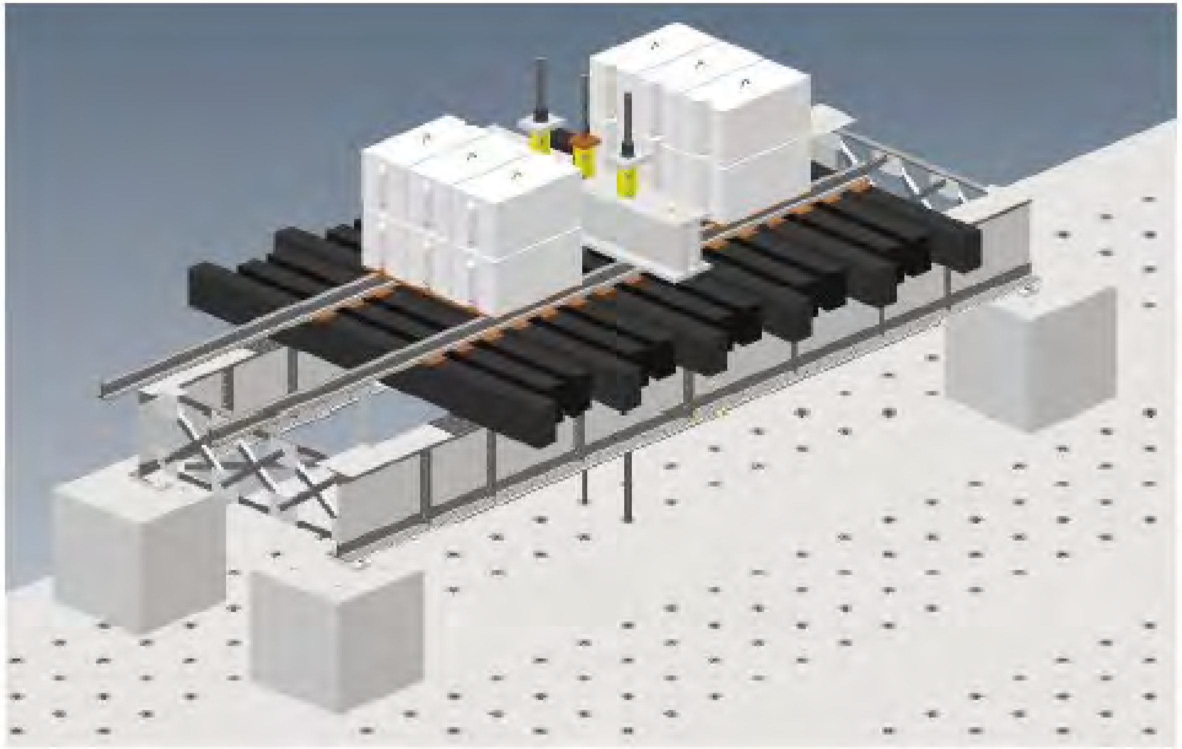
Post-test Destructive Evaluation

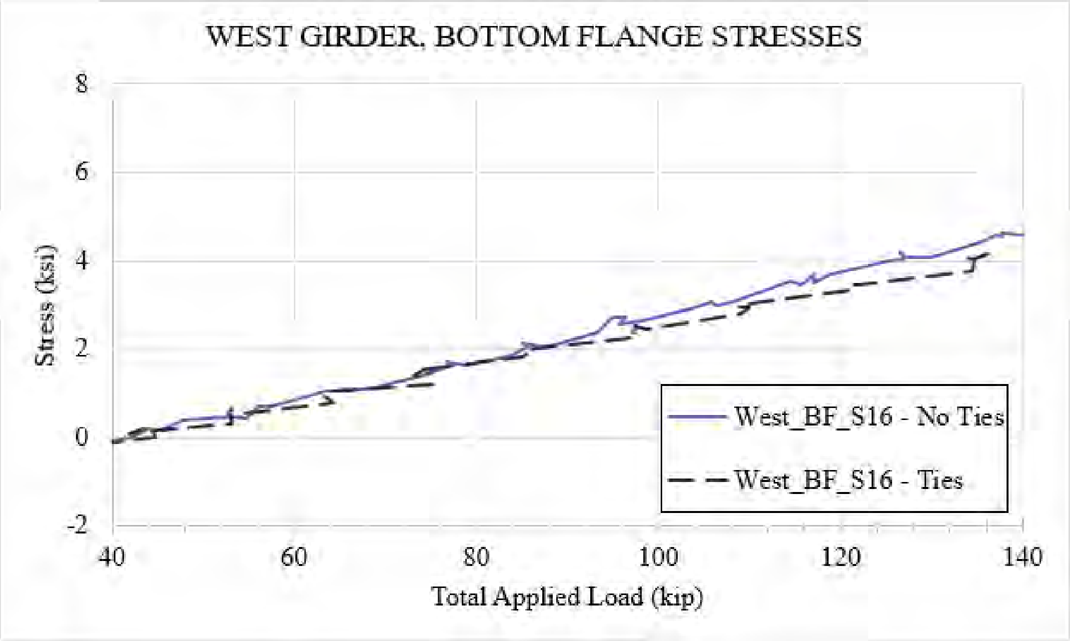
- **Nine cores from tension zone**
  - Seven with larger cracks, two with minimal cracking
  - None had significant cracks in all three layers
  - Evidence of yielding
    - Opening cracks in several cores



Deck Contribution Test

- **Load applied to rails and without deck**
  - 140 kips maximum loading
- **Small reduction in bottom flange stress due to rail and ties**





MLR Summary

- **No fracture observed in the cold weather or ultimate strength tests**
- **Controlled, ductile behavior of girder**
- **Cracks found in post-test evaluation**
- **No cracks were found in all three layers**

Summary

- **New Bridge Deck Test Facility allows continued testing of new bridge deck components**
- **Member Level Redundancy demonstrated in riveted steel girders with multiple layers of steel**

Acknowledgements

- **BNSF, CPKC and UP**
- **Coreslab Structures**
- **Purdue University Bowen Laboratory**

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Revenue Service Testing

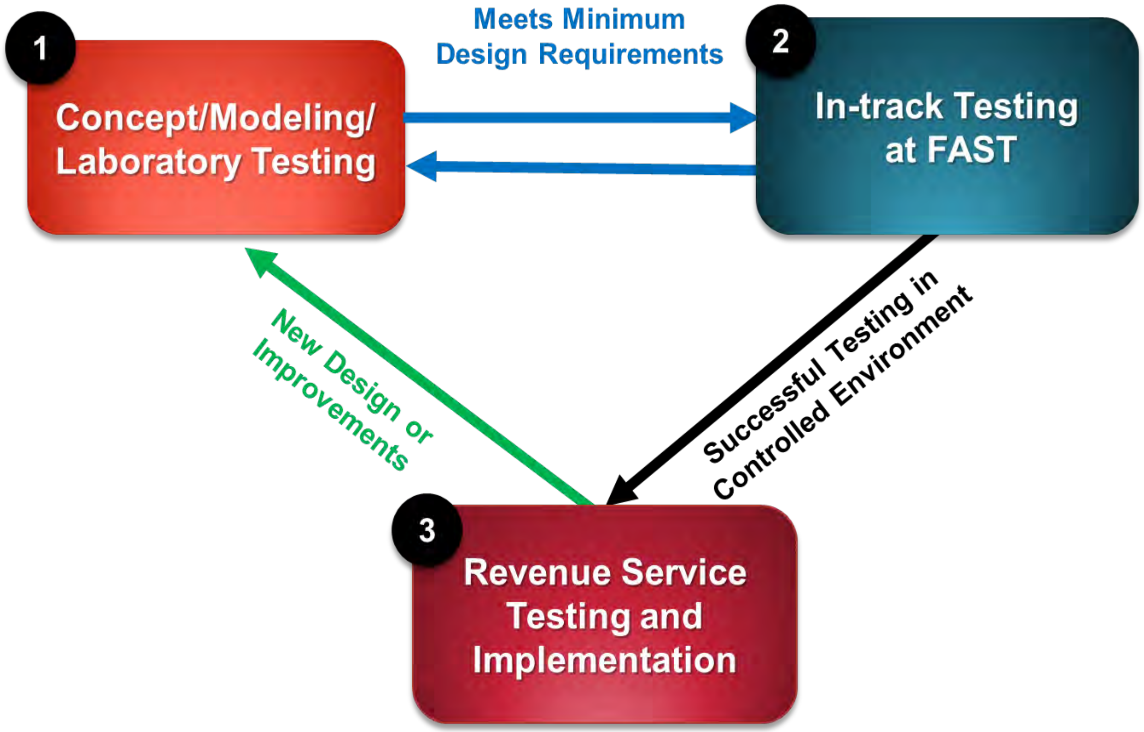
Duane Otter, Ph.D., P.E.
Scientist

Revenue Service Testing

- Background and objectives
- Overview of recent experiments
- Frog profile testing
- CWR behavior near a rigid area of track
- Summary and Acknowledgements

Revenue Service Testing

- **Evaluation of new designs, methods, and components in revenue service**
- **Testing in environments (weather, grade and curve, speed, traffic mix, lubrication, etc.) different from those at Facility for Accelerated Service Testing (FAST®)**



- **Able to test in larger quantities than at FAST (e.g., special trackwork)**
- **Final evaluation step before wider implementation**

Recent and Ongoing Investigations

- **Rail performance – Ananyo Banerjee**
- **Weld performance – Kerry Jones**
- **Ties & fasteners – Yin Gao**

Recent and Ongoing Investigations

- **Continuous welded rail (CWR) effects – Steve Wilk**
- **Ballast, subgrade & track transitions – Steve Wilk**
- **Special trackwork– Duane Otter & Ben Bakkum**

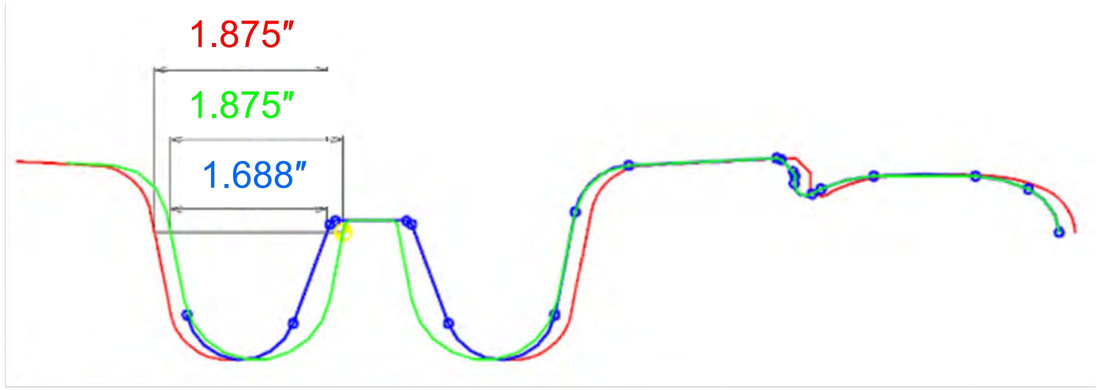
Frog Performance Evaluations on NS

Frog Performance Evaluations

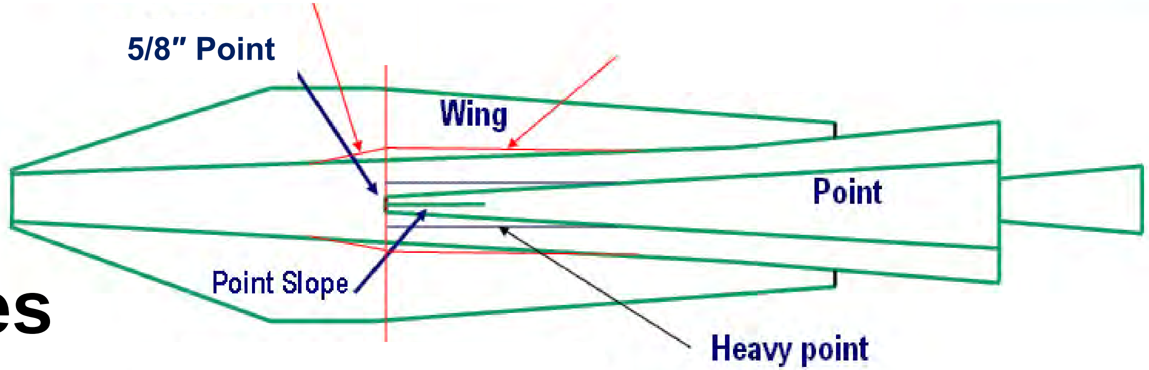
- **Frog testing on NS line south of Cincinnati, OH**
- **Frog points tested:**
  - Standard point, heavy point (HPF), modified heavy point (MHP)
- **Frog wing slopes tested:**
  - Standard (none)
  - 1/8-inch drop over wheel transfer
- **Other turnout tests: Heel designs, experimental weld repaired frog, stock rail flow, base plate pads**

MHP Frogs

- **Designed to meet pre-2020 FRA Class 5 limits without need for waiver**
- **Reduced wing to provide more flangeway width**
- **Two No. 20 MHP frogs**
  - Both frogs welded boltless manganese (WBM) type
- **Frequent diverging route moves**
- **Testing began in 2017**



Blue – Original design HPF
Green – Standard Frog
Red – New design MHP (larger flangeway)



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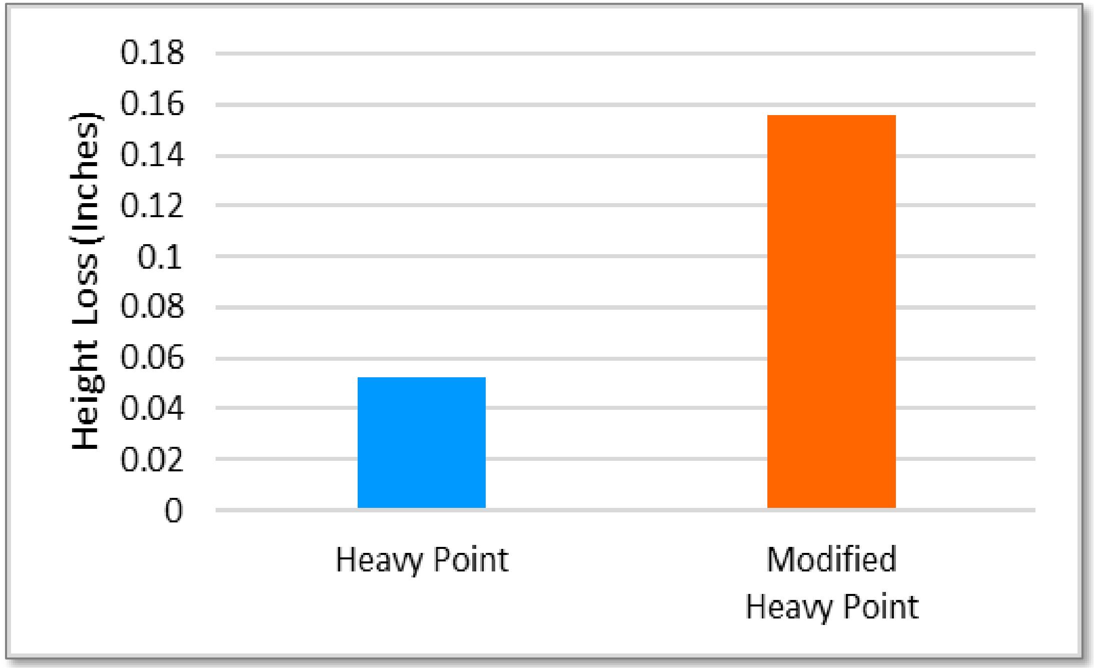
MHP Frogs

- **Frogs removed late 2022**
  - Approx. 380 MGT on each frog
- **Significantly more point height loss on MHP frogs**
- **More impact on MHP frogs due to wider flangeways**
- **FRA removed need for waiver in Oct. 2020 via rule change**
- **No further MHP frog testing planned**



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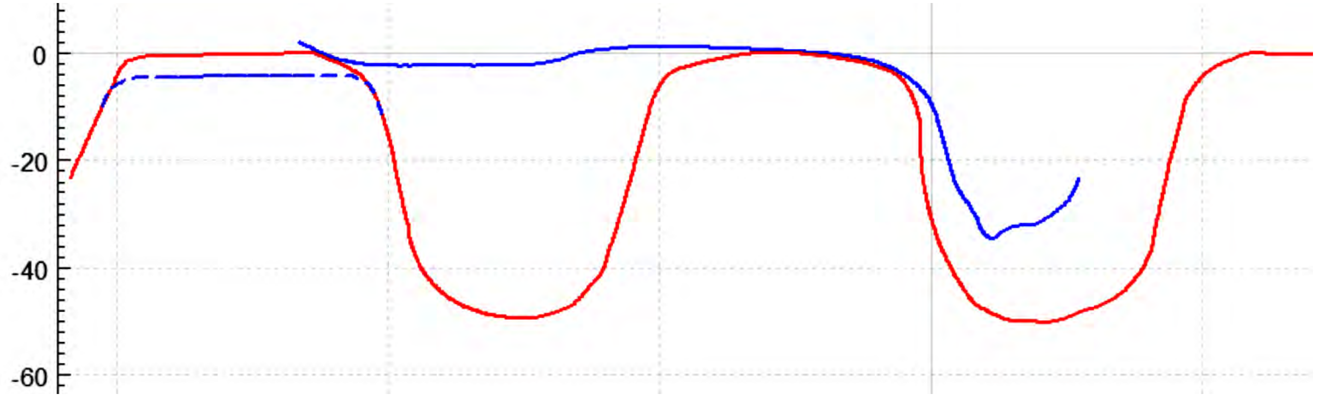
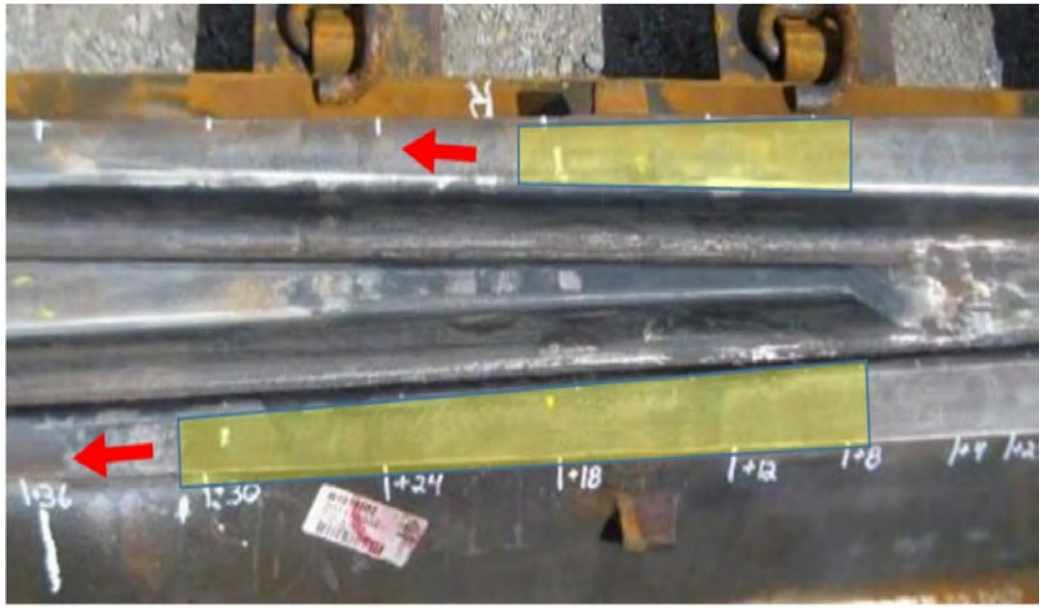
Frogs with Longitudinal Wing Slopes

- **Wing slope reduces impacts from hollow worn wheels**
- **Similar function to a switch point riser**
- **Two (2) No. 20 wing slope frogs in test**
  - One each WBM and Rail Bound Manganese (RBM)





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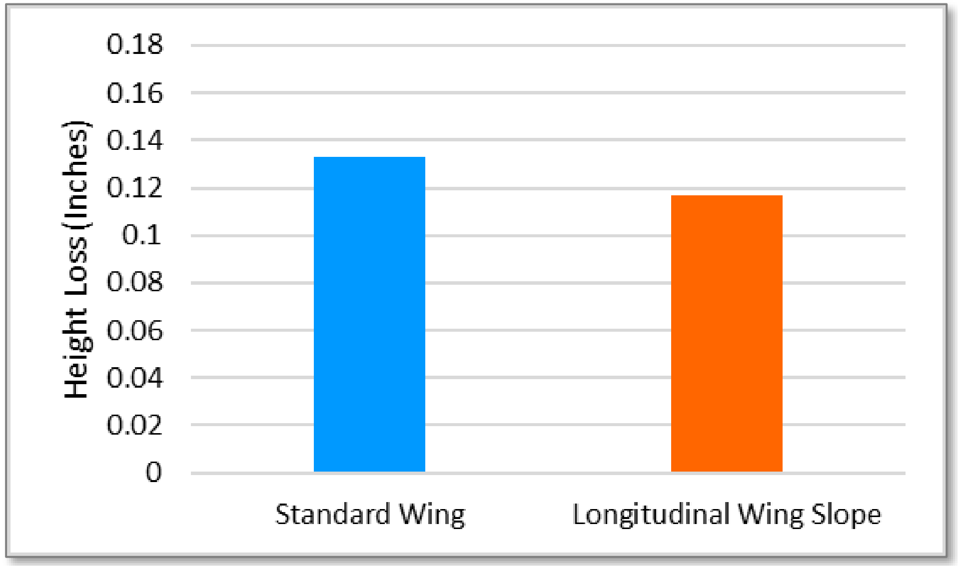
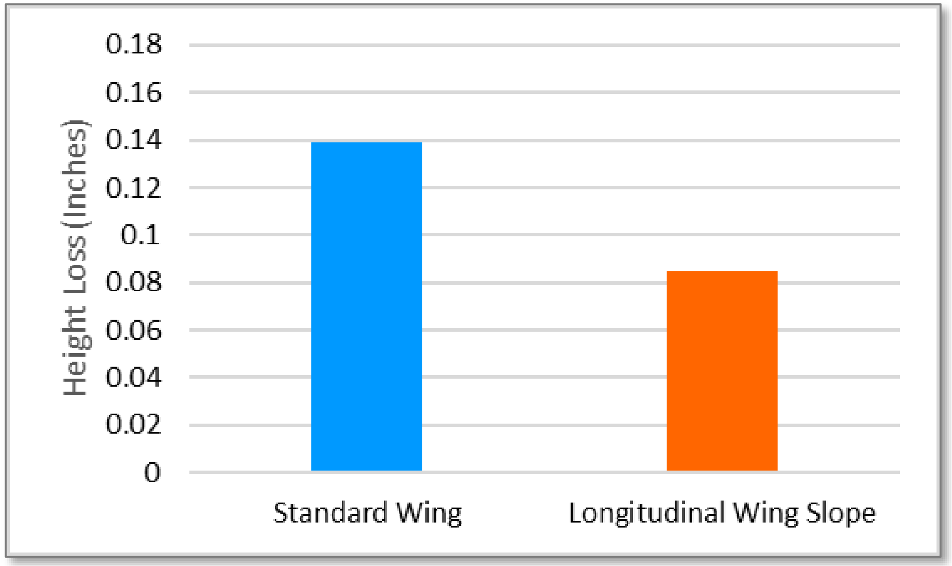
Frogs with Longitudinal Wing Slopes



Main Line Wing Height Loss



Diverging Wing Height Loss

- **No weld repairs to any wings as of 181 MGT inspection**
- **Diverging wings show somewhat more benefit so far**
- **Plenty of hollow worn wheels traveling over these frogs**

Continuous Welded Rail (CWR) Behavior Near a Turnout

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CWR Behavior Near a Turnout

- **CWR near fixed assets**
  - Many stories, many questions
  - Very little test data
- **Measure rail movement and rail forces due to:**
  - Significant track maintenance
  - Train traffic
- **BNSF Track Lifter**

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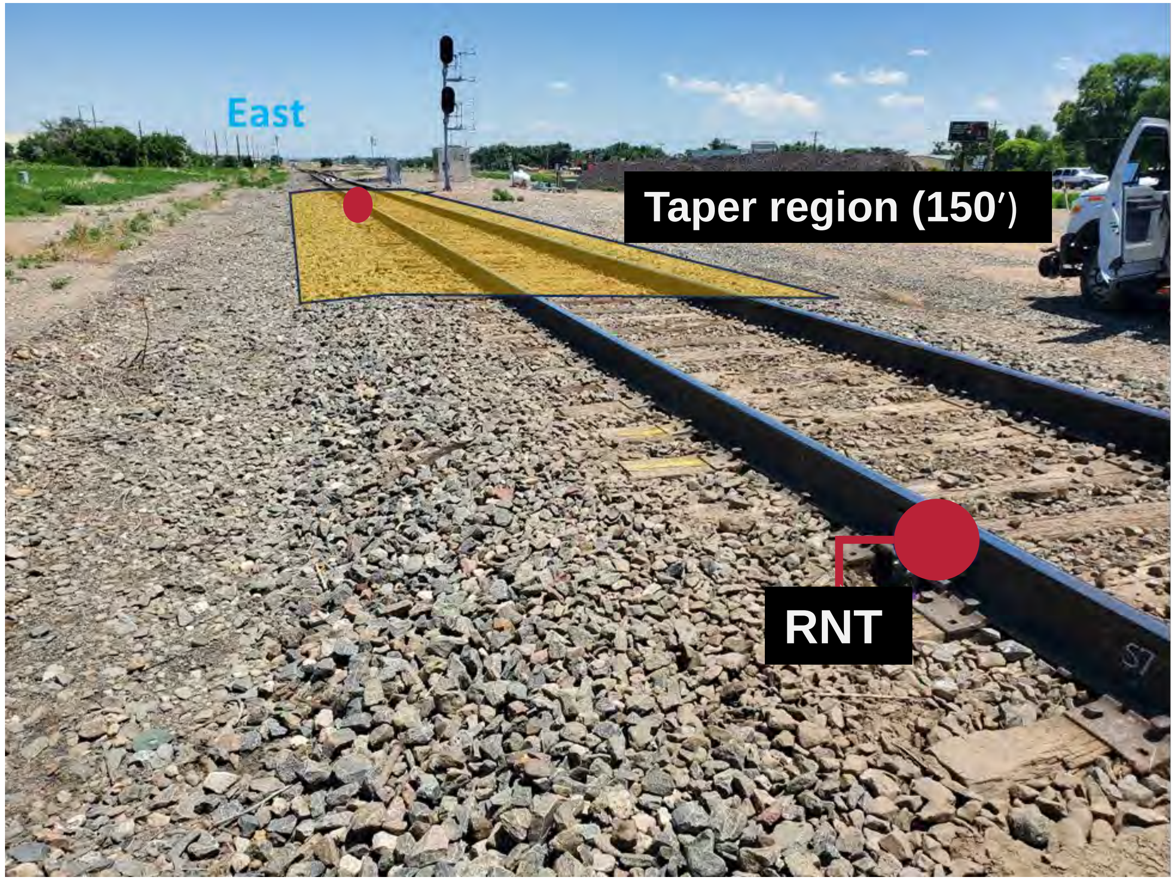
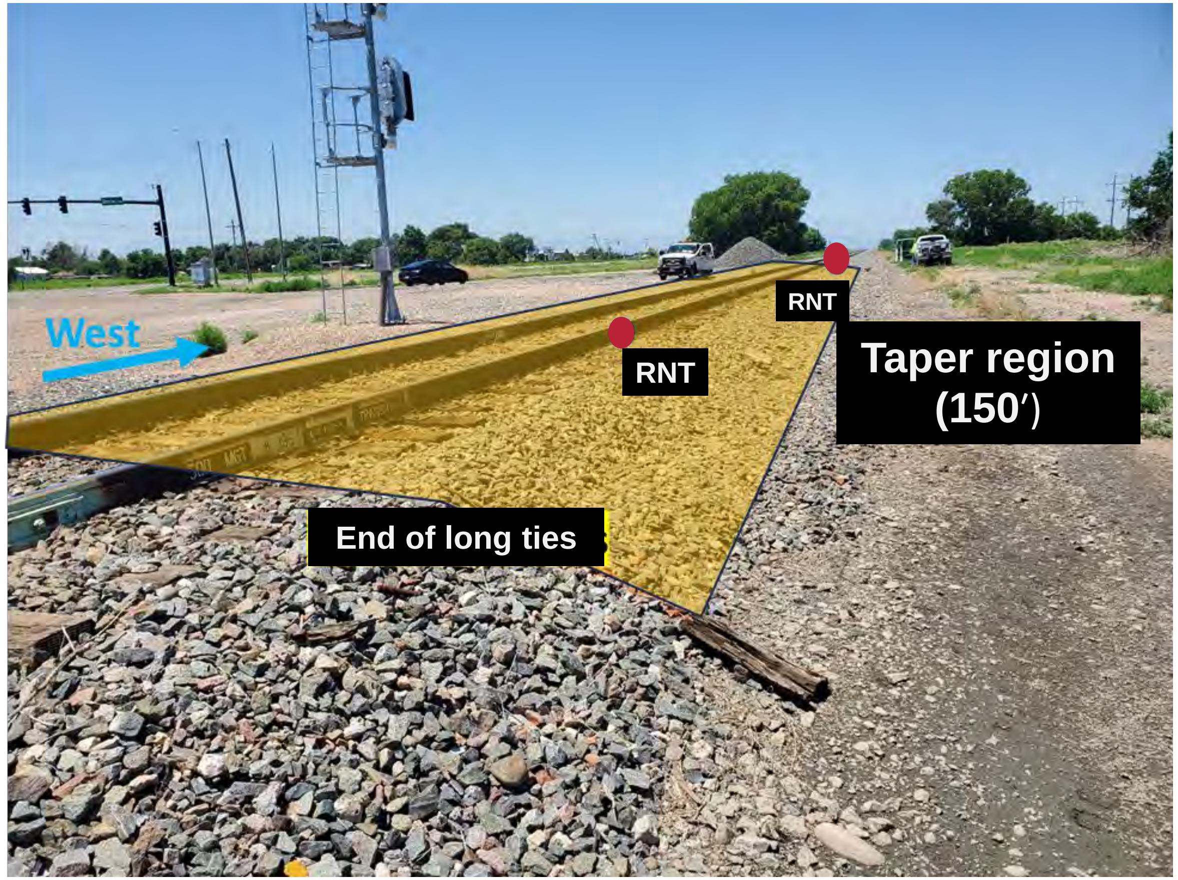
CWR Behavior Near a Turnout

- **Track lifting operations**
  - Track lifter: Lifts ties out of existing ballast
  - Rock train: Dumps new rock
  - Surfacing crew 1: Lifts the ties out of rock
  - Surfacing crew 2: Aligns the track and surfaces into turnout
  - Local surfacing crew: Local crew surfaces after production crew

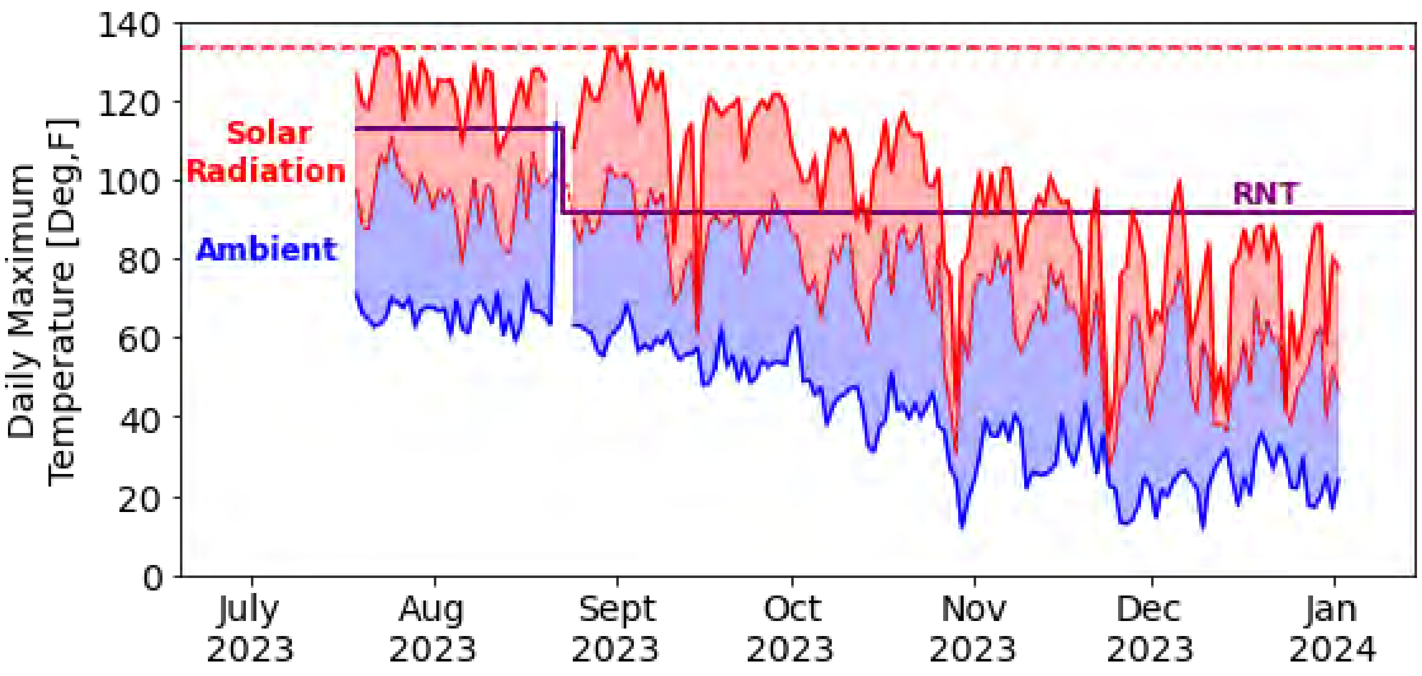
CWR Behavior Near a Turnout

- **Test layout**
  - Measure rail temperature, longitudinal force, and movement





CWR Behavior Near a Turnout



- **Rail temperatures**
  - Ambient temperatures fluctuate daily and seasonally
  - Solar radiation increases rail temperature during the day
  - Maximum measured rail temp: 133°F

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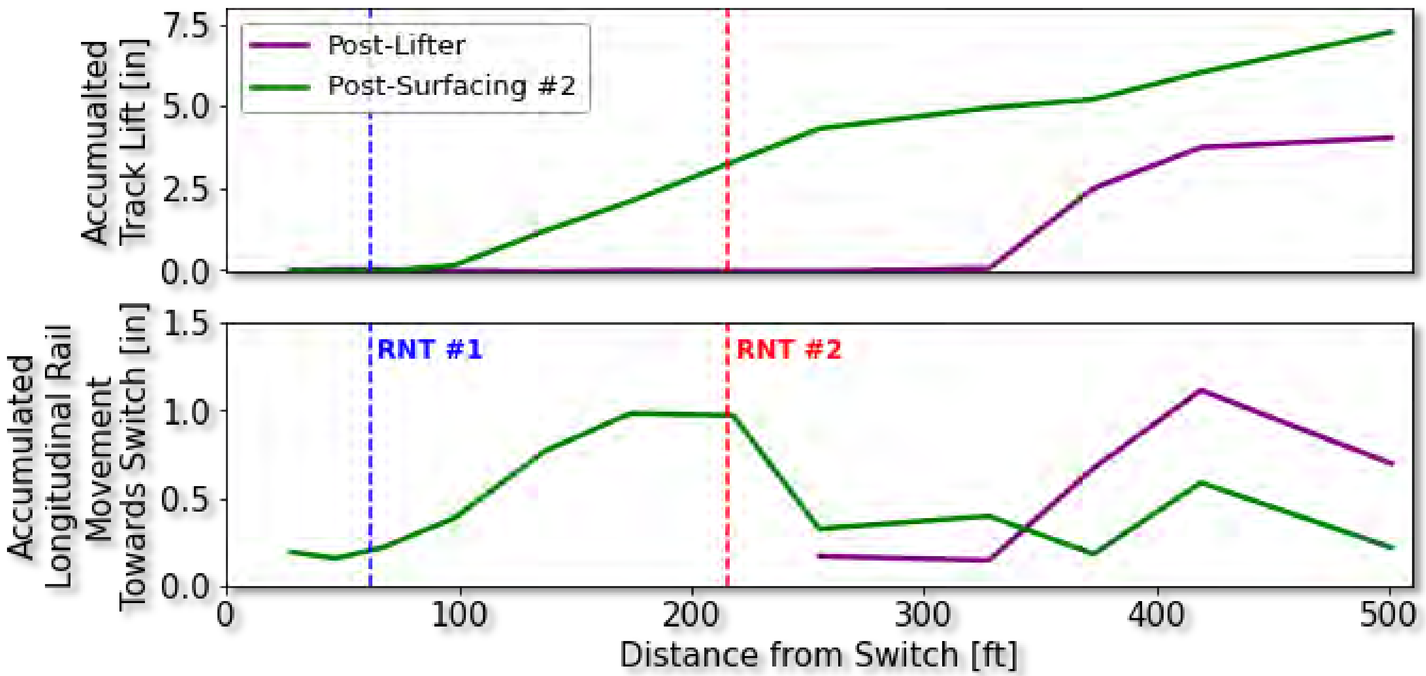
CWR Behavior Near a Turnout



- **Rail/track vertical and longitudinal movements**
  - Longitudinal movement up to 1 inch observed in both the lifter and tamper taper regions

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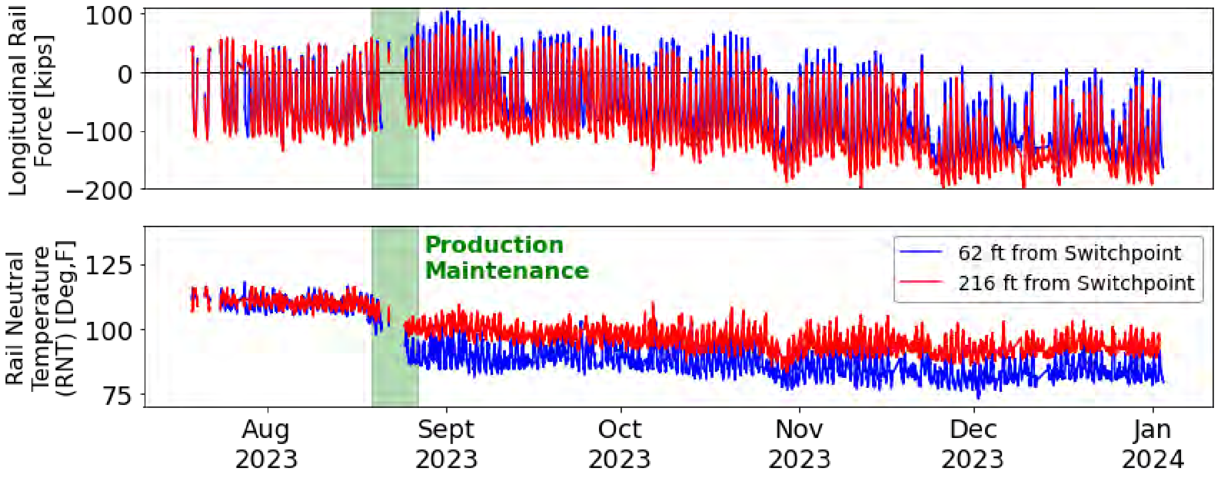
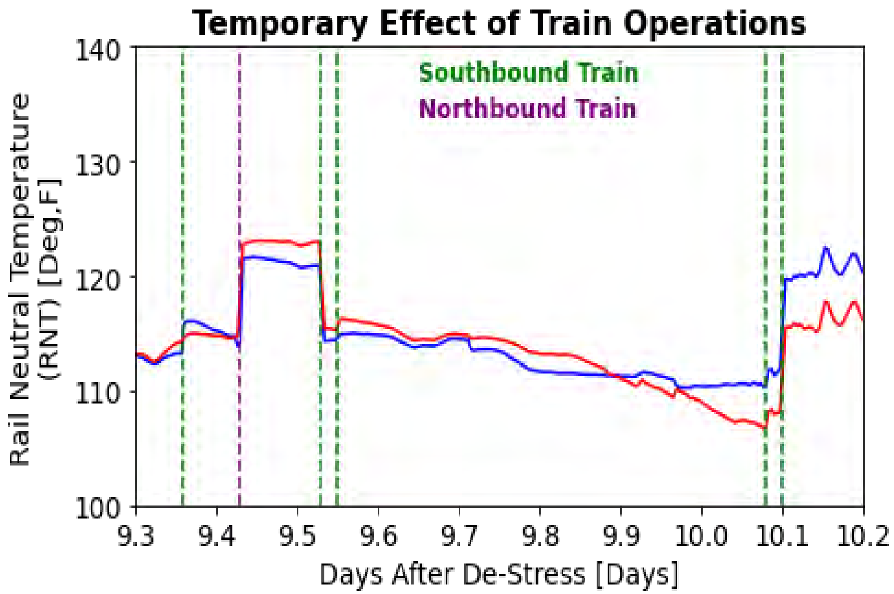
CWR Behavior Near a Turnout

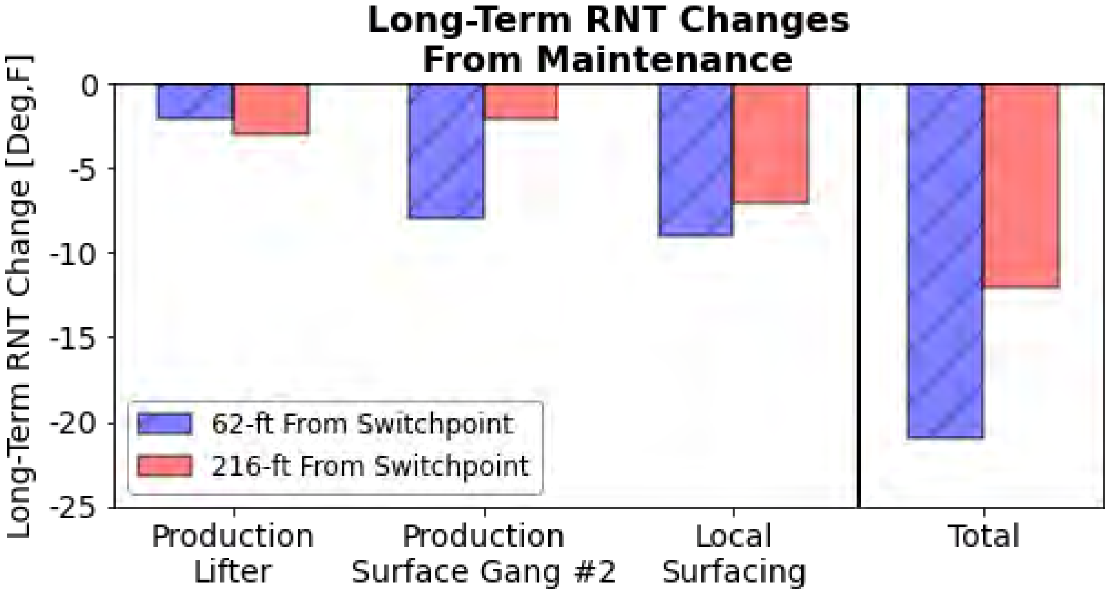
- **Longitudinal rail force and rail neutral temperature (RNT)**
  - Daily swings in rail forces due to temperature and train traffic
  - RNT dropped but still within acceptable target range (No need to de-stress again)



CWR Behavior Near a Turnout

- **RNT**
  - RNT set higher prior to track maintenance operations
  - RNT also changes under train traffic





Summary

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Summary

- **Revenue service tests ongoing for many infrastructure issues, from rail to subgrade**
- **Complements the studies performed at FAST**
  - Conditions not possible at FAST (weather, traffic, grades, curves, sample sizes, etc.)
  - Quantify effects of large-scale production maintenance
- **Look for results in recent and upcoming issues of *Technology Digest***
- **Some results presented by test leaders in other presentations at this Research Review**

Acknowledgements

- Host Railroads: BNSF, CN, NS, UP
- MxV Rail Strategic Research Initiatives test leaders and instrumentation team
- Federal Railroad Administration for co-funding initial phases of several tests
- Additional photos courtesy of Joe Blackwell

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Ballast and Subgrade Research

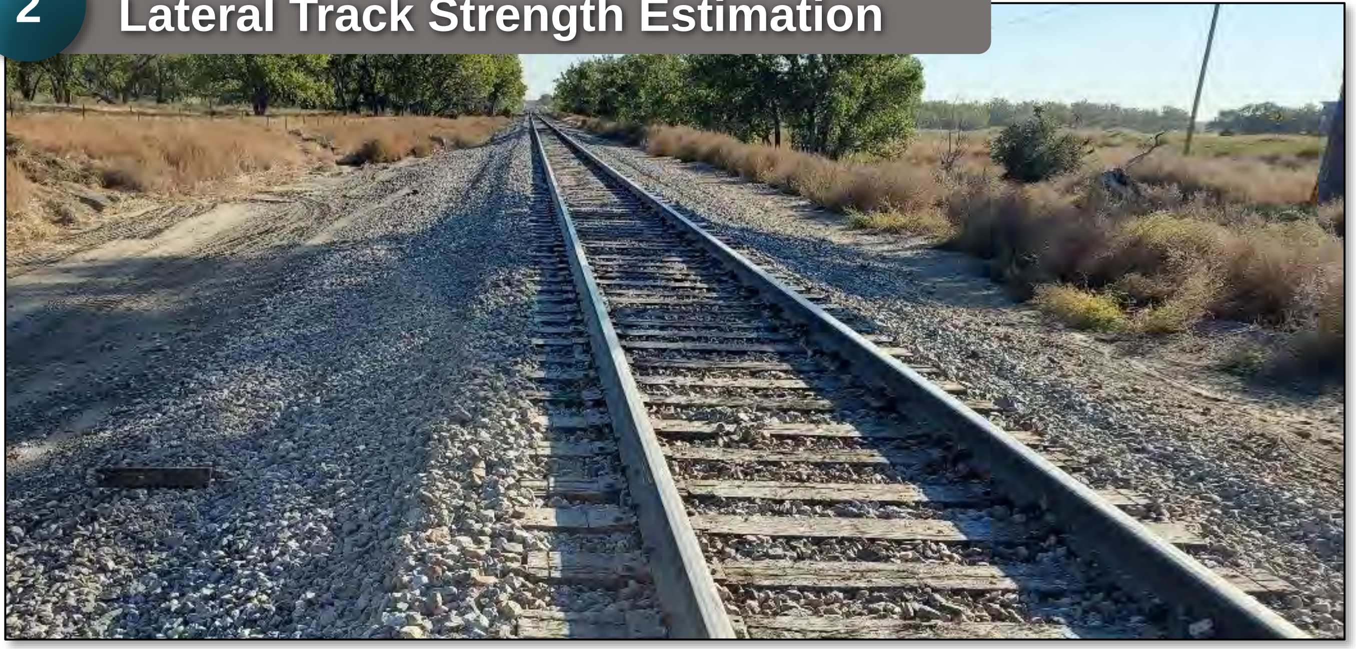
Stephen Wilk, Ph.D.
Principal Investigator I

Outline

29TH AAR RESEARCH REVIEW

1 Ballast Recompaction with Tonnage

2 Lateral Track Strength Estimation



Topic 1:
Ballast Recompaction with Tonnage

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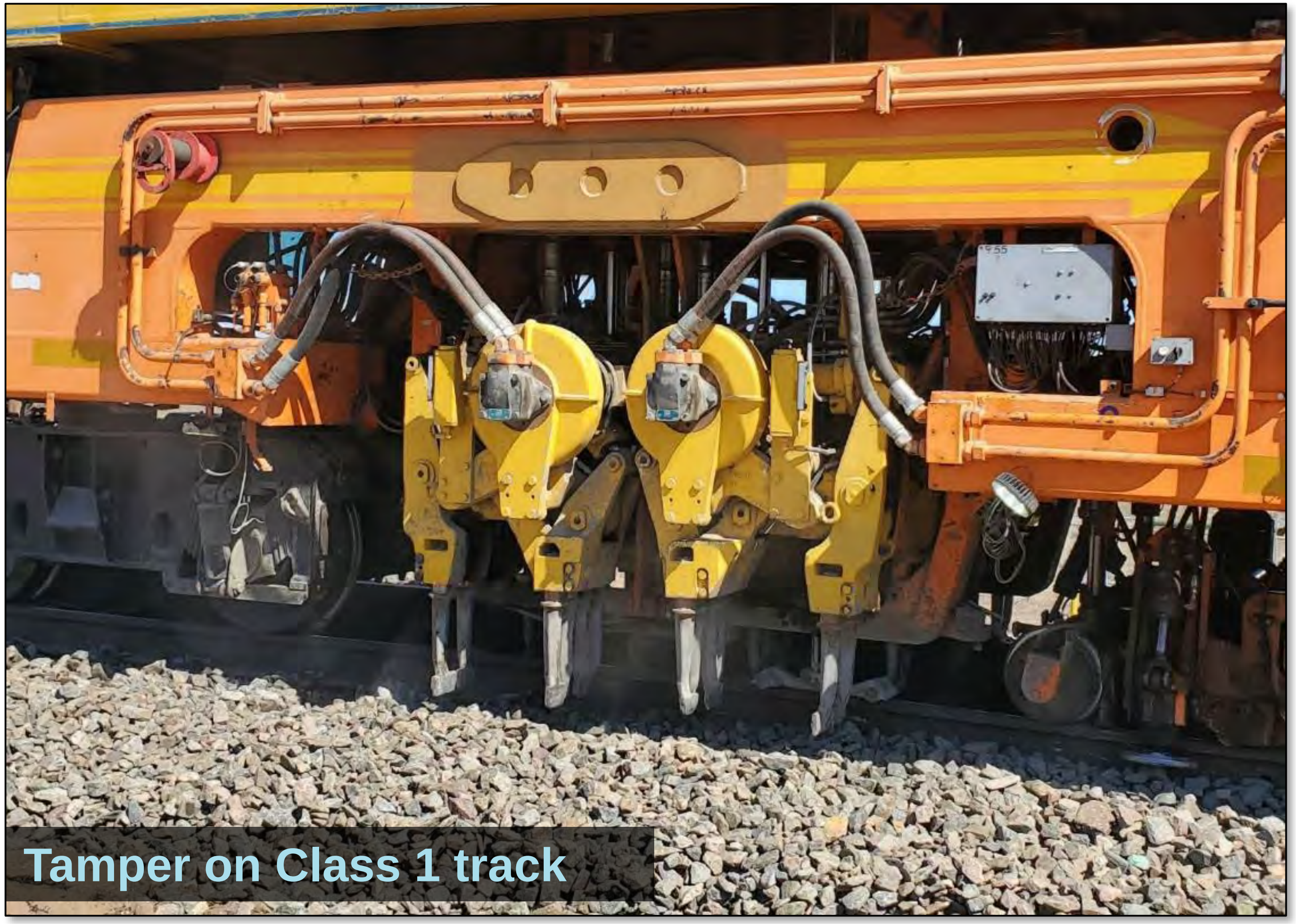
Topic 1: Ballast Recompaction with Tonnage

- **Ballast lateral resistance is one buckle resistance factor**
- **Tie movement resistance occurs when the ballast interlocks**

Track Buckle from 2022 MxV Rail/BNSF Test

Ballast Maintenance and Recompaction



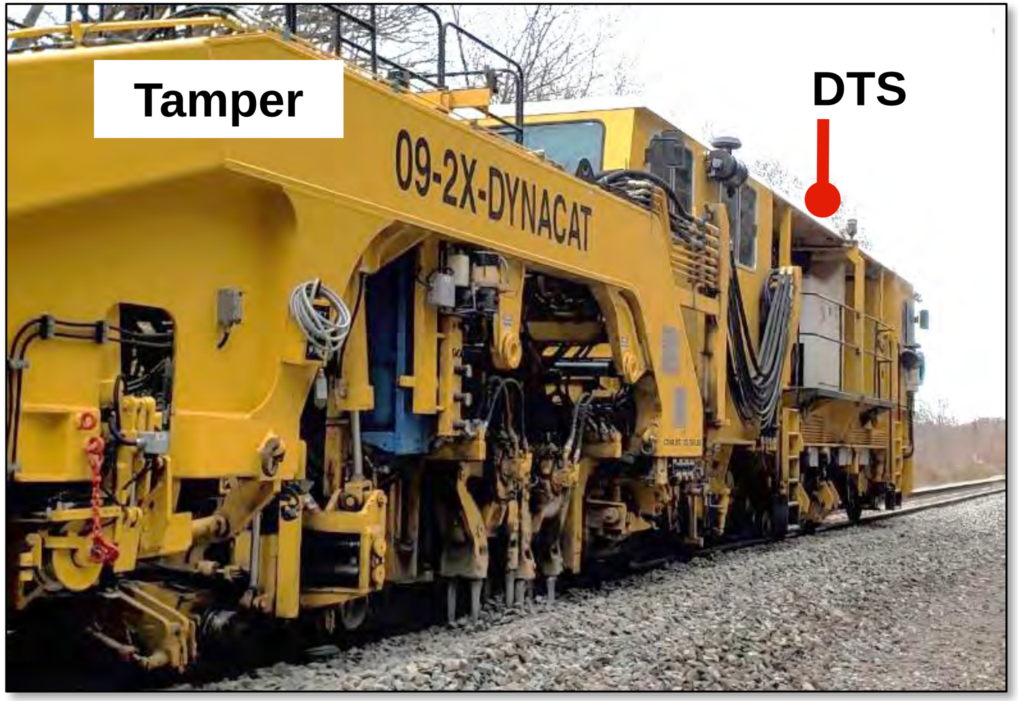
Tamper on Class 1 track

- **Ballast maintenance:**
  - Inherently breaks up ballast structure
  - Reduces track structure strength against tie movement and buckling

Ballast Maintenance and Recompaction

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

Dynamic Track Stabilizer (DTS) – 2023 Update

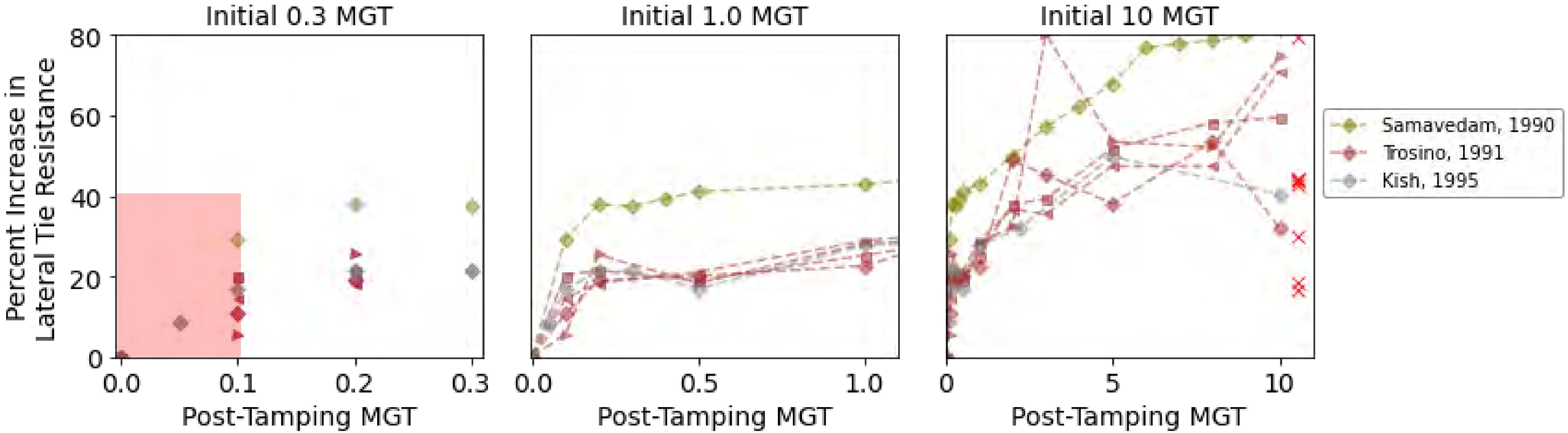


Tonnage under Speed Restriction

Tonnage requires 6+ train passes while DTS requires only one

Compaction Test – Previous Work

- **Different track may require more or less tonnage than 0.1 MGT, depending on track condition, vehicle traffic, geography, and maintenance**
- **Define full lateral strength compaction curve**



Compaction Test – Test Objective

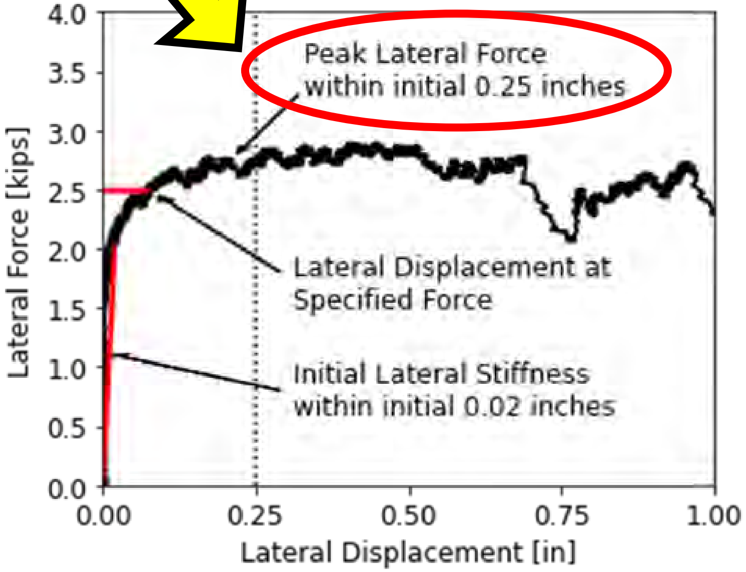
- **New FAST Track:**
  - New mixed hardwood ties
  - New ballast
  - 15 to 16-inch shoulders and mostly filled cribs
- **Compaction from three locomotives and 28 315-kip cars. Train speed ranged from 10 to 25 mph.**
  - 0, 0.01, 0.03, 0.05, and 0.1 MGT

Compaction Test – Measurements

Single Tie Push Test (STPT)

Analysis Steps

- Take maximum lateral force within 0.25 inch
- Normalize by 18-inch shoulders and full crib
- Divide by tie spacing (useful parameter for track buckle models)



Top of Rail (TOR) survey elevations

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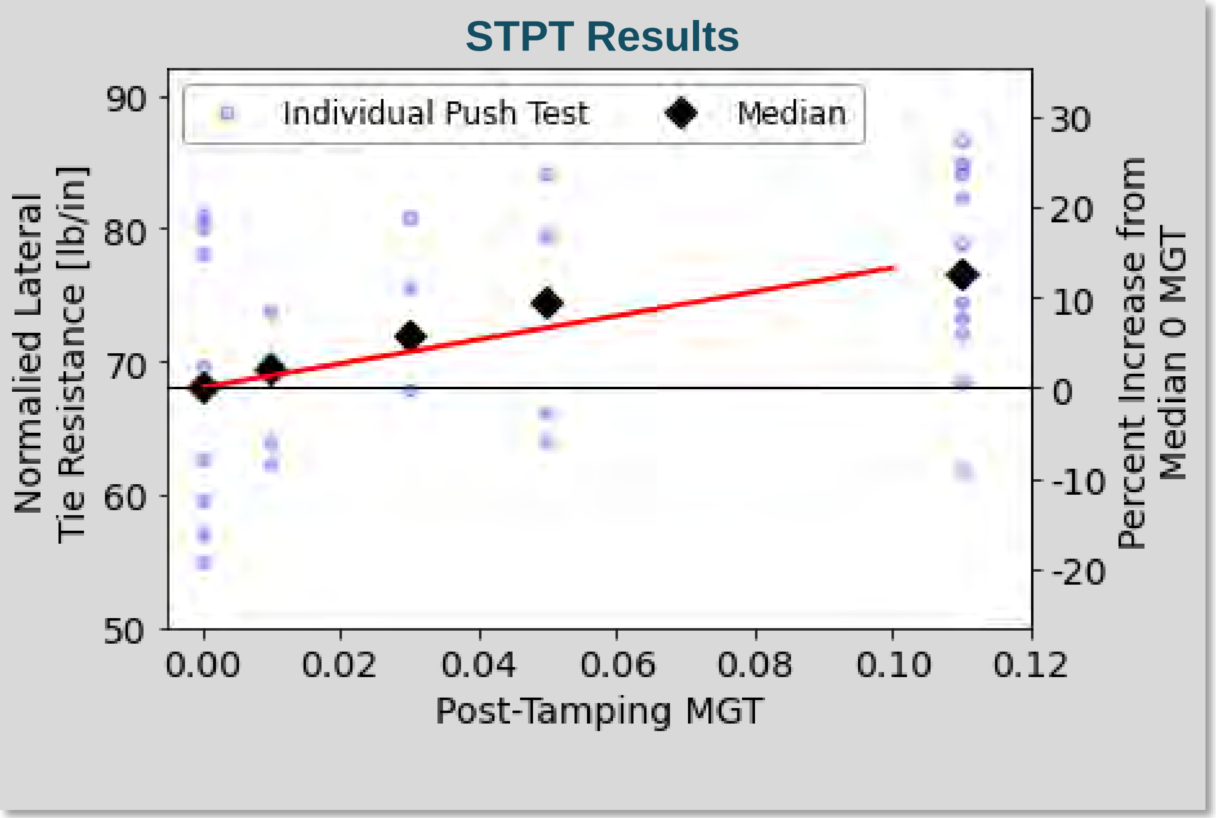
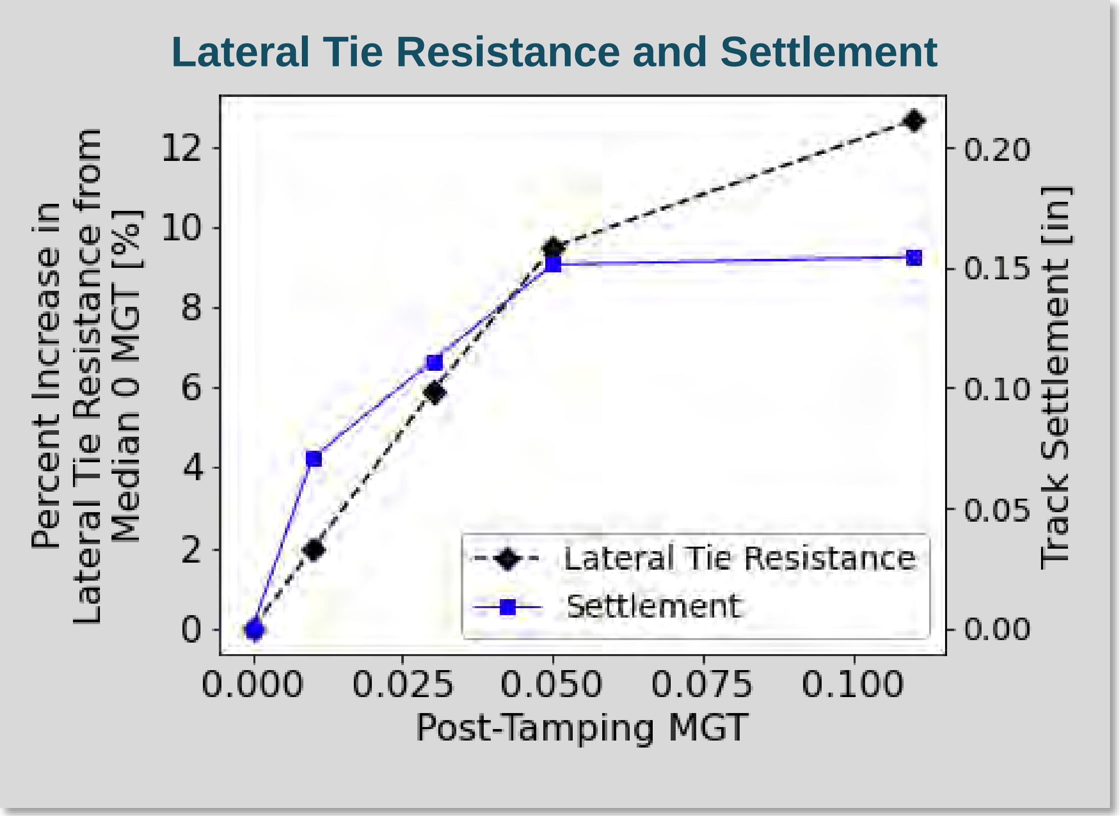
Compaction Test – Results





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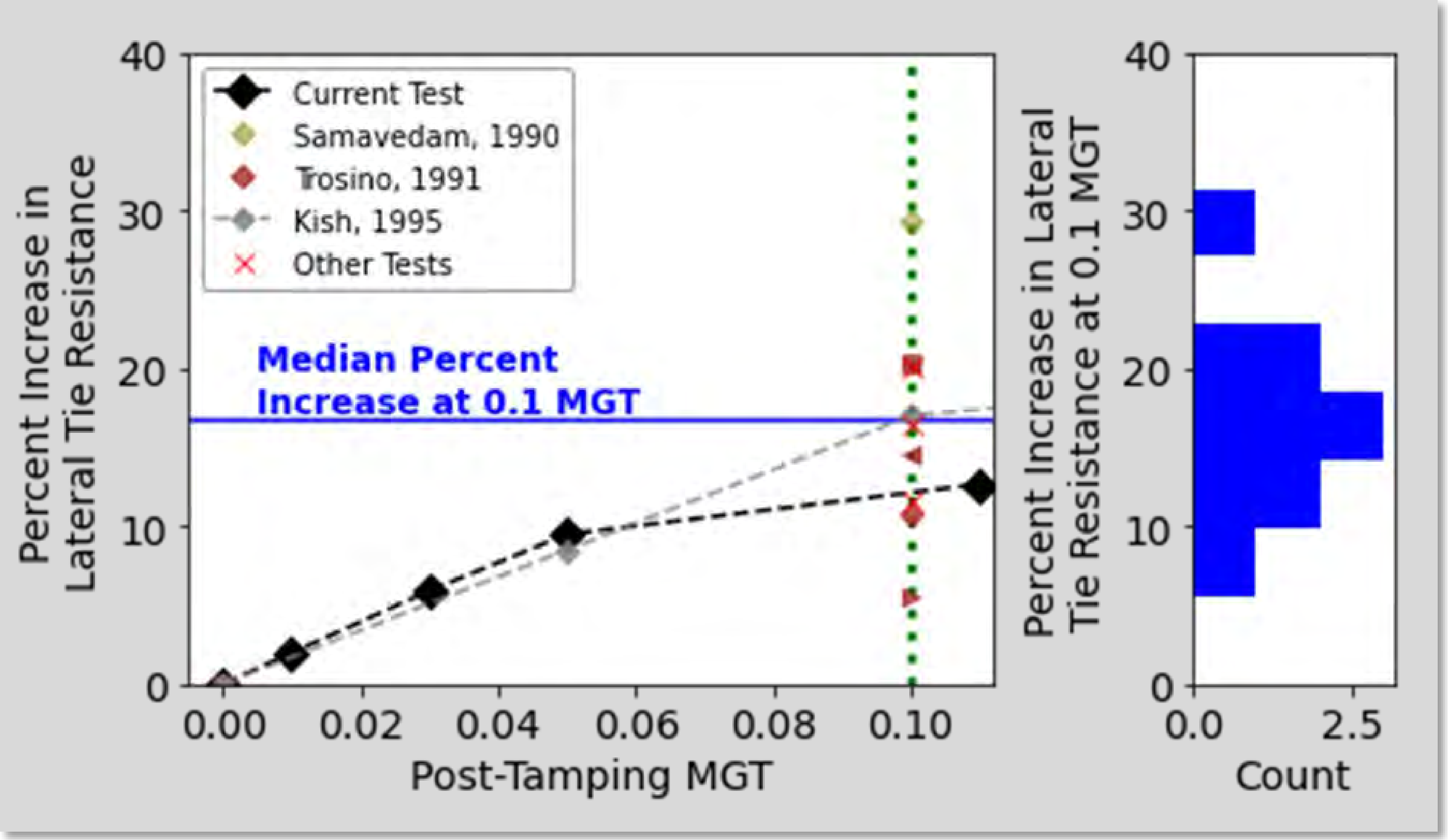
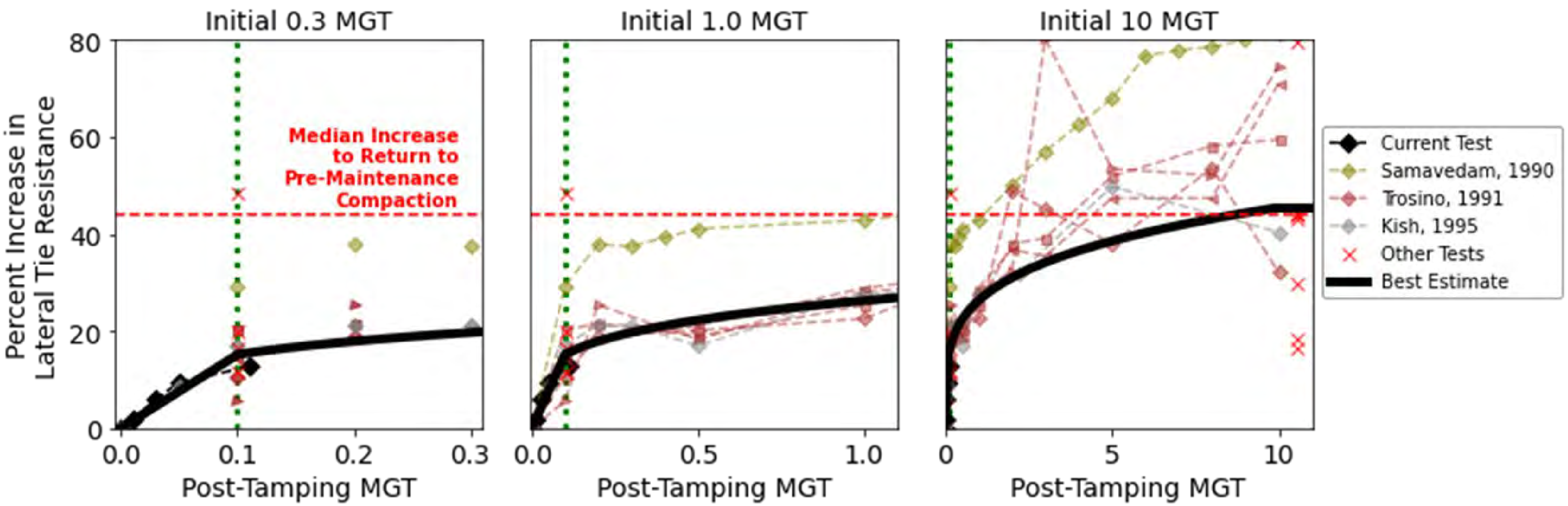
Compaction Test – Results



Key Findings

- **Linear increase in lateral tie resistance until 0.05 MGT. Tonnage may range from 0.05 to 0.1 MGT**
- **13% increase after 0.1 MGT (median from previous tests is 17% and ranges from 10% to 20%)**

Compaction Test – Full Compaction Curve



Key Findings

- Equation and details can be referenced in TD 24-003, “Lateral Track Strength Increase During Maintenance Speed Restrictions”
- Linear up to 0.1 MGT, non-linear (logarithmic fit) from 0.1 MGT to 10 MGT, roughly uniform above 10 MGT

Compaction Test – Interpretation and Findings

- **The curve is a tool that estimates the increase in lateral strength after ballast maintenance.**
- **Ballast compaction is a gradual process and may have diminishing benefits to additional tonnage after 0.1 MGT.**
- **While 0.1 MGT is a general "rule of thumb," the appropriate tonnage may be less or greater depending on track characteristics, vehicle characteristics, geography, season, and type of maintenance.**

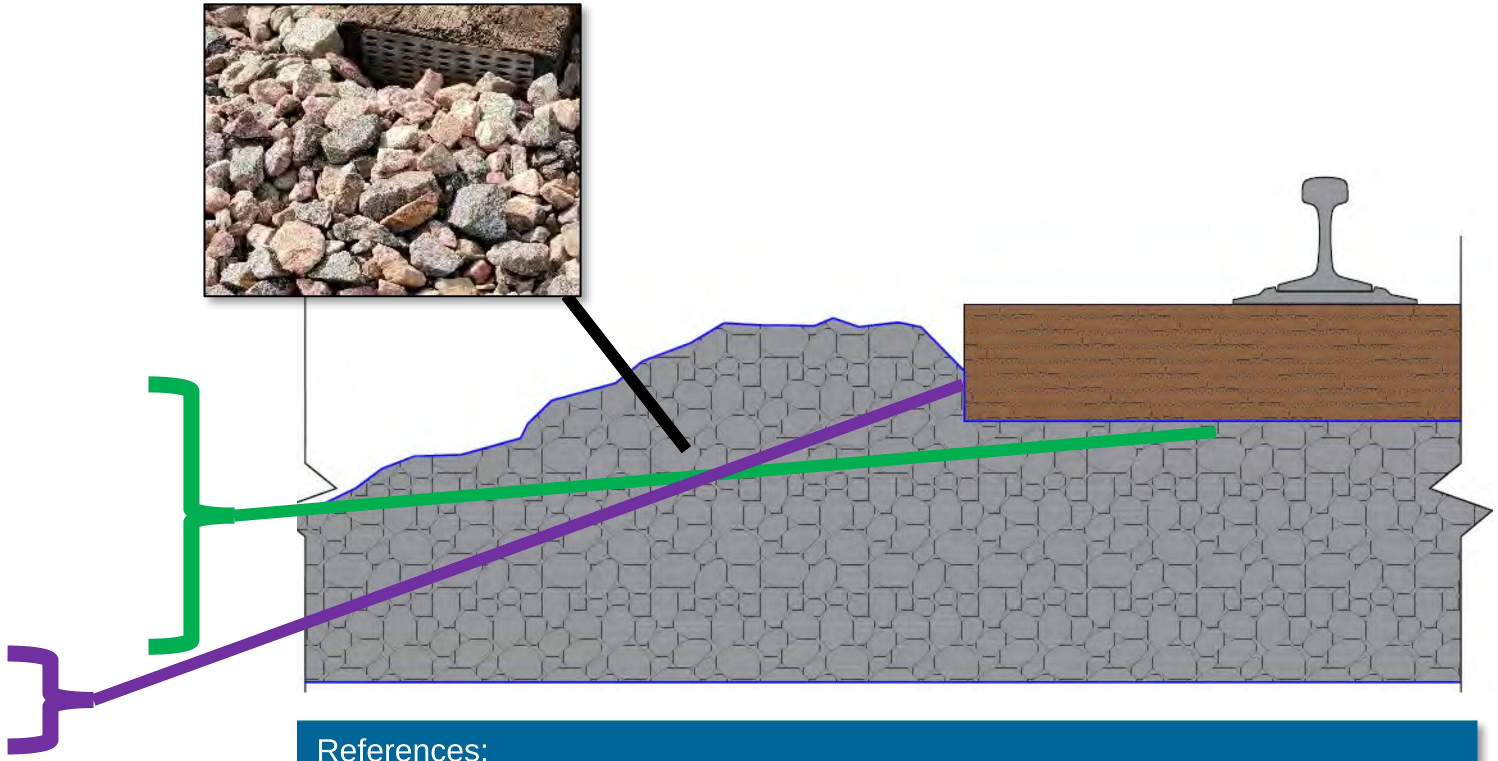
Topic 2: Lateral Track Strength Estimation

Topic 2: Lateral Track Strength Estimation

- **Models estimating lateral track strength may have multiple benefits**
  - Single-tie push tests (STPTs) are difficult to take at scale and require track time
  - Estimate changes in lateral strength from changes in track structure
  - Use track-based inspection systems
- **Develop model from combination of literature review, theory, and data**

Important Parameters

- **Ballast density**
- **Shoulder width**
- **Crib height**
- **Ballast particle characteristics**
- **Ballast/tie frictional resistance**
- **Hanging ties/tie uplift**
- **Tie movement**
- **Maintenance activity**



References:

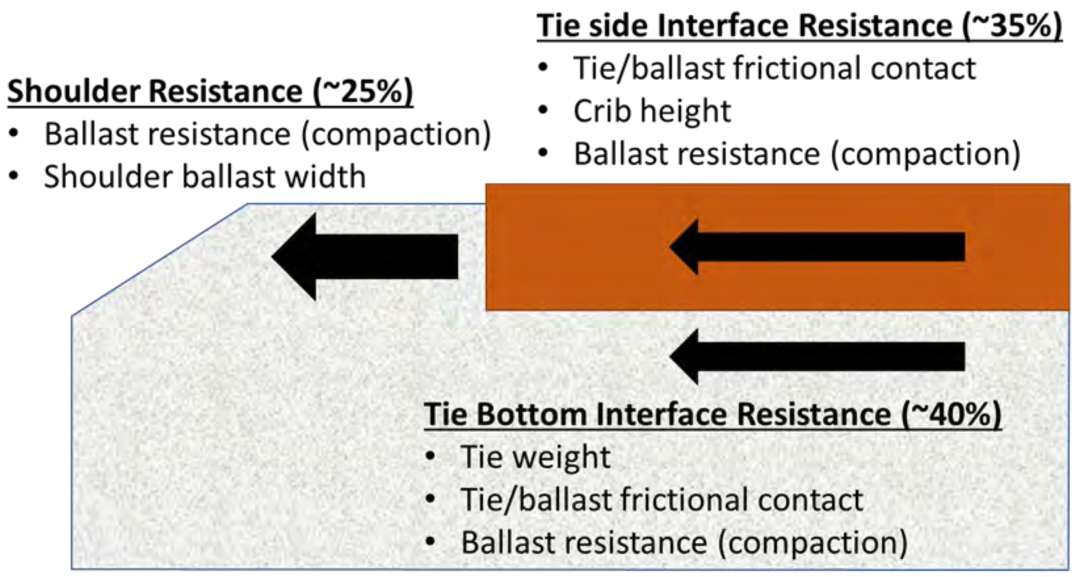
Technology Digest TD23-018 "Estimation of Lateral Track Strength from Track Structure Changes."

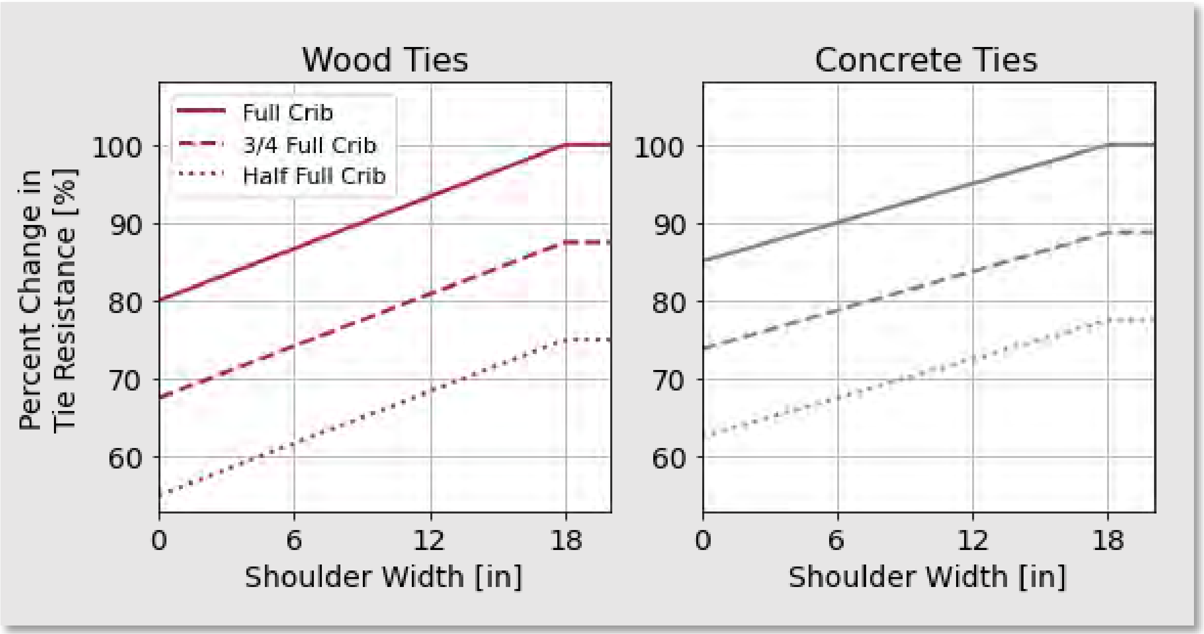
Wilk, S.T.. "Improving Lateral Track Strength After Ballast Maintenance." (IHHA) 2023.

29TH AAR RESEARCH REVIEW

Amount of Ballast

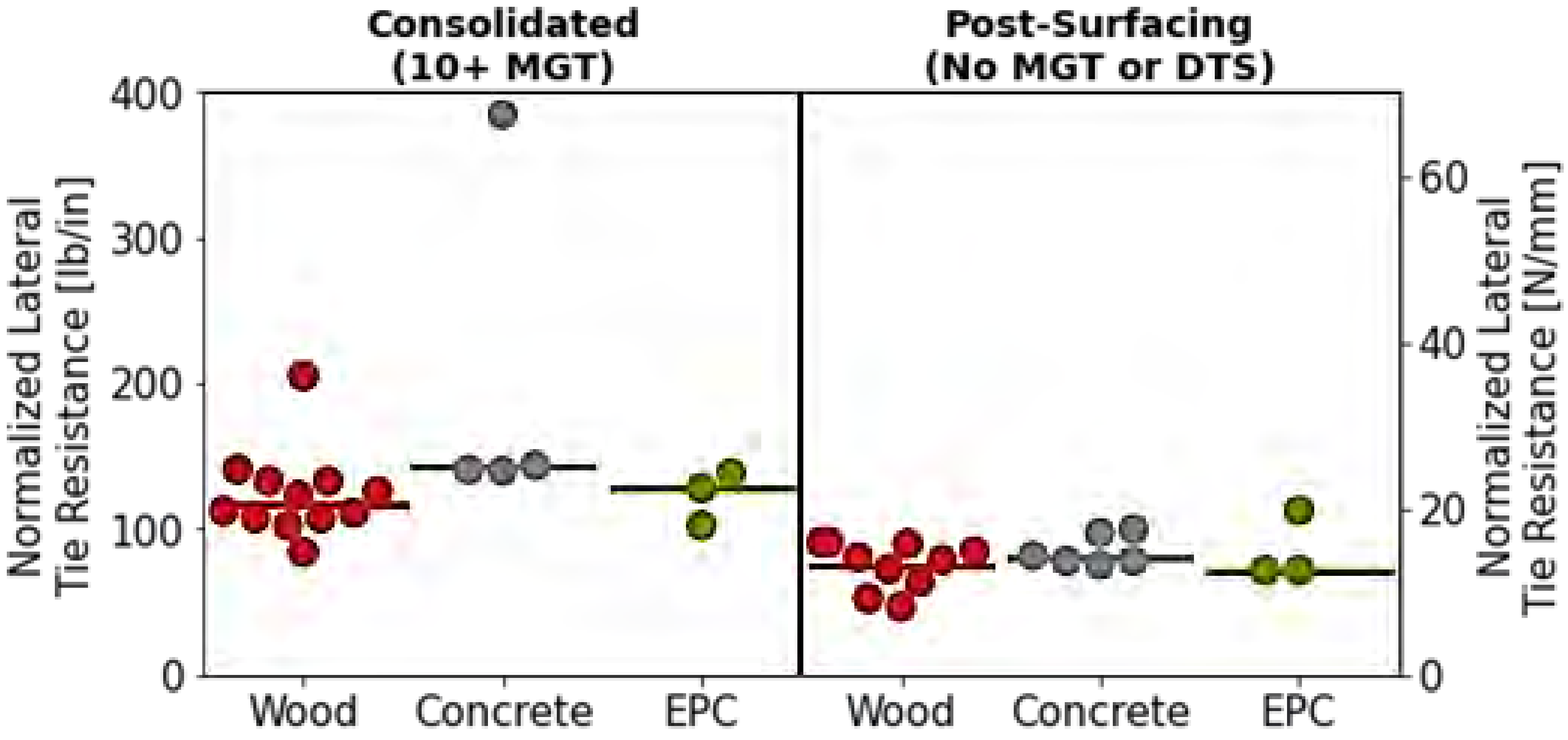
- **Shoulder width and crib height**
- **Additional ballast increases resistance**
- **Influence of shoulder width and crib height previously characterized***
- **Easily measured with new inspection systems (visual, LIDAR, lasers)**





*Data modified from Kish (2013)

Tie Type



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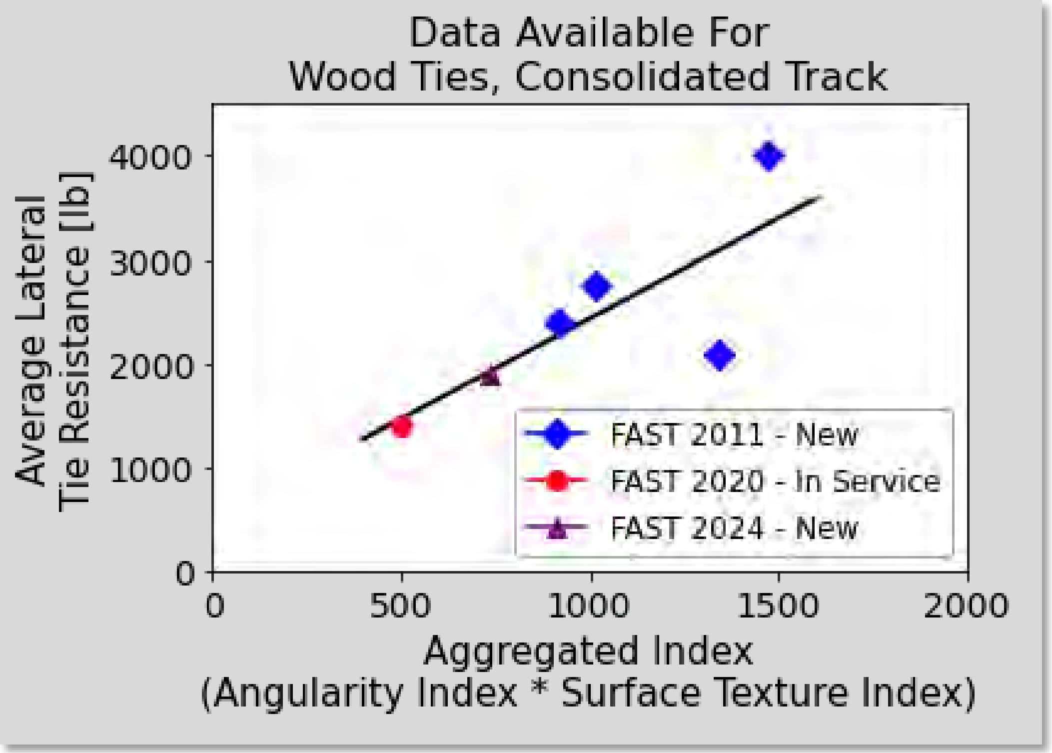
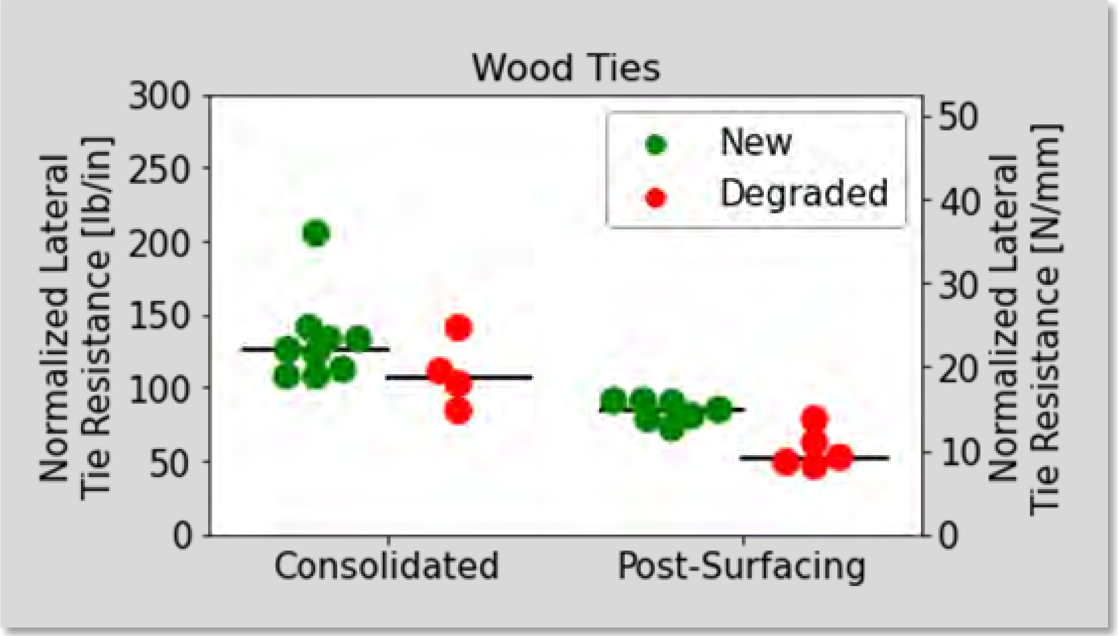
Ballast Characteristics



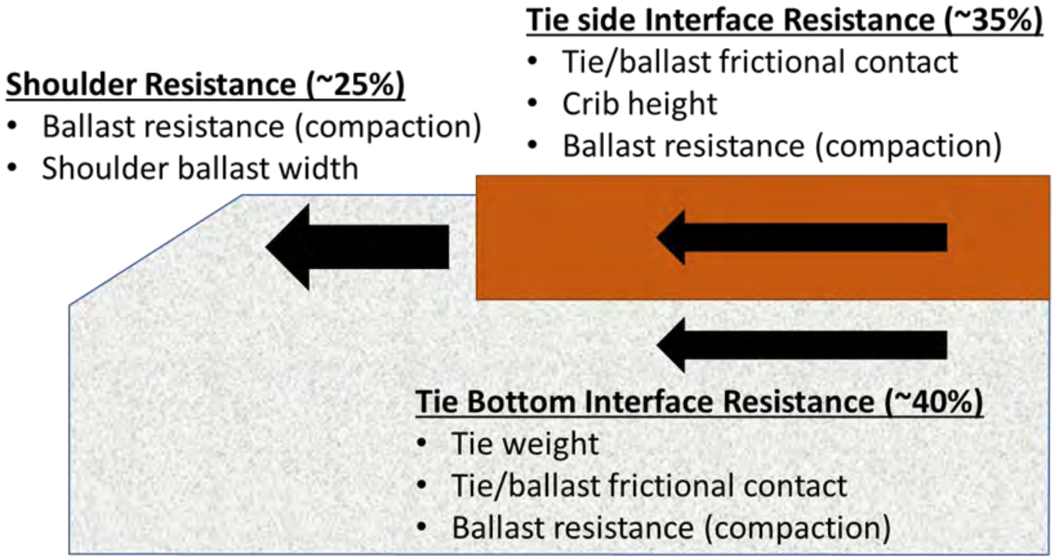
- **Ballast interlock**
- **Significant differences from quarry and degradation conditions**
- **Measurement requires sampling**



- **Possible to simplify based on new and degraded ballast but the outcome is uncertain**

Tie Movement

Tie Uplift / Hanging Ties

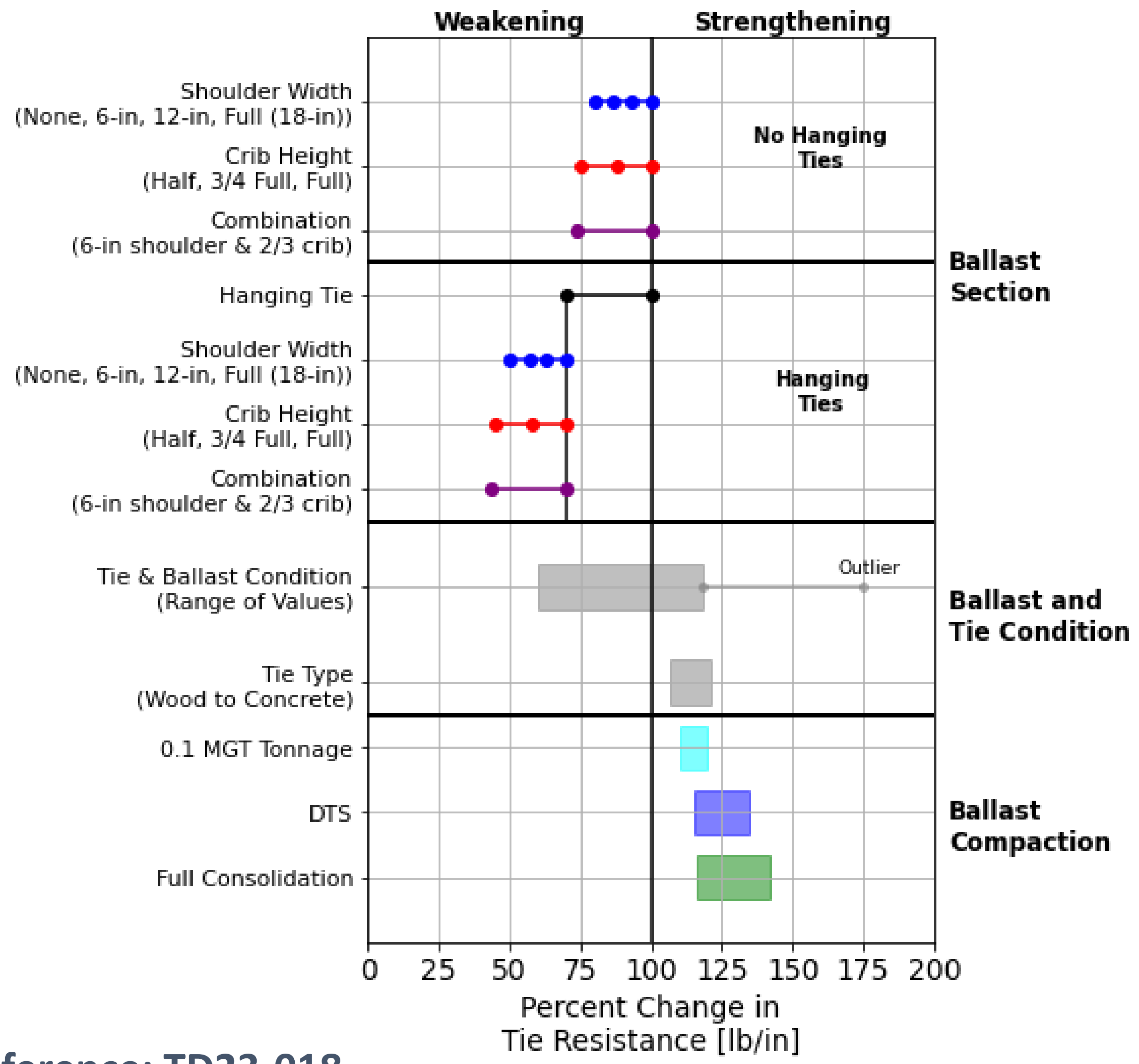


- **Theoretically lose bottom resistance**
- **Dependent on amount of vehicle type, track geometry, and number of ties**

Tie Movement

- **Longitudinal and lateral movement possible**
- **Tie movement can reduce contact between tie and ballast**

Summary of Parameters



Key Findings

- Compare influence of different parameters
- No single dominant factors
- Developed model to estimate lateral strength based on known parameters
- Estimate changes in lateral strength based on most changes in the track structure
- Inspection methods can currently measure only some of the important parameters

Reference: TD23-018

Changes to Track Structure - Maintenance

Commentary

- **Ballast maintenance often involves changing multiple factors**
- **Various examples presented**
- **Track buckle risk must also account for rail temperatures, rail neutral temperature (RNT), rotational stiffness, rail type/wear, track geometry, vehicle forces, and others**

Situation or Maintenance Method	Details	Estimated Change in Lateral Strength
Low Ballast (6″ Shoulder and Half Crib)	Add Ballast, No Compaction	Minimal
	Add Ballast, Compact	25% Increase
2-Inch Tamp Lift	2" Ballast Added	40% Reduction
	No Ballast Added	50% Reduction

Summary

- **Developed full lateral track strength compaction curve by combining new and existing datasets. This curve is a tool that can be used to understand anticipated lateral track strength at various tonnage increments.**
- **Compiled influential lateral track strength parameters and modified the model to estimate lateral strength based on parameters**
  - Can be used to estimate changes in lateral strength based on various maintenance activities
  - Can give guidance on what parameters can be measured with track-based inspection systems – only partial picture

Acknowledgements

- Class 1 railroads and Technical Advisory Groups (TAGs)
- MxV Rail Track, Instrumentation, and Engineering teams

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Machine Learning Approach to Ultrasonic A-Scans for Rail Flaw Detection

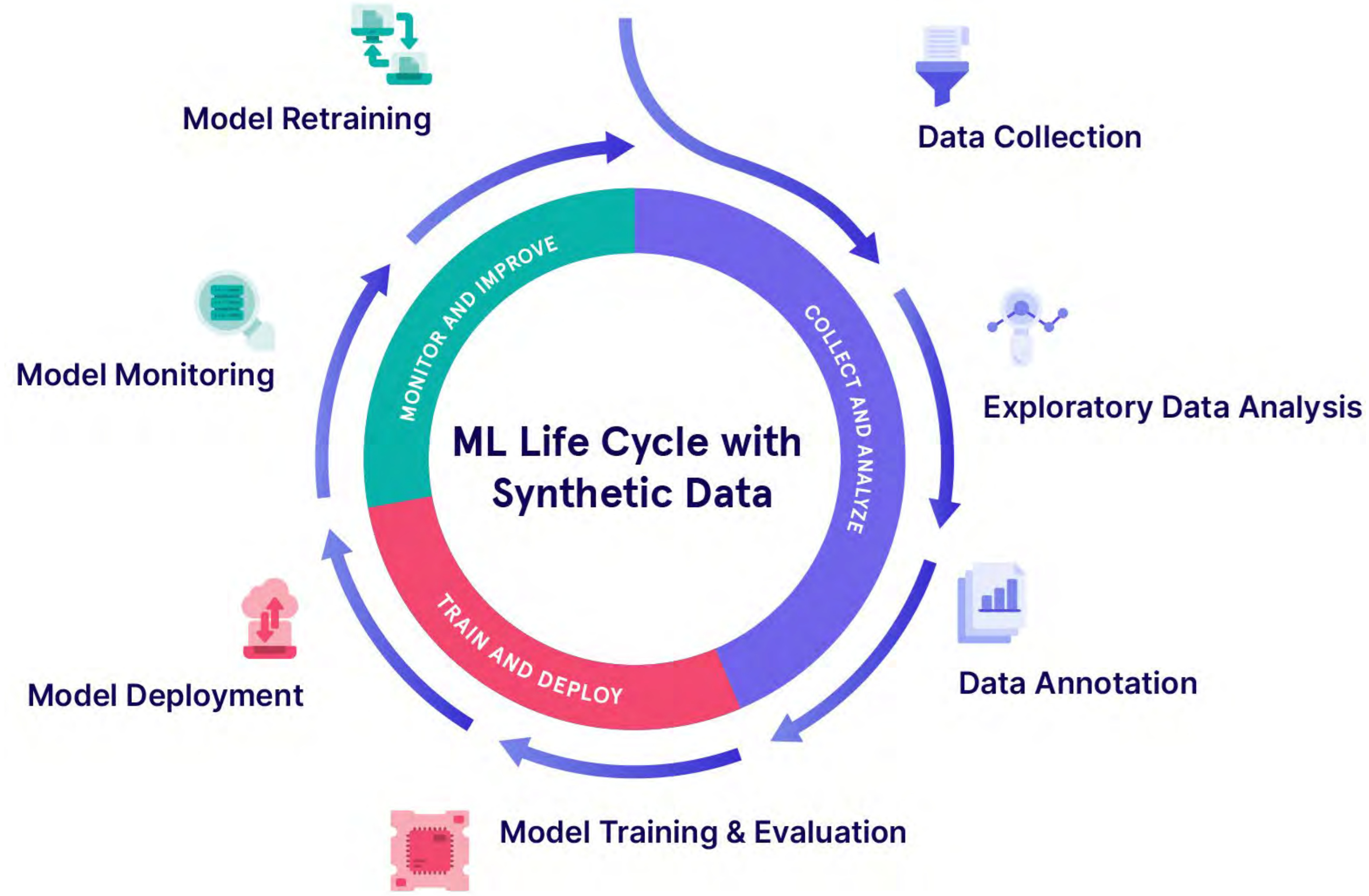
Anish Poudel, Ph.D.
Principal Investigator II

Overview

- **Machine Learning (ML)**
- **Research Motivation**
- **Rail Flaw Detection**
  - Current Approach
- **Ultrasonic A-Scan Data Library**
- **Machine Learning (ML)**
  - Baseline Model
  - Convolution Neural Networks
- **Results**
- **Path Forward**
- **Acknowledgements**

Machine Learning

- **Branch of artificial intelligence (AI)**
- **Allow computers to learn from data and past experiences, recognize patterns, and make predictions**
- **Use cases:**
  - Classification
  - Clustering
  - Regression
  - Decision-making



Typical Machine Learning Lifecycle

Source: https://gretel.ai/

29TH AAR RESEARCH REVIEW

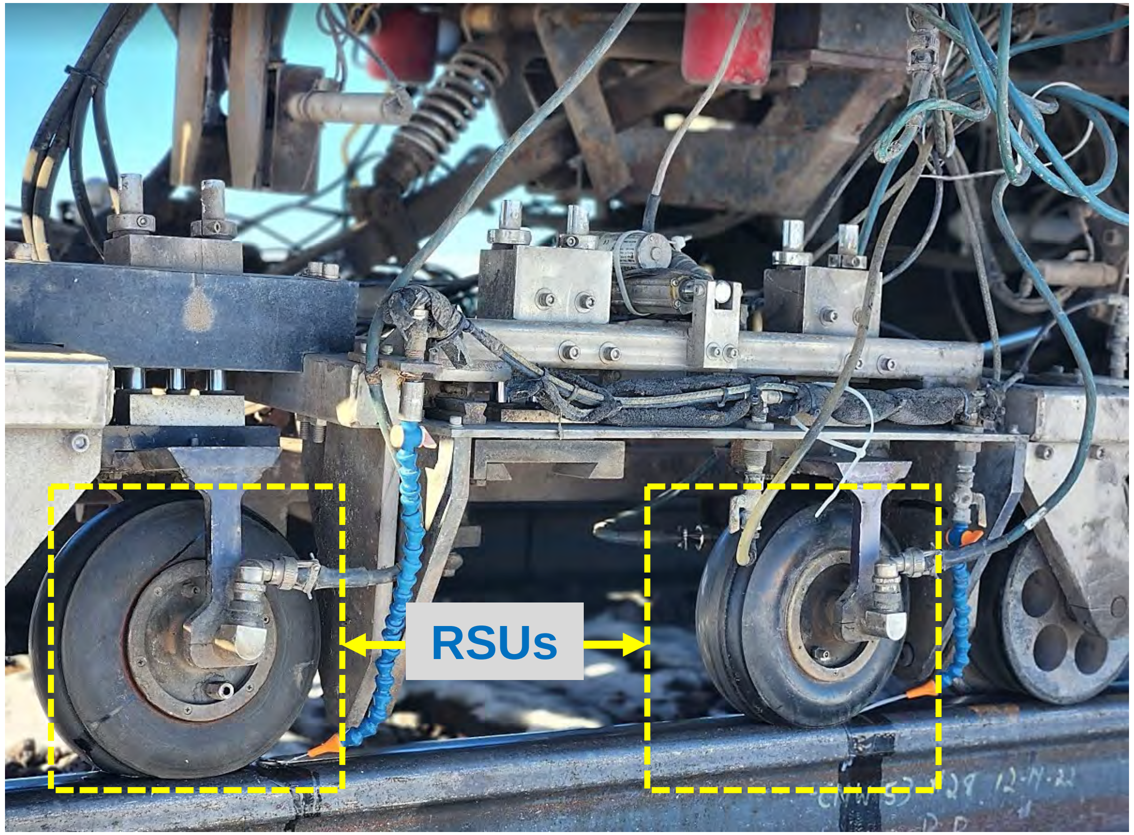
Why AI/ML for Rail Flaw Detection?

- **Safety Enhancement**
- **Increased Speed & Efficiency**
- **Advanced Data Analysis**
- **Predictive Maintenance**
- **Technological Innovation**

Rail Flaw Detection

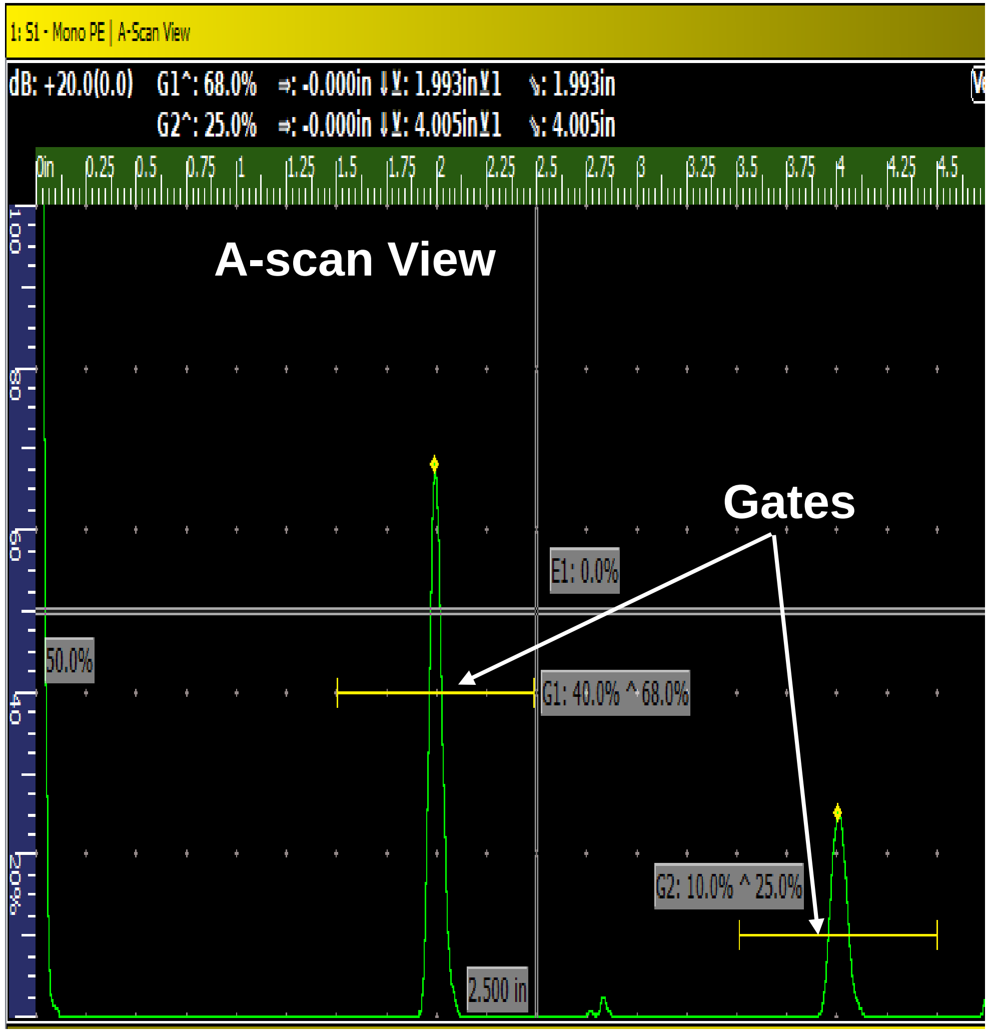
- **Rail detector cars use ultrasonic transducers housed in roller search units (RSUs) to generate and receive ultrasonic waves in the rail**

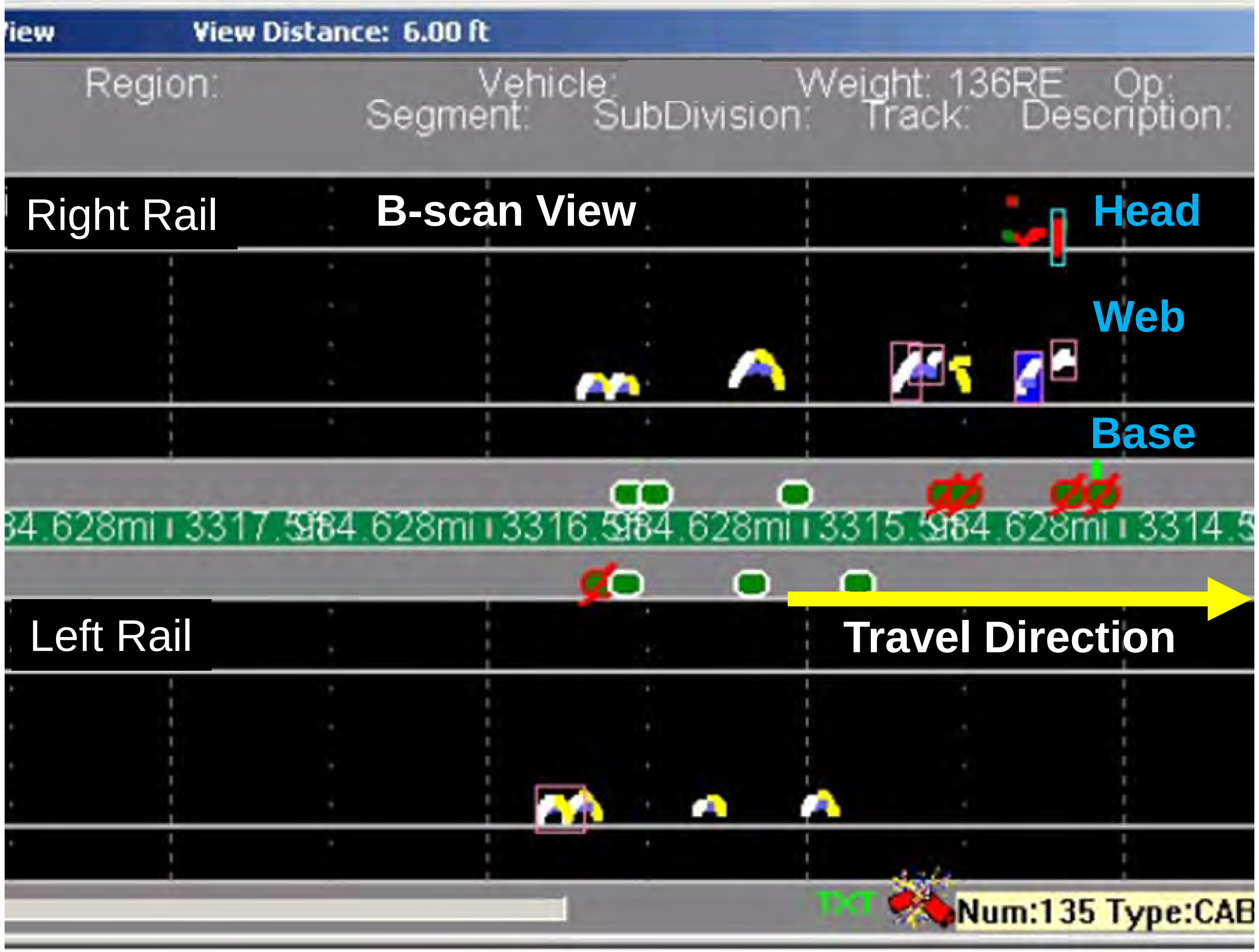
Transducer Types	Target Flaw Types
0°	Flaws oriented horizontally e.g., shells, horizontal split head (HSH), split web
37.5° or 45°	Bolt hole cracks, web defects
70°	Transverse defects (TDs) Weld defects (porosity, inclusions, etc.)
Side Looker (70°)	Vertical split heads (VSH)



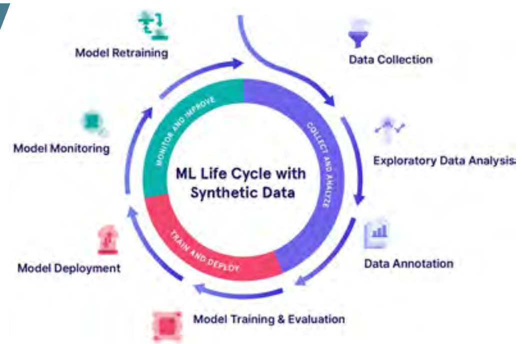
Anomaly Flagging - Current Approach

- **Utilizes B-scans and pattern recognition algorithms**



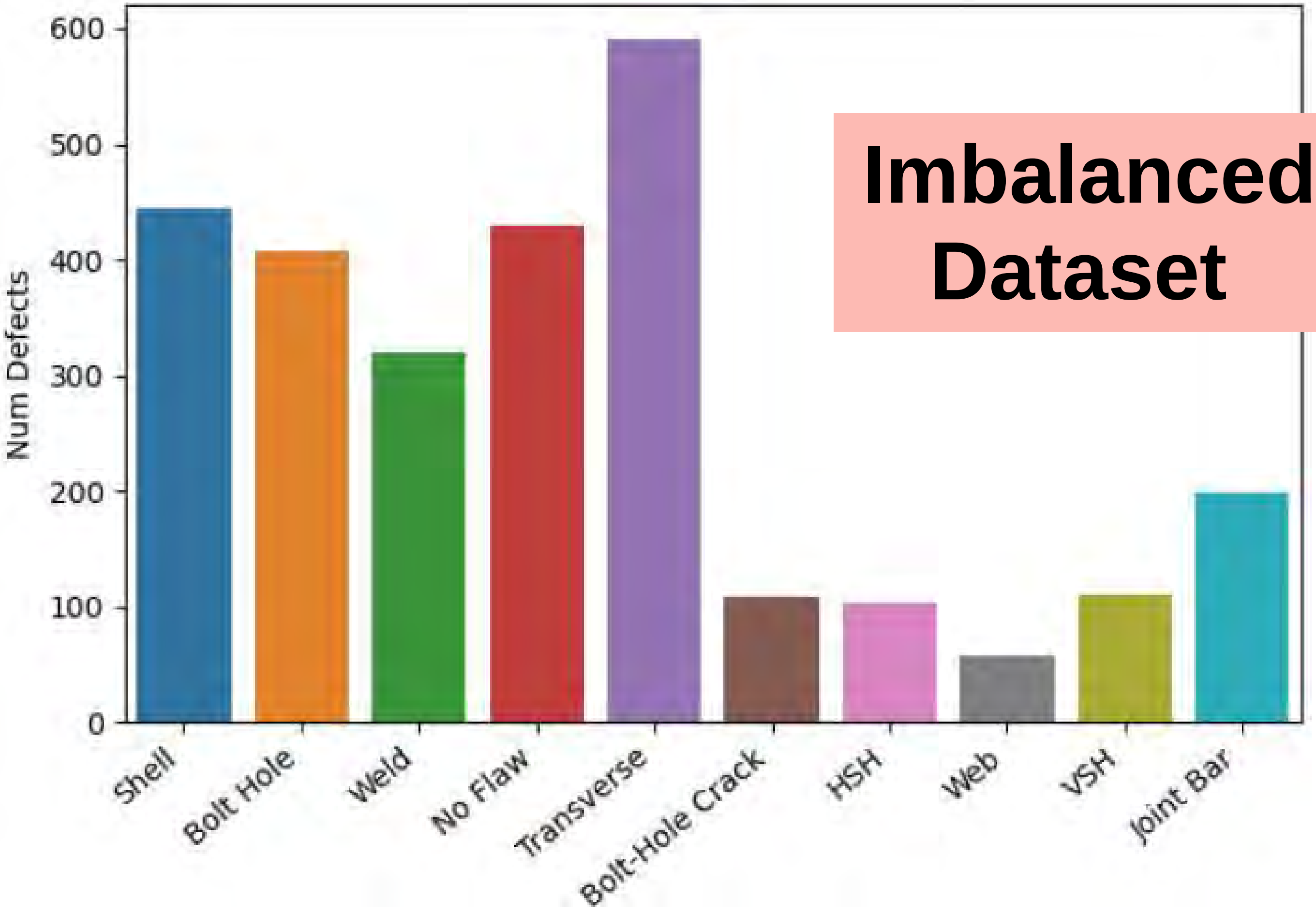


Ultrasonic A-scan Data Repository



- **2,724 unique time-encoded A-scans for 10 different features**
  – Over 207,000 frames
- **Variability**
  - Different rails
  - Three different operators
  - Different transducer angles scan data points

Rail Features	Unique Rails
Shell	28
Transverse Defect	76
BoltHole Crack	2
Horizontal Split Head	3
Web Defect	5
Vertical Split Head	10
Bolt Hole (No Flaw)	3
Weld (No Flaw)	6
Joint Bar (No Flaw)	2
No Flaw	10



Imbalanced Dataset

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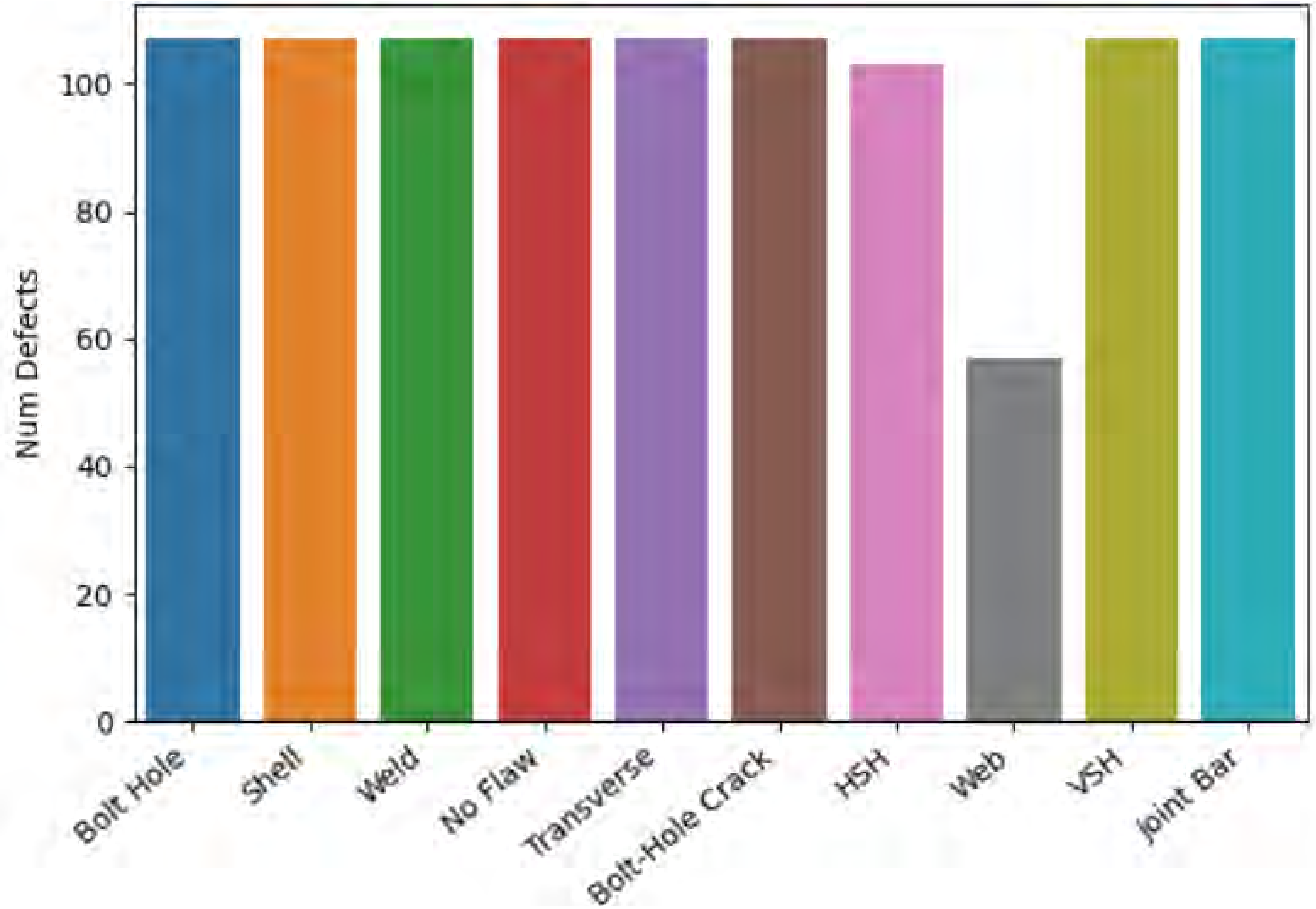
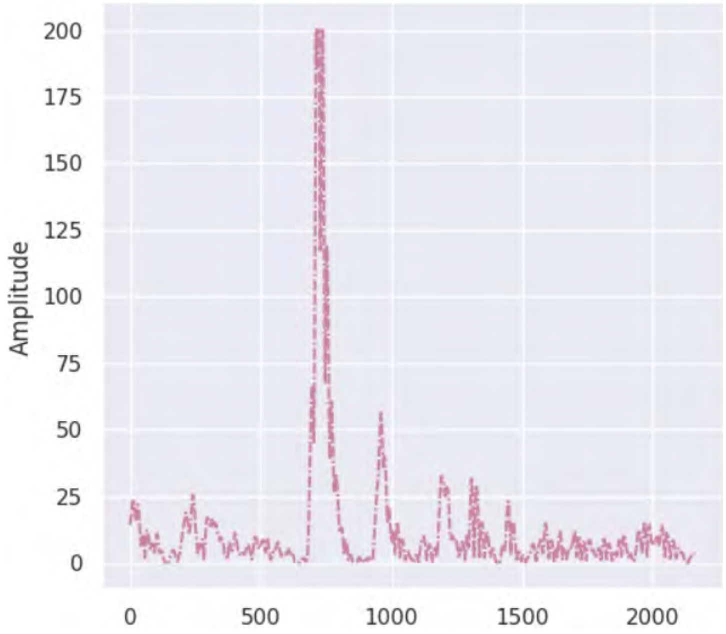
A-Scan Dataset for ML Training/ Testing

- **Reduced to 1,016 A-scans for 10 features**
- **80/20 split**
  - Training/ Validation
    - – 817 A-scan signals
  - Testing
    - – 199 A-scan signals



Baseline Model

- **Supervised learning using k-Nearest Neighbors (k-NN)**
- **Features (time/frequency domain) extracted from raw A-scans**



A-scan Signal

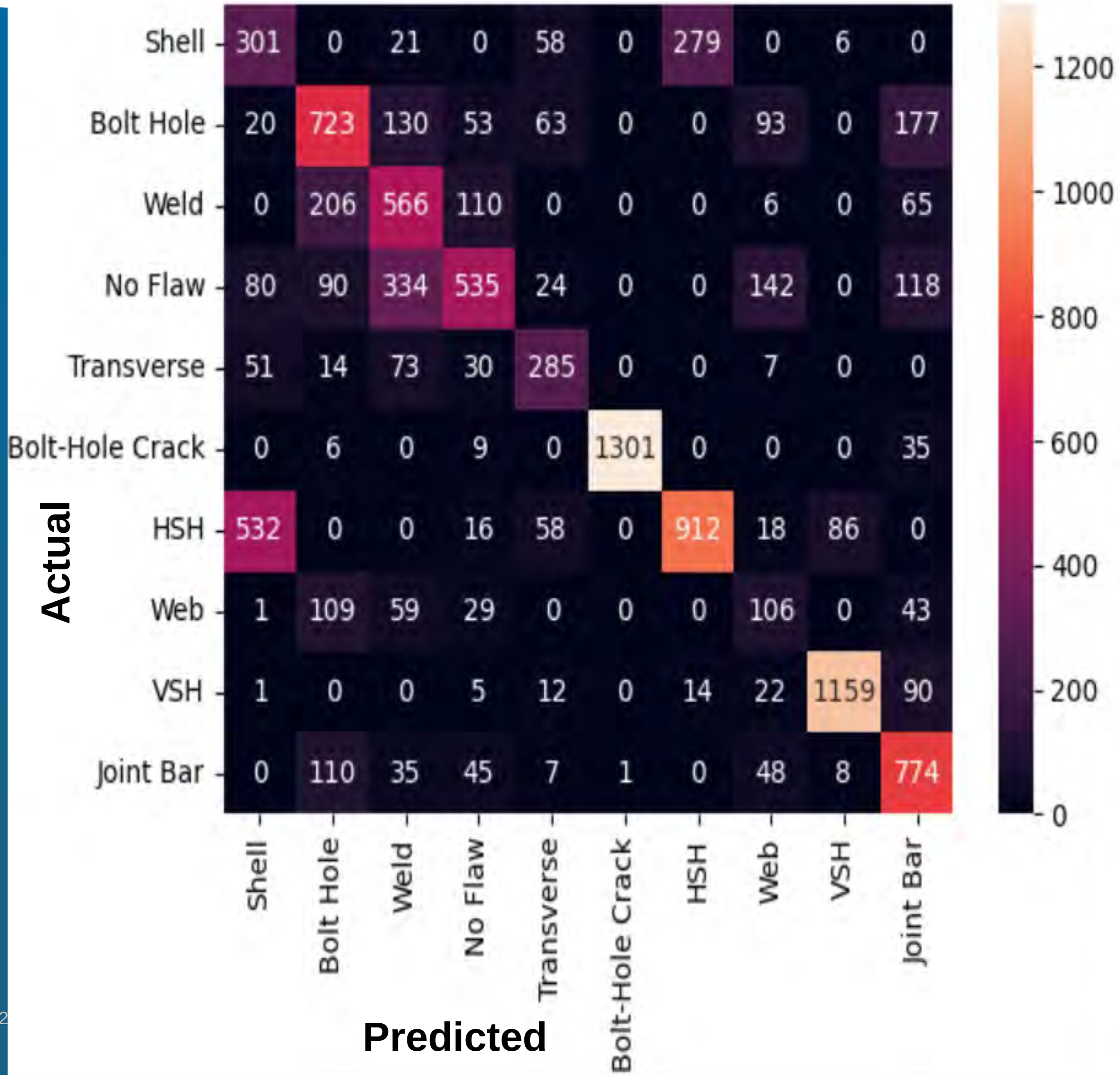
Time Domain		Frequency Domain	
MIN	CREST FACTOR	MIN	KURTOSIS
MAX	SKEW	MAX	
MEAN	KURTOSIS	MEAN	
RMS	POWER	PEAK	
VAR	PEAK	VAR	
STD	P2P	SKEW	

Features Extracted from A-scan Signals

Baseline Model Results

29TH AAR RESEARCH REVIEW

Confusion Matrix

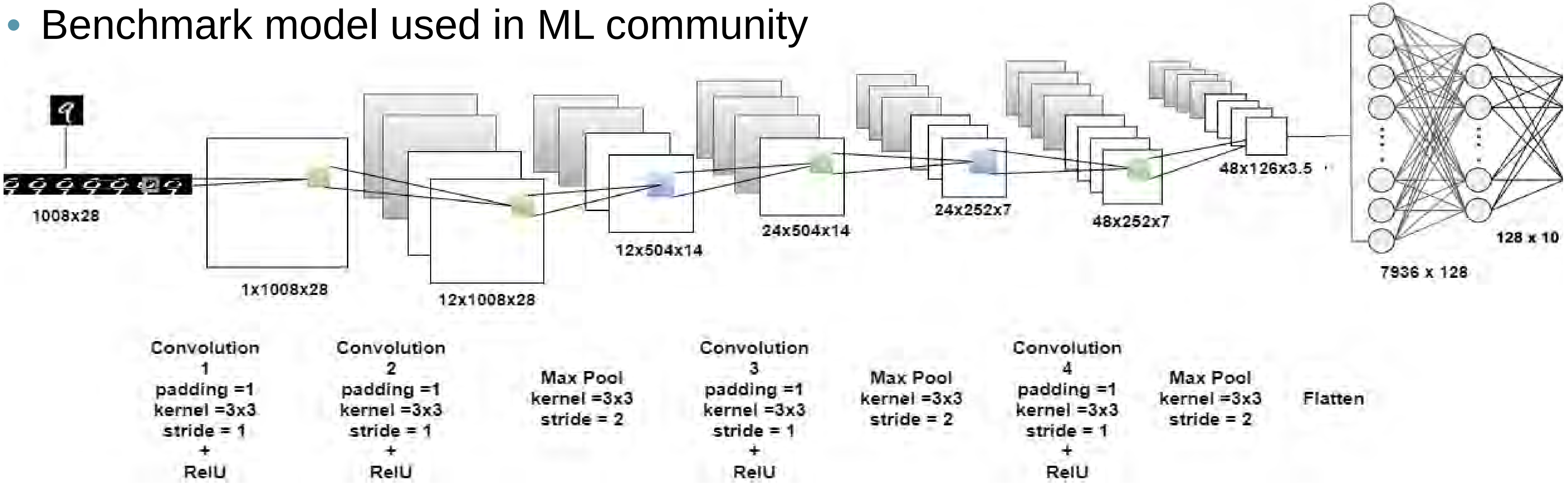


Classification Accuracy

Class Feature	Precision	Recall	F1-Score	Support
Shell	0.31	0.45	0.36	1258
Bolt Hole (No Flaw)	0.57	0.57	0.57	1302
Weld (No Flaw)	0.46	0.59	0.52	1205
No Flaw	0.64	0.40	0.50	1302
Transverse Defect	0.56	0.62	0.59	832
Bolt-Hole Crack	1.00	0.96	0.98	986
HSH	0.76	0.56	0.65	507
Web Defect	0.24	0.31	0.27	1259
VSH	0.92	0.89	0.90	442
Joint Bar (No Flaw)	0.59	0.75	0.66	1218
Accuracy			0.65	10311
Macro Average	0.61	0.61	0.60	10311
Weighted Average	0.67	0.65	0.65	10311

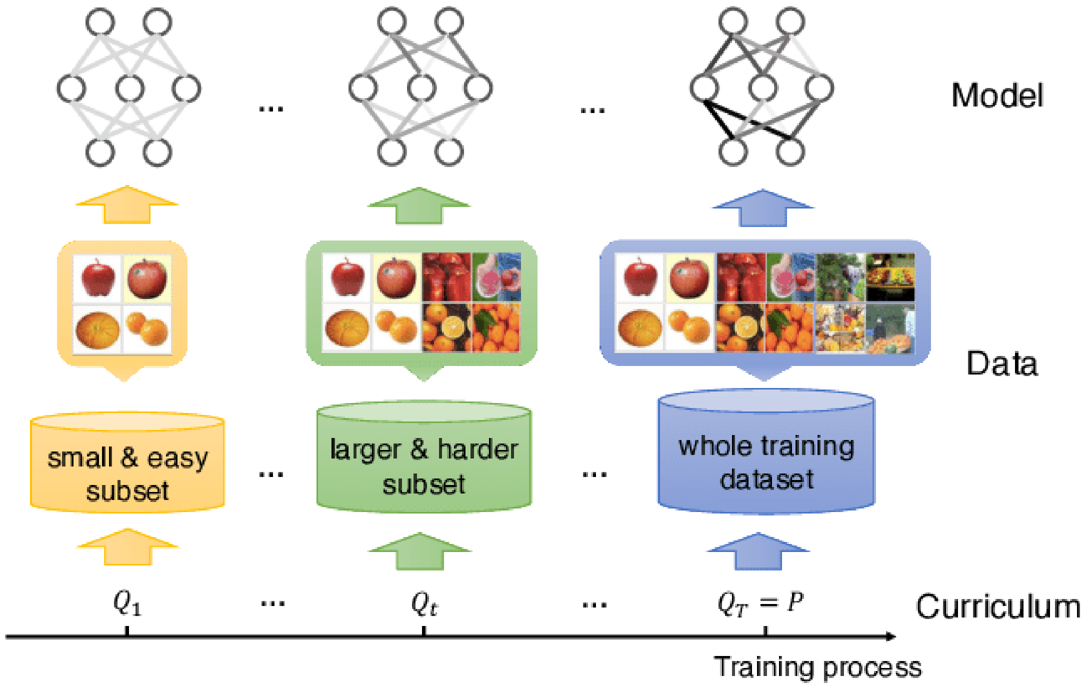
Convolution Neural Networks (CNNs)

- **CNN is a regularized type of feed-forward artificial neural network (ANN) or a deep learning algorithm in a way that is inspired by the human brain that learns feature engineering by itself via filters optimization**
  - Modified National Institute of Standards and Technology (MNIST) architecture was used for model training
    - Benchmark model used in ML community

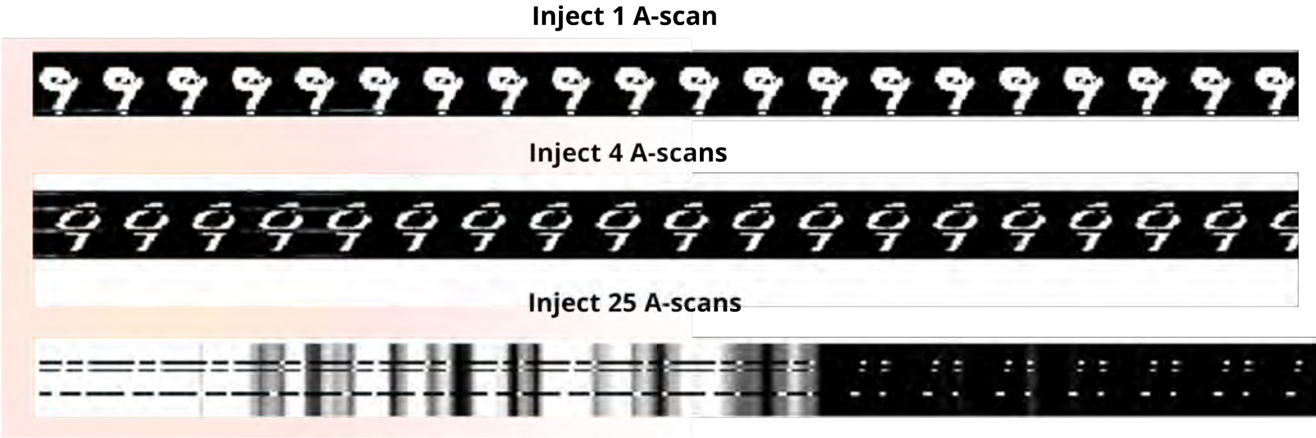


Curriculum Learning

- **Curriculum learning involves gradually increasing the difficulty of the training examples presented to a machine learning model**
  - Blend two datasets: rail UT A-scan data and modified MNIST images, to enhance the model's performance
  - Introduce a frame-by-frame process, where we extracted a frame from random defect example and inject it into the modified MNIST data
  - This progressive approach increased the difficulty level over time, training the model to better detect railway defects



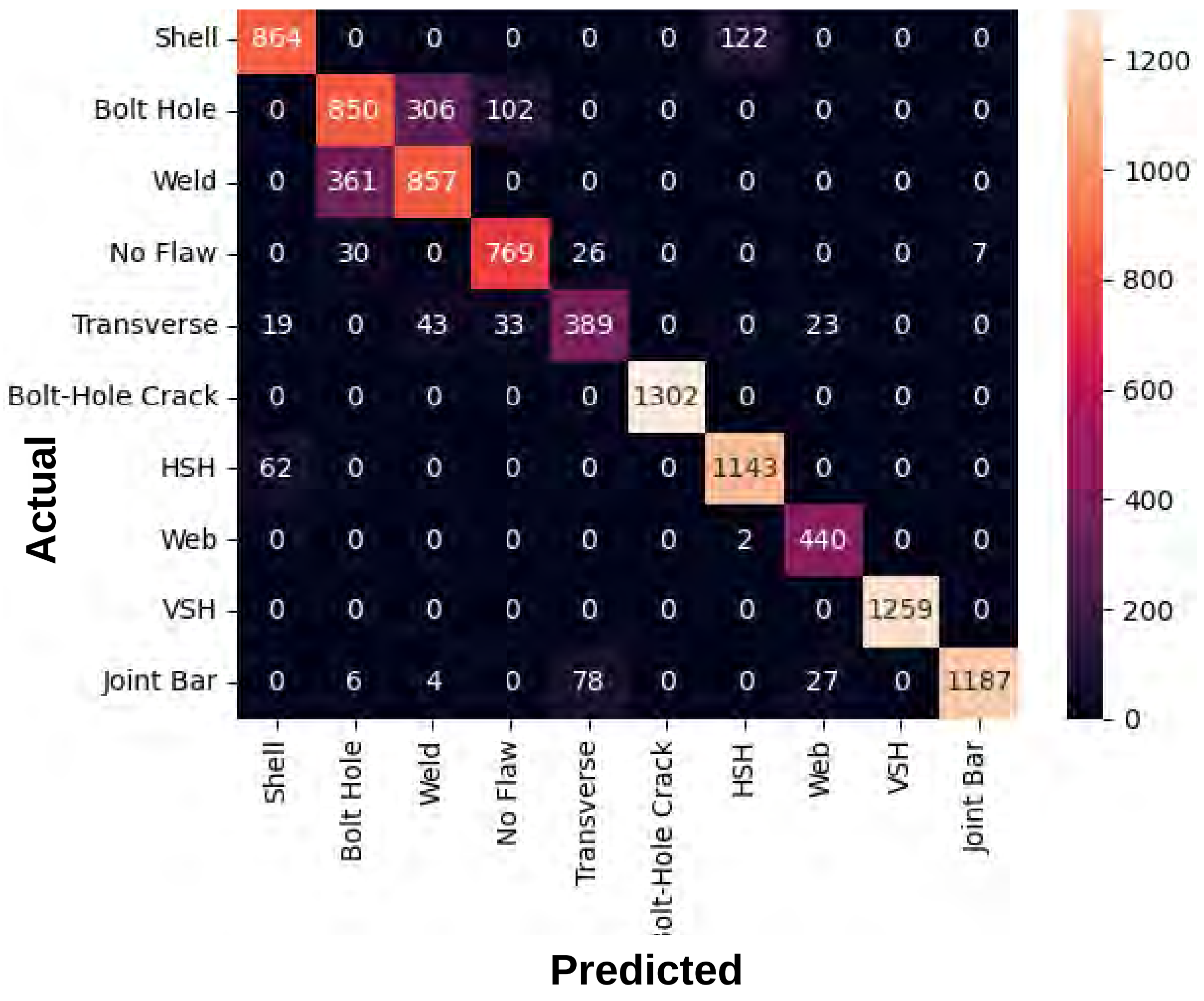
Curriculum Learning (CL) concept*



Modified MNIST Image Injected with A-Scans

**Wang, X. and Chen, Y., 2021, "A Survey on Curriculum Learning, IEEE Transaction on Pattern Analysis and Machine Intelligence, pp. 1-20*

CNN Results



Confusion Matrix

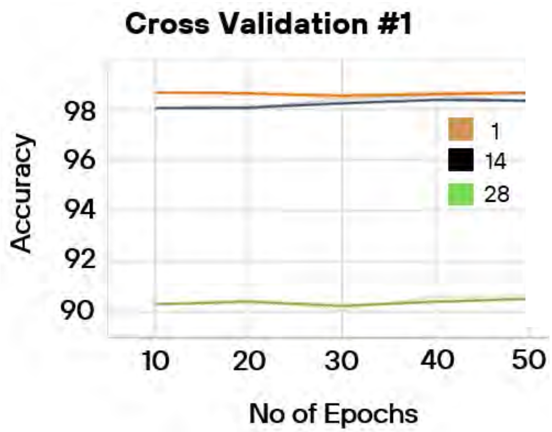
Class Feature	Precision	Recall	F1-Score	Support
Shell	0.91	0.88	0.89	986
Bolt Hole (No Flaw)	0.68	0.68	0.68	1258
Weld (No Flaw)	0.71	0.70	0.71	1218
No Flaw	0.85	0.92	0.89	832
Transverse Defect	0.79	0.77	0.78	507
Bolt-Hole Crack	1.00	1.00	1.00	1302
HSH	0.90	0.95	0.92	1205
Web Defect	0.90	1.00	0.94	442
VSH	1.00	1.00	1.00	1259
Joint Bar (No Flaw)	0.99	0.91	0.95	1302
Accuracy			0.88	10311
Macro Average	0.87	0.88	0.88	10311
Weighted Average	0.88	0.88	0.88	10311

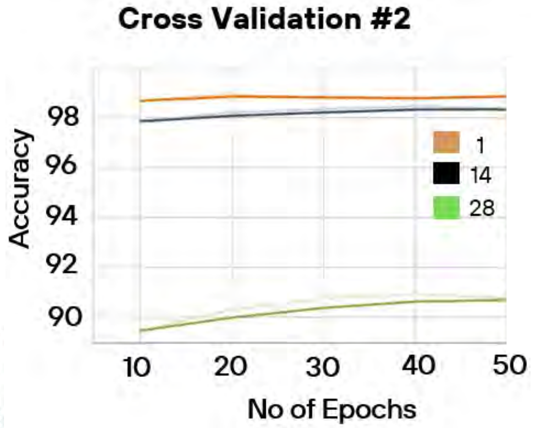
Classification Accuracy

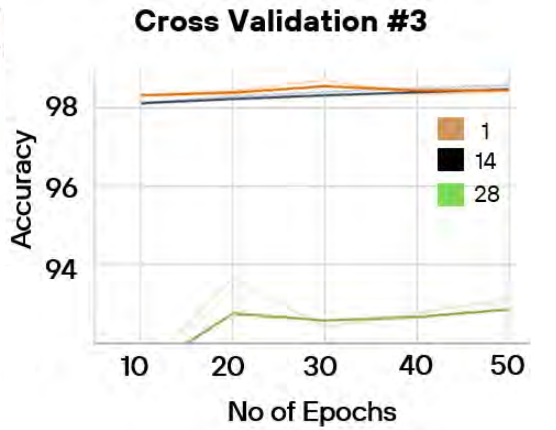
29TH AAR RESEARCH REVIEW

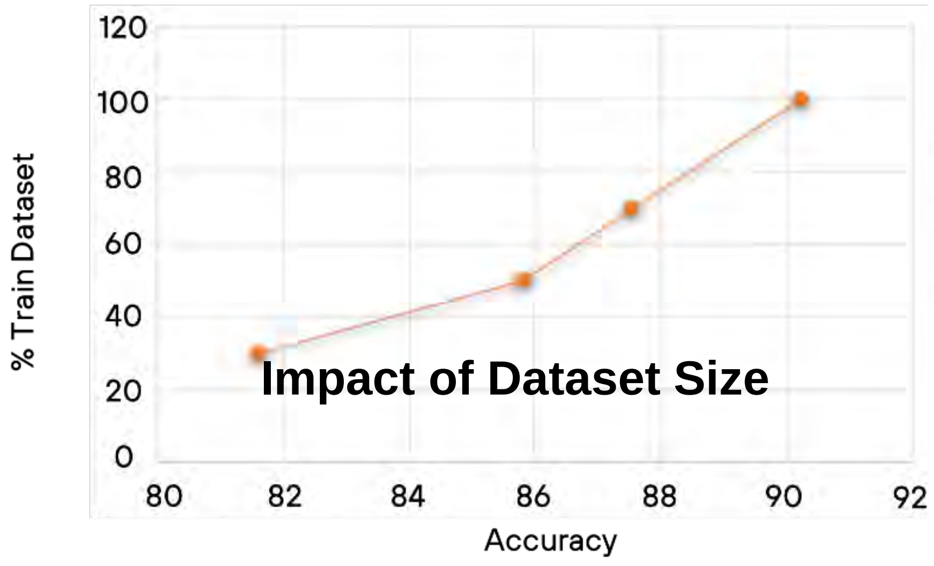
Ablation Studies

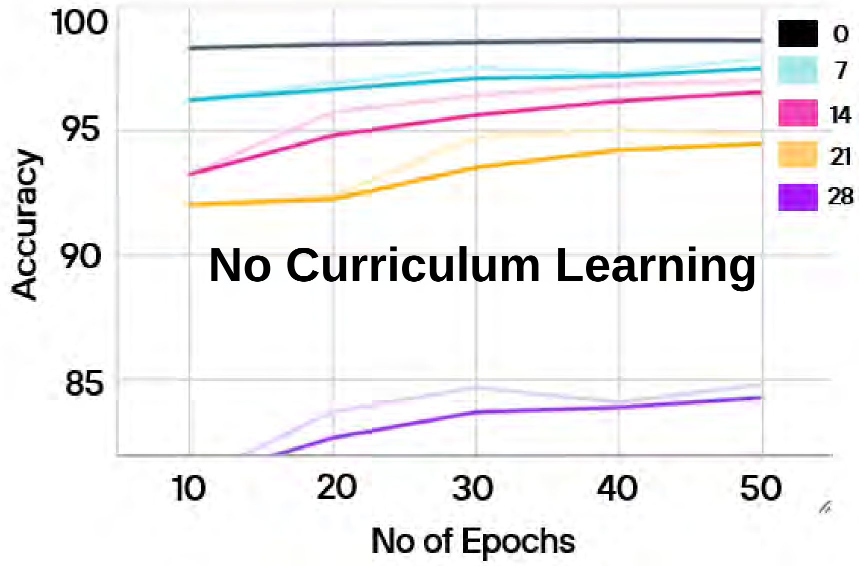
- **Three-Fold Cross Validation**
  - Model achieved accuracy levels above 98% when injected with 1 or 14 A-scan signals but dropped to 91% when injected with 28 A-scan signals
- **Impact of Dataset Size**
  - Model accuracy increased when trained with larger dataset
- **Impact of Curriculum Learning (CL)**
  - Model accuracy was dropped when trained without using CL





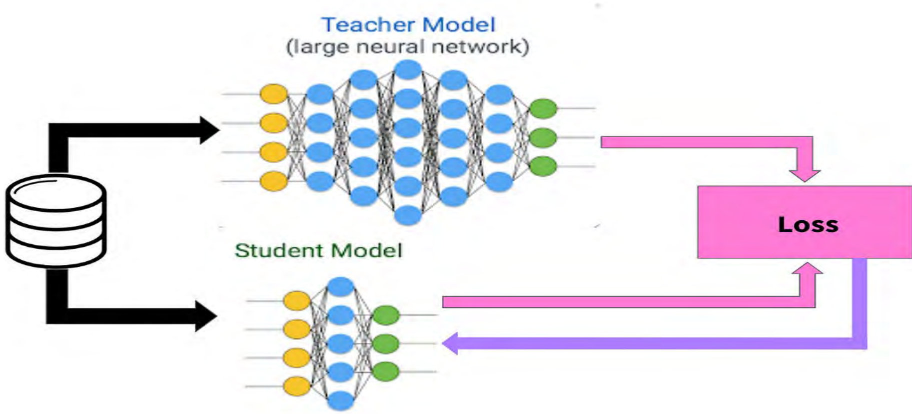


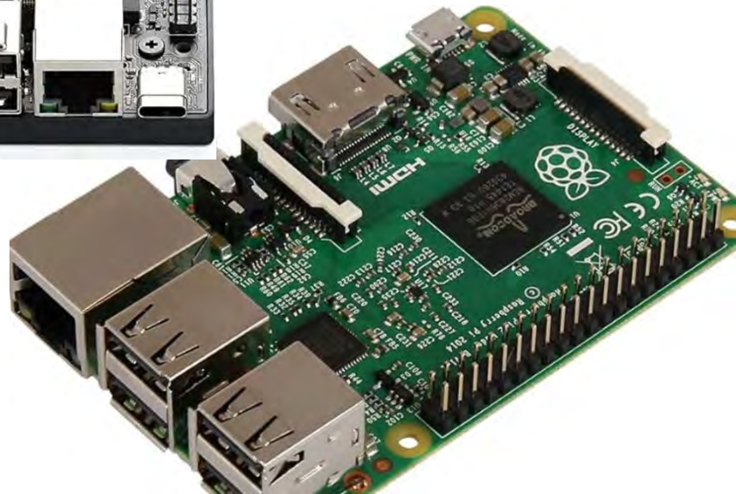




Path Forward – Edge Computing

- **Smaller network**
  - Less computational resources and can be trained faster
  - Enables faster inference
- **Pruning and compiling**
  - Pruning: Removing unused nodes
  - Compiling: Converting floating-point numbers to integers
- **Edge inference**
  - Uses Edge Graphics Processing Unit (GPU)
- **MxV Rail's role**
  - Advance technology; No product development





Acknowledgements

- **MxV Rail Team**
  - Survesh Shrestha
  - Brian Lindeman
  - John Krasovic
- **Project JeZero Team**
- **AAR SRI Program**
- **AAR Research Committee**

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29TH ANNUAL Association of American Railroads RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS | MxV RAIL

Wednesday, April 24, 2024 –Technical Sessions – Mechanical

MECHANICAL 1:

Draft Systems Research

Bearing Performance and Integrity

EMAT Wheel Inspection Update

Adam Klopp
Principal Investigator II, MxV Rail

Matt Wenger
Senior Engineer III – VTI, MxV Rail

Anish Poudel, Ph.D.
Principal Investigator II, MxV Rail

MECHANICAL 2:

Brake Systems Research

Wheel Performance and Integrity

Measuring Wheel Impact Loads

Yi Wang
Principal Investigator I, MxV Rail

Kerry Jones, P.E.
Principal Investigator II, MxV Rail

Nate Stoehr
Principal Systems Engineer I

Draft Systems Research

Adam Klopp
Principal Investigator II

29TH AAR RESEARCH REVIEW

Overview

- **Project Objectives**
- **Background**
- **Draft System Evaluations**
- **Damage Prevention Impact Tests**
- **Concluding Remarks**

29TH AAR RESEARCH REVIEW

Project Objectives

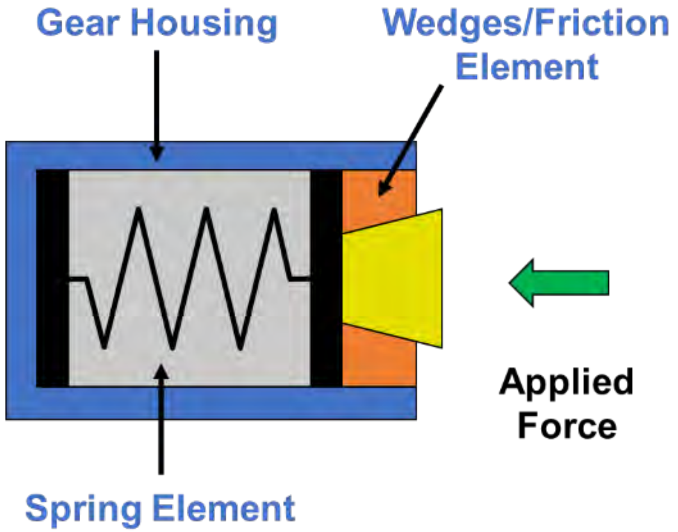
- **Improve draft system performance**
  - Impact protection
  - Train action control
  - Limit in-train forces

- **Reduce service disruptions from:**
  - Component failures
  - Broken knuckles
  - Train separations

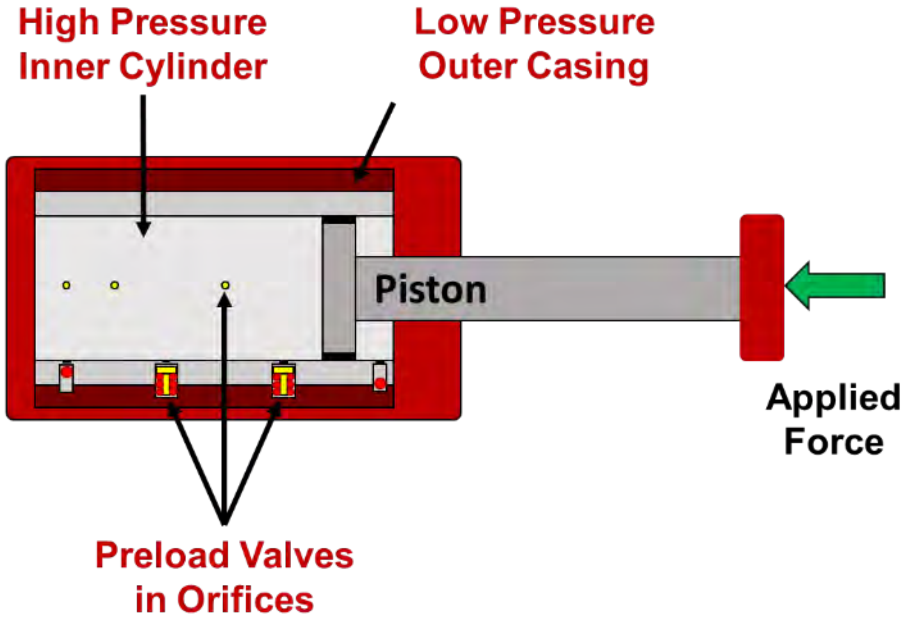
Background

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

Friction Draft Gear



EOCC Unit

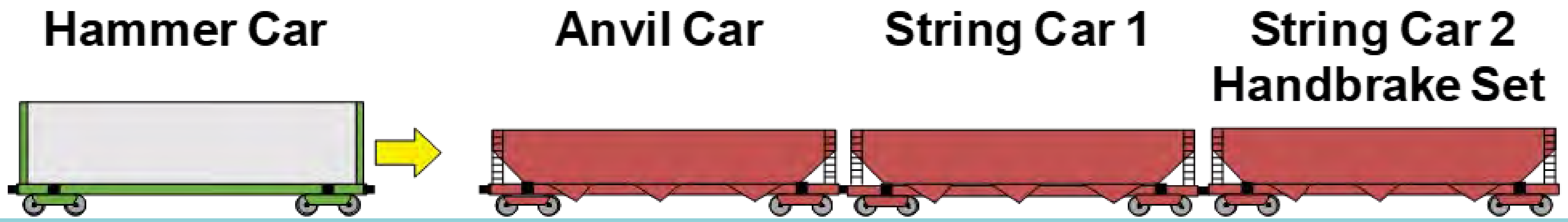


29TH AAR RESEARCH REVIEW

Draft System Evaluations

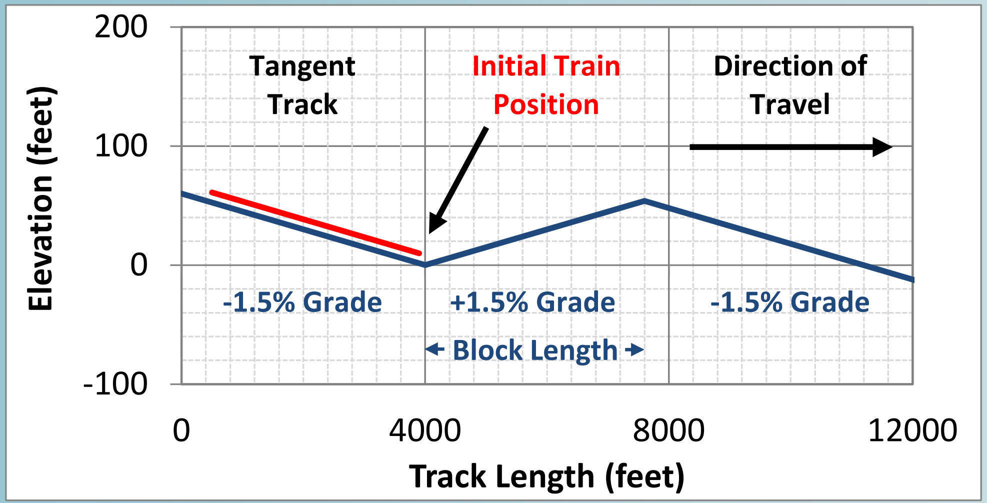
- **Historically done in North America through car-to-car impact tests or drop hammer tests**
  - Good for evaluating impact protection and energy absorption
  - Not good indicators of in-train performance and slack control
- **Working with EOC Energy Management Task Force to update standards using testing and simulations**

M-921B Impact Performance Test Setup

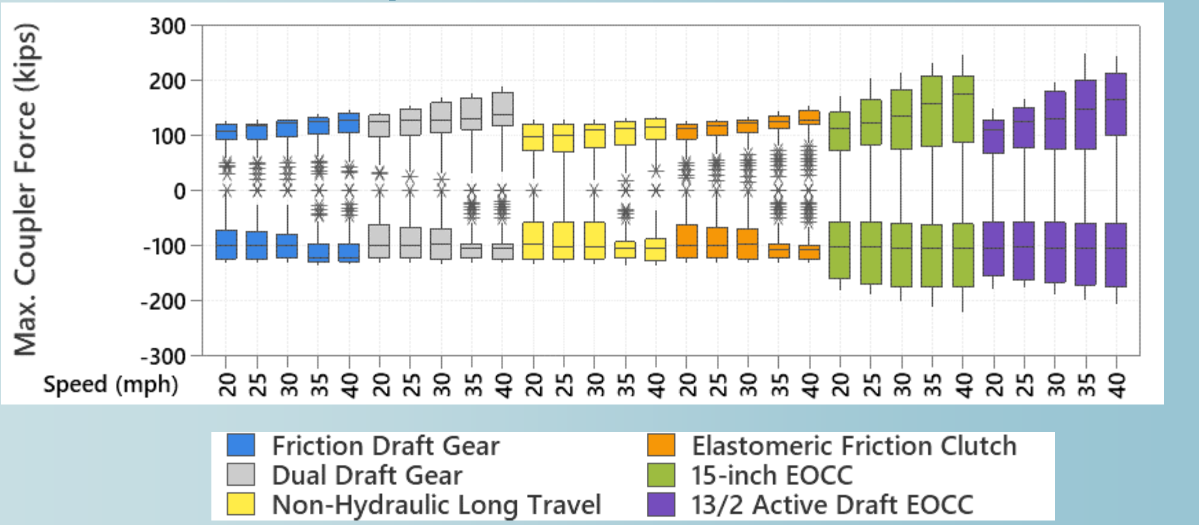


Draft System Evaluations

Drift Simulation Setup



Example Drift Simulation Results



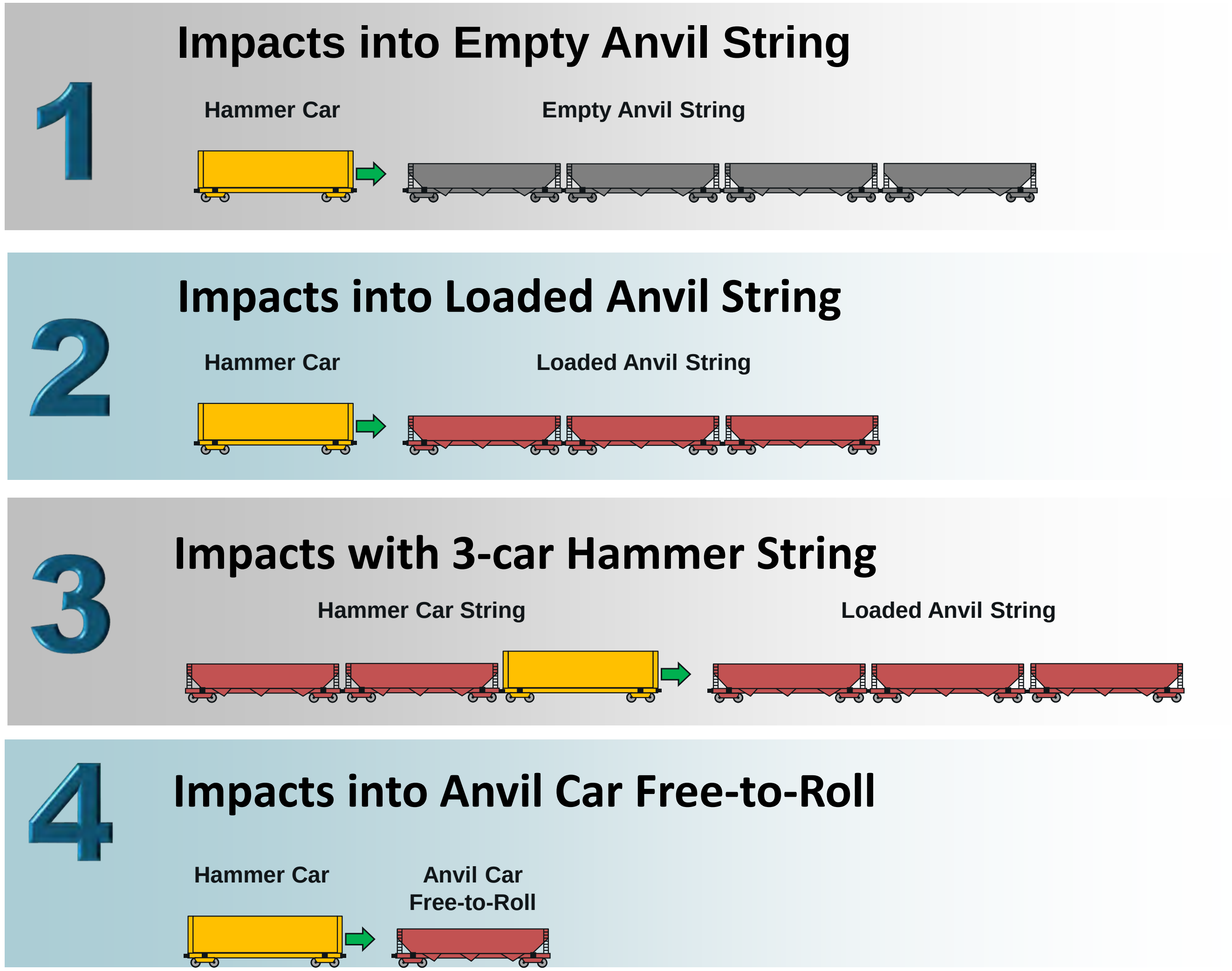
- **Support EOC Energy Management Task Force in draft system evaluation updates**
  - Supplement current impact tests with train action modeling
  - Update standards to accommodate new draft system types

Damage Prevention Impact Tests

- **Collaborating with Damage Prevention and Loading Services (DP&LS) group to conduct live load impact tests**
- **Support the evaluation and modernization of current Closed Car Loading and Open Top Loading Rules (OTLR)**
- **Characterize the current impact environment experienced by cars**
- **Evaluate the freight effects and performance of different draft systems**
  - Phase 1: Boxcar with 15” EOCC units
  - Phase 2: Boxcar with hybrid units
  - Phase 3: Boxcar with draft gears

Impact Test Setup

- **60-foot boxcar equipped with 15-inch EOCC, loaded with paper rolls**
- **Measurements included:**
  - Car speed
  - Coupler force and displacement
  - Carbody accelerations
  - Paper roll accelerations



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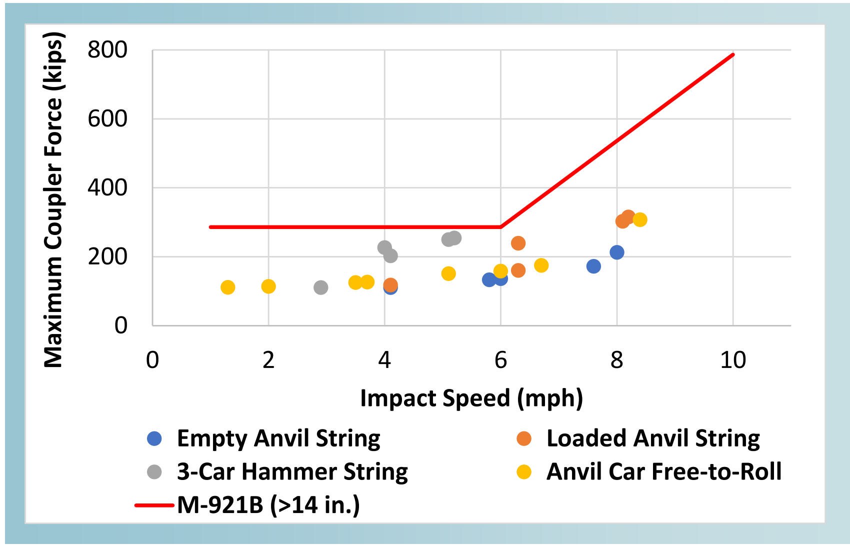
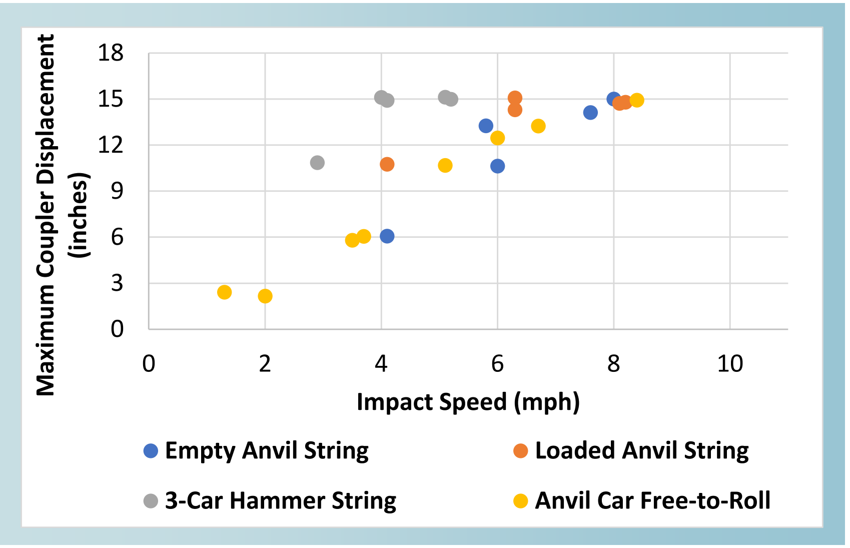
Impact Test Results



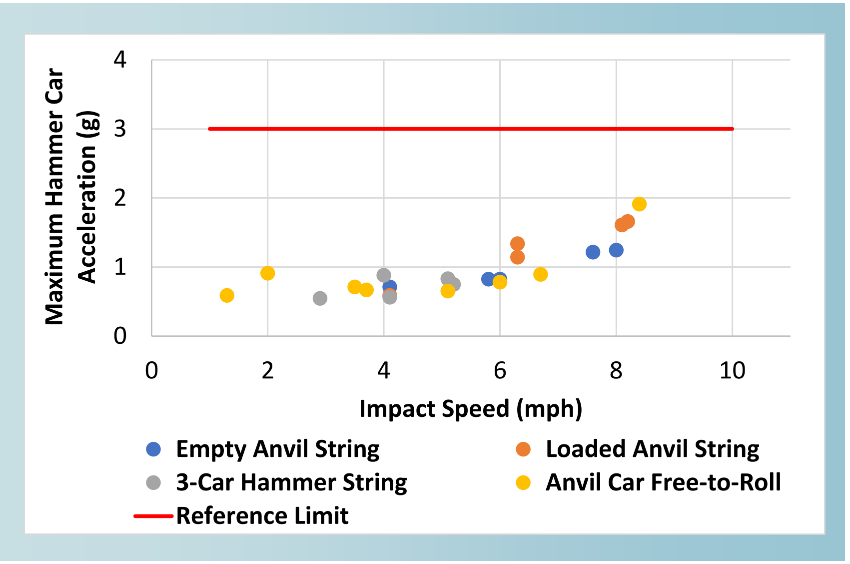


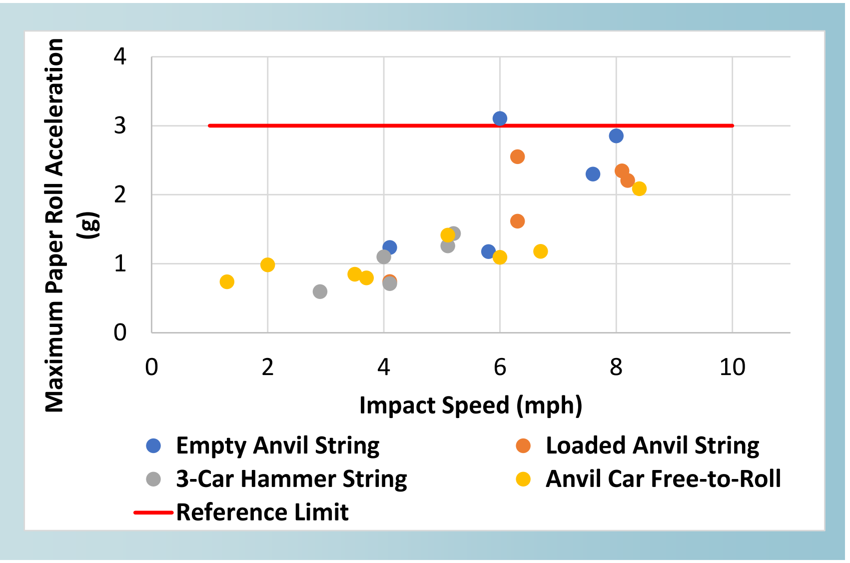
- **Maximum forces below M-921B limits for tested impact speeds**
- **Similar forces, displacements for impacts into the empty, loaded, and free-to-roll anvils**
- **For three-car hammer string, EOCC units used all the available strokes at 4 mph**
  - Higher forces at lower speeds
  - Due to increased mass of the moving hammer string

29TH AAR RESEARCH REVIEW

Impact Test Results

- **Maximum hammer car accelerations all below 3g**
  - Differences in values at 8 mph for impacts into the empty, loaded, and free-to-roll anvils
  - Lower accelerations with three-car hammer string due to smaller change in velocity for larger mass
- **Paper roll accelerations higher for impacts to the empty and loaded anvil strings**





Freight Observations

- **Load rebuilt after each test scenario**
  - Early signs of damage increased with impacts
  - Load shifts and voids opened
- **Rolls with issues were documented and moved to less susceptible locations**

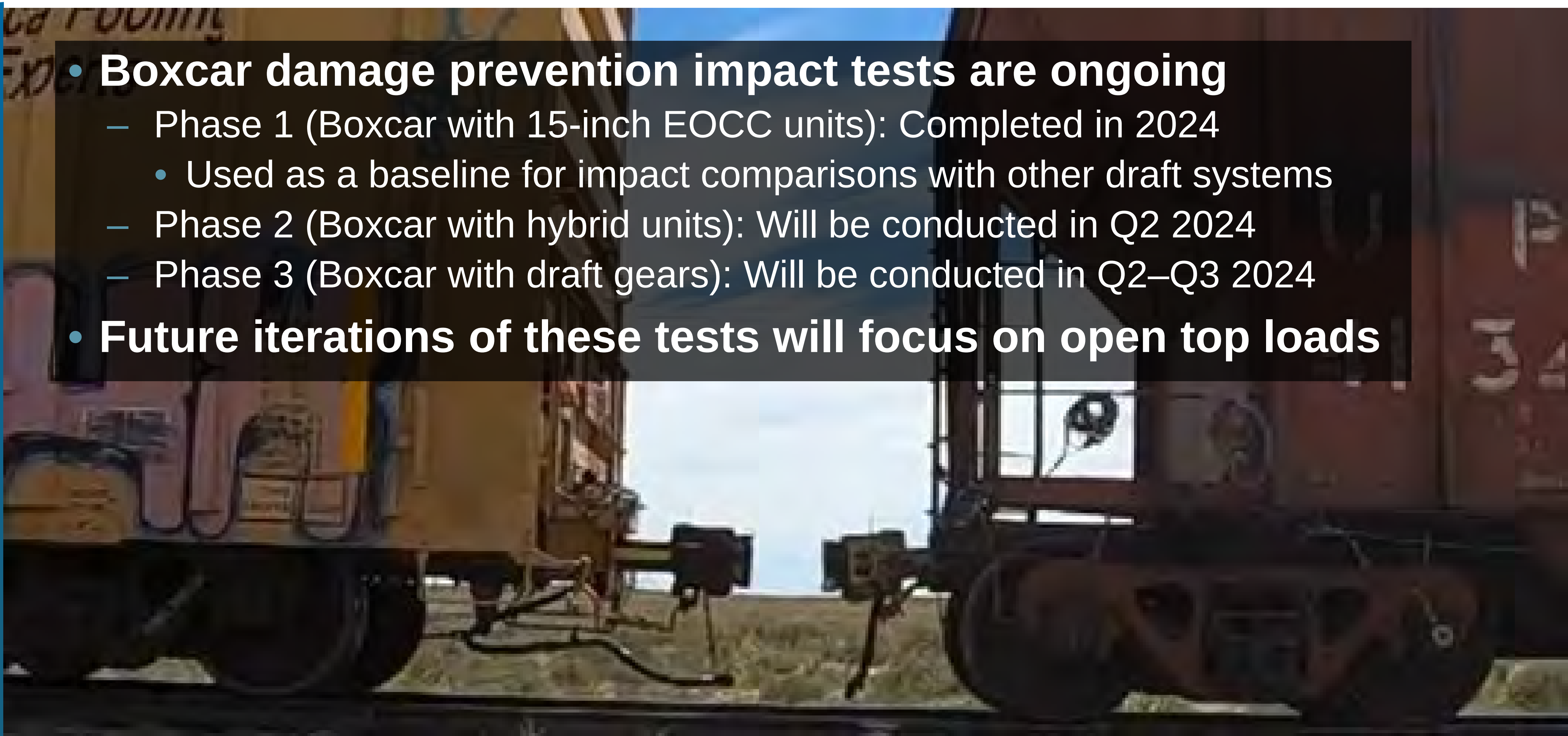
Void opening between rolls

Crushed core

Movement into the doorway area

Continuing Impact Tests

- **Boxcar damage prevention impact tests are ongoing**
  - Phase 1 (Boxcar with 15-inch EOCC units): Completed in 2024
    - Used as a baseline for impact comparisons with other draft systems
  - Phase 2 (Boxcar with hybrid units): Will be conducted in Q2 2024
  - Phase 3 (Boxcar with draft gears): Will be conducted in Q2–Q3 2024
- **Future iterations of these tests will focus on open top loads**



Summary

- **MxV Rail is working with the EOC Energy Management Task Force to update draft system standards**
  - Supplement current impact tests with train action modeling
  - Update standards to accommodate new draft system types
- **First phase of live load boxcar impact tests with DP&LS group completed**
  - Evaluate current Closed Car Loading rules and OTLR
  - Characterize the current impact environment

Acknowledgements

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- TTX Company
- Union Pacific Railroad
- EOC Energy Management Task Force
- MxV Rail Staff

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Bearing Performance and Integrity

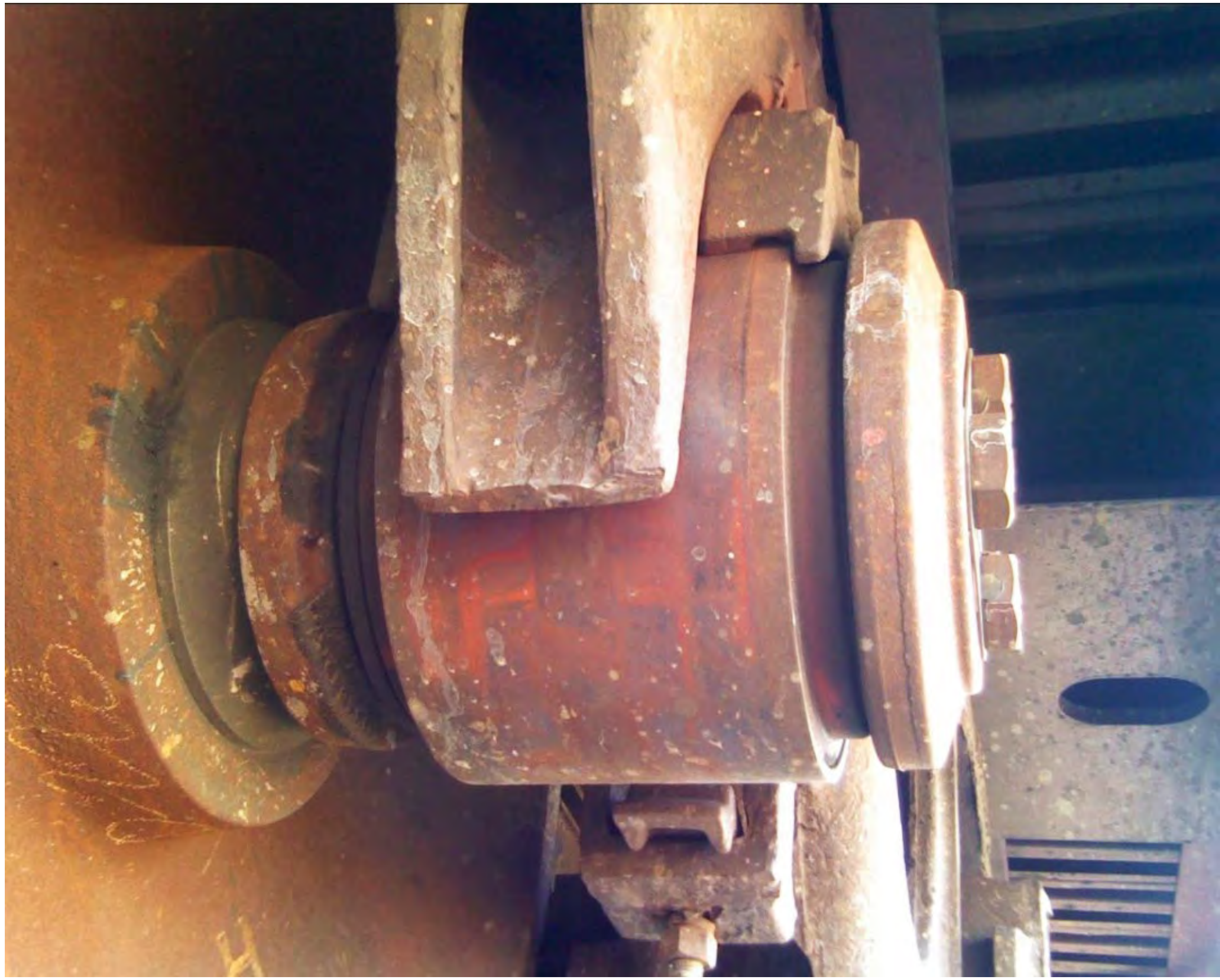
Matt Wenger
Senior Engineer III – VTI

Overview

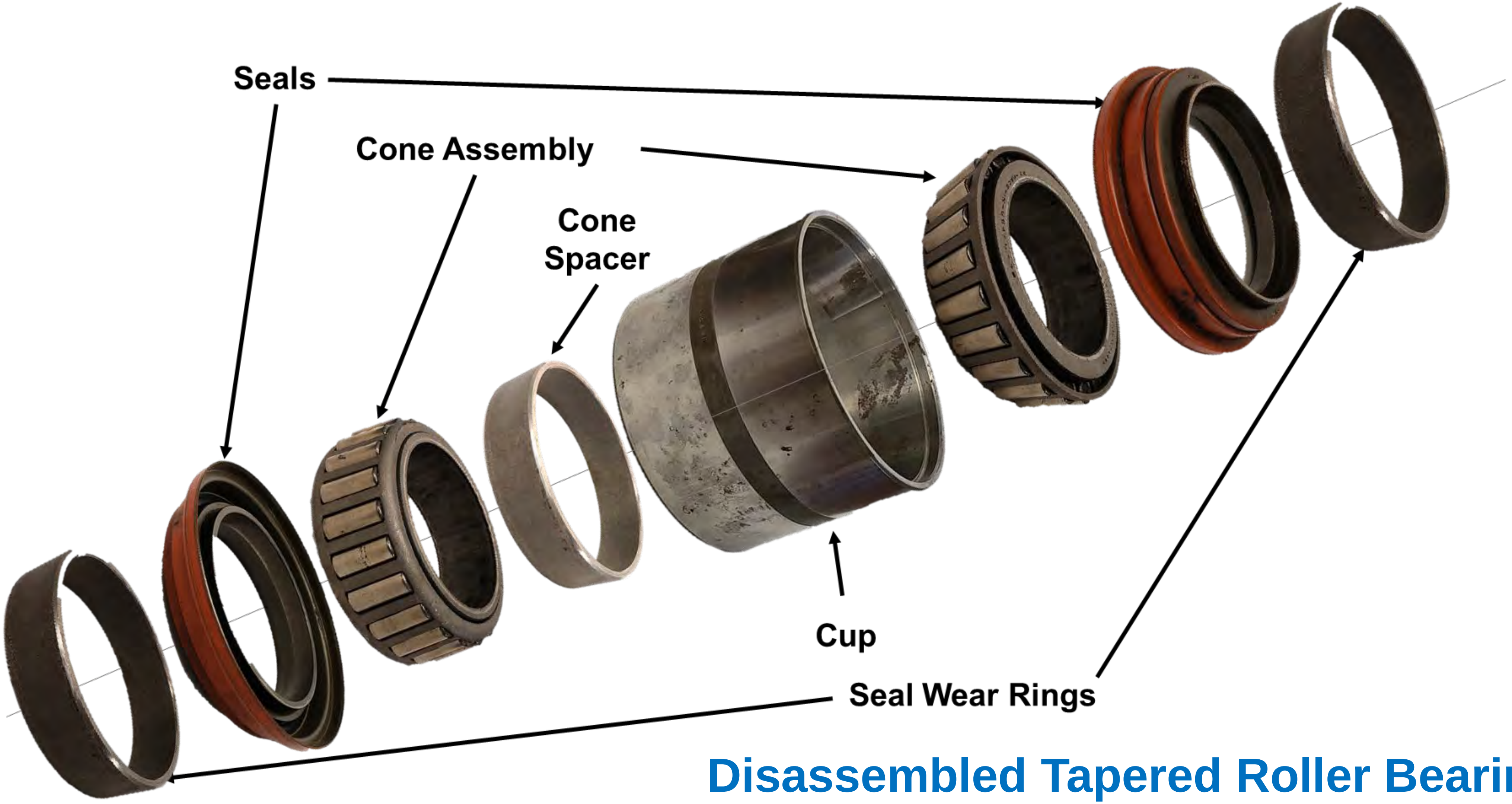
- Project Objectives
- Review of the Reconditioning Process
- Nondestructive Evaluation (NDE) Technology for Bearing Inspection
- Rig Testing: Water Etched Cups
- Additional Research: Grease Analysis

Project Motivation

- **Improve the safety and reliability of bearings**
- **Evaluate methods to improve the reconditioning process**
- **Investigate the root causes of bearing performance degradation**



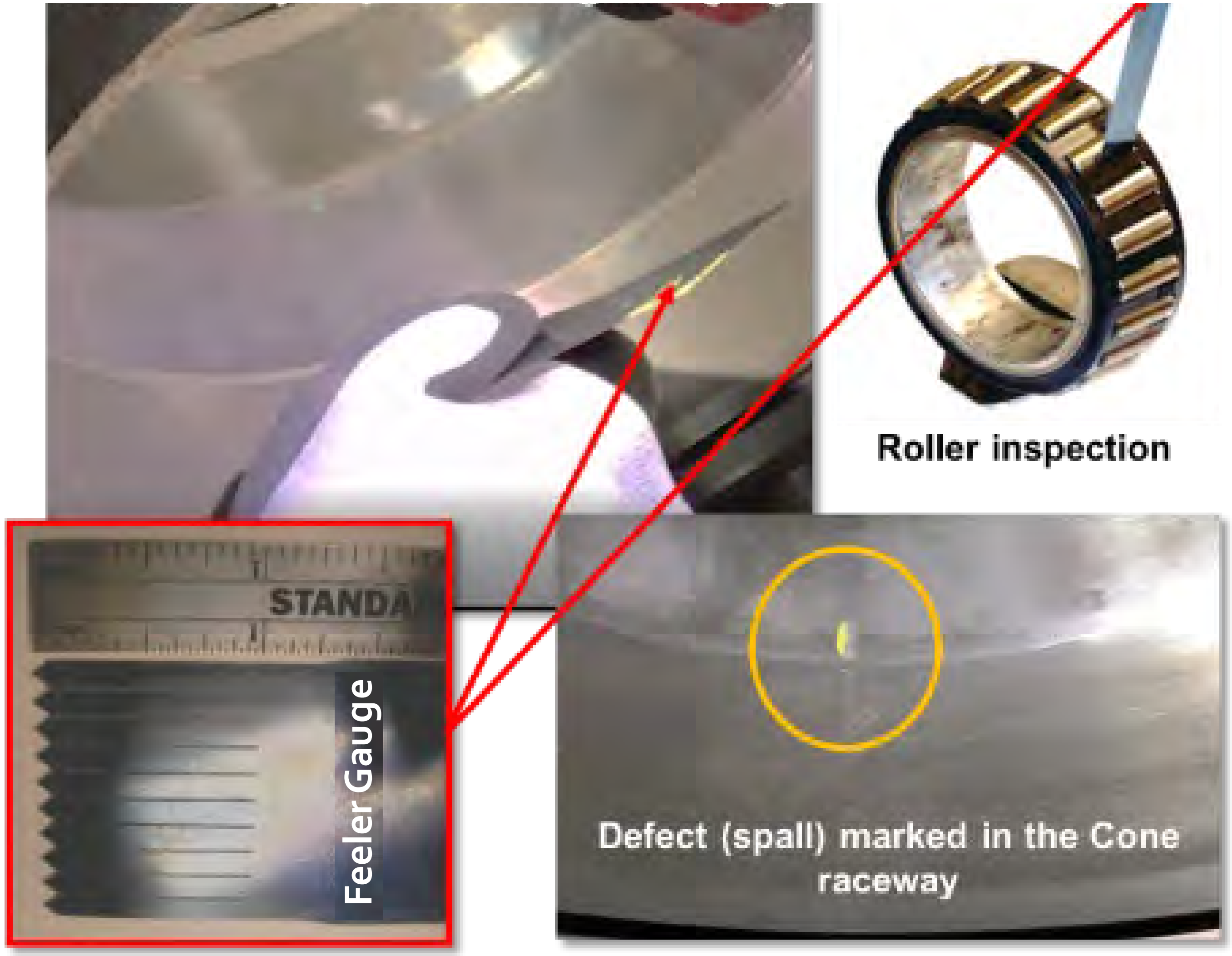
Bearing Inspection and Reconditioning



Disassembled Tapered Roller Bearing

Inspection

- **Current inspection practices:**
  - Visual inspection of component surfaces
  - Feeler gauge on raceway surfaces
- **MxV evaluating NDE system to detect subsurface flaws during reconditioning inspection**



Reconditioning

Spall repairs

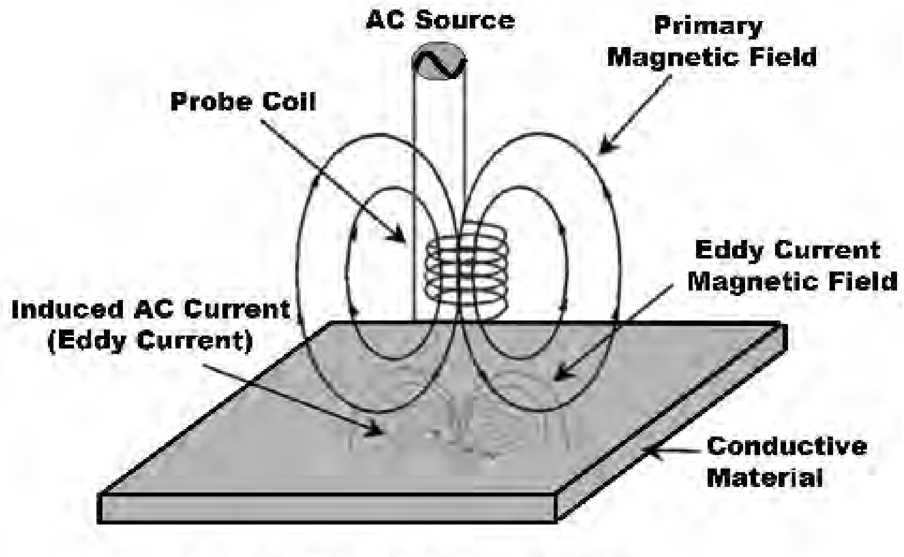
Before repair

After repair

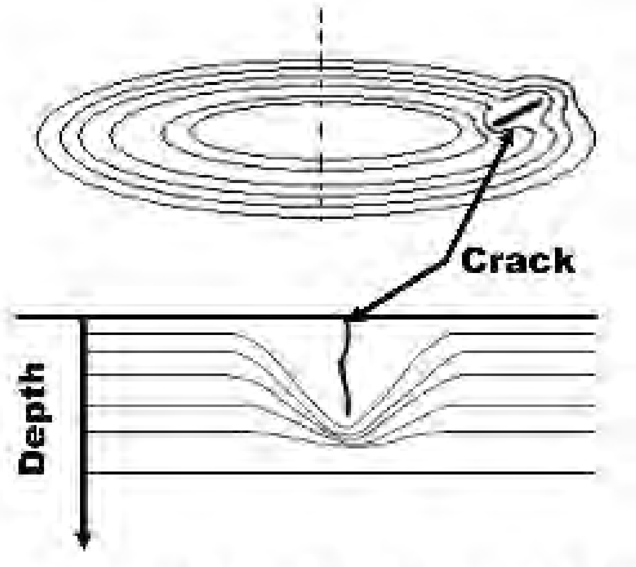
Superficial water etch before and after polishing

NDE Technology for Bearing Inspection

- **Eddy Current NDE uses electromagnetic induction principles**
  - Coil is excited with AC current
  - Induced current on the material surface interacts with discontinuity in the material, disturbing eddy current flow
  - Changes in impedance are detected by eddy current coil



Principle of eddy current testing



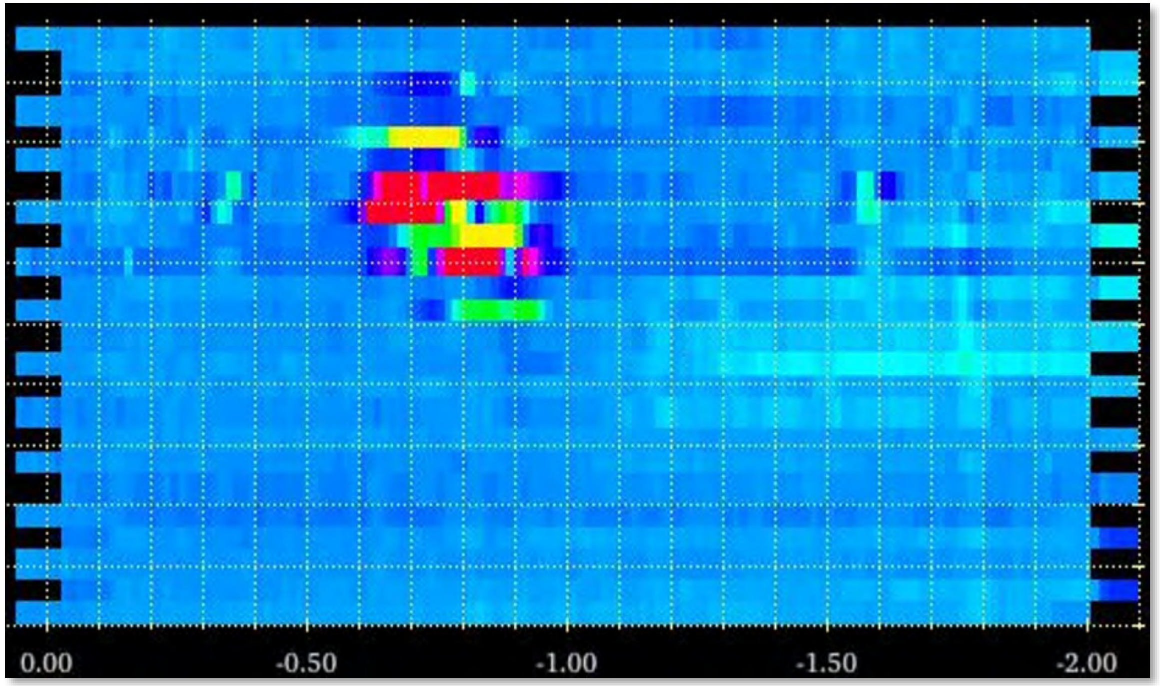
Distortion of eddy current in presence of crack

NDE Technology for Bearing Inspection

- **Eddy Current Array (ECA) technology uses several coils simultaneously to scan large surfaces**
  - *Flexible* ECA probes allow scanning of complex surfaces and is well-suited for bearing components

NDE Technology for Bearing Inspection

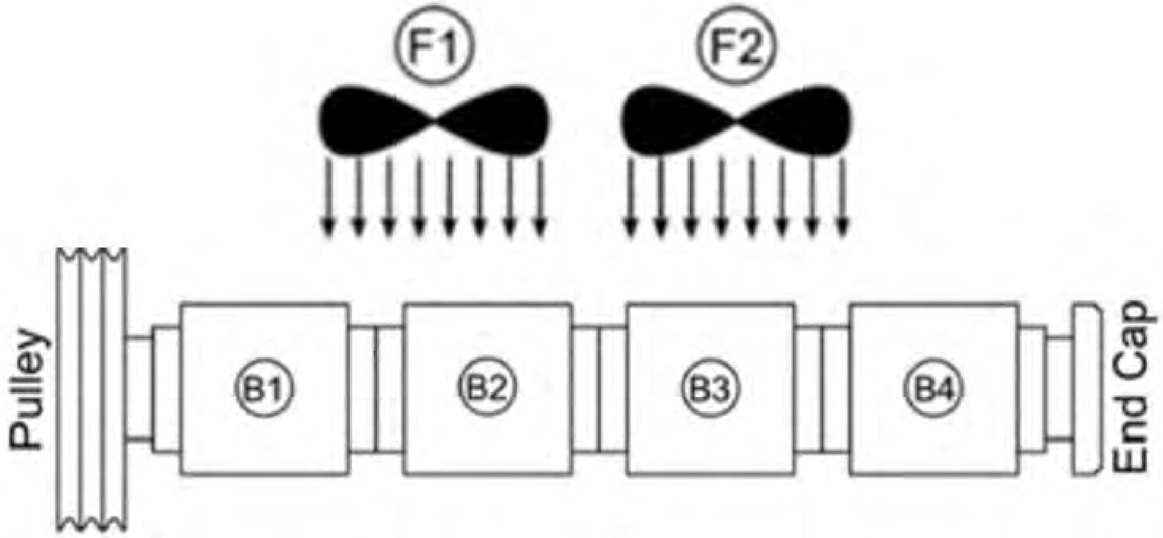
- **Flexible ECA provides a C-scan showing the locations of anomalies throughout a surface**
  - Larger gradients represent significant changes in impedance

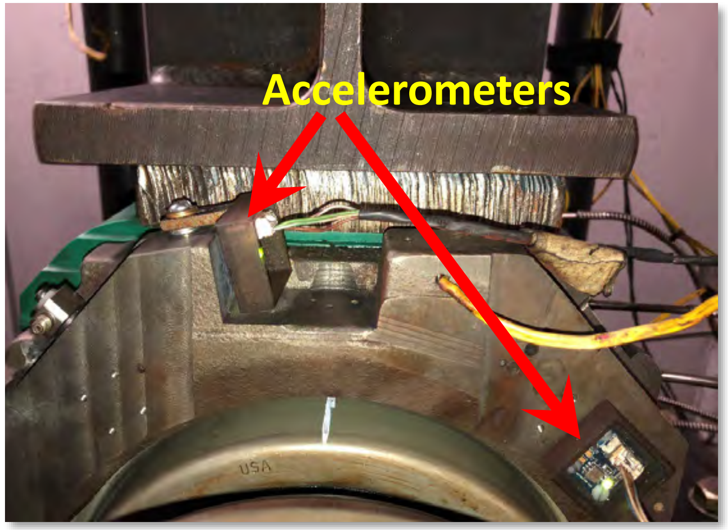


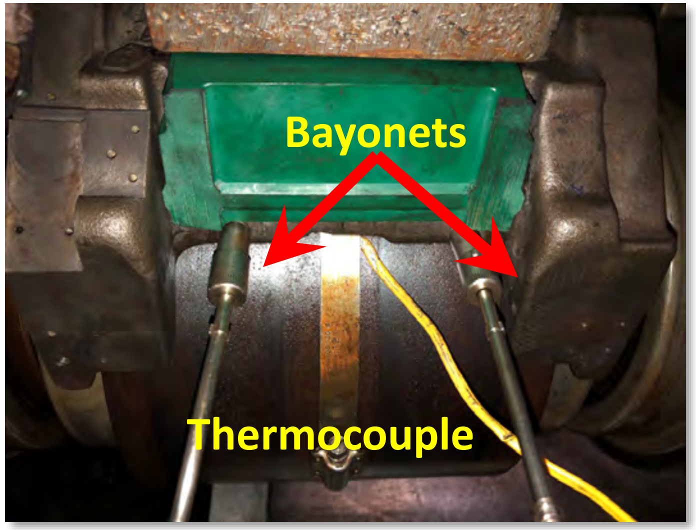
2023 Rig Testing: Water Etched Cups

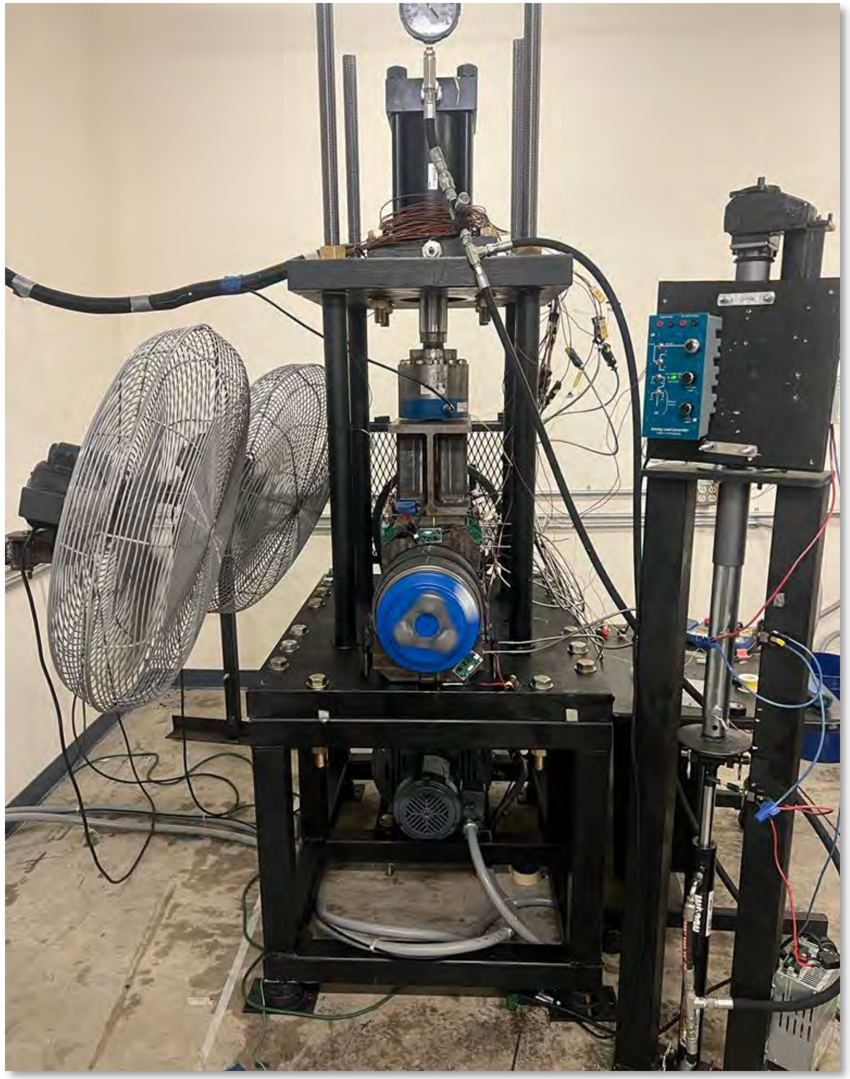
- **ECA scanned 192 reconditioned cups that previously had superficial water etch**
  – Seven showed indications (3.6%)
- **Bearings were assembled and tested at the University of Texas-Rio Grande Valley (UTRGV)**
- **Vibration and temperature were monitored to detect raceway damage**

2023 Rig Testing: Water Etched Cups









2023 Rig Testing: Water Etched Cups

- **Two sample sets selected, each with prior water etching:**
  - Seven cups with ECA indications (completed 2023)
  - Eight cups without indications (underway in 2024)
- **Bearings are loaded to 34,400 pounds each (286k car)**
- **Axle is spun at an equivalent train speed of 85 mph**
- **Tests run for up to 240,000 simulated miles**
- **Cup is positioned so ECA indication or polished water etch is directly under load**

2023 Rig Testing: Water Etched Cups

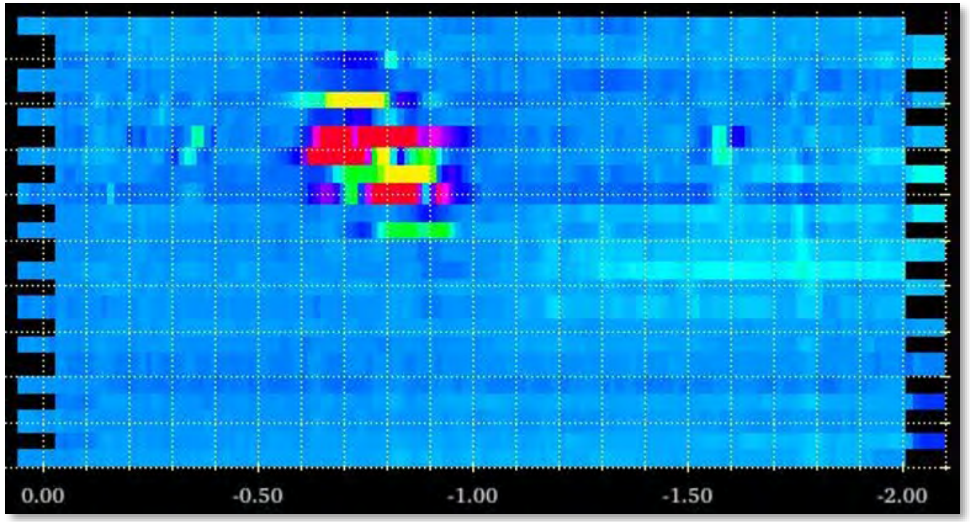
- **Six of seven cups with ECA indications spalled early in testing**
- **Strong correlation between indication size and spall occurrence**

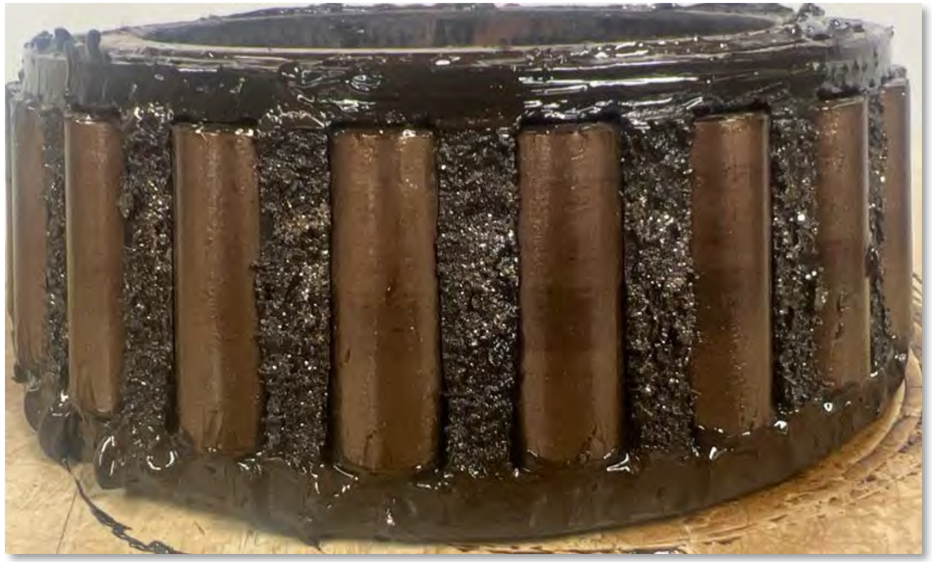
Cup #	Total ECA Indications	Total Indication Area (in^2)	Actual Spall Area (in^2)	Spall Initiation (miles)	Total Test (miles)
1	1	0.003	0.00	N/A	111,220
2	1	0.062	4.37	18,000	48,690
3	1	0.034	3.49	15,100	62,530
4	1	0.048	0.95	9,980	17,120
5	2	0.046	1.98	<17,121	17,120
6	2	0.010	N/A*	11,491	65,740
7	1	0.019	1.09	41,502	65,740

*Small spalls across loaded area too small to cast and measure total area

2023 Rig Testing: Water Etched Cups

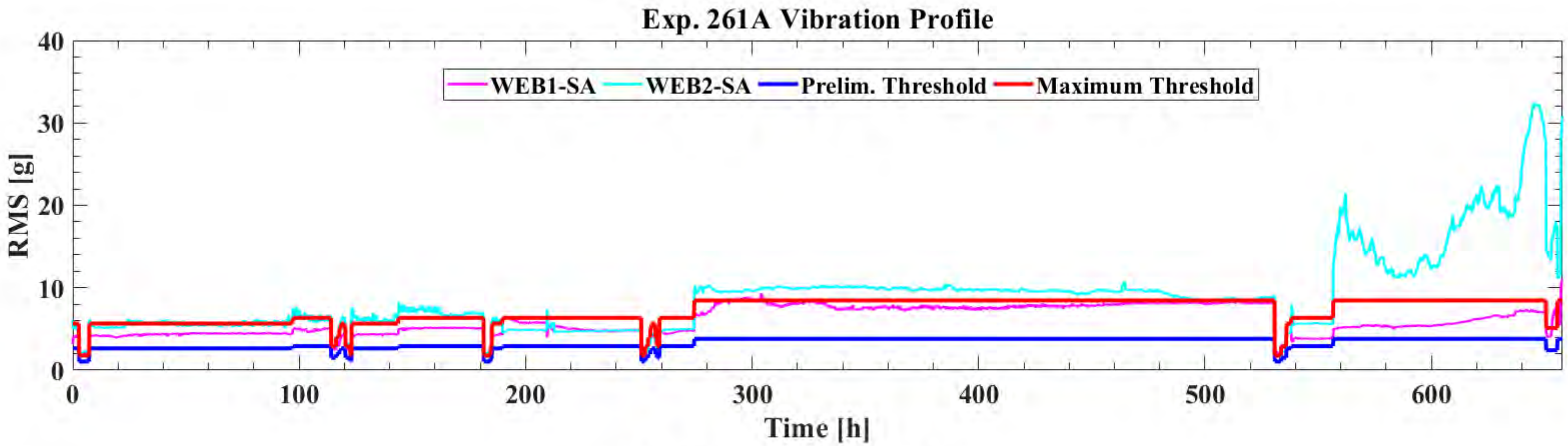
- **Cup #2 had the largest indication and largest resulting spalling damage.**

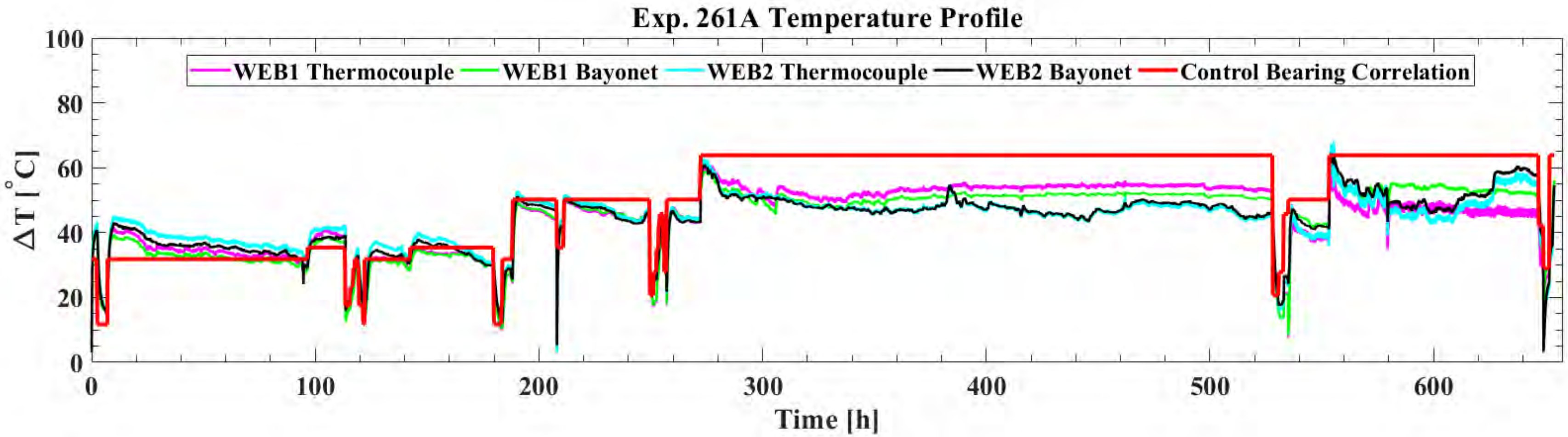




2023 Rig Testing: Water Etch Cups

- **Cup #2 – Spall detected from elevated vibration after 18,000 miles**





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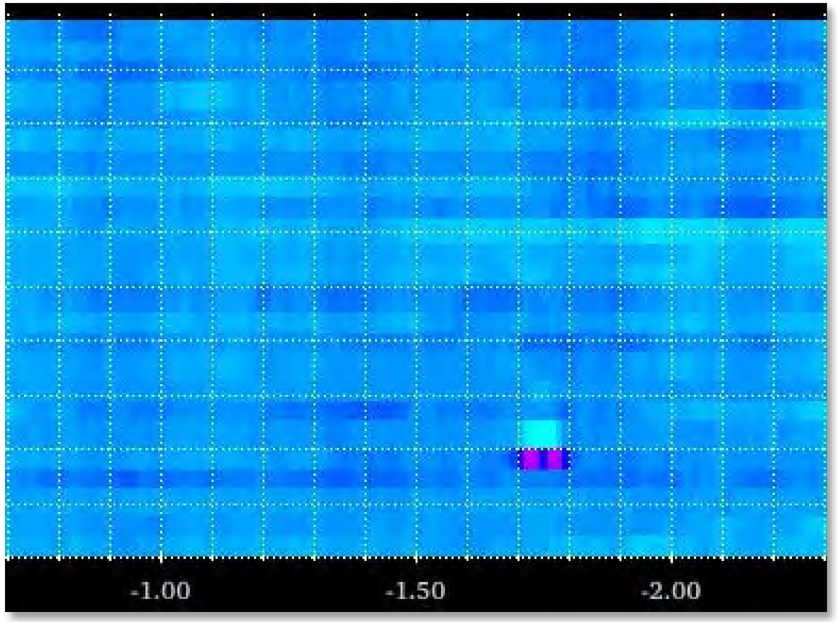
2023 Rig Testing: Water Etch Cups

- **Cup #1 did not spall after 111,220 miles but ran hot for most of the test and was stopped short**
  - Circumferential score marks found throughout loaded zone of raceway

Small ECA Indication

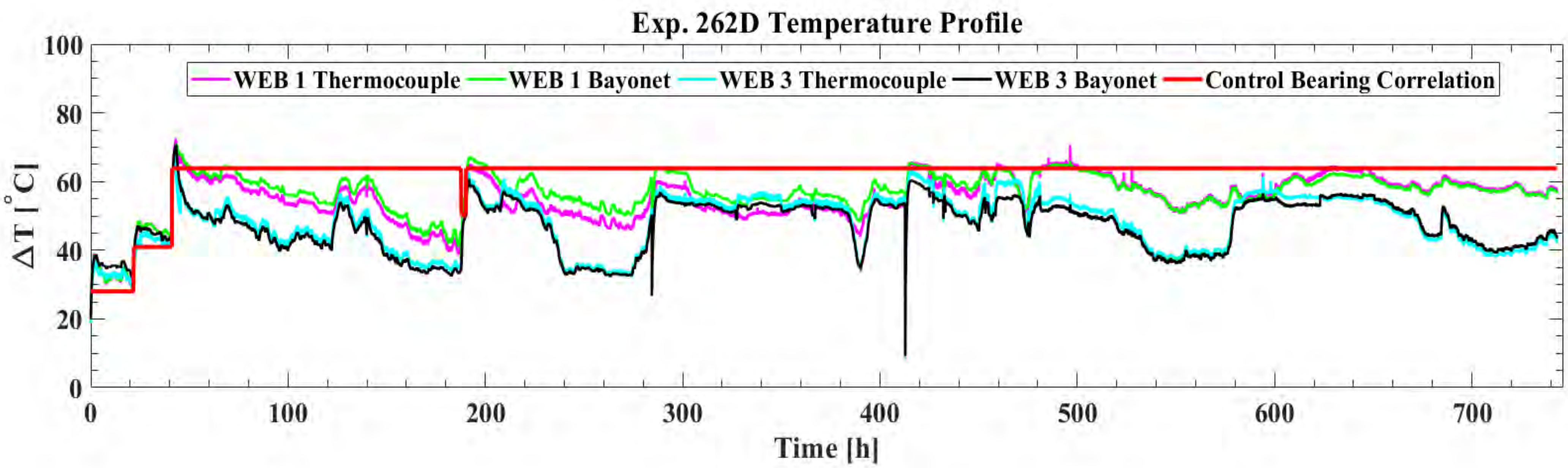


Pre-Test

After 111,000 miles

2023 Rig Testing: Water Etch Cups

- **Cup #1 consistently ran 10-20ºC hotter than its neighboring bearings**
  - Exceeded UTRGV temperature threshold for healthy bearings several times throughout test



2023 Rig Testing: Water Etched Cups

- **Preliminarily in water etched cups, ECA indications are predicting the outcome of spalling under test with 86% accuracy.**
  - Testing will conclude in 2024
  - Current results are much better than the final results from spall-repaired rig testing in 2022 (56% accuracy)

Preliminary Water Etch Results (2023-2024)

Bearing Outcomes	Spall During Test	No Spall During Test	Total
ECA Indication	6	1	7
No ECA Indication	Underway		8

Final Spall-Repaired Results (2021-2022)

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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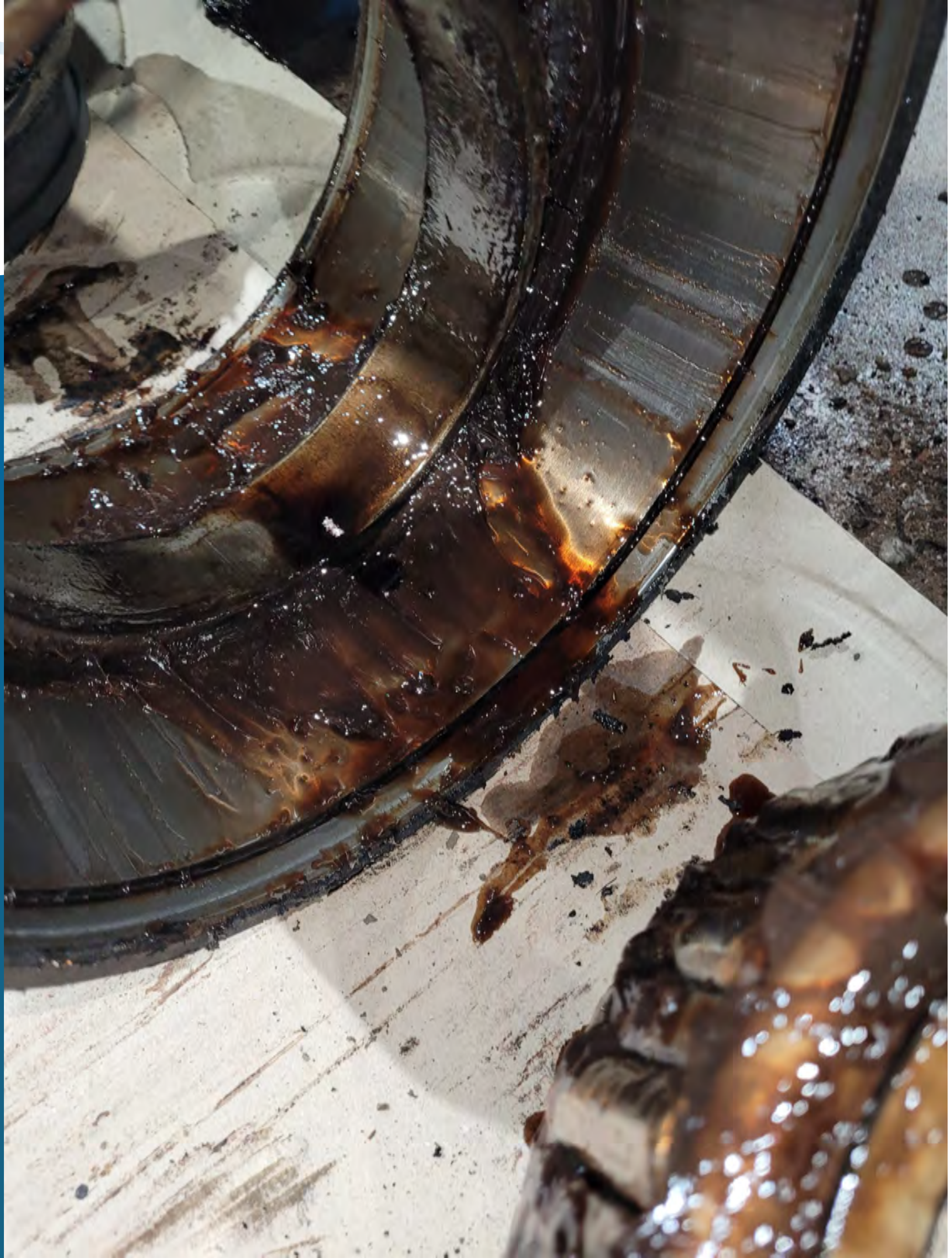
Path Forward

- **Characterize the ECA indications through advanced, destructive analysis**
- **Investigate ECA indications at the micro-structure level to understand root cause and damage propagation:**
  - Scanning electron microscopy
  - Micro computed tomography
  - Micro hardness measurements



Additional Research

- **Degradation of bearing grease during periods of inactivity:**
  - Understand the characteristics of grease when allowed to settle for extended periods
  - Determine how long cars may safely sit idle and still maintain proper lubrication properties

Oil/Soap separation from idle bearing

Summary

- **Reconditioning process**
- **ECA technology for bearing inspection**
- **Preliminary results of water etch rig testing**
  - ECA indications predicting rig test outcome 86% of the time
- **Path forward**
  - Characterize ECA indications through destructive analysis
  - Understand degradation of bearing grease during inactivity

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Acknowledgements

- **MxV Rail Team**
- **Progress Rail**
- **University of Texas – Rio Grande Valley**

Magnetostrictive EMAT Technology Development for Automated In-Motion Wheel Inspection

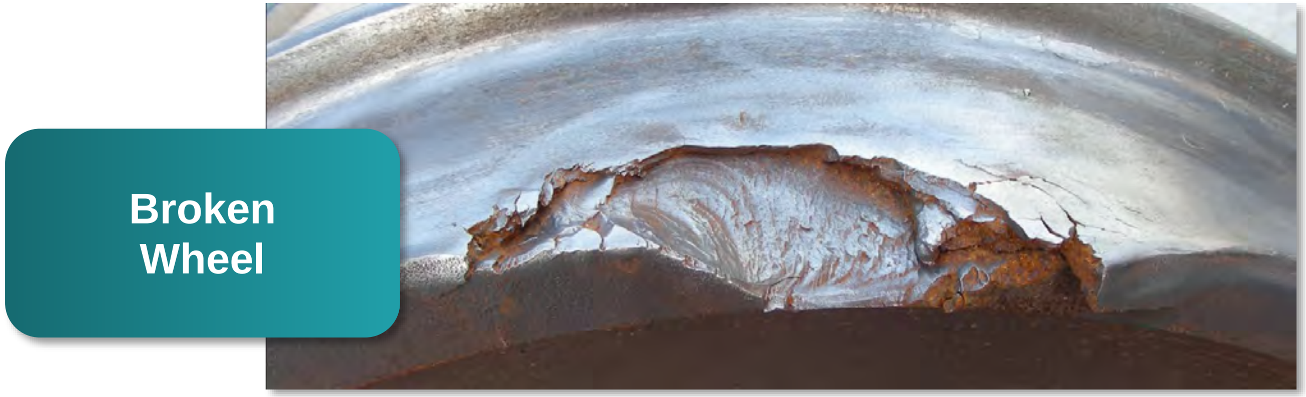
Anish Poudel, Ph.D.
Principal Investigator II

Overview

- **Research Motivation**
- **Electro-Magnetic Acoustic Transducer (EMAT) Principle**
- **Magnetostrictive Patch (MP) EMAT Sensor Development**
- **MS EMAT Assembly Durability Testing**
- **Results**
- **Path Forward**
- **Summary**
- **Acknowledgements**

Research Motivation

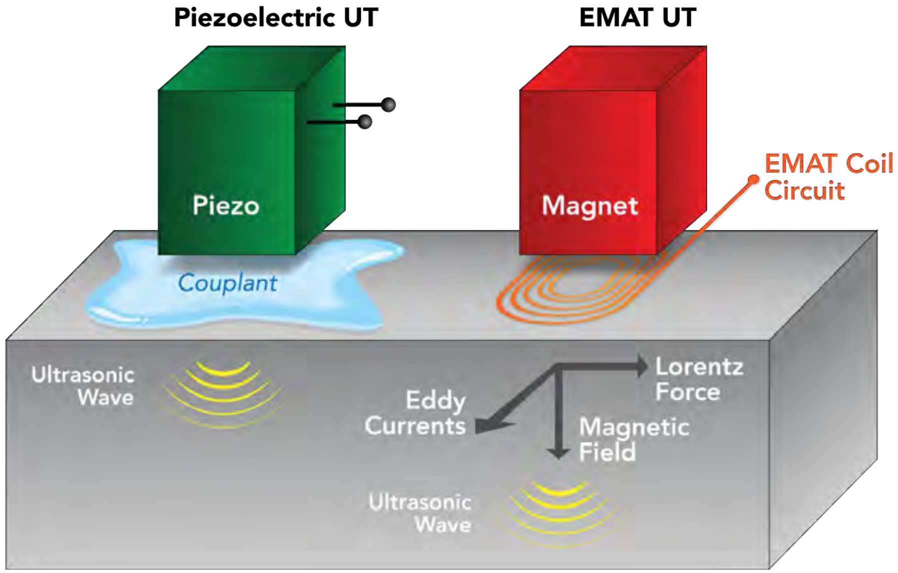
- **Promote safe, reliable, efficient train operations**
- **Reduce broken wheel derailment risk**
- **Explore automated wheel inspection systems**
  - Reliable and efficient
  - Real time, in motion
  - No couplant, minimal infrastructure



EMAT Principle

- **EMAT Ultrasonic Testing (UT)**
  - Generates ultrasound in the part using electromagnetic induction through two basic mechanisms:
    - Lorentz force
    - Magnetostriction
- **Traditional Piezoelectric UT**
  - Generates ultrasound in a piezoelectric transducer
  - Ultrasound is transmitted (coupled) into the part using a liquid (couplant)

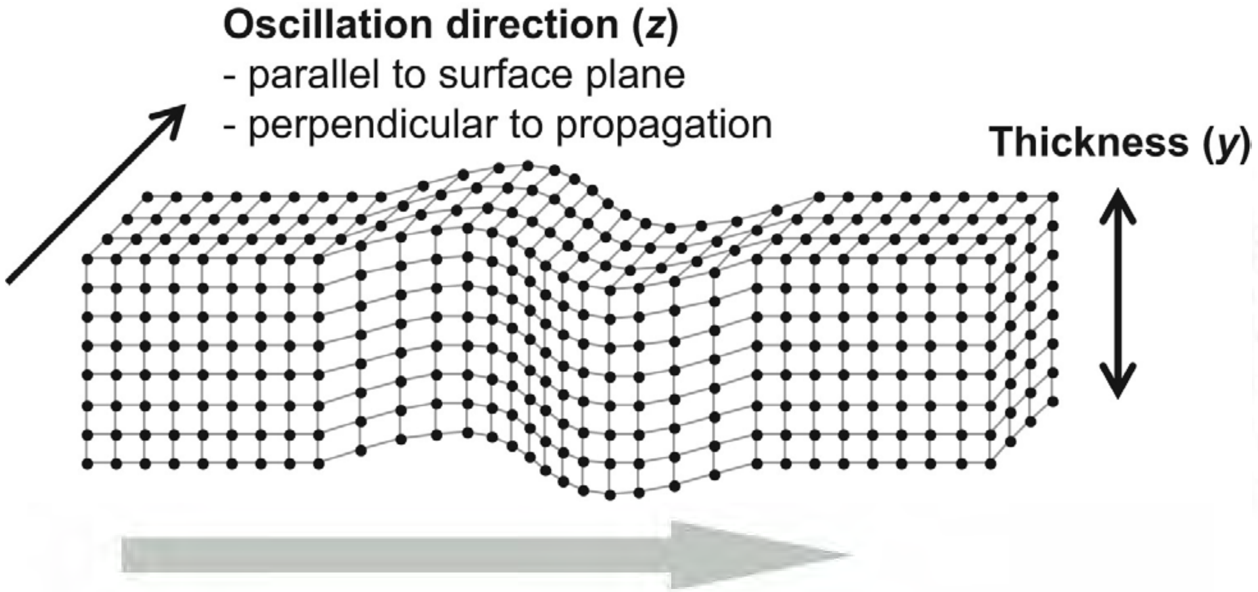
TECHNOLOGY COMPARISON



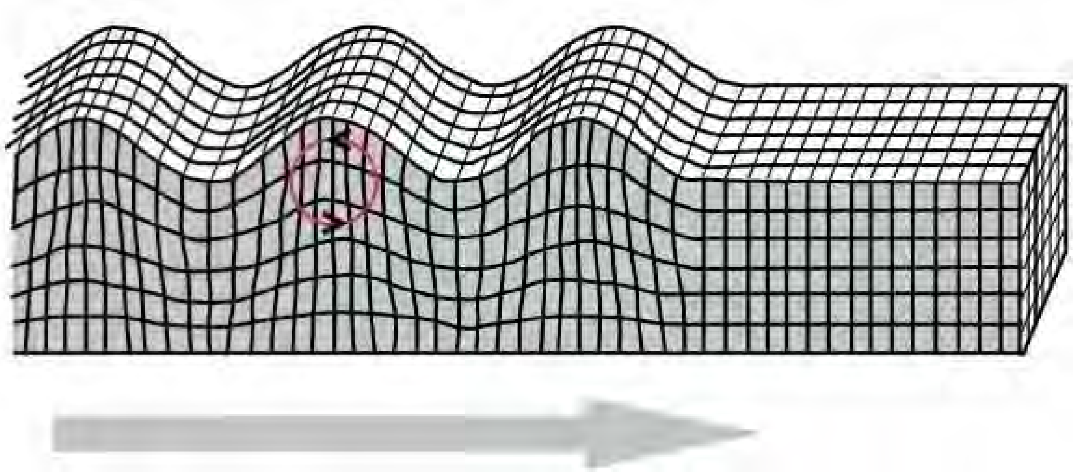
Video/Photo Courtesy: Innerspec Technologies

Shear Horizontal Guided Waves

- **Particle motion is parallel to the surface plane of entry and perpendicular to the direction of propagation**
- **Penetration depth is equal to one wavelength with a practical range up to 1 inch**
- **Not affected by dirt, water, or rolling surface conditions**



Shear Horizontal Waves



Surface Waves

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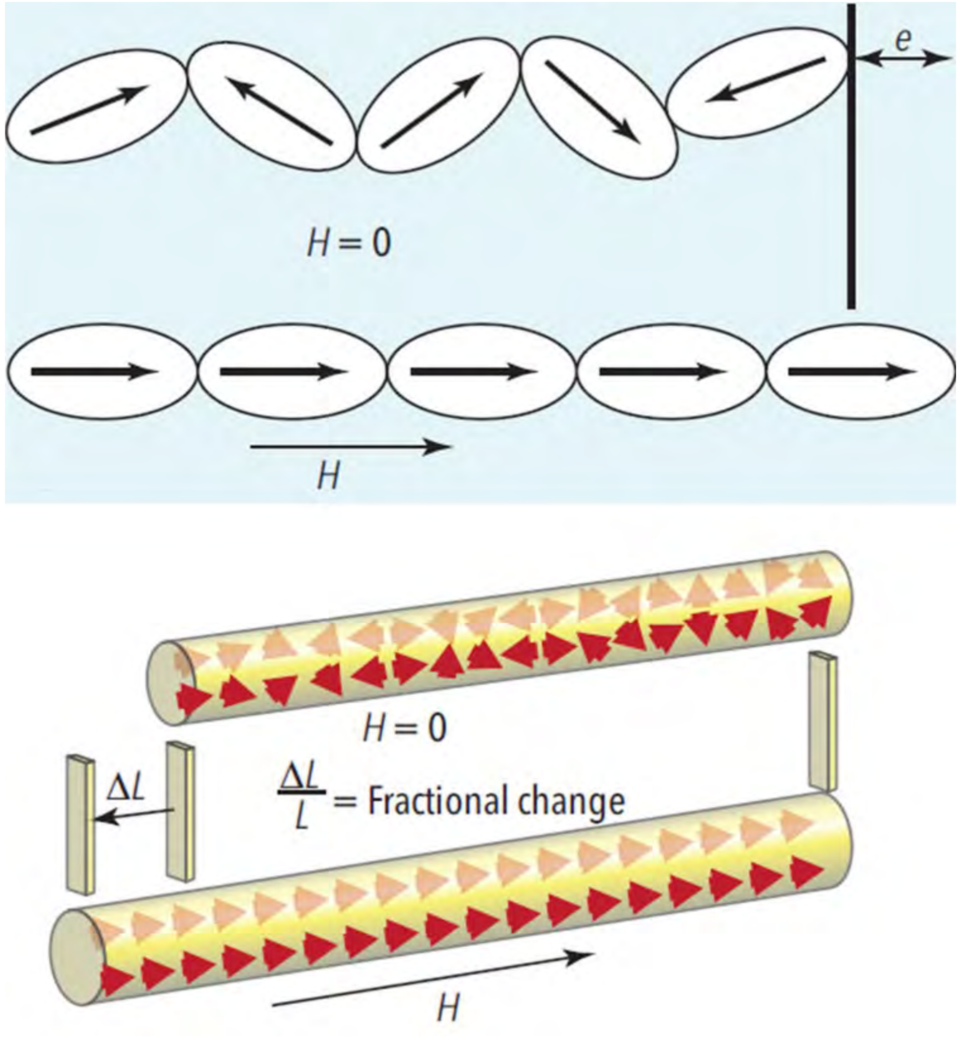
Magnetostriction Principle

- **Magnetostriction is a property of ferromagnetic materials that causes them to change shape or dimension when exposed to a magnetic field**
  - This effect allows magnetostrictive materials to convert electromagnetic energy into mechanical energy and vice versa
- **Magnetostrictive materials have been widely used as magnetostrictive patches to efficiently generate and receive ultrasound in different applications**

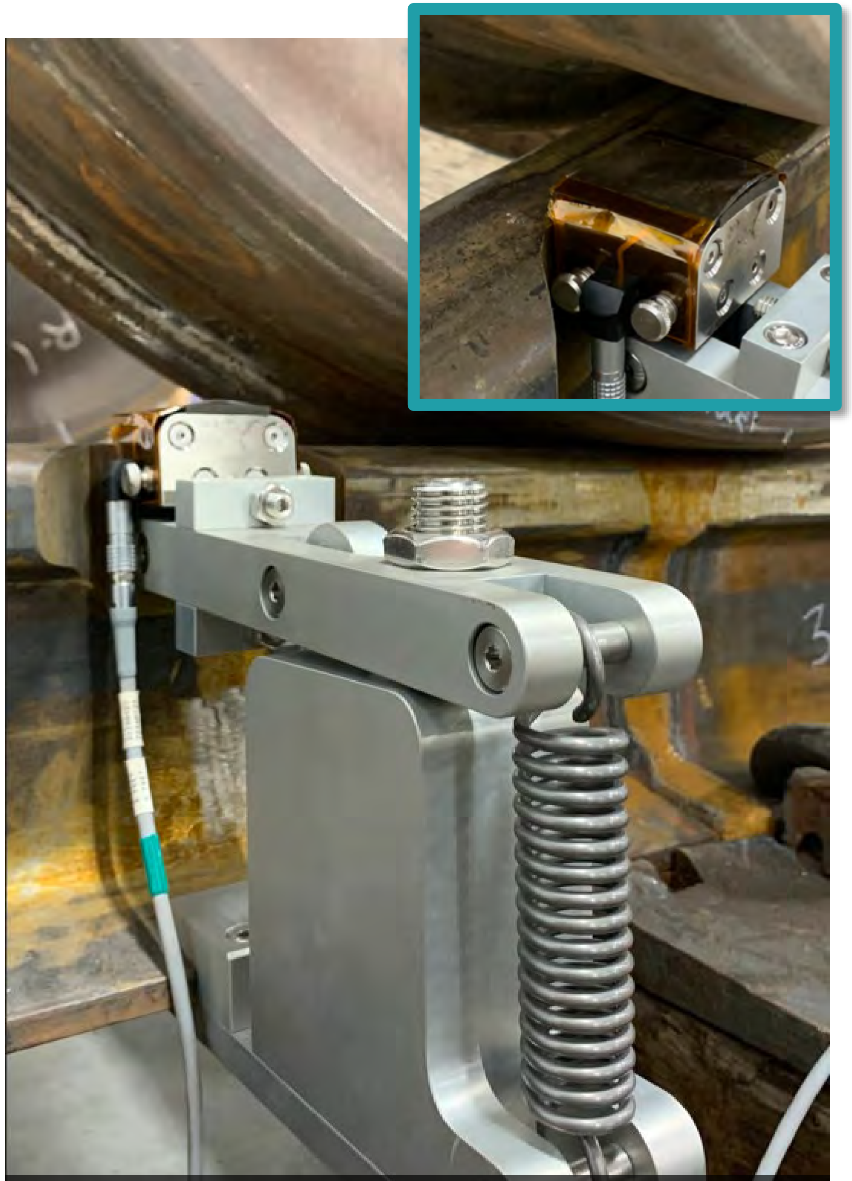


Magnetostriction phenomena in ferromagnetic materials

Magnetostrictive Patch EMAT Sensor Early Version

- **A magnetostrictive patch EMAT sensor is a type of EMAT with high energy conversion efficiency**
  Early design includes:
  - Magnetostrictive patch (MP)
    - 2-inch x 2-inch and 0.010-inch-thick Iron-Cobalt (FeCo) alloy
    - Wheel tread coverage: 2-inch x 2-inch
  - Meander-line (zig-zag) coil
  - Permanent magnet providing biasing field
- **Spring assembly**

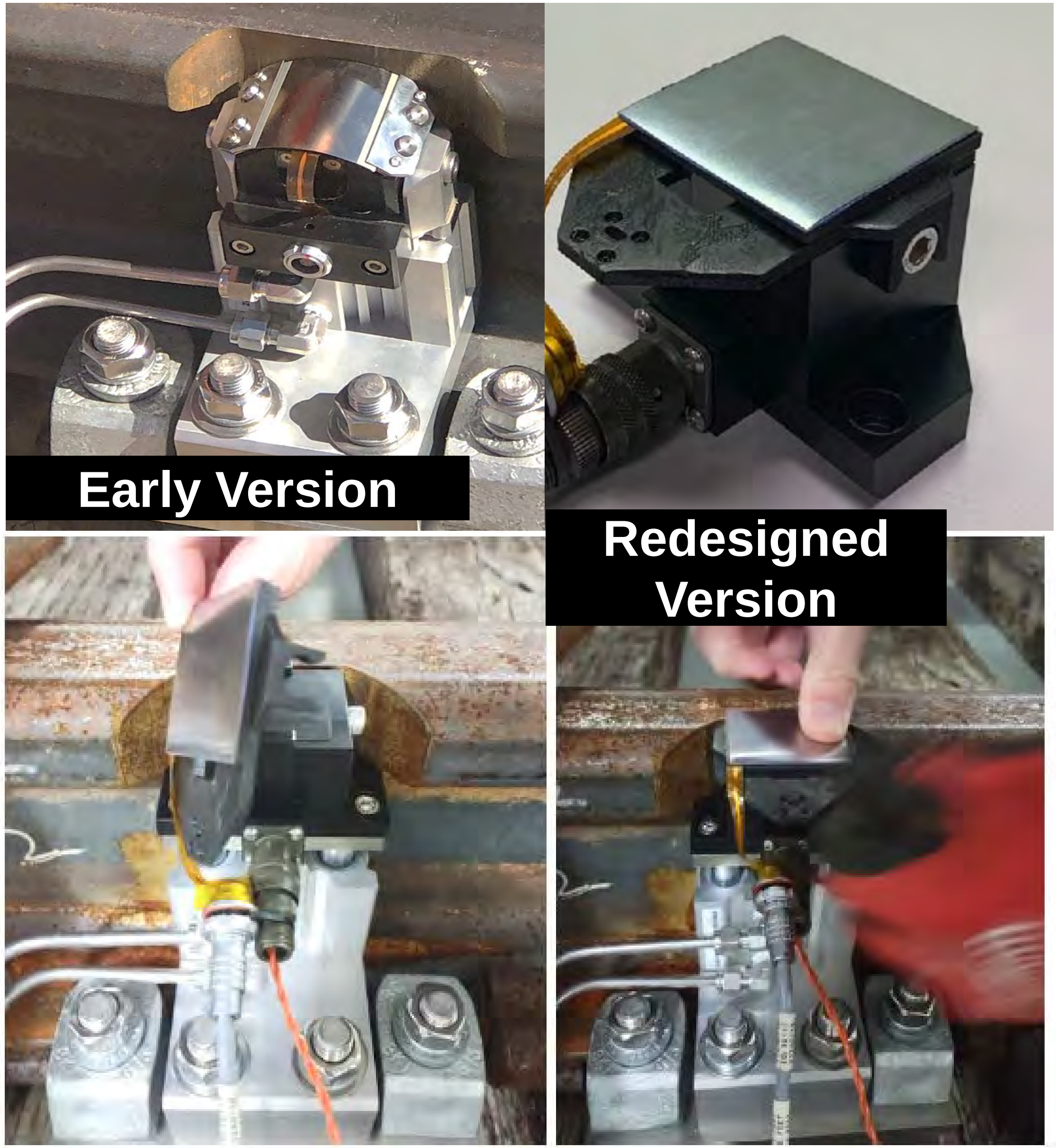
The EMAT technology belongs to Innerspec, Inc.



First MS EMAT Prototype

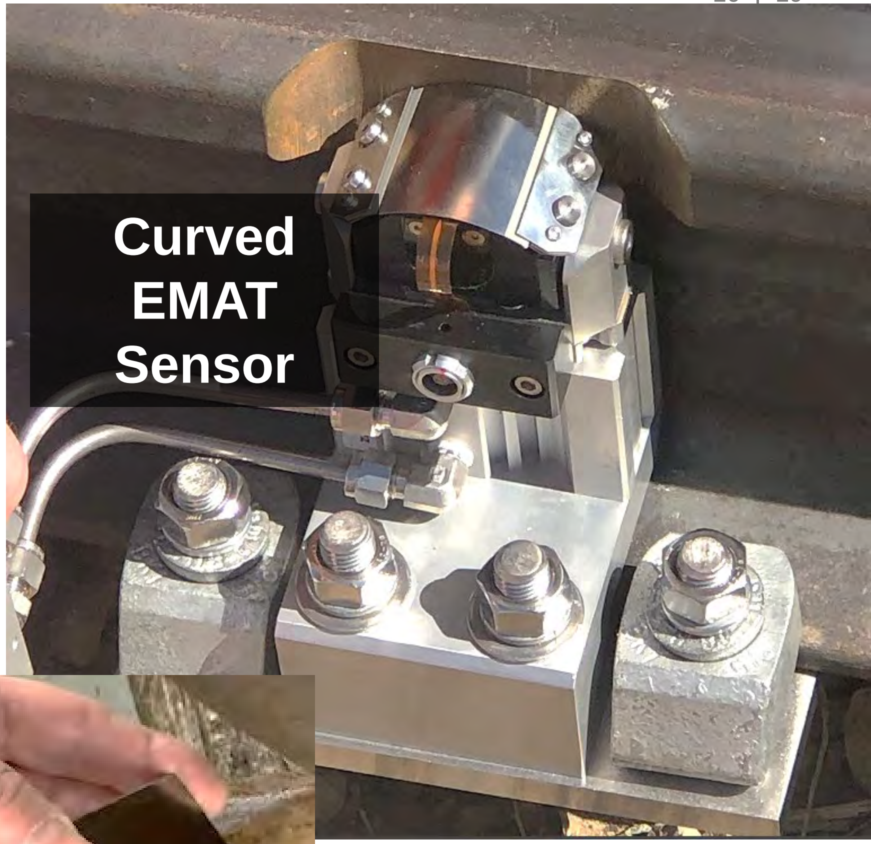
Flat MP EMAT Sensor Development

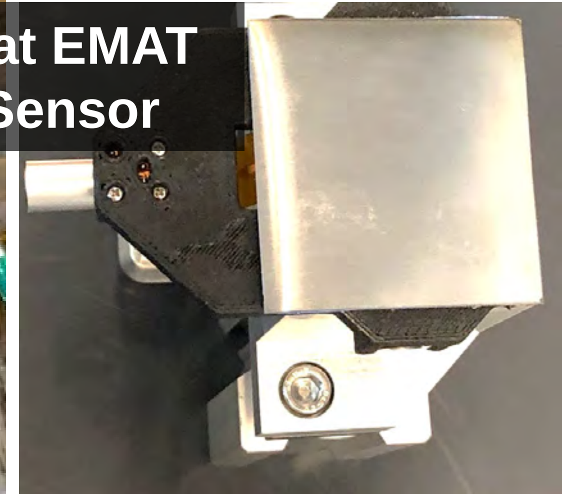
- **Stationary sensor contacts wheel through MP strip, without couplant**
- **Requires a field-side notch in the rail head**
- **Clamp-on design easily removed for sensor maintenance and track work**
- **Quick disconnect mechanism to replace the MS patch, electrical power, signal, and compressed air connections**



Durability Testing

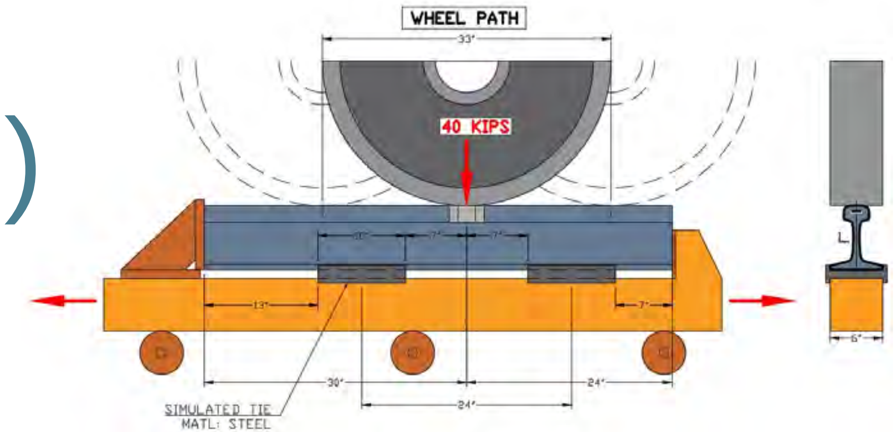
- **The goal is to test the endurance of:**
  - Magnetostrictive patch and coil assembly
  - Coupling mechanism
  - Pneumatic actuator
  - Notched rail
- **Different versions of the patch with different annealing methods were explored and load tested**

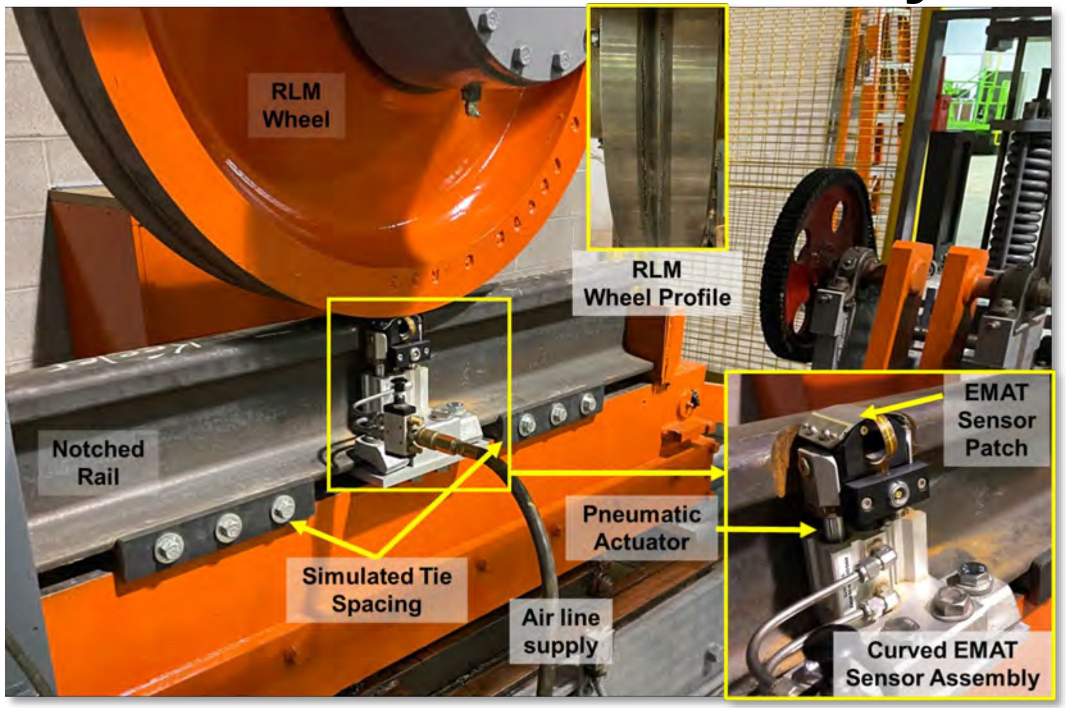




Rolling Load Machine (RLM)

- **Subject the notched rail and EMAT sensor to repeated 40-kip wheel loads**
- **Two million wheel passes = 40 MGT**
- **Cyclic rail bending stresses**
- **Sensor contact wheel each cycles**





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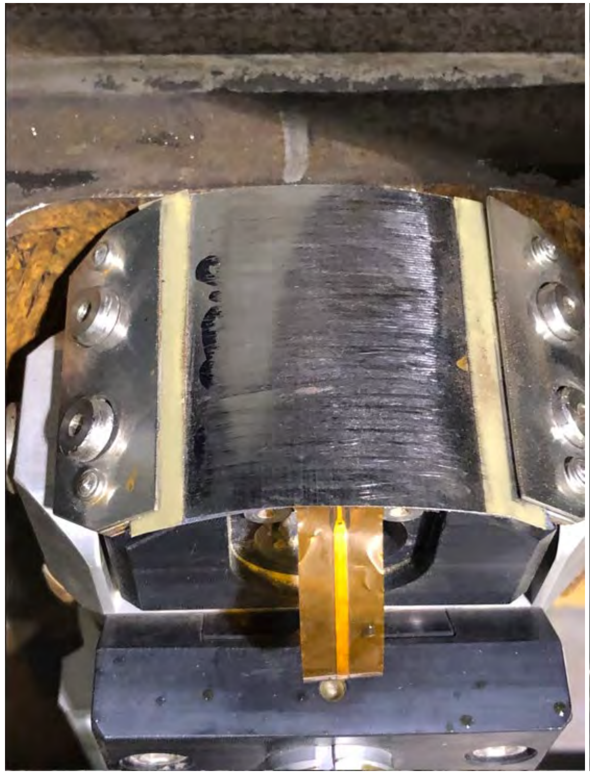
RLM Tested MP EMAT Sensors



Curved Sensor

1 M wheel passes

Flat Sensor v1

0.5 M wheel passes
Patch debonded

Flat Sensor v2 “D”

2 M wheel passes

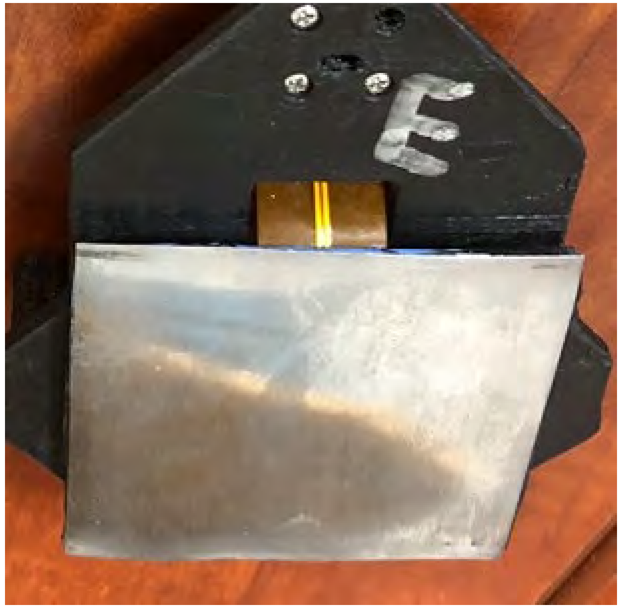
Flat Sensor v2 “E”

2 M wheel passes

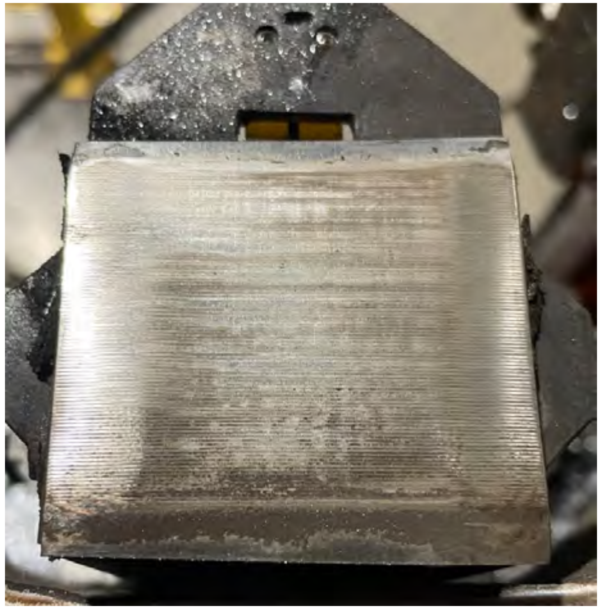
2M wheel passage @ 40 kips equivalent to 40 MGT

MP EMAT Flat Sensor Signal Quality

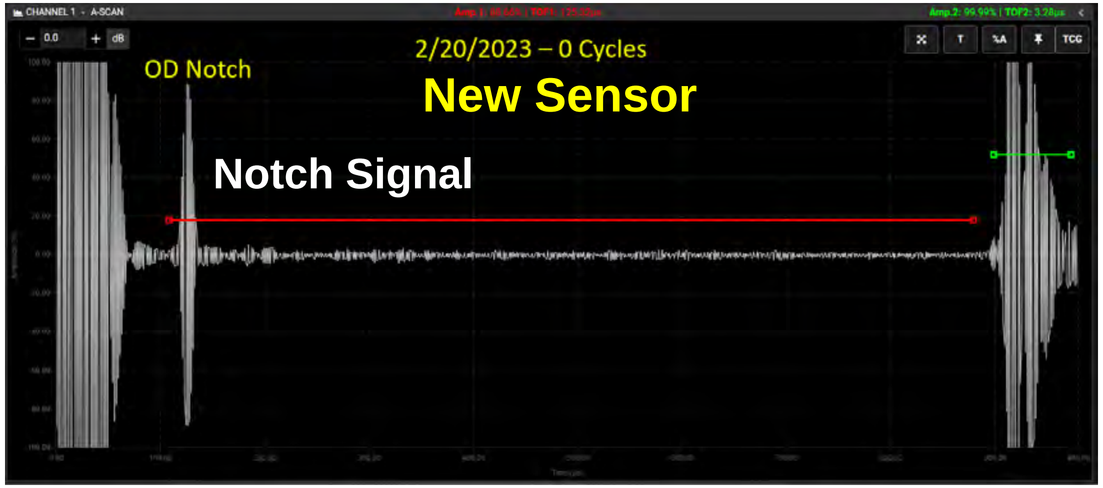
- **No deterioration in EMAT signal when tested over wheel with artificial notch**

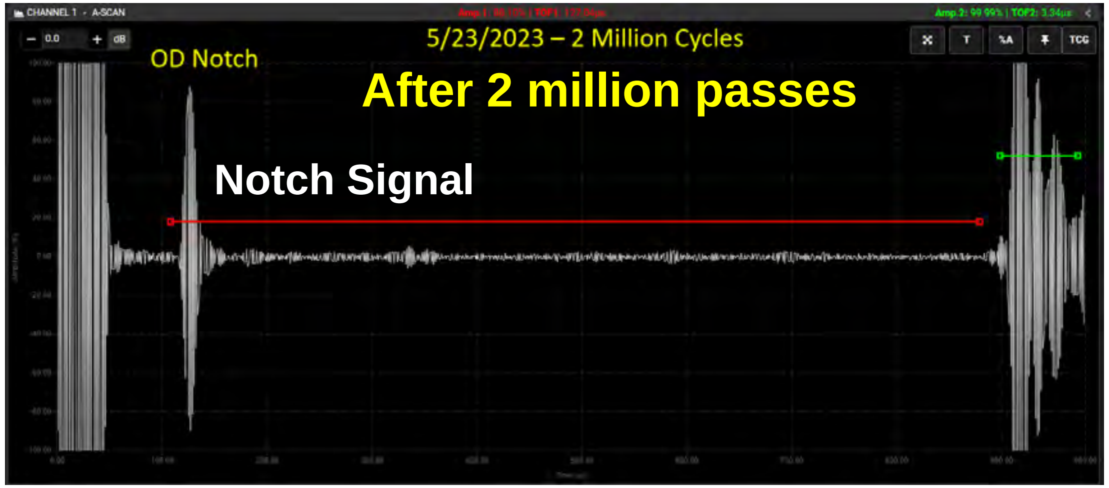


New



After 2 million passes

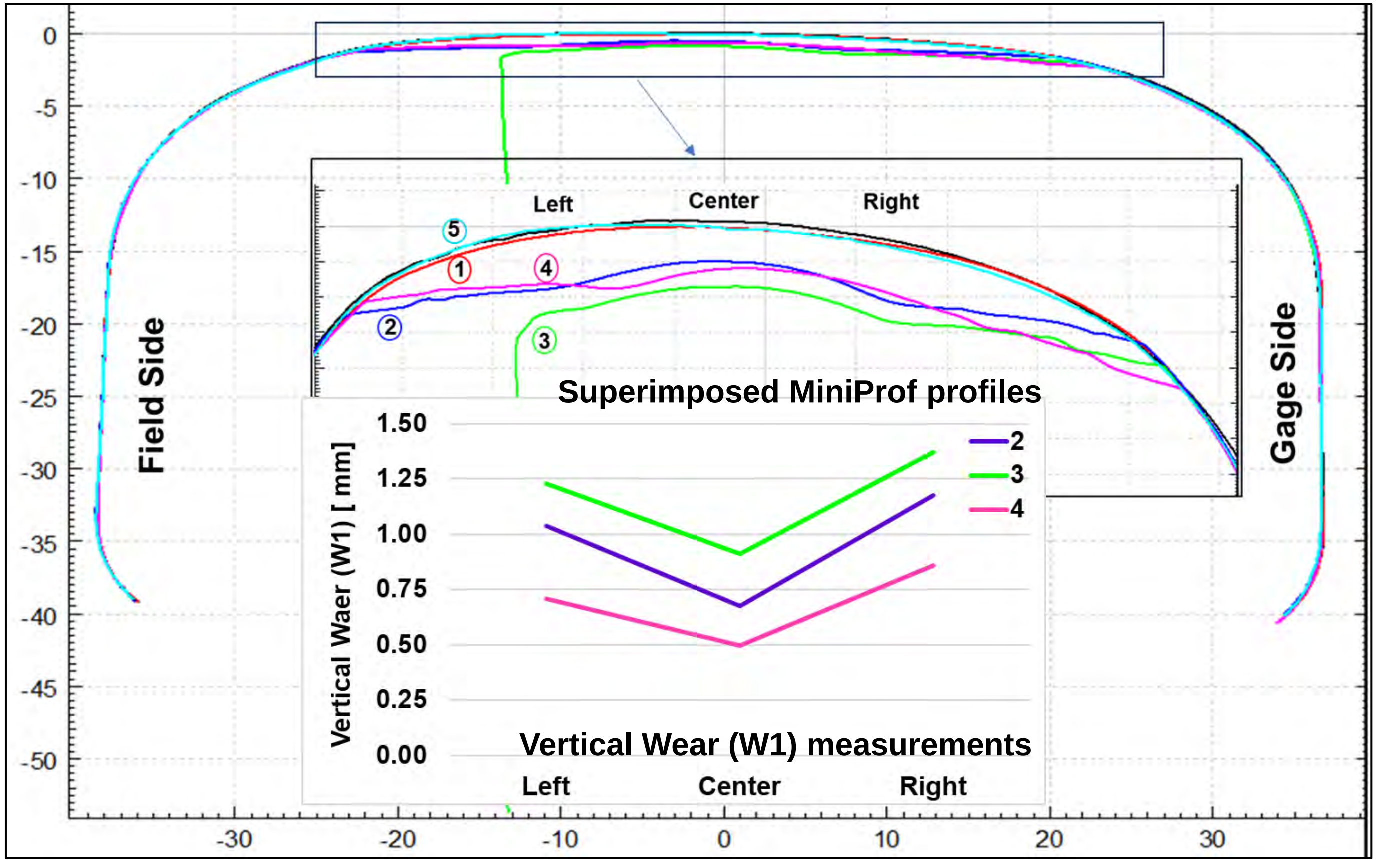




EMAT Signal Amplitudes

Notched Rail Wear Analysis

- **Minimal wear observed after 110 MGT equivalent**
- **Average area loss of 29 mm²**

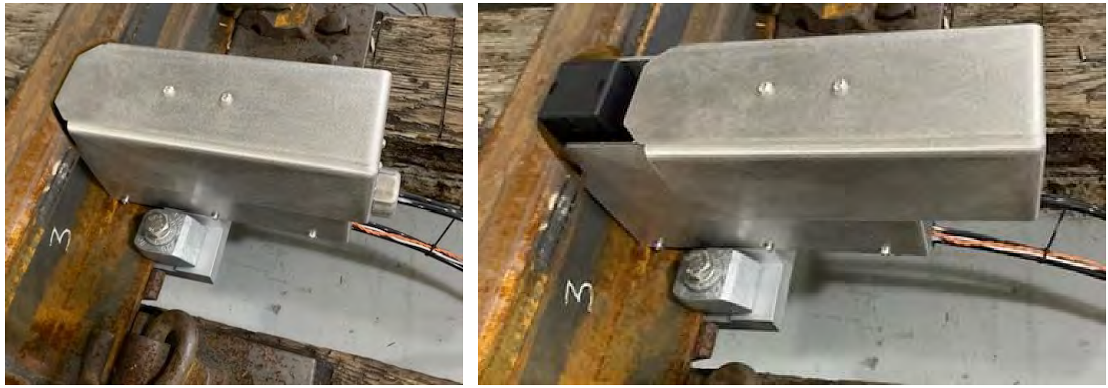


Rail Profile measurement locations

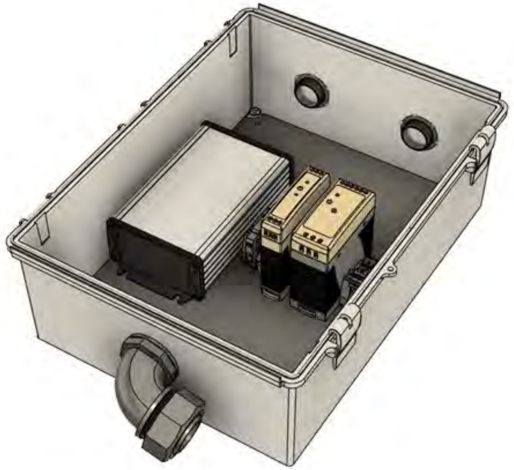
Measurement Locations	Vertical Wear (W1) Measurement [mm]		
	Left	Center	Right
2	1.04	0.67	1.18
3	1.23	0.91	1.37
4	0.71	0.50	0.86
Average 2 & 4	0.87	0.59	1.02
Difference of 3 & avg. 2 & 4	0.35	0.33	0.36

Field Prototype System

- **Sensor assembly includes:**
  - Actuator (single cylinder)
  - Replaceable coil and wear surface (tool-less replacement) with upgraded latching
  - Built-in direct current (DC) electromagnet under coil
  - Extendable cover to protect the sensor when not in use
- **Connections to external remote-control box includes**
  - Air
  - Transmit/receive channel
  - Proximity switches
  - Cover extension control



EMAT sensor assembly with actuator



Signal Conditioning, Power and Air Control Box

Remote Control Box

Innerspec, Inc. developed the field protype system

Actual Implementation Scenario

- **Requires a minimum of four to five MP EMAT sensors per rail**
  - Accommodate different wheelbase distance
    - Focus is on 36-inch and 38-inch diameter wheels
  - Wheel tread coverage inward from the rim face: 2-inch x 2-inch
- **MP EMAT sensor spacing / placement considerations**
  - Avoid electromagnetic interference (resulting from the simultaneous two EMAT sensor triggering)
- **Theoretically, can test at speeds up to 30 mph**

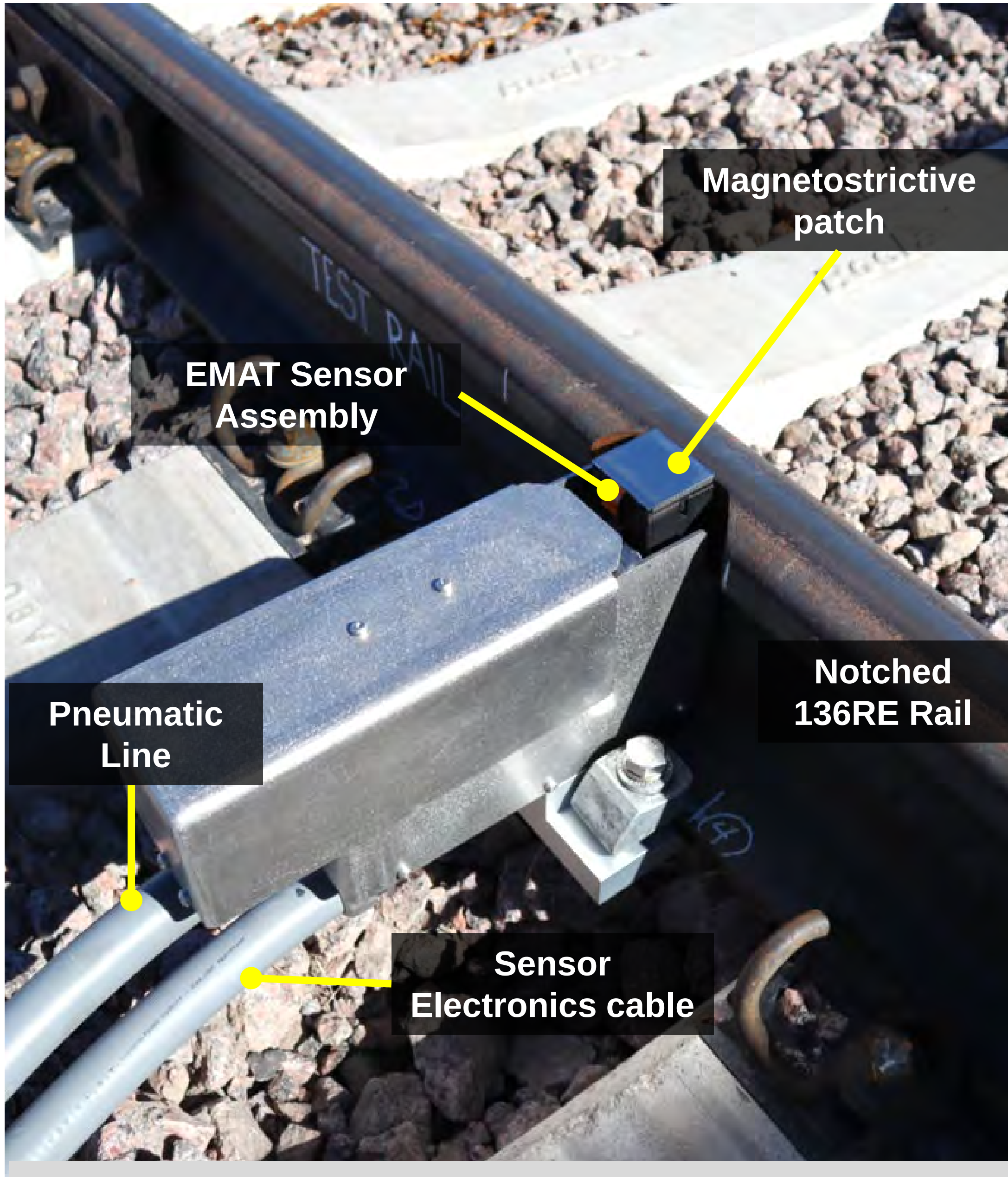
Path Forward

- **Facility for Accelerated Service Testing (FAST®)**
  - Field installations and testing started Q1 2024
  - Endurance testing under heavy axle load train (FAST train) and different wheel geometry/surface conditions
  - Reliability testing

FAST Testing

Summary

- **MP EMAT Development – Key Points**
  - Does not require couplants
  - Less sensitive to dirt, grease, and other wheel surface conditions
  - Removable clamp-on installation
  - Quick disconnect mechanism to replace the MS patch and other components
  - Requires notch in field side of rail head
  - Good Signal-to-Noise Ratio (SNR)
  - Detects cracks at different depths (up to 25 mm)
  - Up to 30 mph inspection speed



EMAT sensor assembly installed on notch rail track

Acknowledgements

- **MxV Rail team**
  - Brian Lindeman, Sr. Engineer I
  - Sirius Roybal, Sr. Instrumentation Engineer II
  - Beatrice Rael, Associate Data Analyst
- **Innerspec, Inc. team**
- **AAR Strategic Research Initiatives Program**
- **AAR Research Committee**

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Brake Systems Research

Yi Wang
Principal Investigator I

Outline

- **Brake Systems Research Overview**
- **Project Highlight: Effect of Brake Pipe Flow on Average Brake Cylinder Pressure**
  - Background
  - Approach
  - Results
  - Summary

Brake Systems Research Overview

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Research Objectives

- **Detect and address brake performance issues**
- **Explore modern approaches to brake safety**

Ongoing Topics

Single-car testing of control valves in cold temperatures

Secondary securement devices

Simulation studies to understand how braking performance is affected

Develop understanding of more advanced modeling techniques

Effect of Brake Pipe Flow on Average Brake Cylinder Pressure

Background

Brake Test Requirements

- 49 CFR § 232.205 (c)(1): *Brake pipe leakage shall not exceed 5 psi per minute or airflow shall not exceed 60 cubic feet per minute (CFM).*
  i. Leakage Test.
  ii. Air Flow Method Test.

- Transport Canada Train Brake Rules
  7.11 A train having received a No. 1 or 1A brake test or a continuity test may only depart a terminal if the combined air flow to the brake pipe does not exceed ninety (90) CFM with no individual source of air having a flow greater than sixty (60) CFM, as indicated by the flow indicator.

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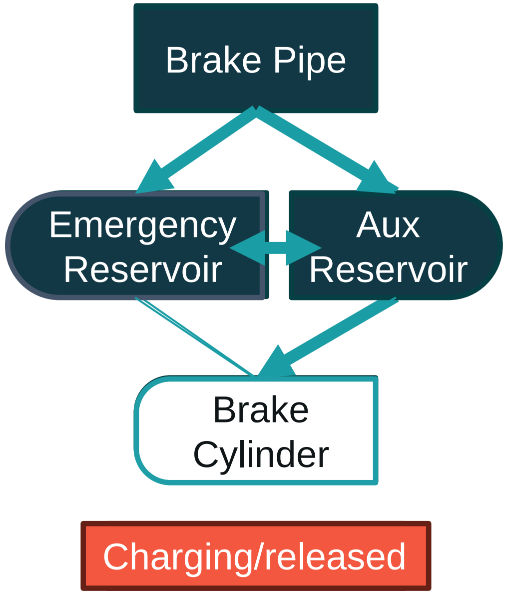
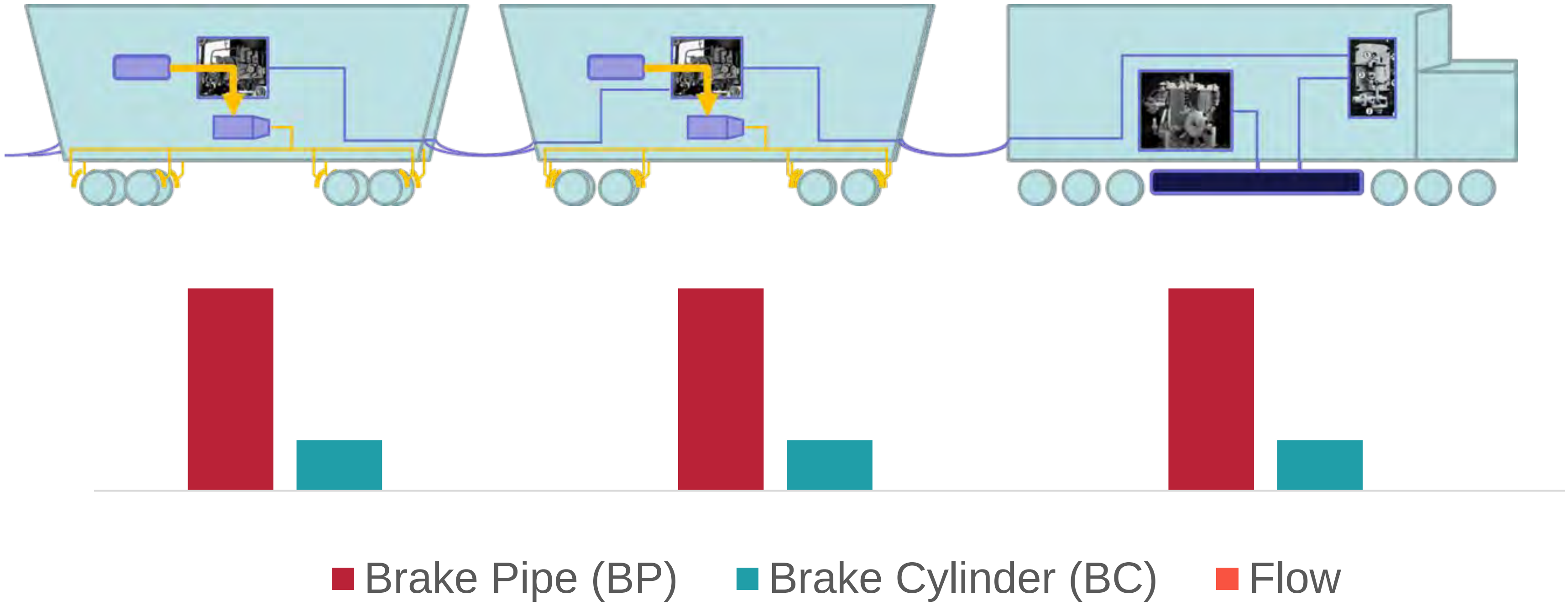
Brake System

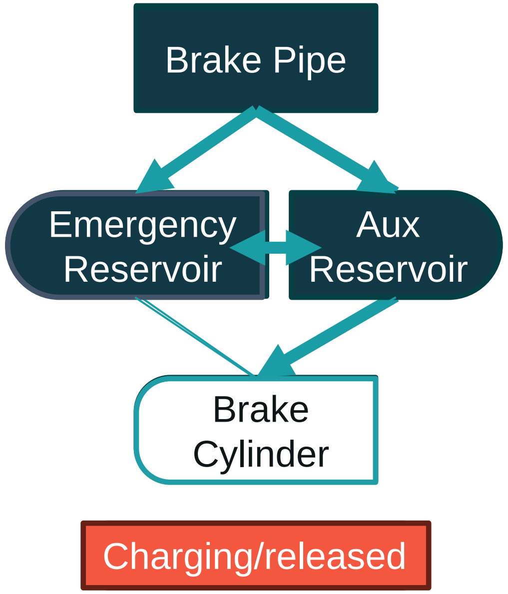
- **Without leakage, i.e., zero flow when fully charged**

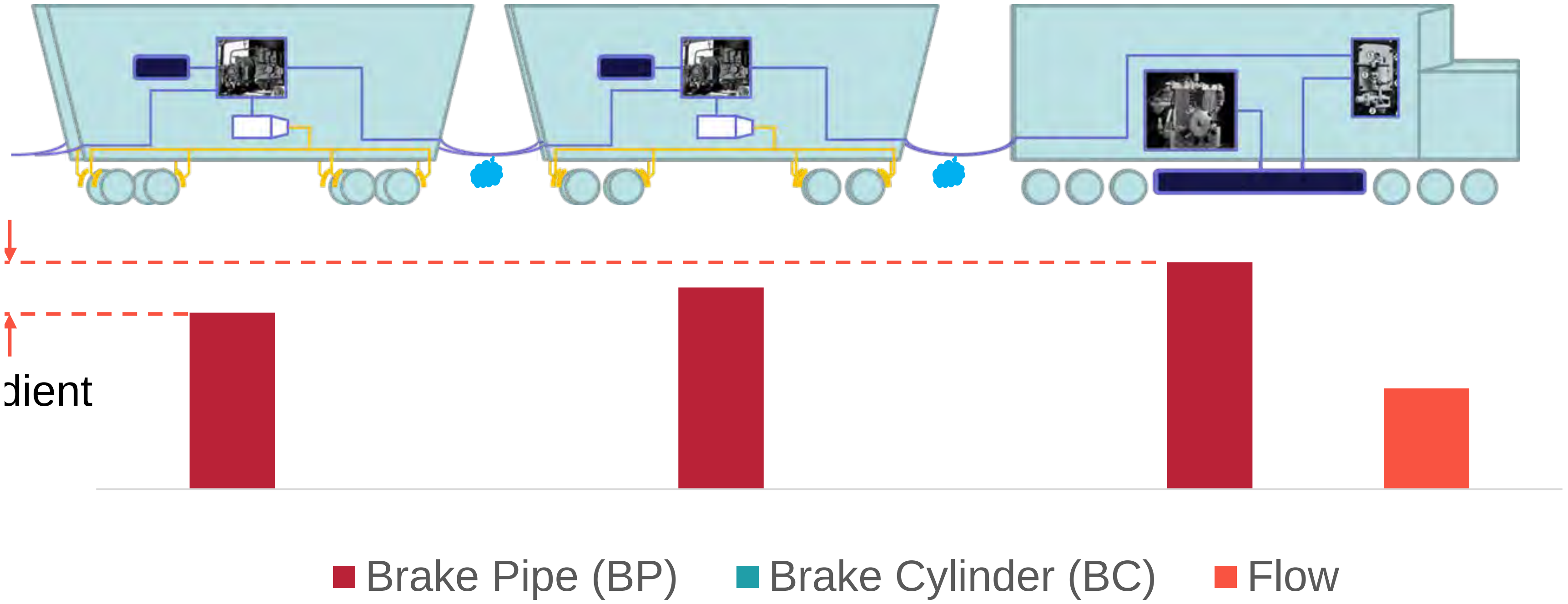




Leakage, Flow, and Gradient

- **Leakage-induced flow in the brake system**





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Effect of Brake Pipe Flow on Average Brake Cylinder Pressure

Approach

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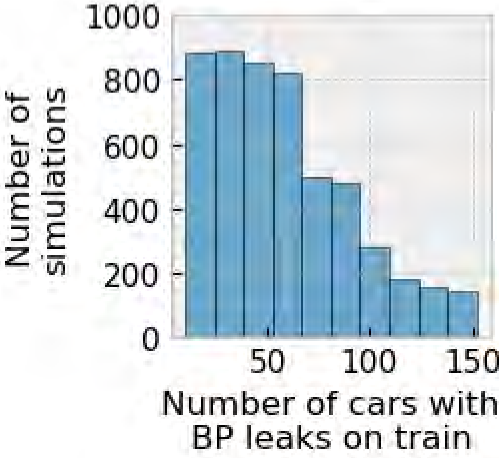
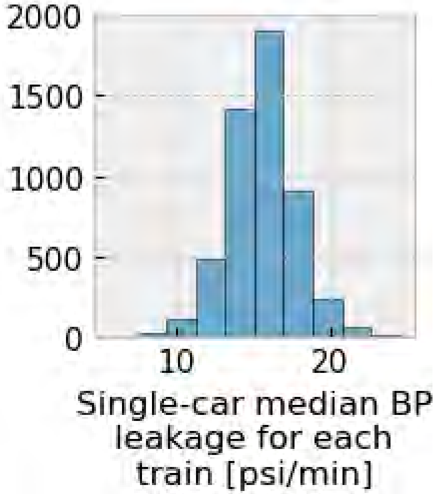
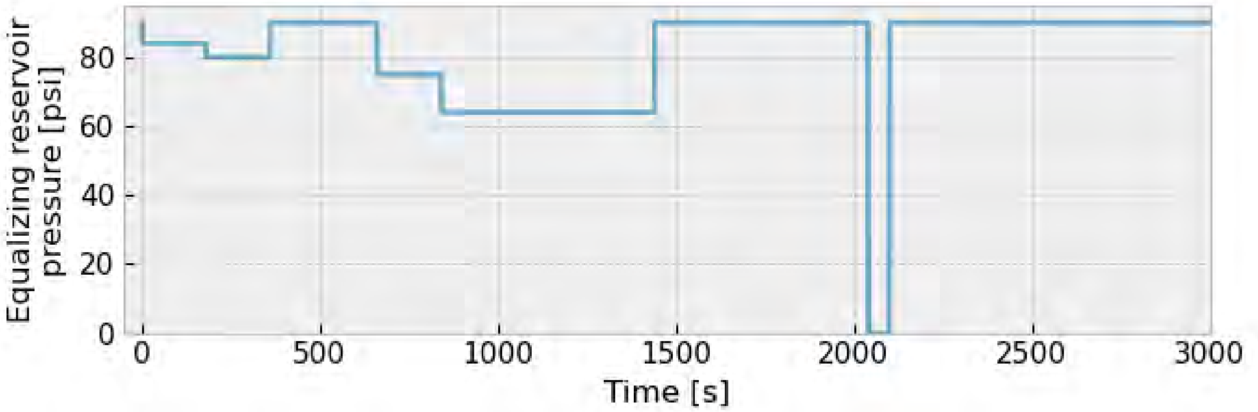
TOES™ Simulations

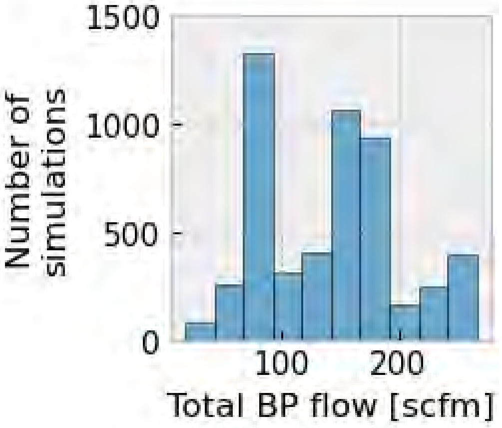
Simulation inputs

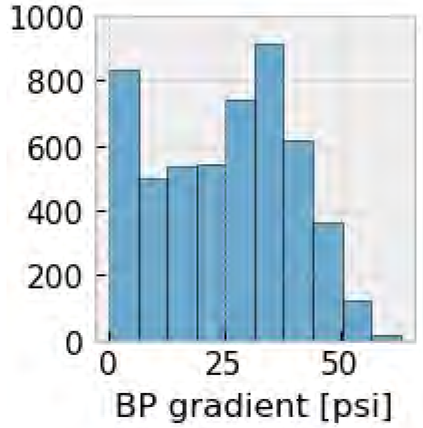






Raw outputs





Simulations further analyzed, $Flow_{max}$ ≤ 90 scfm

Simulation Consist	Simulation Count
Loco + 200 cars	495
Loco + 200 cars + rear DPU	501
Loco + 133 cars + mid-DPU + 67 cars	500
Loco + 100 cars + mid-DPU + 100 cars + rear-DPU	501

Effect of Brake Pipe Flow on Average Brake Cylinder Pressure

Results

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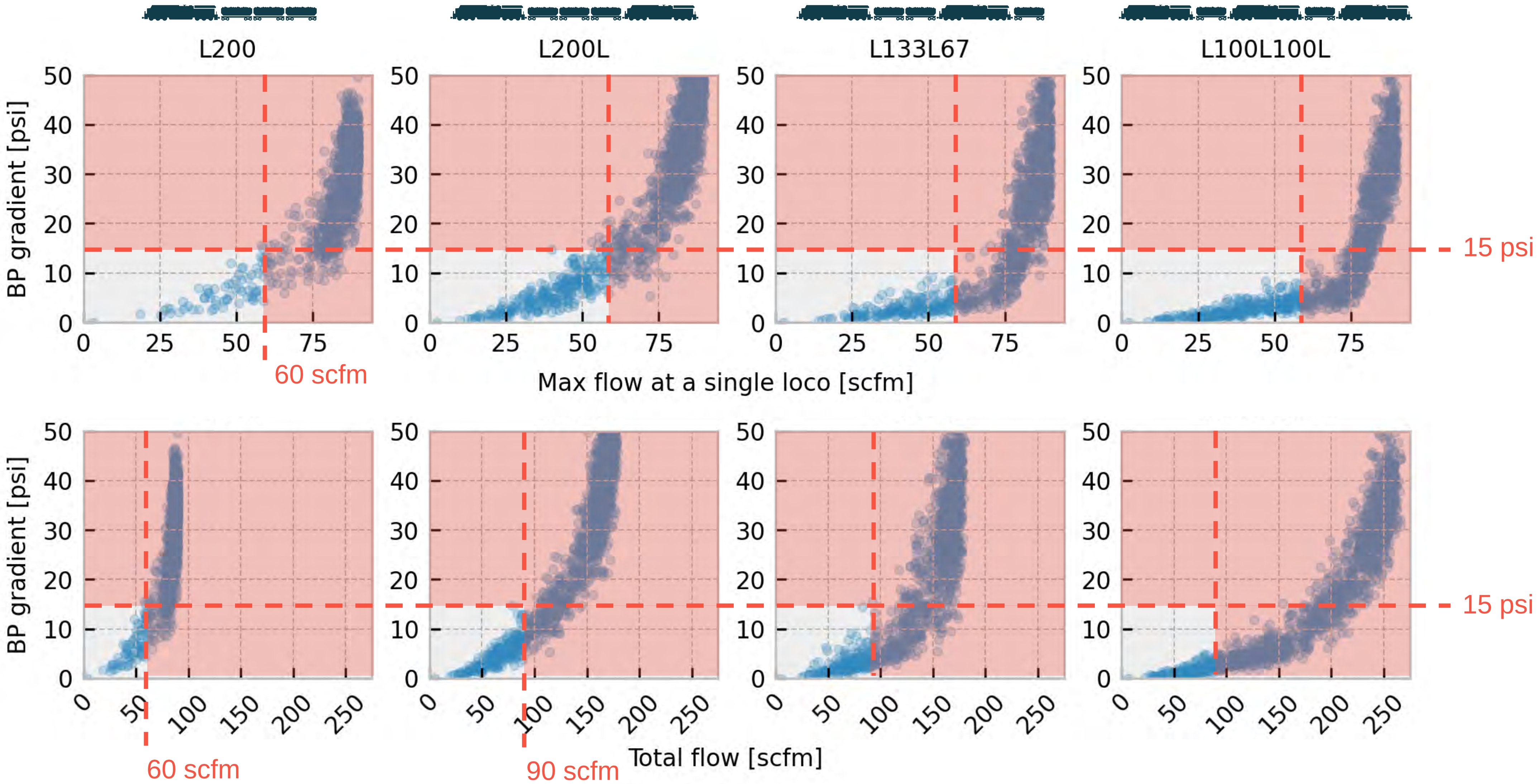
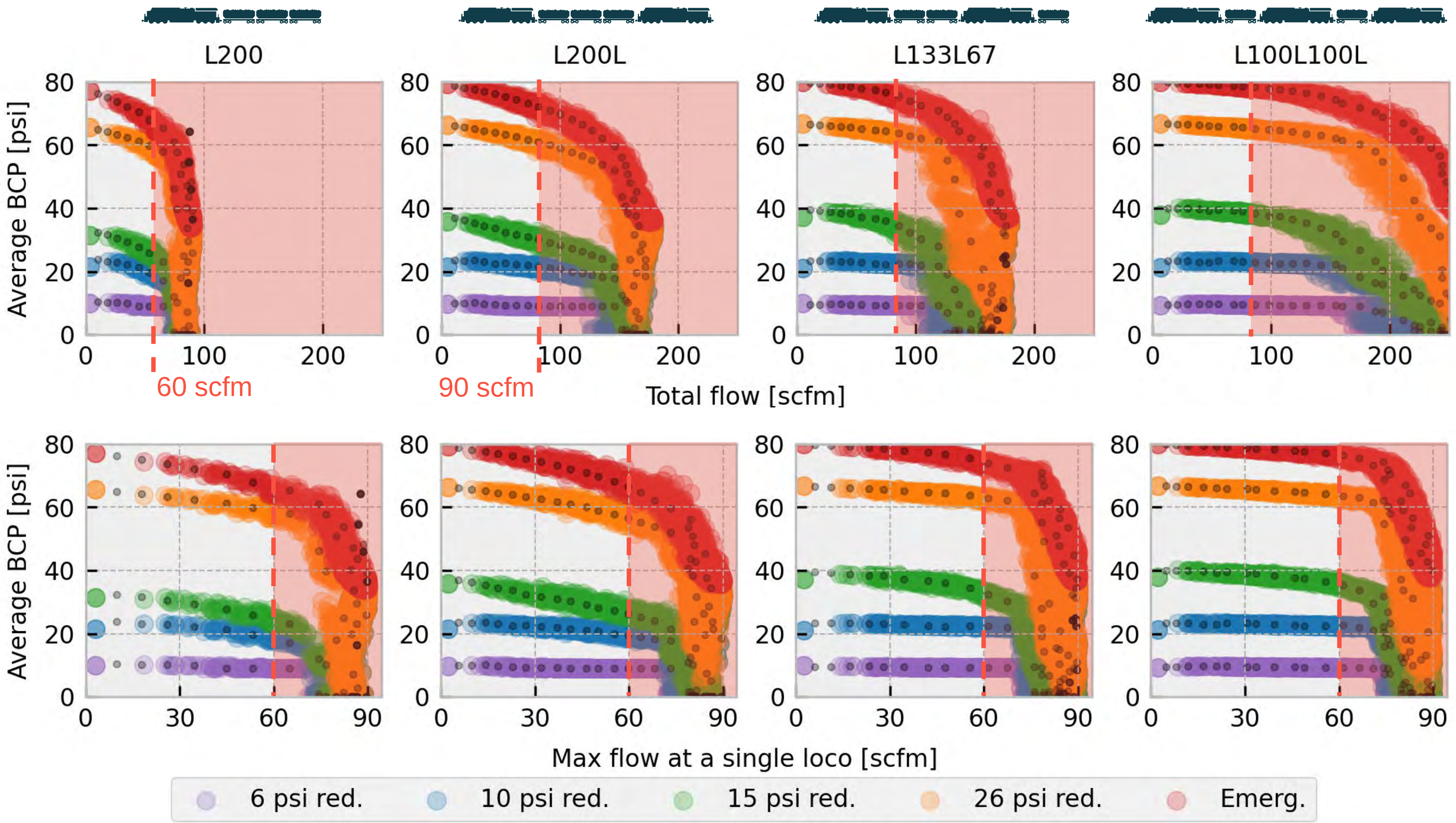
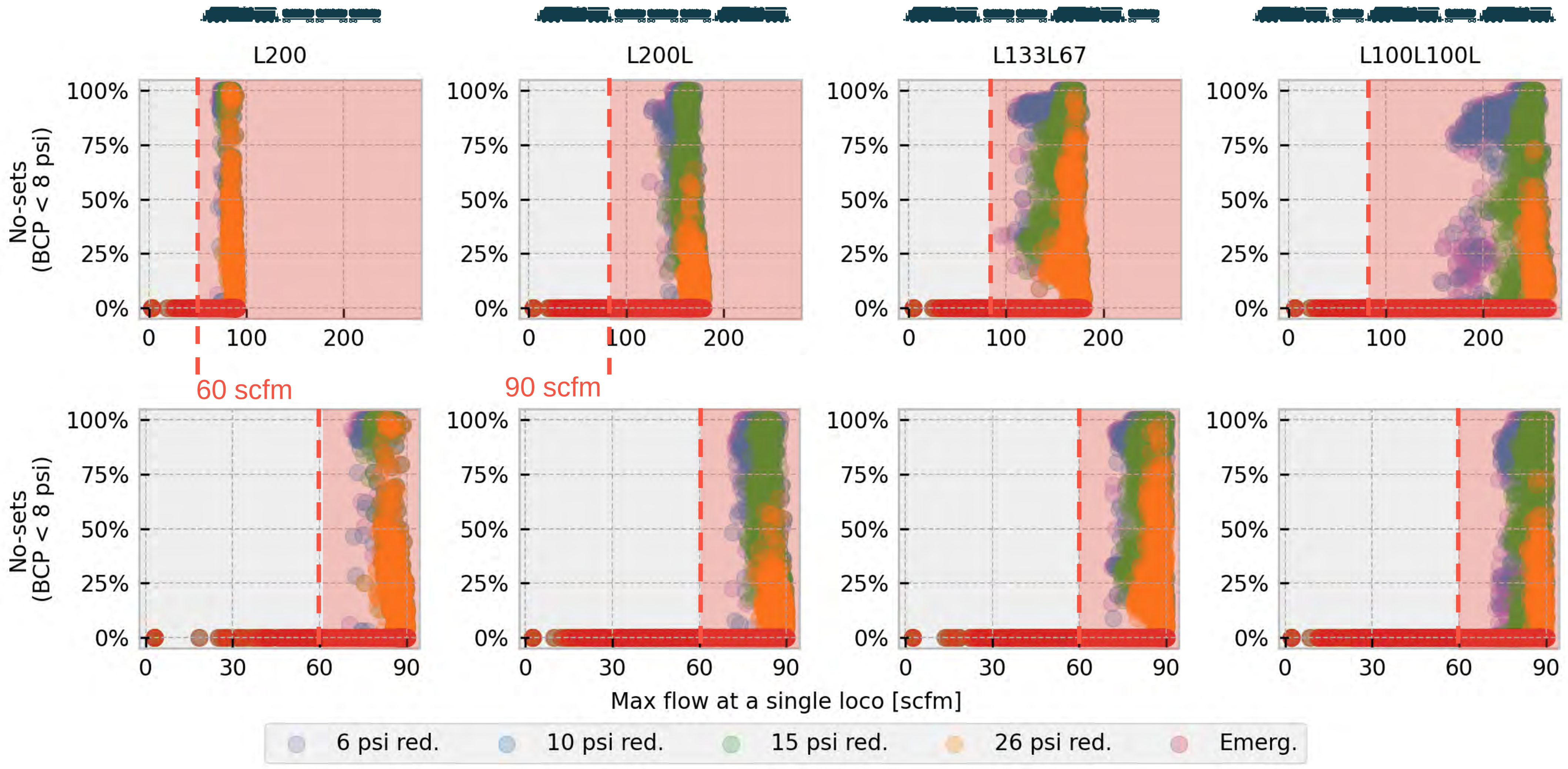
Flow vs. Gradient



Brake Cylinder Pressure (BCP)



Number of No-Sets



29TH AAR RESEARCH REVIEW

Effect of Brake Pipe Flow on Average Brake Cylinder Pressure

Summary

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Summary

- **Current maximum flow limits for a locomotive consist on a train appear conservative enough to achieve acceptable average BCP**
- **Trains with shorter BP length per air source can achieve the same average BCP at a higher flow than those with longer BP length**

Acknowledgements

- **MxV Rail colleagues: Adam Klopp, Steven Belport, Dennis Rule, and Nash Gonzalez**
- **Class 1 railroads and industry partners**

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Wheel Performance and Integrity

Kerry Jones, P.E.
Principal Investigator II

Overview

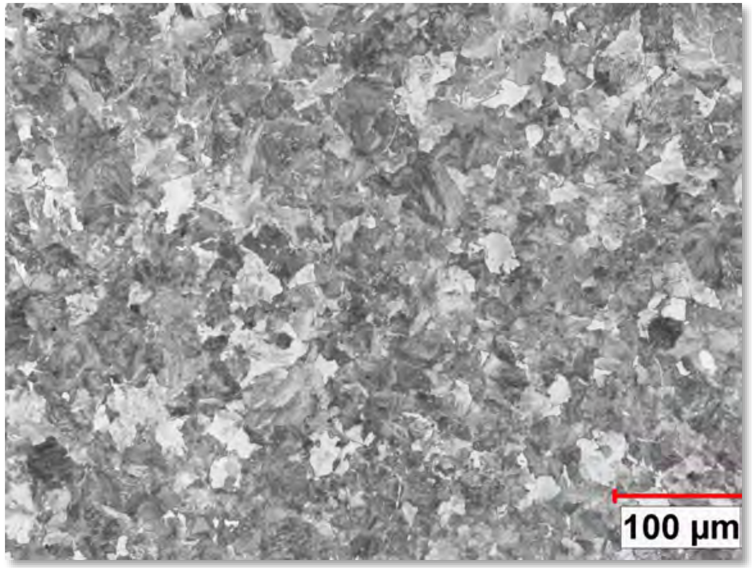
- **Current testing**
  - High Performance Wheel Test 1
  - High Performance Wheel Test 2
    - Coal, grain service
- **New testing**
  - High Performance Wheel Test 3
    - Intermodal service

29TH AAR RESEARCH REVIEW

Background

- **Definitions:**
  - Class C Wheel – The “standard” class of freight wheel in North America for several decades
  - High Performance Wheel (HPW) – A wheel made from “better performing” steel, which will resist damage and have longer life
- **Objectives:**
  - Determine which properties optimize wheel performance and extend service life
  - Reduce number of vertical split rims (VSRs), which are rare but potentially catastrophic

Vertical split rim



Pearlite microstructure in wheel

High Performance Wheel Tests 1 and 2

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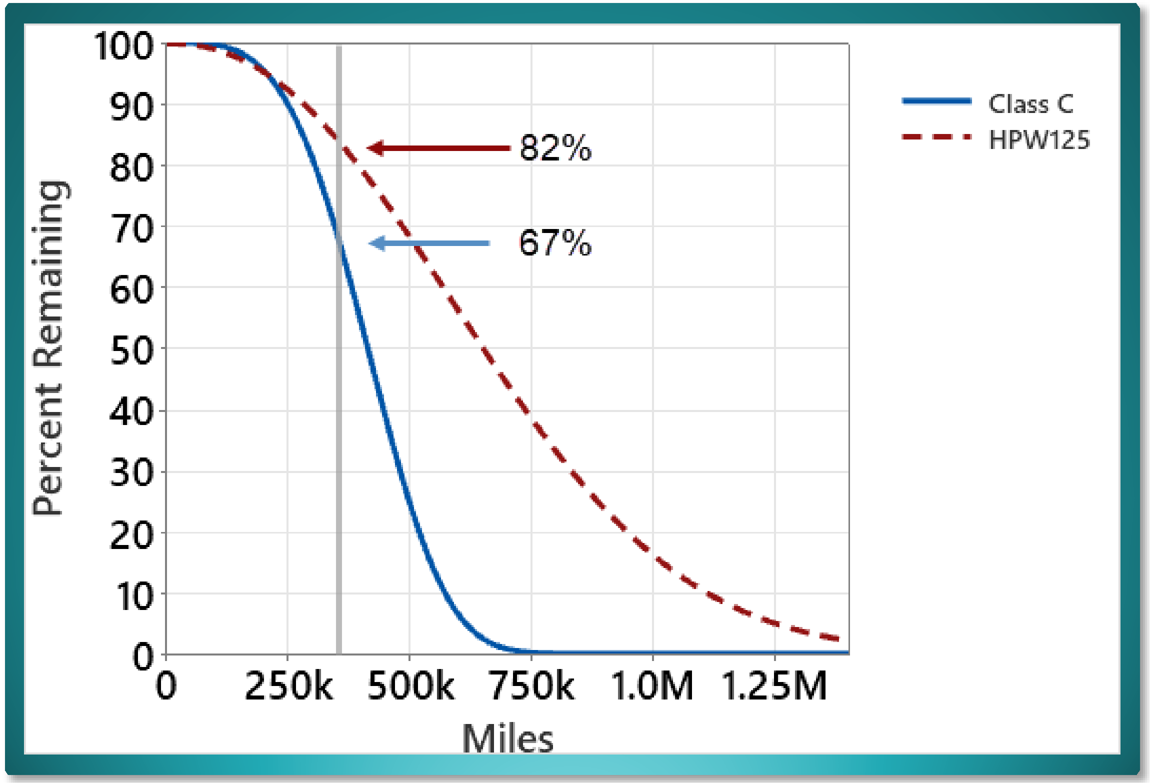
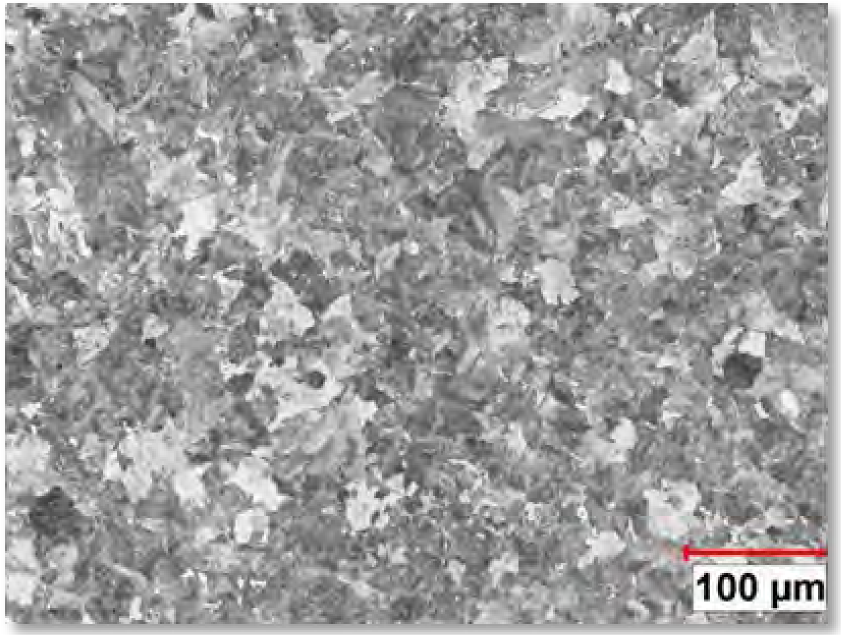
High Performance Wheel Test 1 Recap

- **First HPW test began in 2009 in coal service**
- **Seven manufacturers plus Class C**
- **Tracked high impact, shelling – 67% of Class C wheels remain**
- **82% of best three HPW1 wheel types remain**
- **Confidence intervals are wide and overlap due to relatively low HPW failure rate; no significant statistical difference**



High Performance Wheel Test 2 (HPW2)

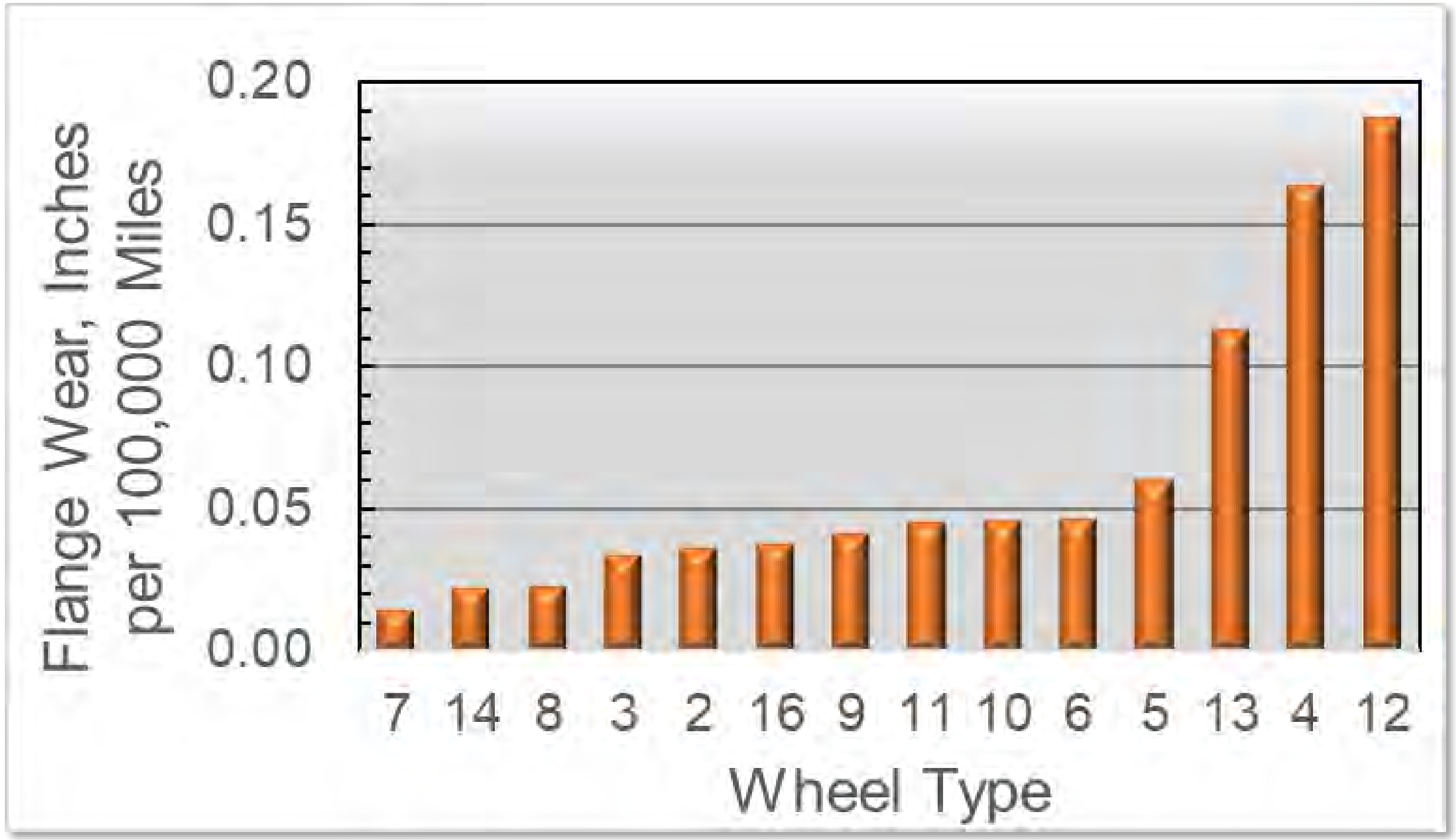
- **Fourteen different wheel steels**
- **HPW2 test phases:**
  - Laboratory testing (2017-2018)
  - On-track testing at MxV Rail's Facility for Accelerated Service Testing (FAST®)
    - 2017-Present
    - Ten similar cars, 56 test wheelsets
    - Loaded to 286,000 pounds
    - Mean of 96,500 miles accumulated
  - Revenue service under grain cars



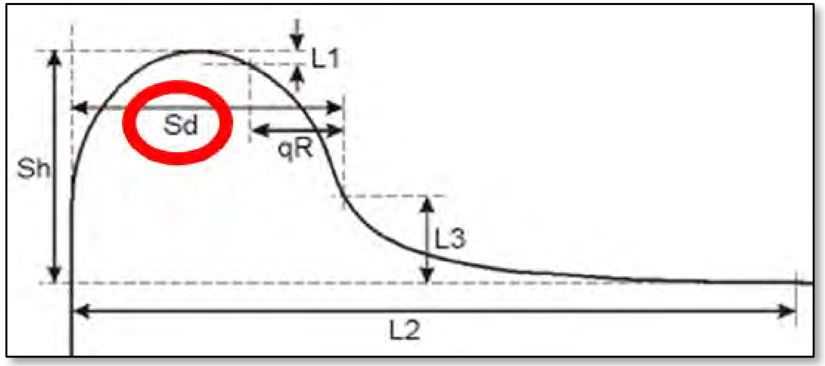
HPW2 FAST Removals

- **Seven wheels removed for subsurface fatigue defects**
  - Detected by ultrasonic testing
- **One shattered rim**
- **Two wheels reached condemnable flange thickness limit**

HPW2 FAST Wear Data

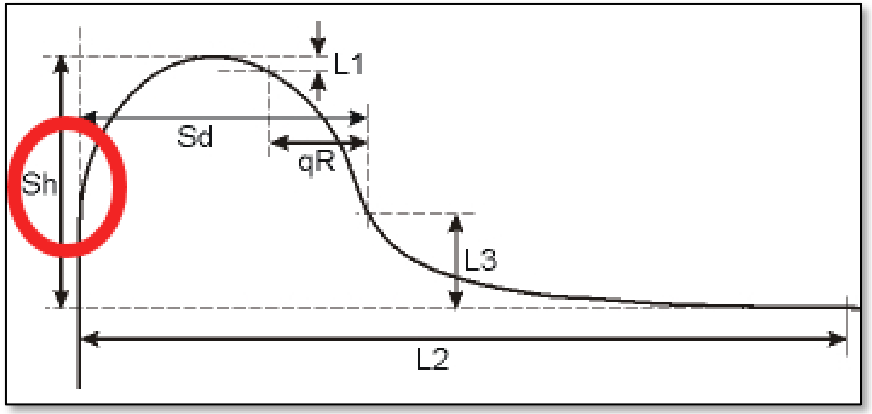


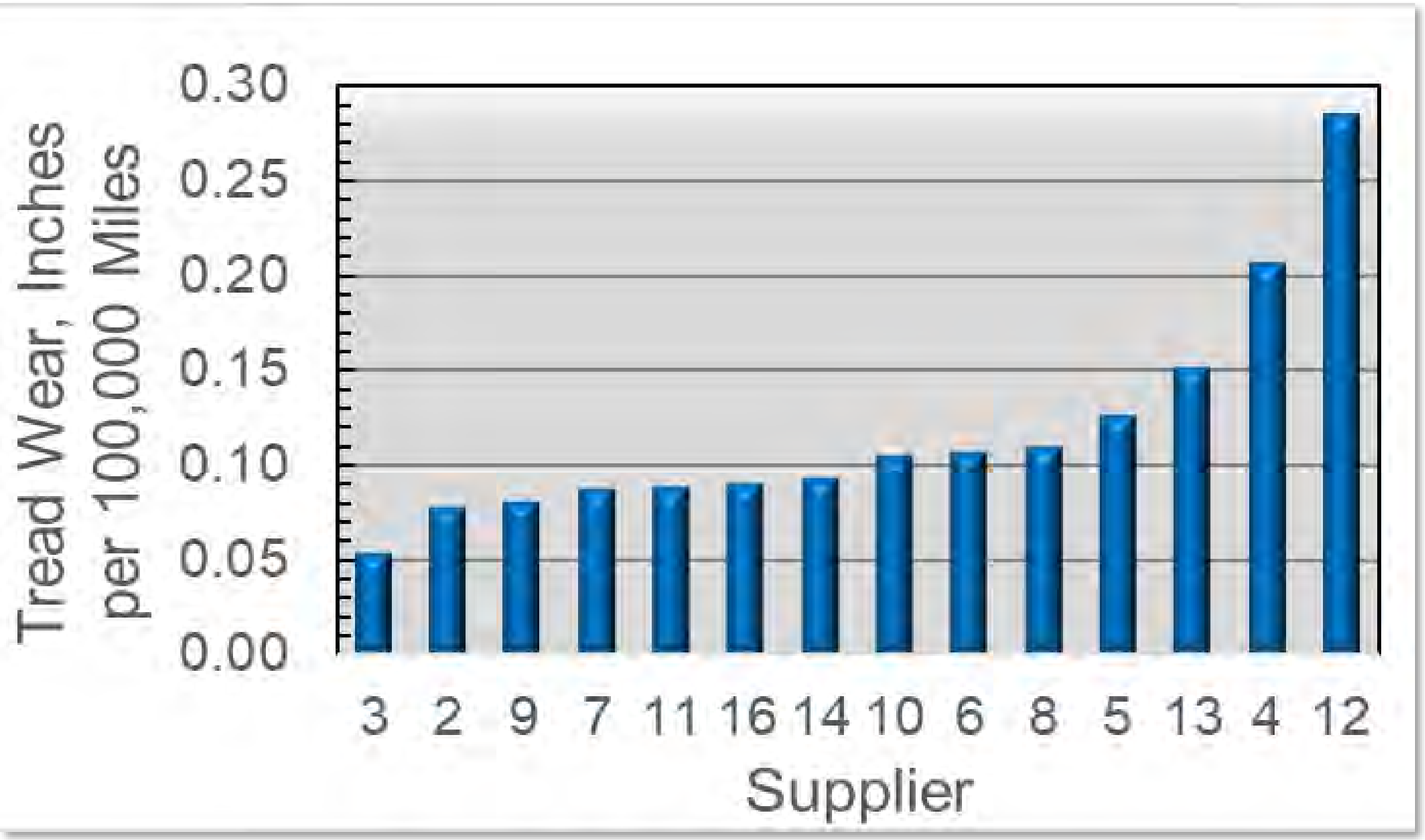
- **Normalized flange wear (wear divided by miles traveled)**



HPW2 FAST Wear Data

- **Normalized tread wear (wear divided by miles traveled)**





HPW2 Revenue Service Test Mileage

- **Six HPW2 manufacturers in this test**
  - Most supplied 25 wheelsets
- **44 AAR Class C wheelsets**
- **Some wheelsets have been removed, but removal causes not available for each wheelset**
- **Some wheelsets removed for non-wheel issues**

Manufacturer	Average Miles
3	193,800
6	136,900
10	111,100
11	117,400
13	153,300
16	144,200
AAR Class C	160,000

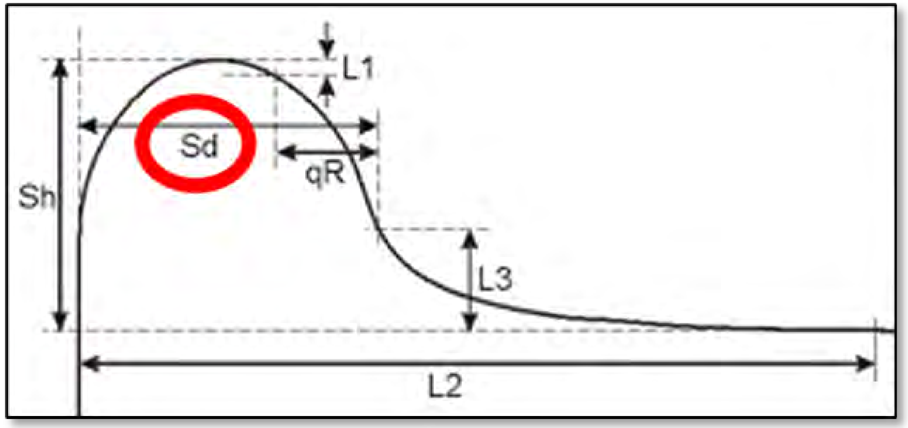
HPW2 Revenue Service Wear

- **Wear results at FAST obtained by contact profilometer**
- **In revenue service, wheel profile detectors (WPDs) are used**
  - WPDs use wayside lasers to measure flange width, flange height, rim thickness, and tread hollowing
- **Not every wheelset crossed profile detectors at regular intervals**
- **The Class C wheels did not have enough detector passes to create a valid data set**

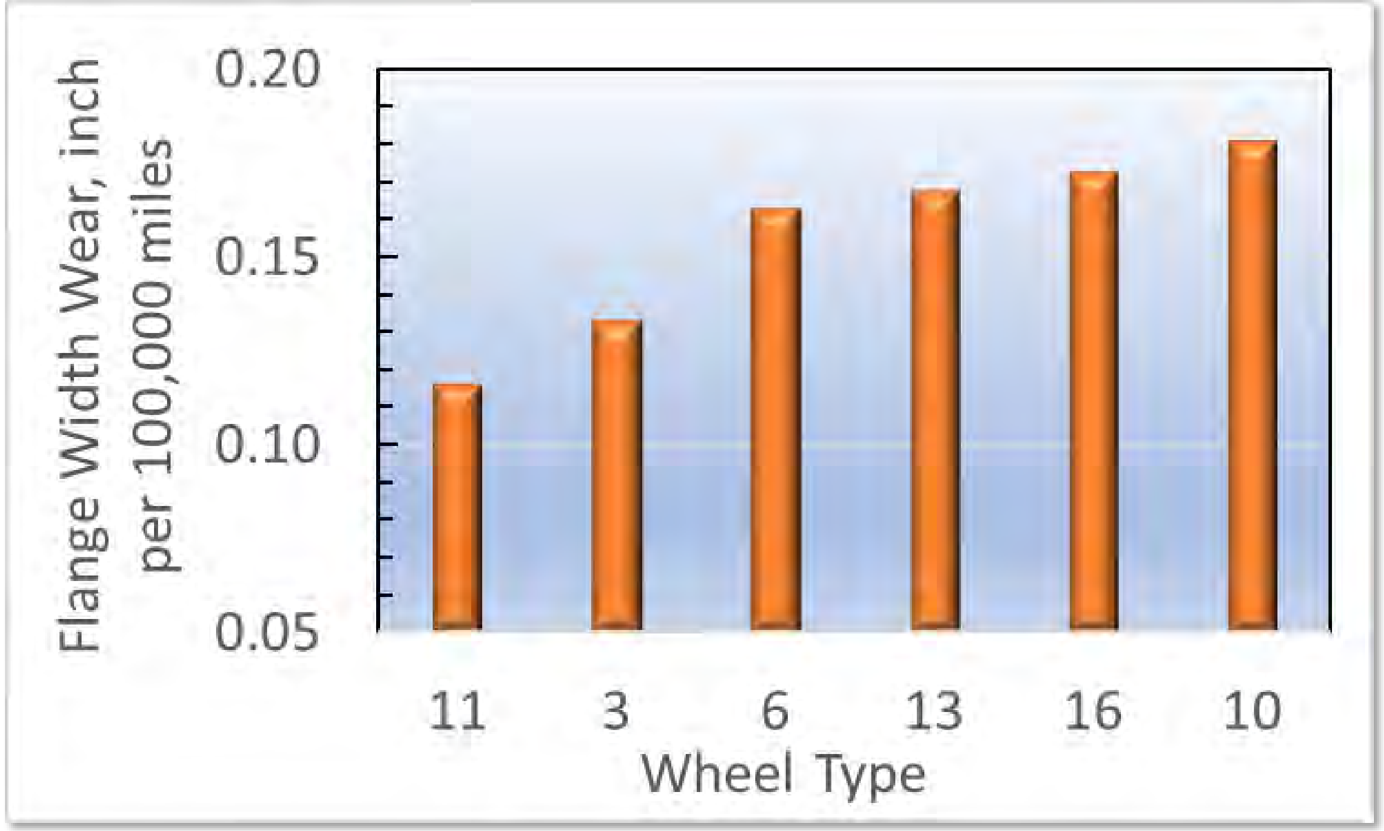
Photo credit: www.railway-technology.com

HPW2 Revenue Service Wear

- **Flange width wear:**
  - No statistical difference among HPWs

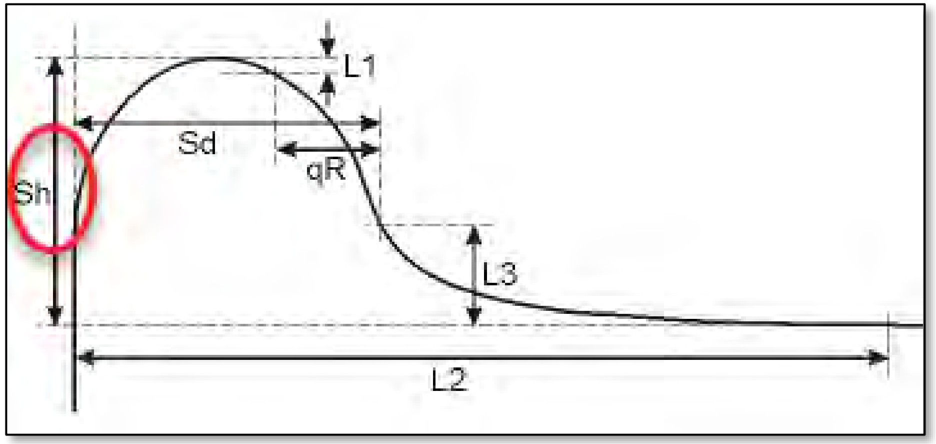


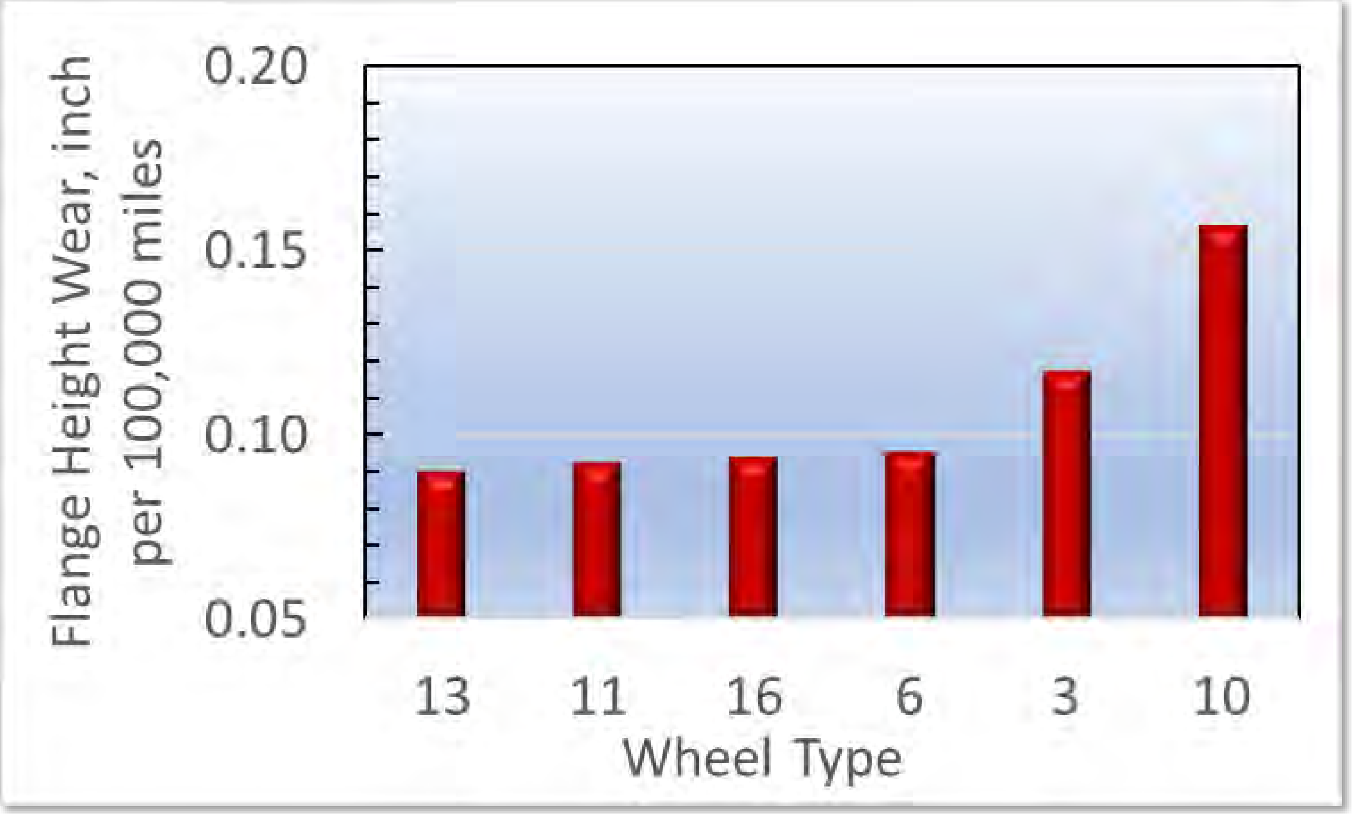
- **Rim thickness wear:**
  - No statistical difference among HPWs



HPW2 Revenue Service Wear

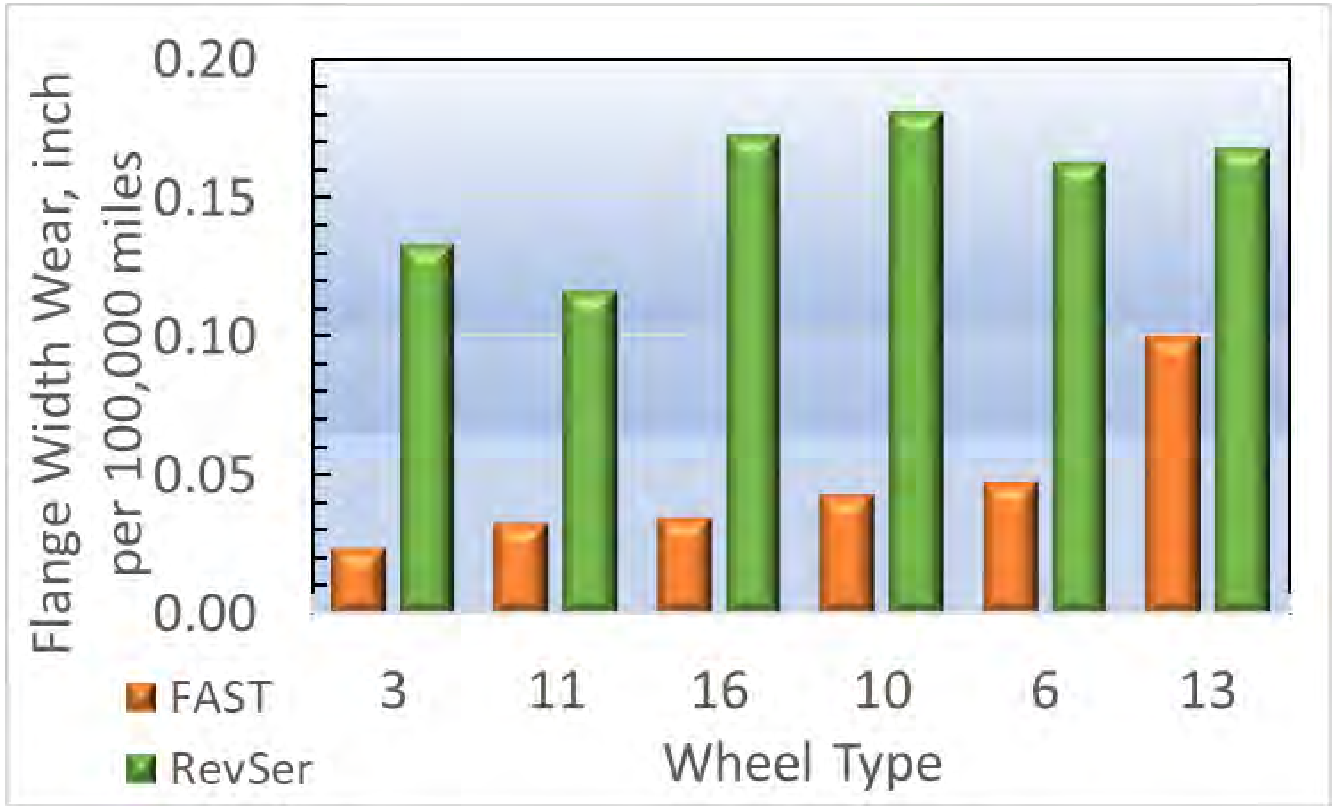
- **Flange height wear rate:**
  - Type 10 showed statistically higher wear than types 11, 13, and 16





- **Tread hollow:**
  - Types 3 and 13 had higher wear

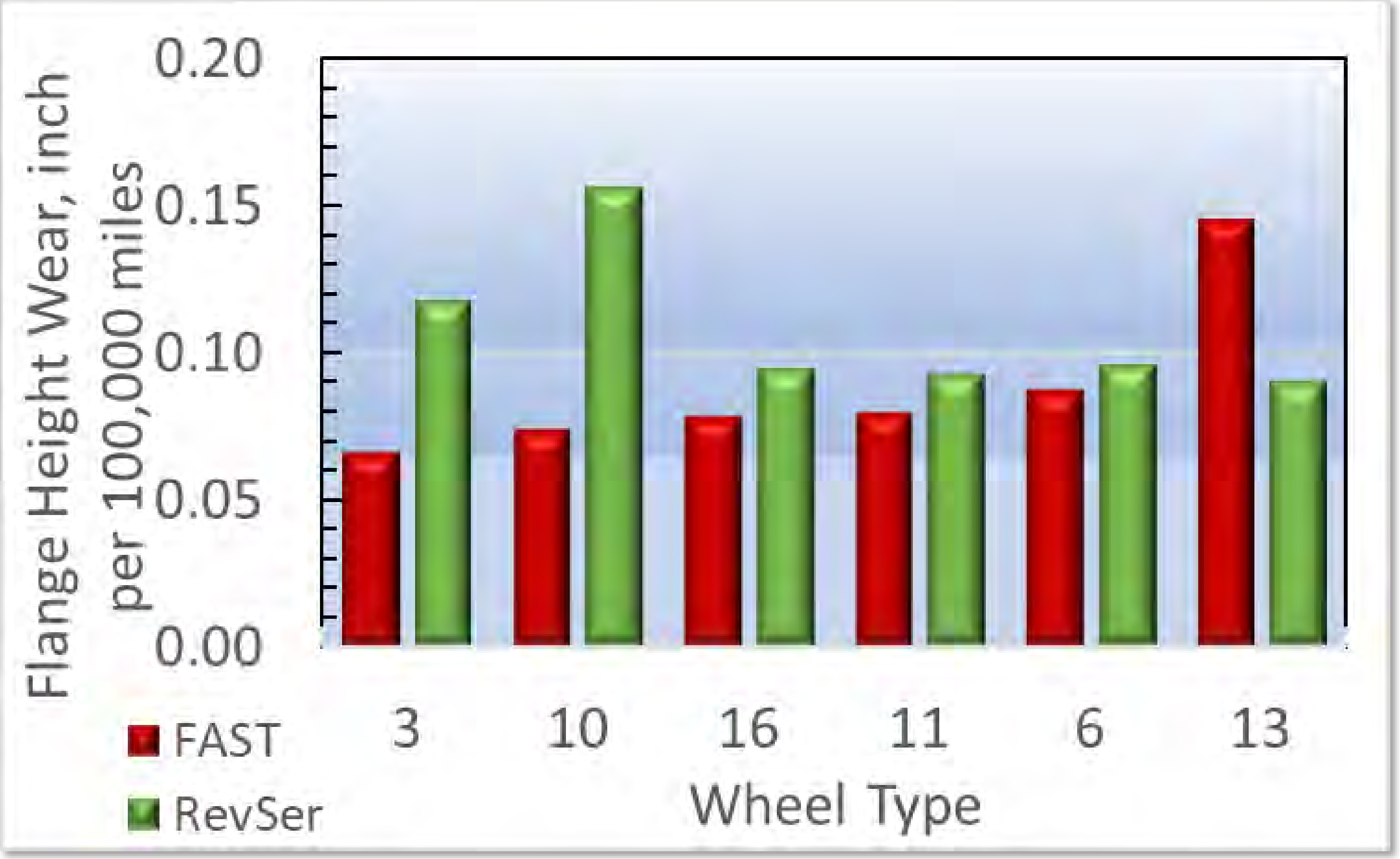
FAST vs. Revenue Service Wear: Flange Width



- **WPD measurements were 1.5 to 6 times higher than those at FAST**
- **WPD measurements were generally proportional to FAST measurements**

FAST vs. Revenue Service Wear: Flange Height

- **Most WPD measurements were generally closer to values from FAST**
- **Type 3 had lowest wear for flange width and height**
- **Types 6 and 13 had highest wear for flange width and height**



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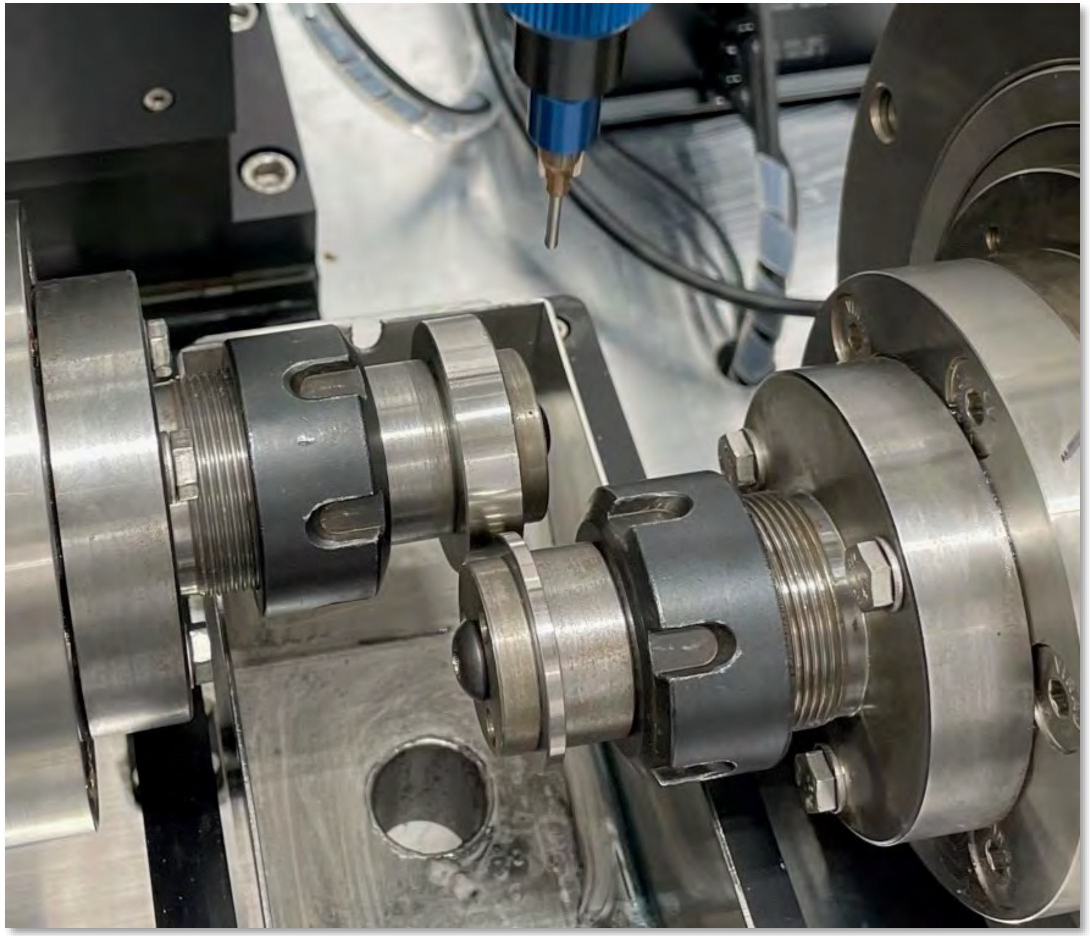
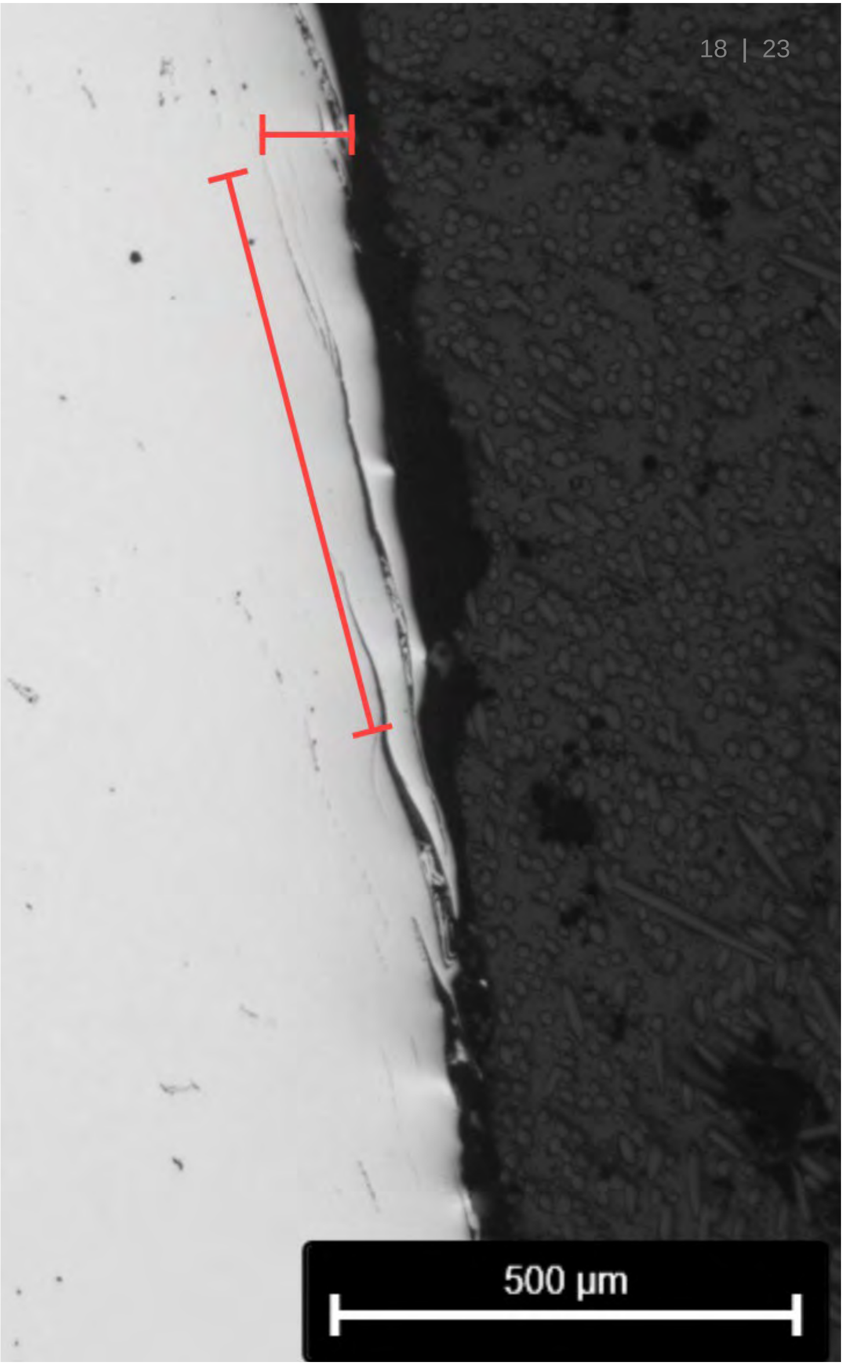
HPW2 Twin Disk Testing: UTM 5000 Twin Disk Tribometer

- **Simulate wheel-rail interface on a small scale**
  - Samples under 2 inches diameter
  - Samples extracted from rails and wheels
  - Inputs: Force, rotation speeds (to simulate slip), lubrication
  - Machine output: displacement, torque, coefficient of friction
  - Sample output: mass loss, visual condition, crack morphology



HPW2 Twin Disk Testing: Wear and Subsurface Fatigue

- **Wear – Relative wear rates**
  - Measure mass loss of HPW2 and Class C wheels against intermediate strength rails
  - Polish cross-sections to measure resulting surface crack length and depth
- **Fatigue – Subsurface cracks**
  - Use NDE to determine cycles to subsurface crack initiation
  - Polish cross-sections to measure resulting surface crack length and depth



High Performance Wheel Test 3

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High Performance Wheel Test 3 (HPW3)

- **Objective: Test 38-inch diameter Class D wheels in intermodal service**
- **Represents a very different service environment compared to previous tests**
- **Wheels on articulated trucks**

HPW3

- **HPW3 suppliers: Amsted Rail, Ma Steel, Nippon Steel, Taiyuan Heavy Machinery Group**
- **First phase: Laboratory testing beginning 2024 Q2**
- **Second phase: On-track testing at FAST under 315,000-pound cars**
  - Minimum of 10,000 miles before beginning revenue service test
  - Frequent visual and ultrasonic testing
- **Third phase: Installation on articulated trucks under TTX intermodal cars**

Summary

- **HPW1 Test**
  - 67% of Class C wheels remain; 82% of HPW1 wheels remain
- **HPW2 Revenue Service Test**
  - HPW2 wheels have accumulated 150,000 miles
  - Class C wheels have accumulated 160,000 miles
  - Type 10 has greater flange height wear
  - Types 3 and 13 have greater tread hollowing
  - No statistical difference in flange thickness or rim thickness wear
- **HPW3 Test**
  - Testing 38-inch Class D wheels beginning Q2 2024

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Acknowledgements

- Union Pacific Railroad
- TTX Company
- Railinc
- Wheel manufacturers participating in HPW1, HPW2, and HPW3
- MxV Rail team

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Measuring Wheel Impact Loads

Nate Stoehr
Principal Systems Engineer I

Wheel/Rail Force-based Validation

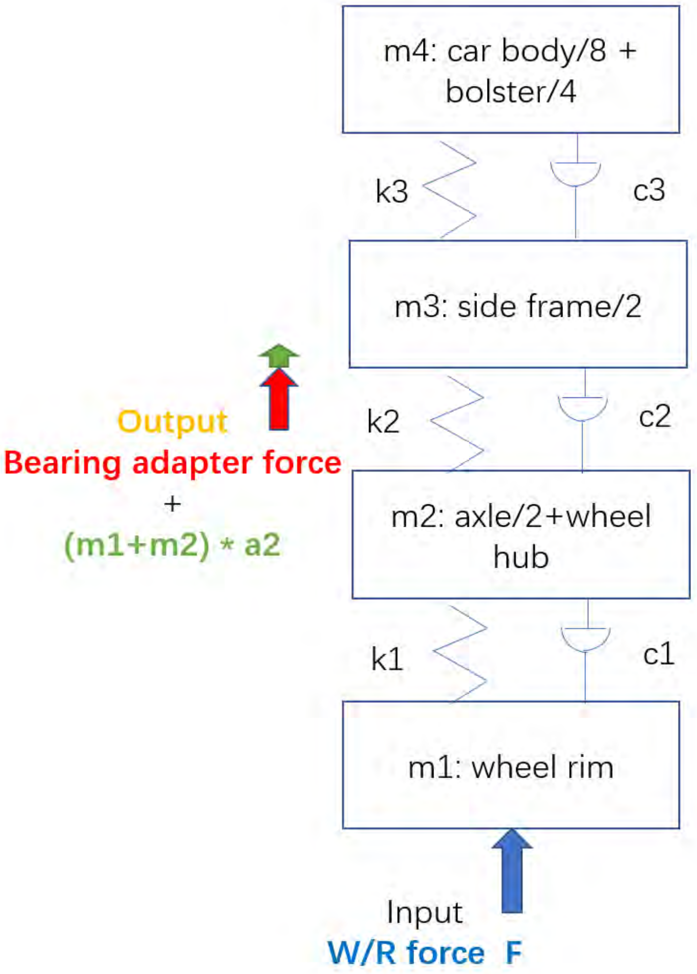
- **Industry desires validation of alternative WILD technologies**
  - Requires updates to AAR Standards
    - S-6101: Detector Validation and Calibration Requirements
  - Dynamic calibration/validation method applicable to any WILD technology
    - Traditional static calibration not always suitable
    - Anticipate on-board sensors in the near future
  - Requires benchmark measurement of the wheel/rail impact load
    - Dynamic measurement of transient peaks is tricky

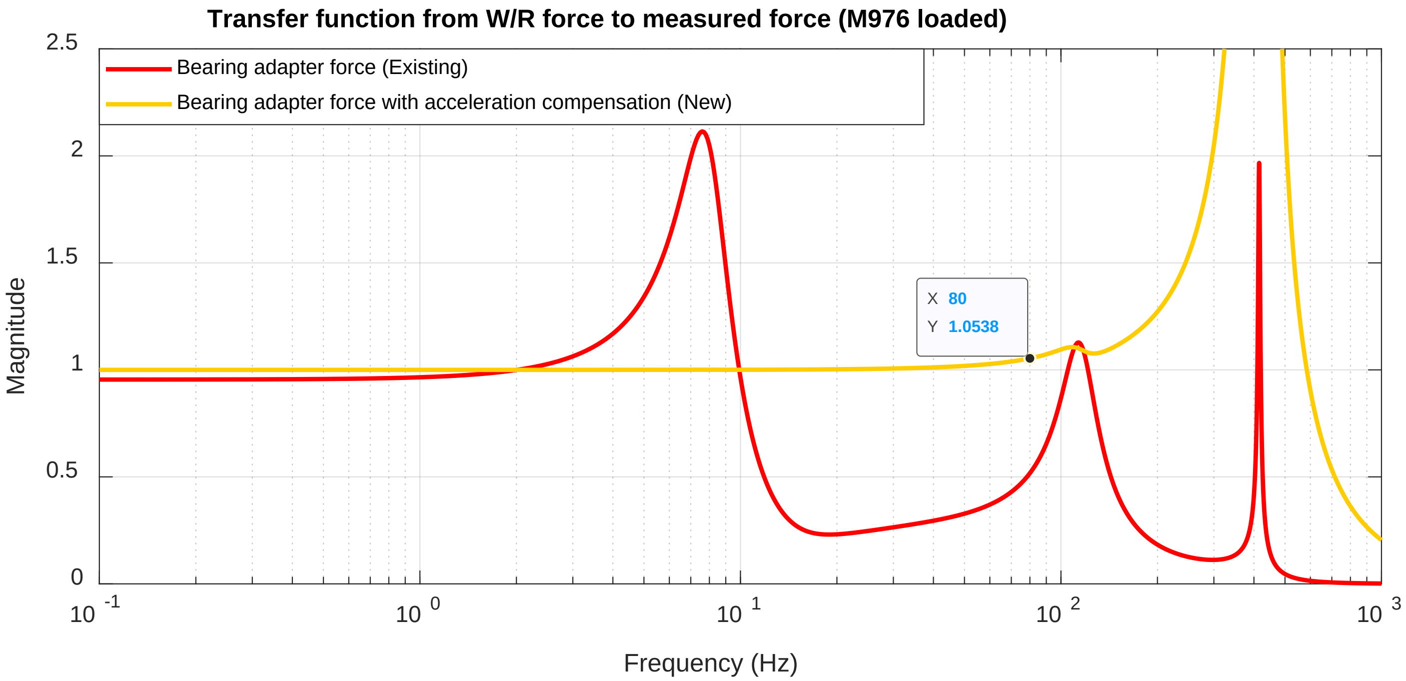
Methods to Benchmark W/R Impact Force

- **MxV Rail adopted a three-tiered approach:**
  - High Accuracy In-Track Circuit (HAC)
    - Impact magnitude from track side at one location
  - On-board measurement of wheel impact load (NBA)
    - Relative magnitude and precise location of every wheel impact event
  - Instrumented Wheelset (IWS)
    - Familiar measurement for wheel/rail force
    - Requires an artificial bump on the rail to create controlled impact
- **All systems synchronized using auto-locating devices (ALD)**
    - Reflectors and optic sensors on the track and on the test car

New Bearing Adapter – On-board Method

Bearing adapter force with acceleration compensation (NBA) – good transmissibility to 80Hz





$$\frac{(m_1+m_2)\times x_{2s}\times s^2 + c_2\times(x_{2s}-x_{3s})\times s + k_2\times(x_{2s}-x_{3s})}{F_s}$$

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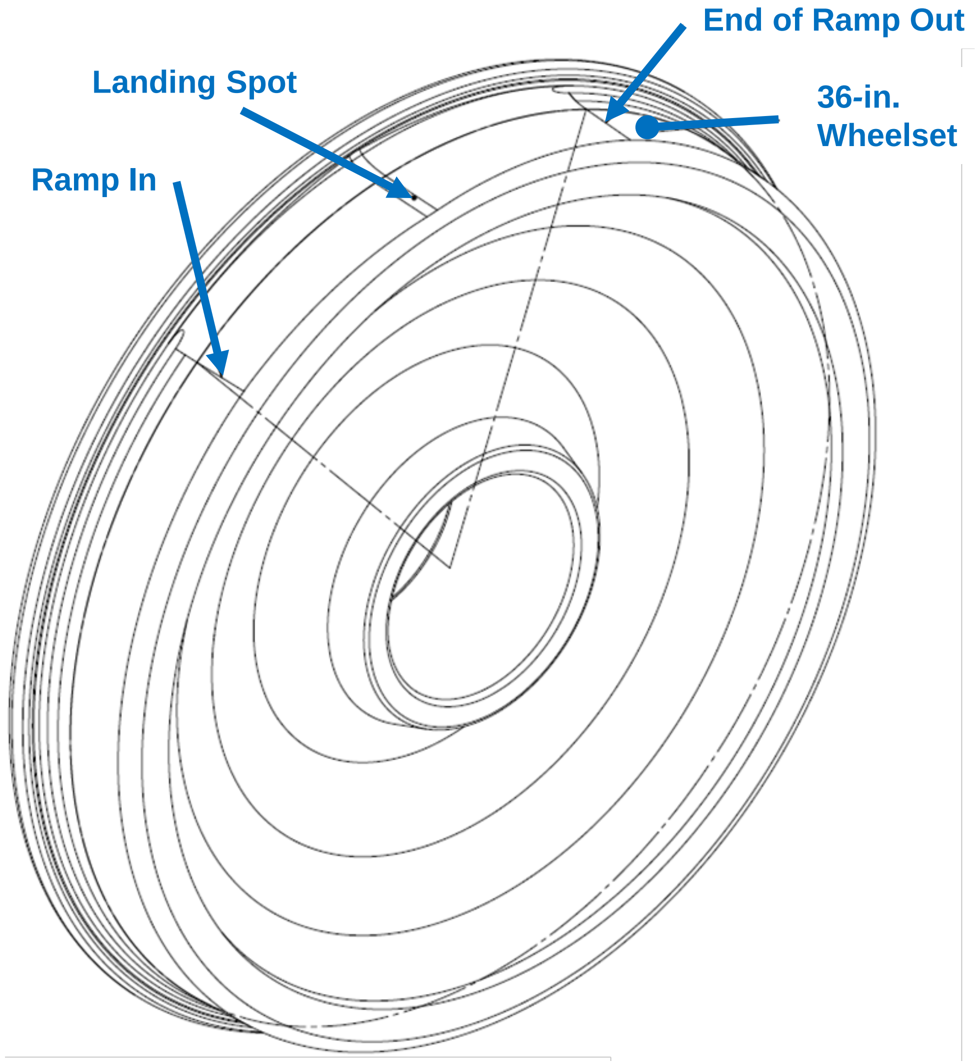
Engineered Wheel Defect



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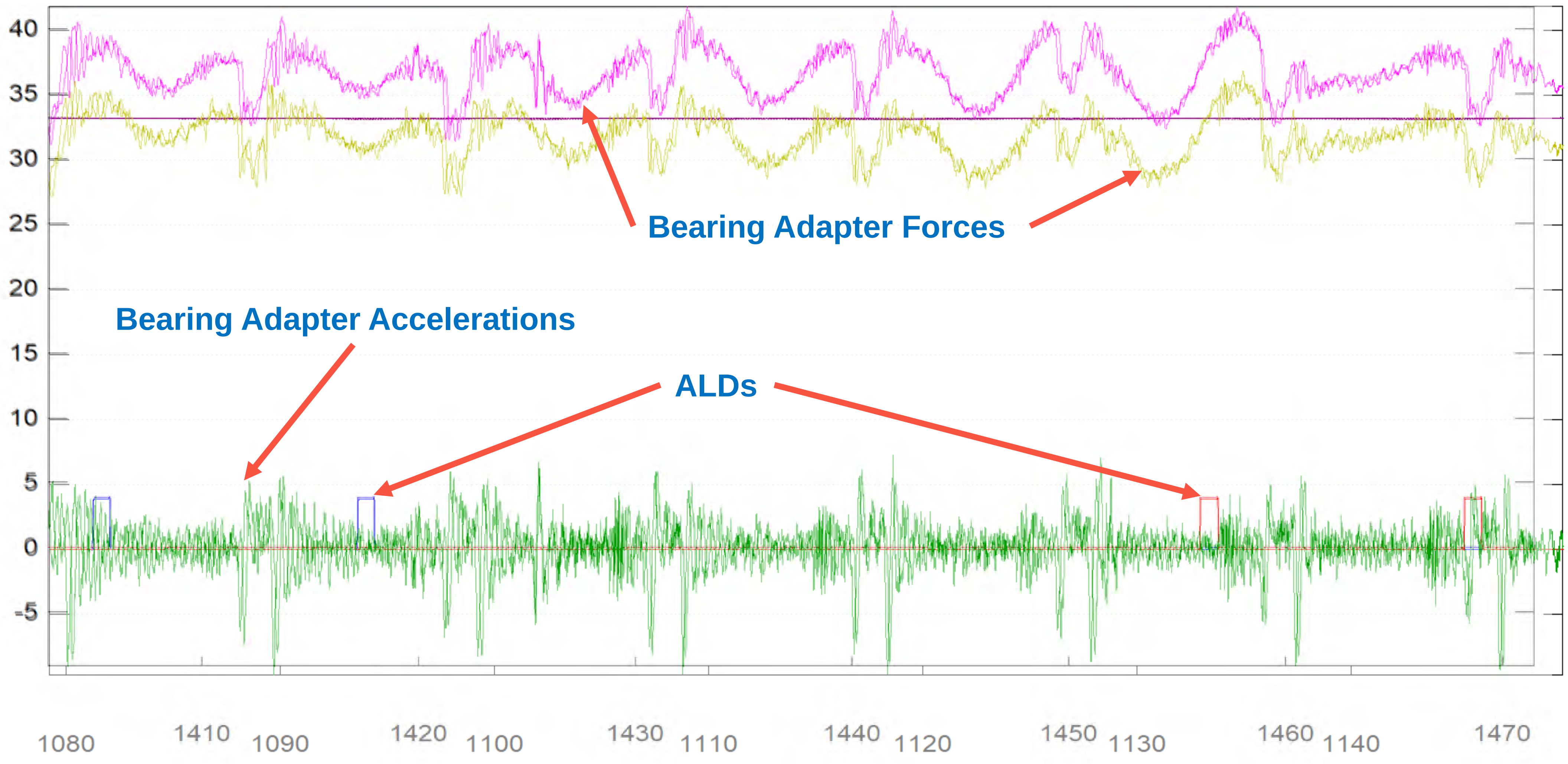
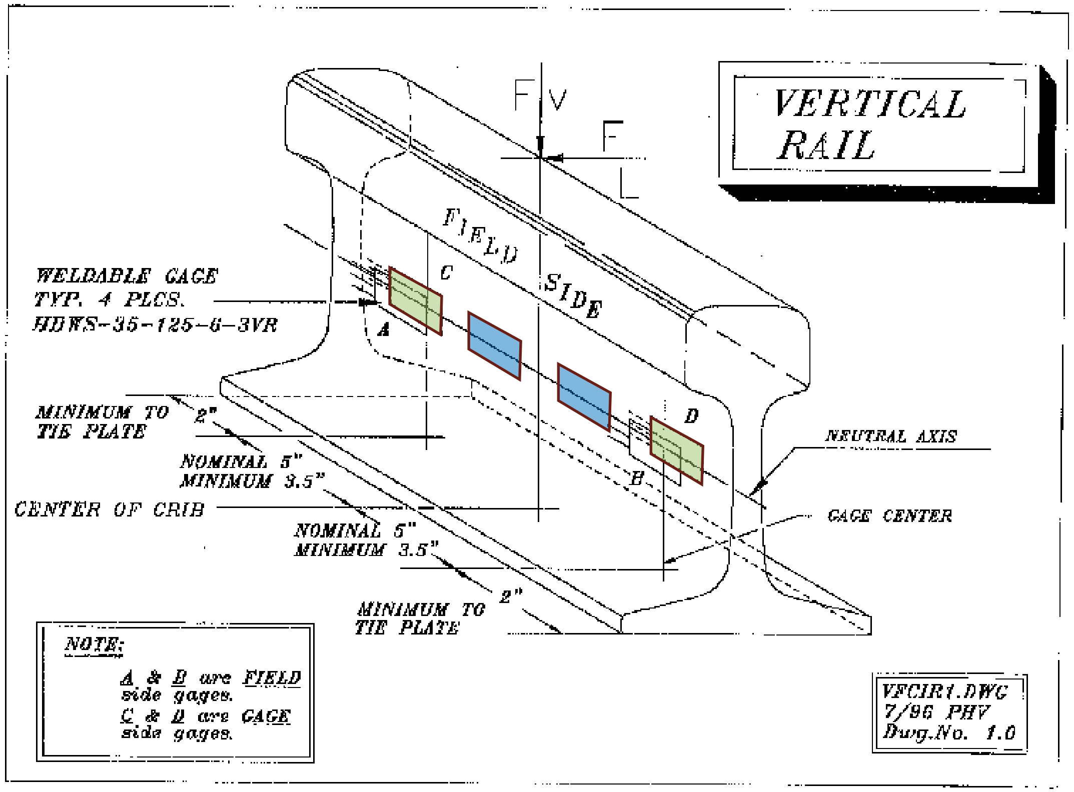
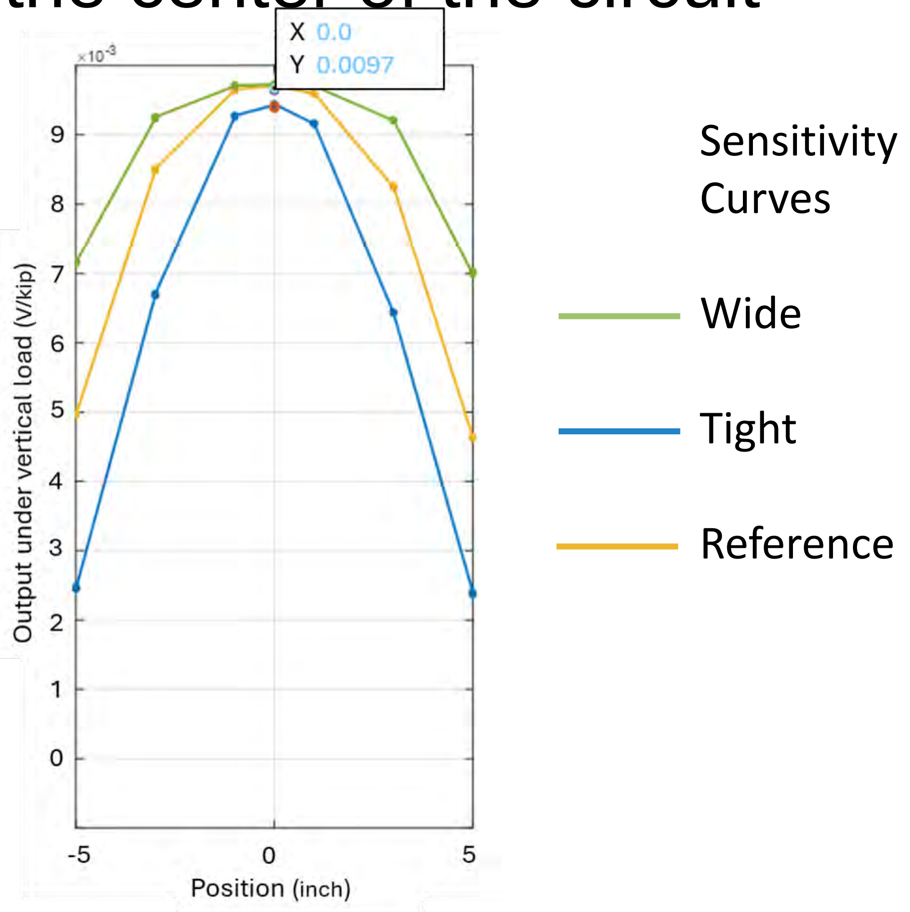
Behavior of the Engineered Wheel Defect



In-track Circuit

- **Existing WILD is based on classical shear differential method**
  - –Performs well when W/R contact is on the center of the circuit





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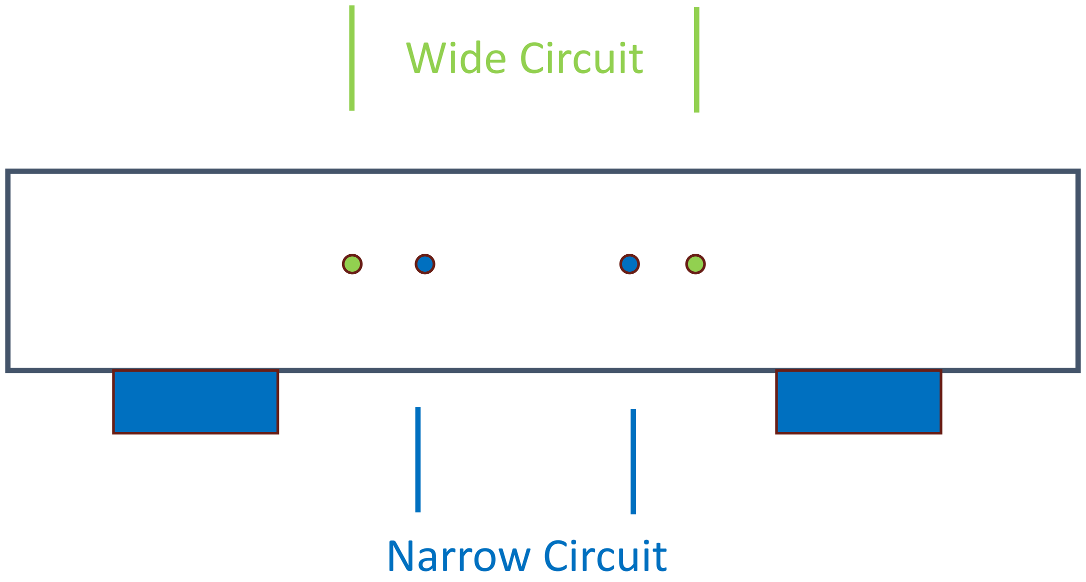
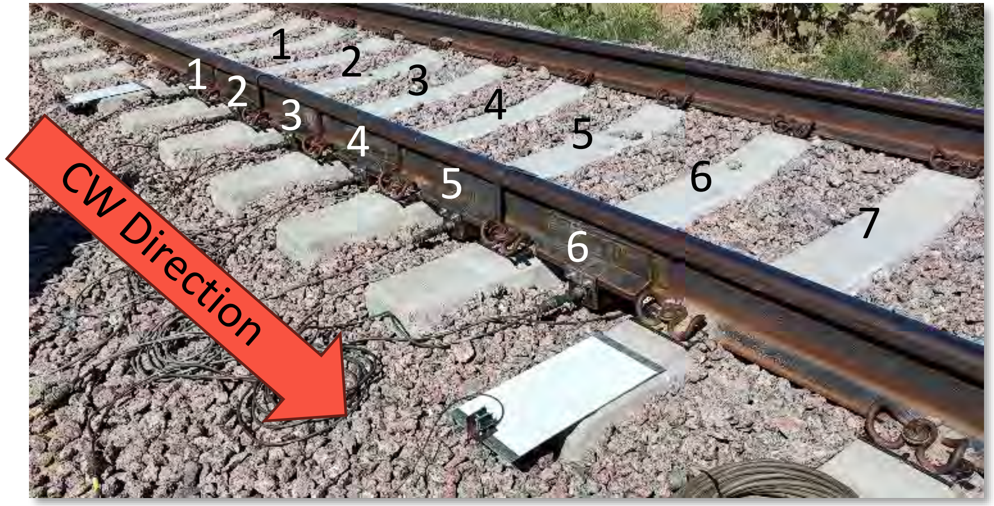
New Wayside High Accuracy Circuit

- **High accuracy vertical circuit (HAC, Bi-circuit)**
  - Two vertical circuits with different gauge distances per crib
  - Identifies the W/R contact position along the rail
  - Get high accuracy W/R vertical force
    - Compensated by location of load application



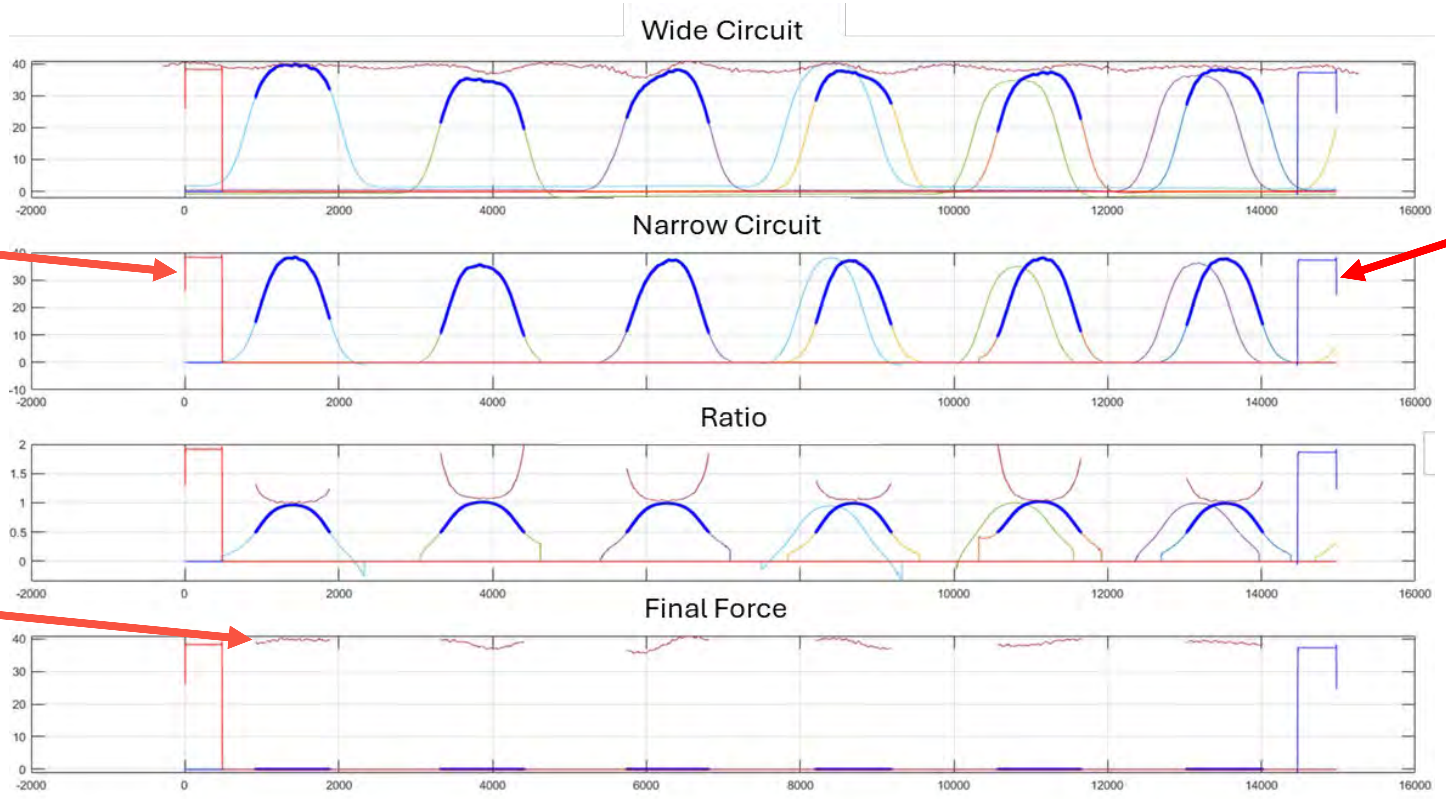


In-track Measurements – Bi-Circuit

ALD Tie 1

ALD Tie 7

Compensated Load



- **Ratio between wide and narrow circuits is stable**
- **Use this relationship to determine where the wheel is in the crib**
- **Then compensate applied load with the calibration curve based on location**

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Test Layout (Onboard)

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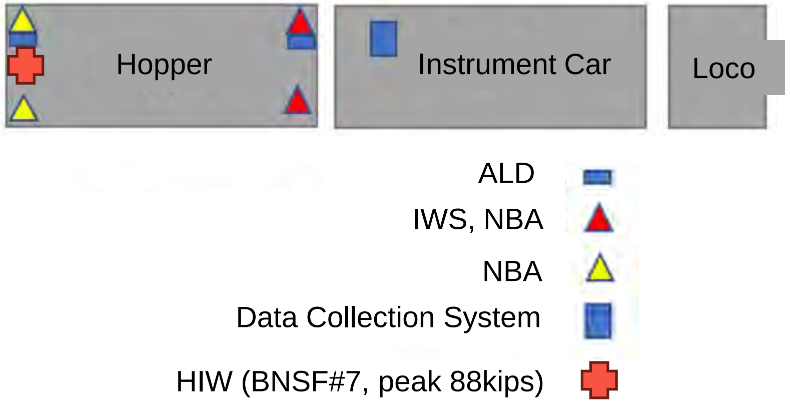
Onboard ALD
(Both ends of car)

HIW (Trail Axle)
BN7 from
Service

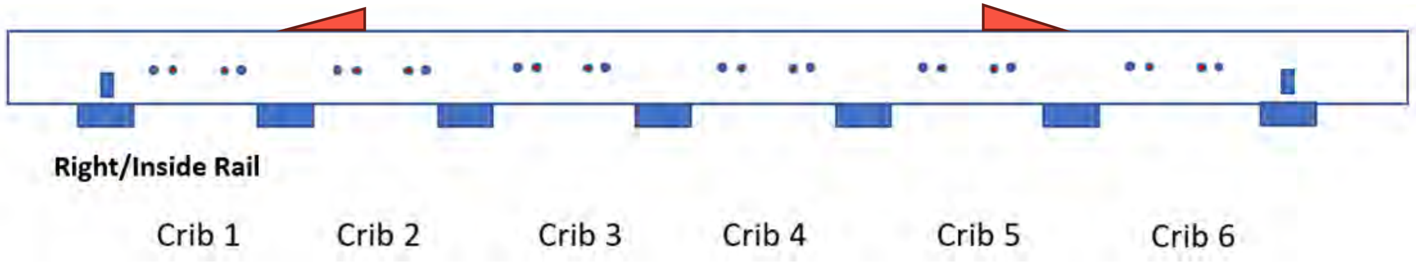
IBA with
Accel (NBA)

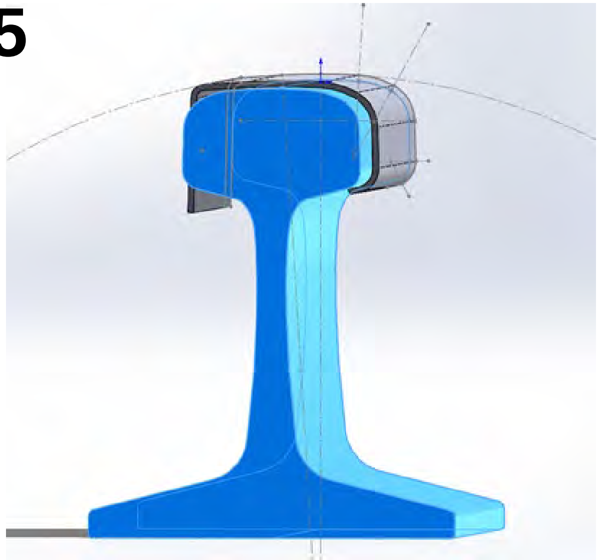
IWS (Lead
Axle)



Test layout (wayside – IWS impact)

- **Ramped rail bumps (RRB) on crib 2 and crib 5**



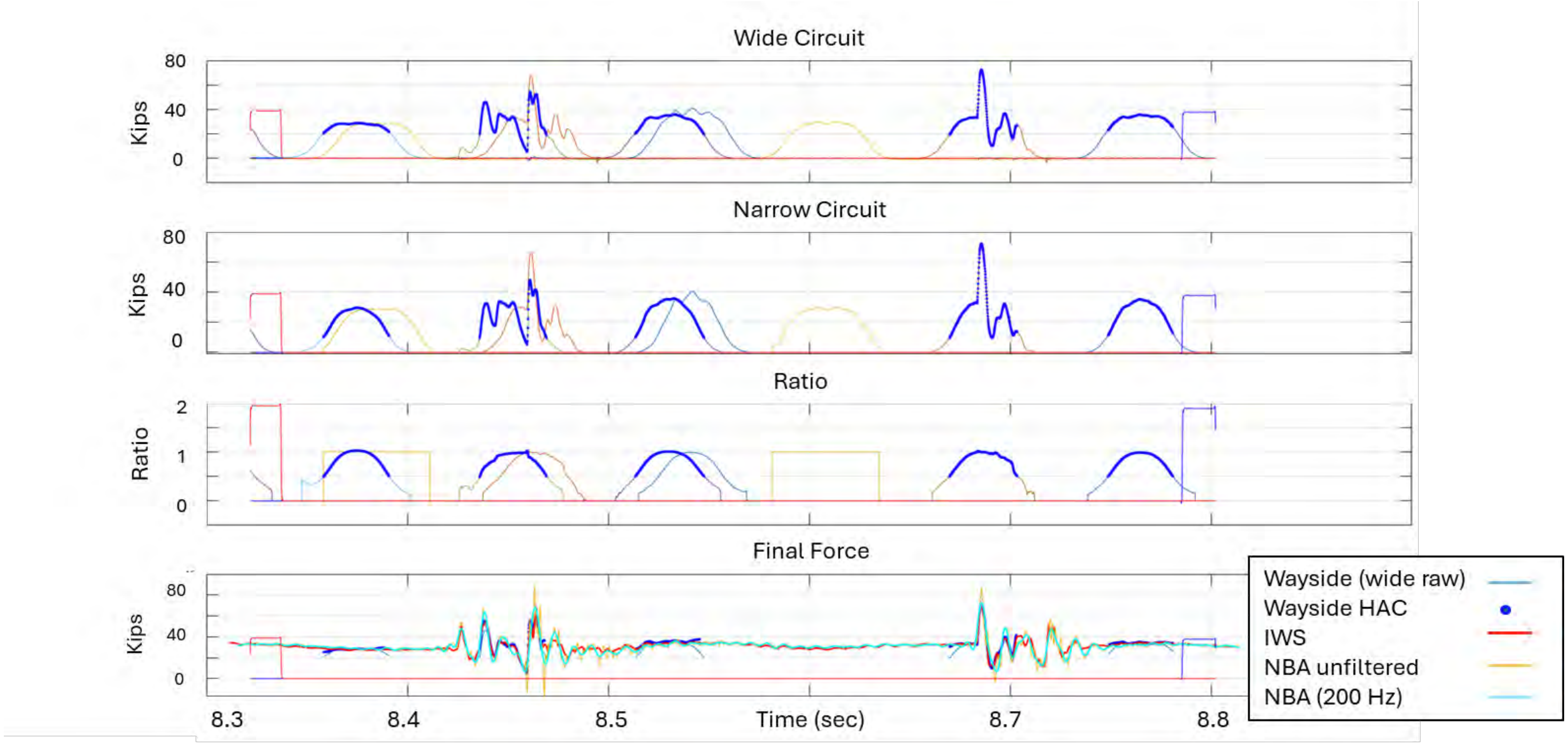


On-board Signal Quality – IWS

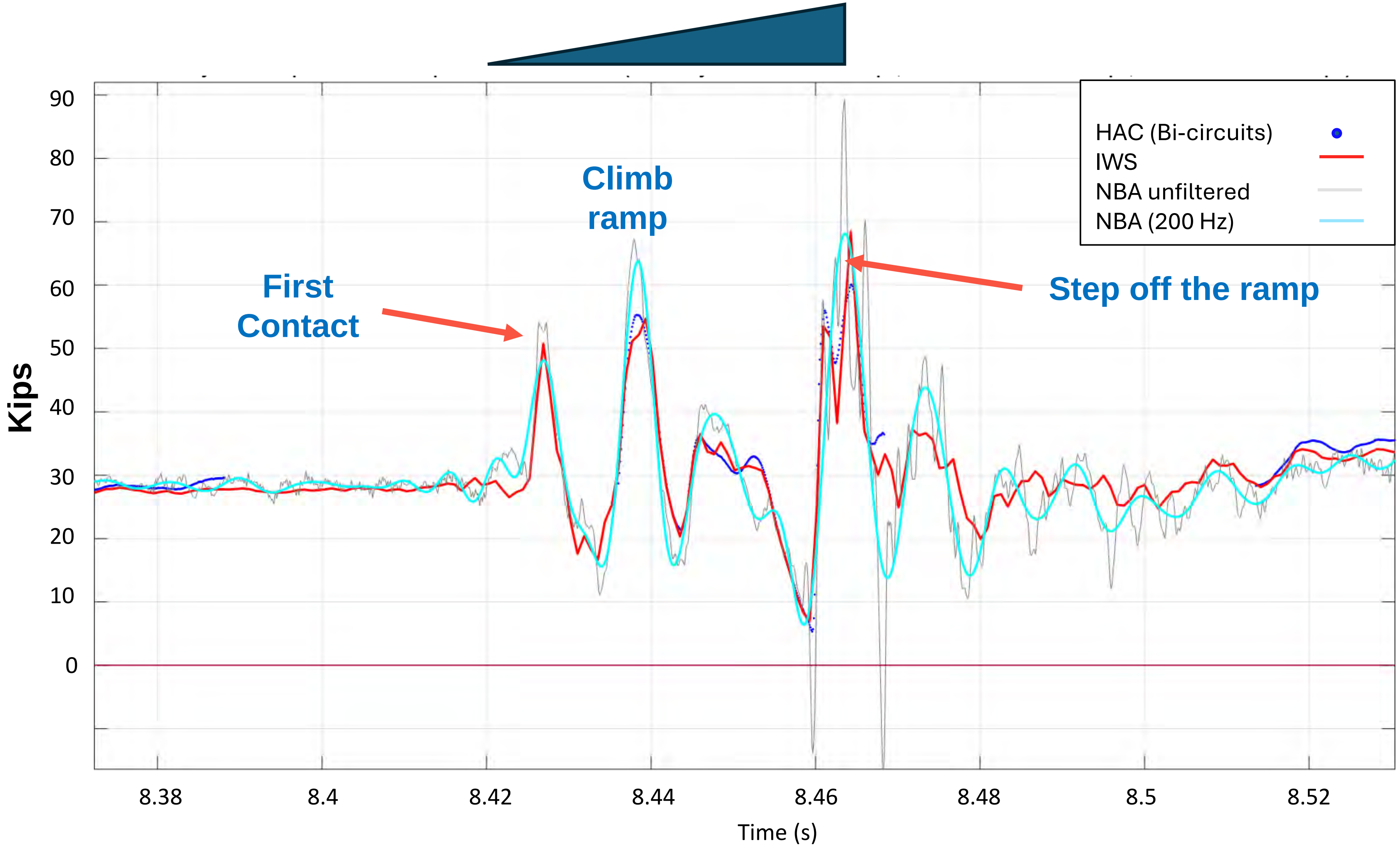
- **Digital IWS signal synchronized with analog ALD signal**
  - Good repeatability and no obvious noise for ramped IWS runs

Test Results with Rail Bump

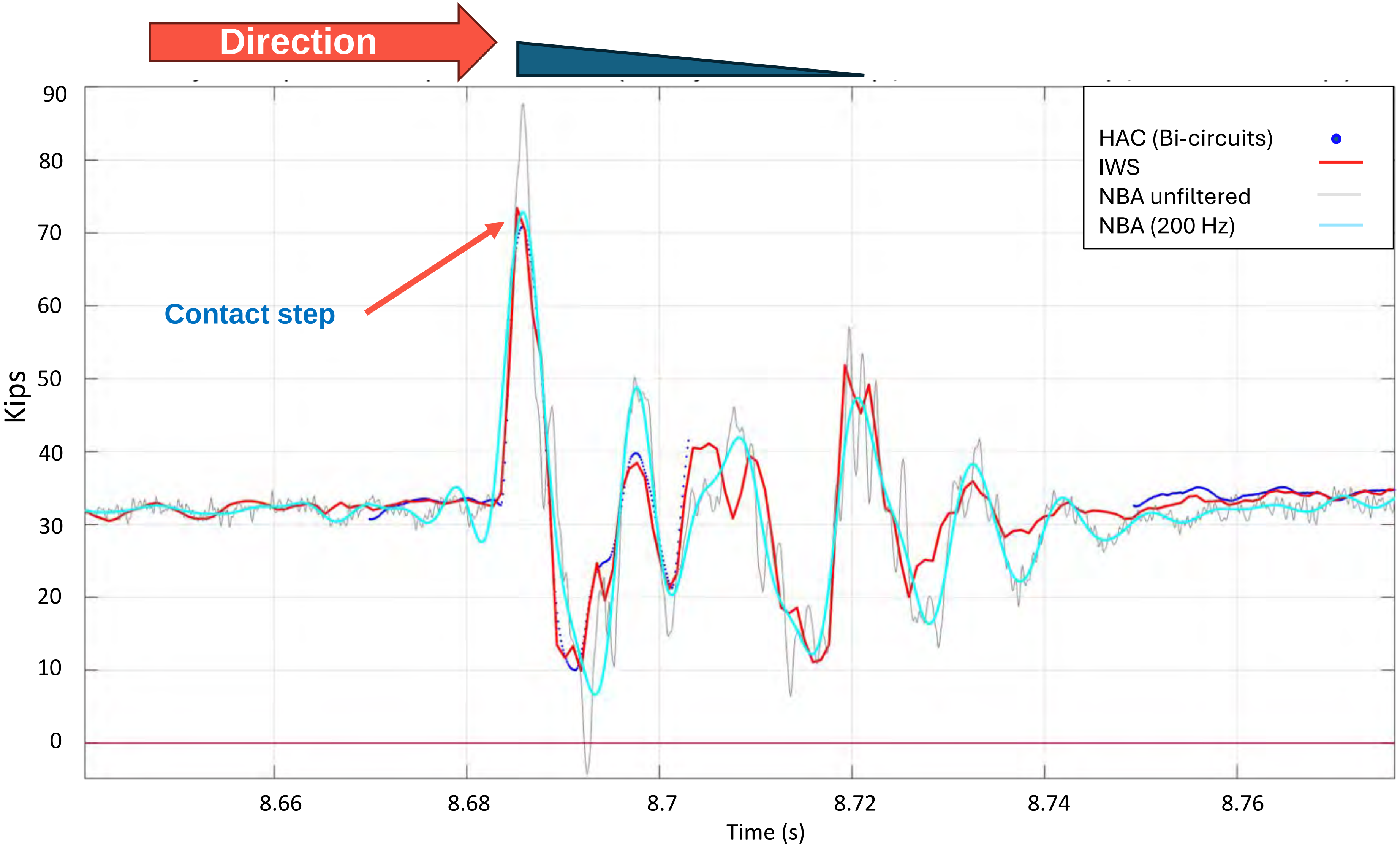
- **Make code to combine wayside data and onboard data**



20 mph IWS up ramp on track



20 mph IWS up step on track



Conclusions

- **Step-up ramp provides a consistent and repeatable impact**
- **Agreement between three independent measurements**
  - In-track high-accuracy bi-circuit
  - Acceleration compensated bearing adapter
  - Instrumented wheelset
- **Need a little more testing**
  - Determine confidence intervals to establish accuracy
  - Inform updates to S-6101: detector validation requirements

What it all comes down to…

- **A consistent method to create impact is demonstrated**
  - Agreement between measurements suggests a valid benchmark
- **Possible validation procedure with controlled conditions**
  - Put step-up bump on the subject WILD system
    - IWS synchronized with ALDs
  - Run the loaded test car with IWS over the bump
    - Compare the readings from subject WILD to the known input
  - NBA and HAC are available for redundancy if needed

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Acknowledgements

- **EHMC for their guidance**
- **AAR SRI program for the backing**
- **MxV Rail support team for expertise**
  - Instrumentation
  - Engineering Services
- **This was truly a team effort**
- **Patents pending for:**
  - Yuqing Zeng
  - Nick Wilson
  - Brian Smith
  - Matt Witte
  - Shawn Trevithick
  - Michael Craft

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Thank You

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