Brake Health Effectiveness (BHE) Test Waiver Development Summary

BNSF Railway

TUESDAY, MAY 29, 2018

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BHE Waiver – Overview

Objective:

- Use detector technology to support California to Chicago intermodal trains
- Trans-con intermodal
- Improve network velocity
- Improve brake effectiveness
- Employee risk reduction

Method:

- Utilize Wheel Temperature Detectors (WTDs) to identify ineffective car brakes & improve overall safety
- Identify outlying wheel temperatures before and after downhill braking events with differential temperature algorithms
- Intermodal trains from the intermodal facilities in California to Chicago
- Apply existing WTD technology with “BNSF” differential temperature algorithms tailored to lesser gradients

Technology:

- Utilize industry established WTD monitoring and equipment
- Technology & differential temperature algorithms demonstrated on CP in Canada past 6 years
- UP also heavily invested in technology - 10 years testing and 3 waiver applications

Challenges:

- Technology application & validation of differential temperature algorithms
- Confidence in technology driven inspections
- Potential operating concerns with additional braking events to determine brake effectiveness
- Optimal detector placement for train velocity

Test Waiver Summary

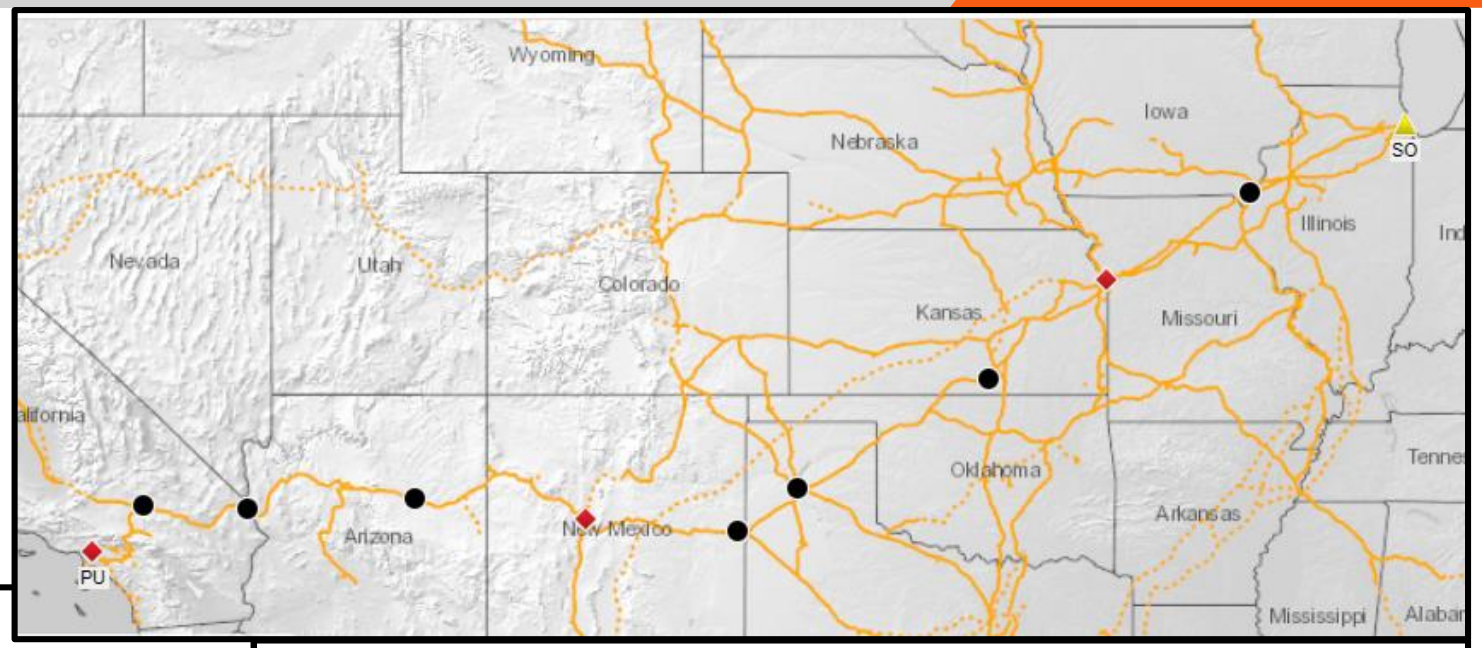
- High priority intermodal revenue service trains operating between Los Angeles, CA and Chicago, IL (S, Q, & Z Trains)
- Detectors surrounding Belen, NM
- Power braking initiated to elevate wheel temperatures for analysis at:
  - McCarty's & Acomita for eastbound trains
  - Mountainair & Abo for westbound trains
- BNSF developed algorithms identify suspected ineffective brake valves
  - Cars with ineffective brake valves have notifications applied
  - Automatic single car airbrake tests (ASCAT) conducted to address suspected ineffective brake components
- If the train has greater than 95% effective brakes valves, the intermediate inspection will be bypassed

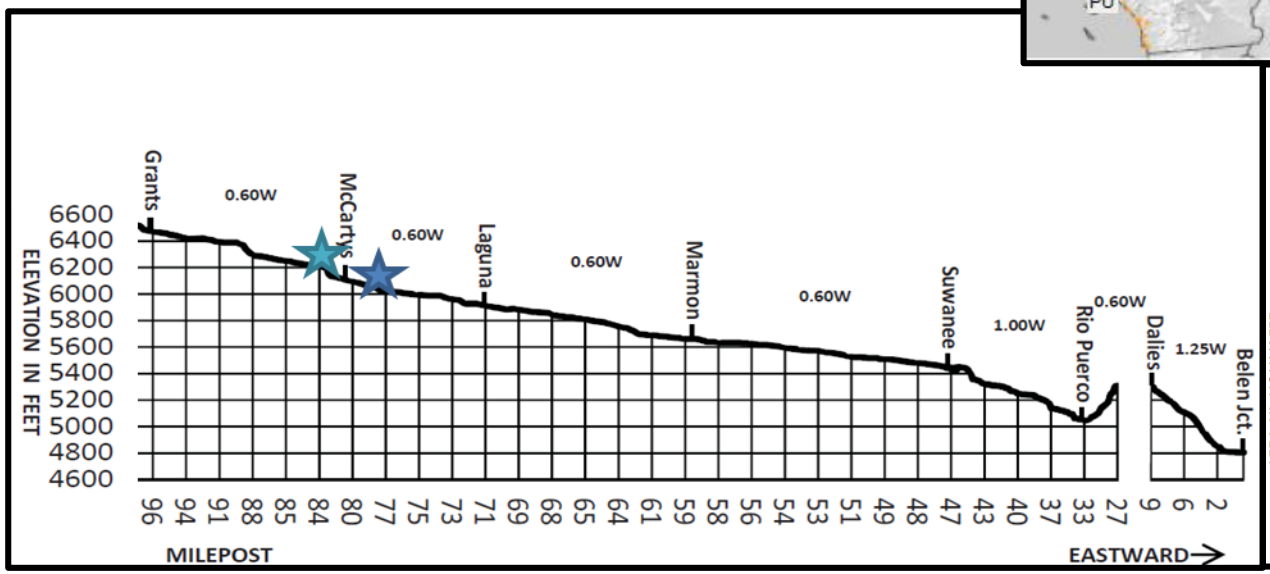
Pilot Route

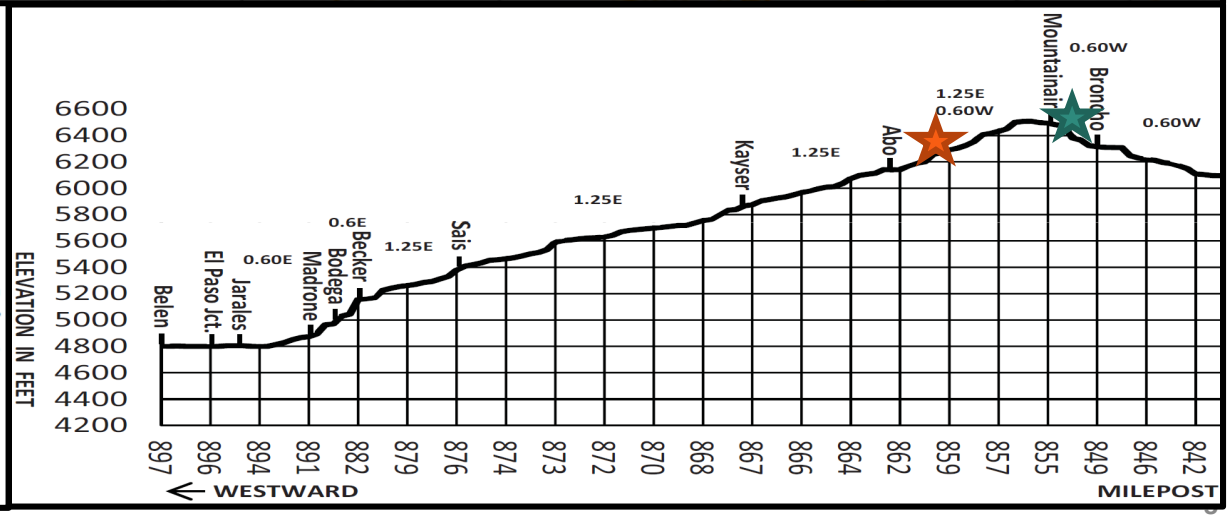
- Origin:

  Intermodal Facilities in California or Chicago, IL
- Destination:

  Chicago, IL or Los Angeles, CA
- Distance: ~2600 miles

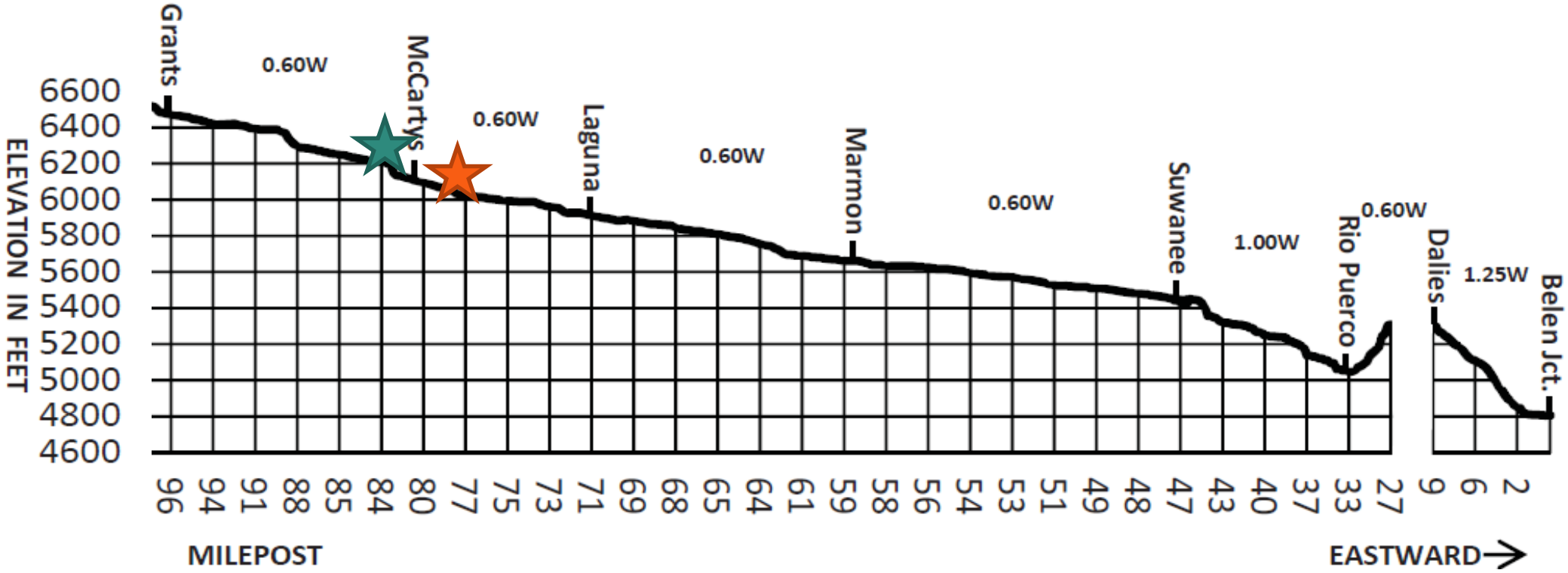






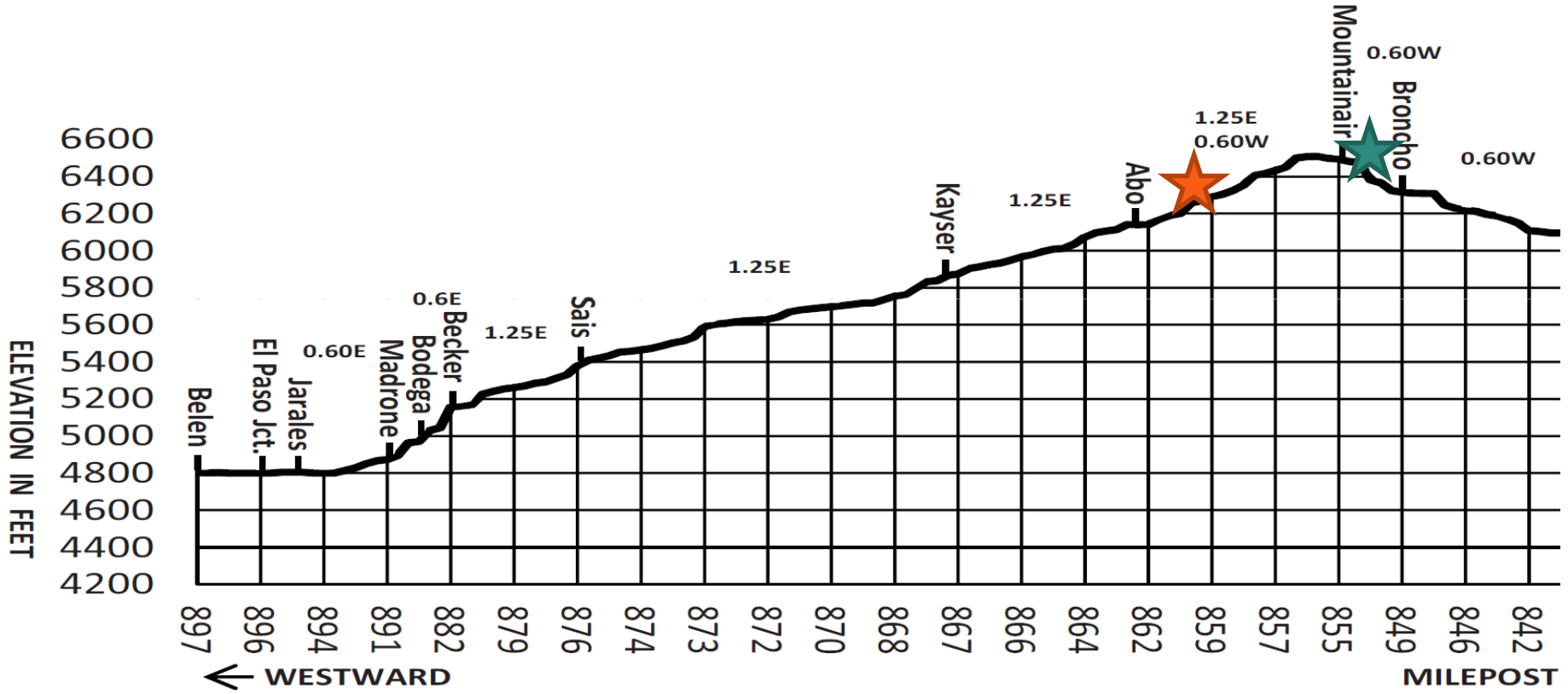
Cold Wheel Detection (CWD) Systems

- Eastbound brake health effectiveness test
  - Gallup Subdivision test for eastbound traffic
    - MP 82.3 (McCarty's) – Baseline measurement using CWD to ensure brakes are NOT applied.
    - MP 78.0 (Acomita) – Brake effectiveness test using CWD to identify inoperative brakes.



Cold Wheel Detection (CWD) Systems

- Westbound brake health effectiveness test
  - Clovis Subdivision test for westbound traffic
    - MP 851.8 (Mountainair) – Baseline measurement using CWD to ensure brakes are NOT applied.
    - MP 860 (Abo) – Brake effectiveness test using CWD to identify inoperative brakes.



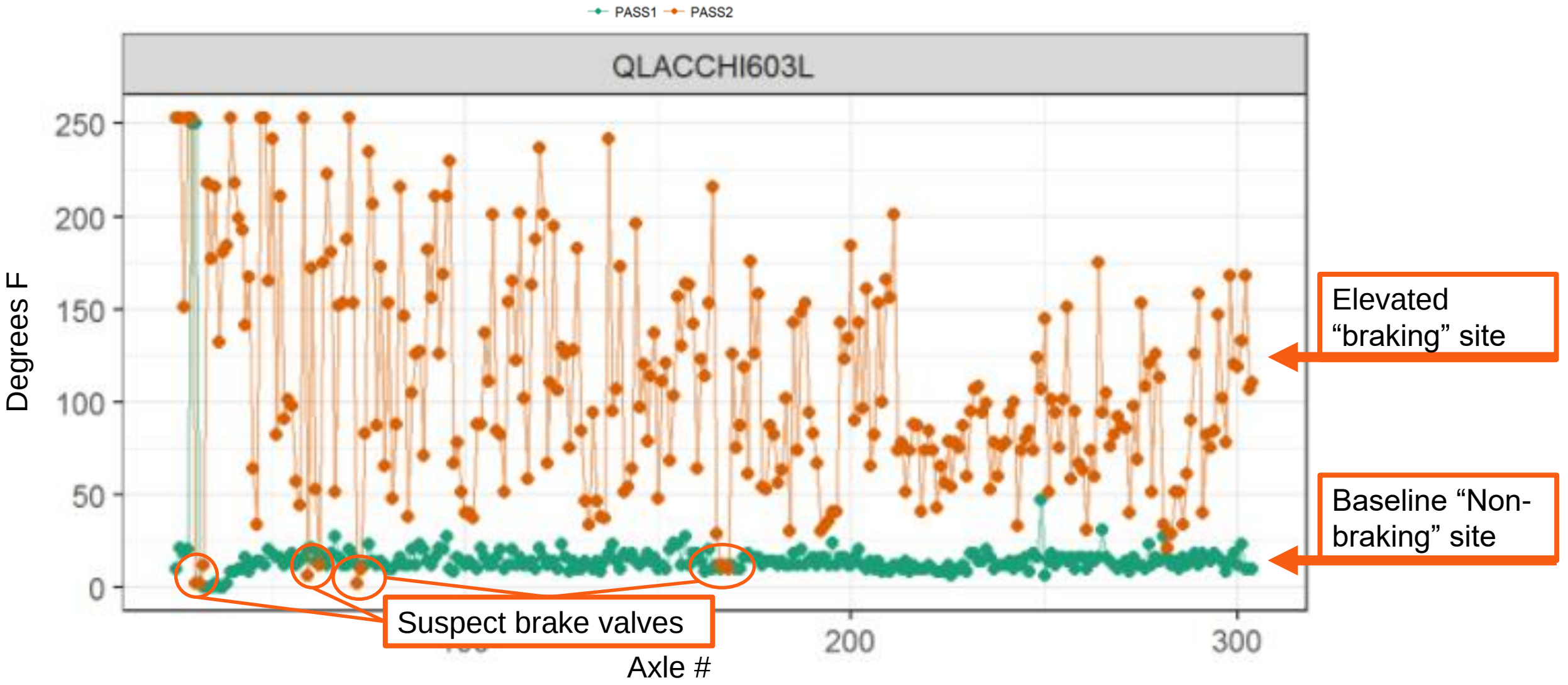
Brake Health Effectiveness (BHE) Process Summary

- **Process Overview**
  - Train passes two Cold Wheel Detectors (CWD). The first is a baseline measurement and the second is the braking site
  - The braking site measurements are compared to the baseline site to verify an increase in wheel temperature
- **Test Logic**
  - Compare WTD readings from the braking site to the baseline
  - Train must show that the brakes were sufficiently applied
  - Evaluate each valve on each car for effective brakes
  - Calculate the train's percentage of valves effectively braking
- **Test Method - Wilcox Signed-rank Test**
  - Goal: Prove the valve is not braking
    - No temperature differences between the non-braking and braking sites
  - If the valve fails the test then it is considered braking

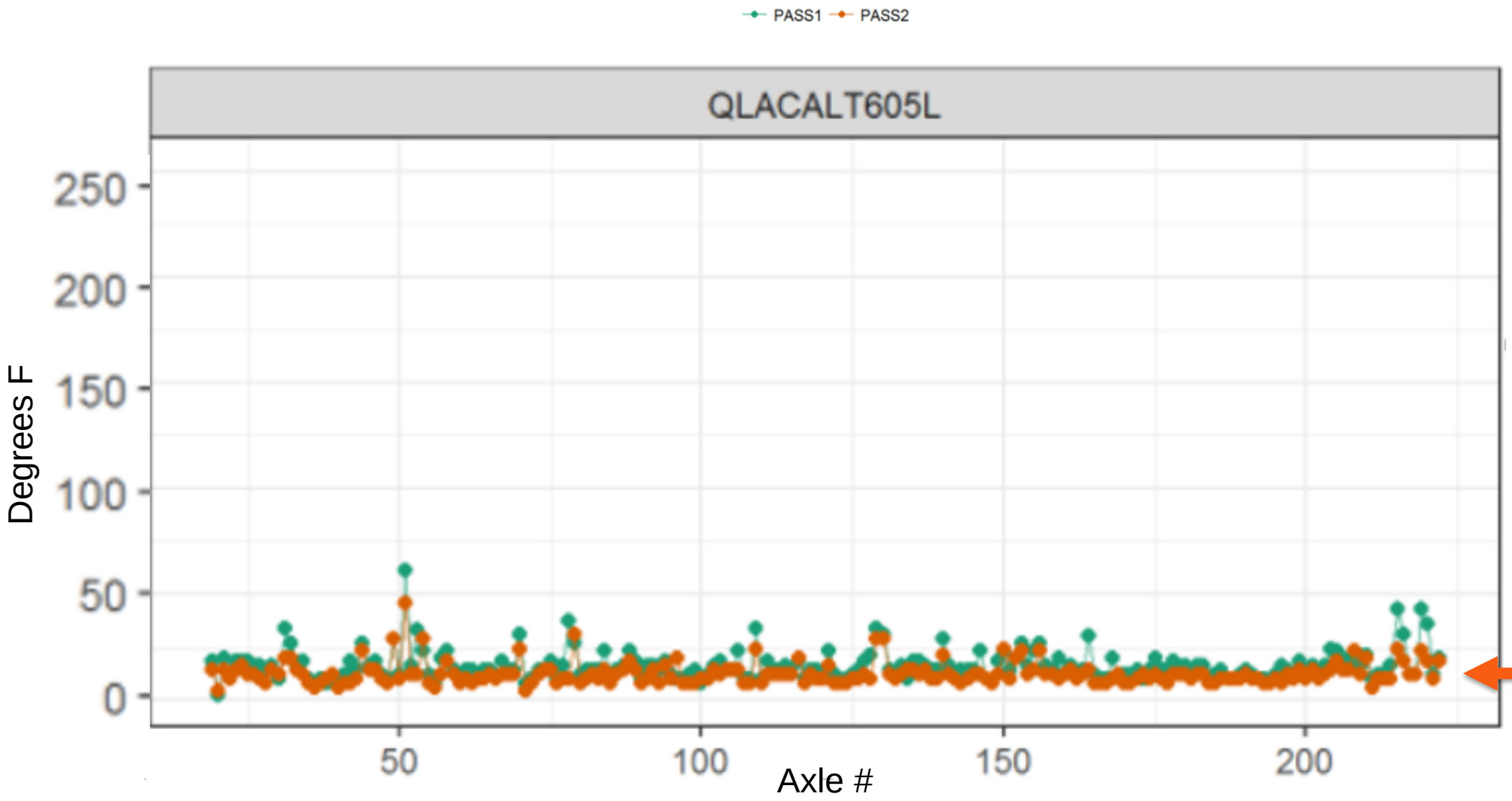
Equipment

- Each CWD system is comprised of two WTD sites
  - Baseline site where the train is not braking
  - Braking site
    - Utilizes Form C for communication to the train crews
    - Crews are instructed to make a 10 lb. running air brake set 1 mile prior to the CWD braking site and hold the set until the rear of the train has cleared WTD (SAP Appendix C)
    - Stretch braking is permitted while performing this running air brake set

Examples Braking Train (Conventional)

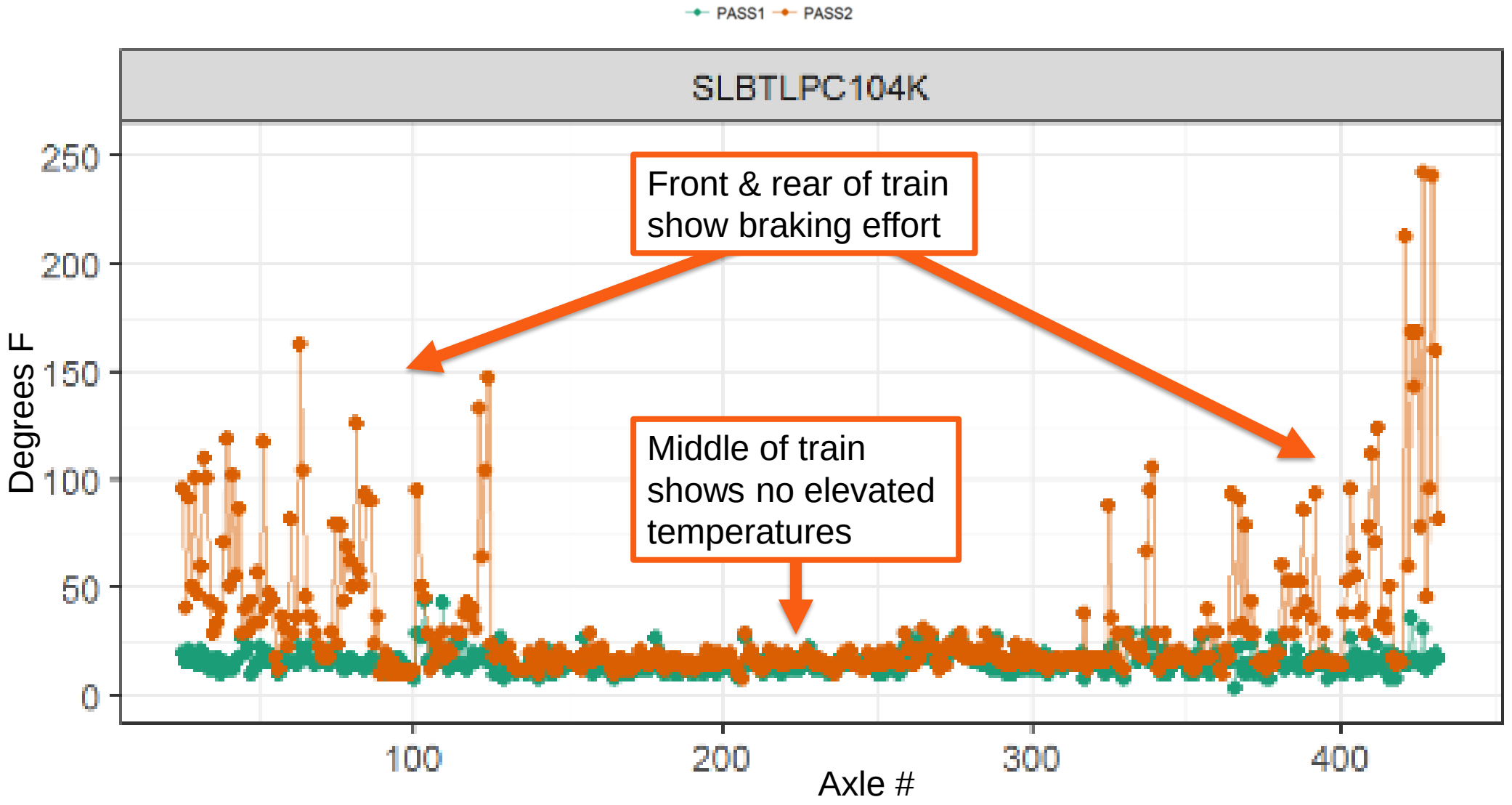


Examples Non-Braking Train



No significant difference between sites

Examples Train Braking Too Late (DP Train)



Data Matching & Analysis Summary

- As the train passes the WTD sites, each message is matched to the train ID and the AEI consist list
- Train IDs are then filtered to analyze only the trains of interest
  - Intermodal (Z, S, and Q) symbols are being analyzed
  - Measurements from all other symbols are only stored
- Once both the baseline and braking passes are received, the messages are paired for analysis
- Analysis is conducted at the valve level using the statistical results from the Wilcox signed-rank test

Valve Level Analysis

Each valve is being analyzed using the **Wilcox signed-rank test**

- Designed to prove that the valve is not braking
  - I.e. no difference in temperatures between the baseline WTD site where the train is not braking and the braking WTD site
- The output utilized is a “P-value” calculation
  - The smaller the P-value the stronger the evidence of the valve braking
  - To pass the test, the P-Value must be greater than threshold
- If the valve fails the Wilcox signed-rank test it is considered braking
  - I.E. P-value is less than threshold and the valve is braking

Valve Level Analysis

The P-Value threshold is set to catch all cars with ineffective brakes with few false positives

- Used historical & field reported data to adjust the P-value threshold to identify cars with suspected ineffective brakes
- Pilot effort will further improve refinement of P-value
- Automated identification with manual review used to set pilot value

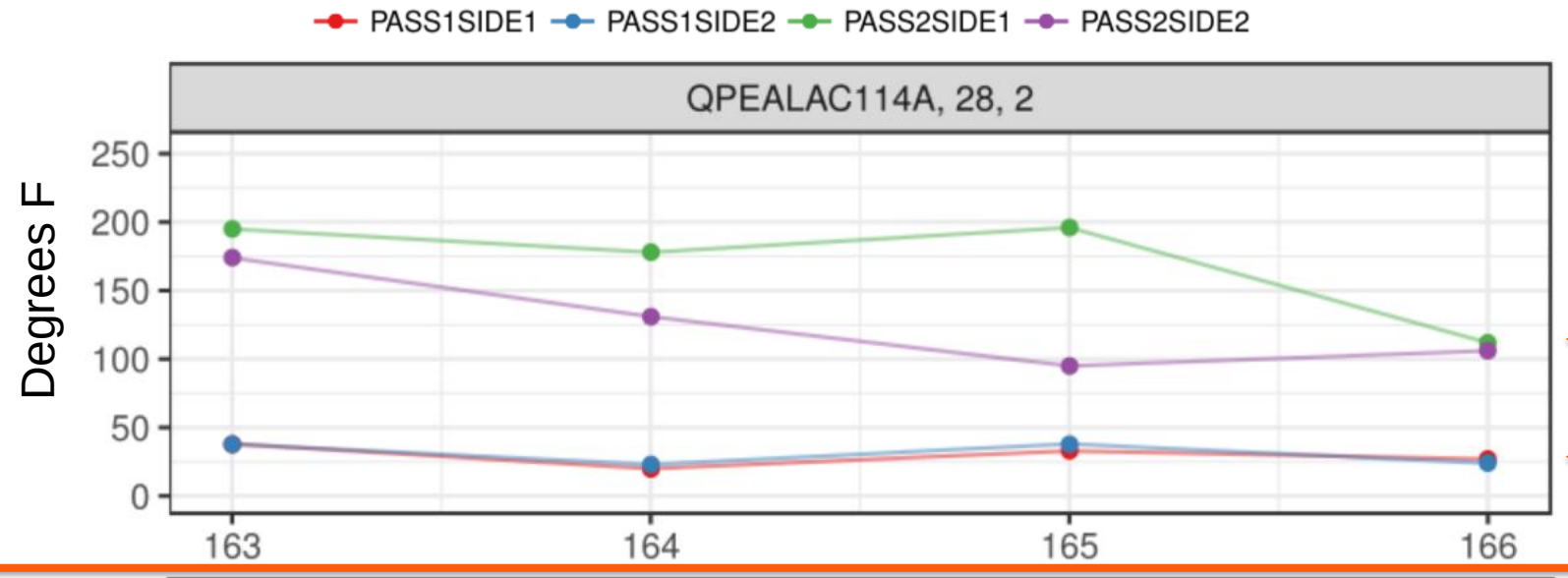
	P-Value	*Too High*	
		Manually Evaluated Answers	
Algorithm Answer		Not Braking	Braking
	Not Braking	4	0
	Braking	7	253

	P-Value	*Too Low*	
		Manually Evaluated Answers	
Algorithm Answer		Not Braking	Braking
	Not Braking	11	12
	Braking	0	241

	P-Value	*Optimal*	
		Manually Evaluated Answers	
Algorithm Answer		Not Braking	Braking
	Not Braking	11	0
	Braking	0	253

Examples of Passing Valves and Corresponding Wheels

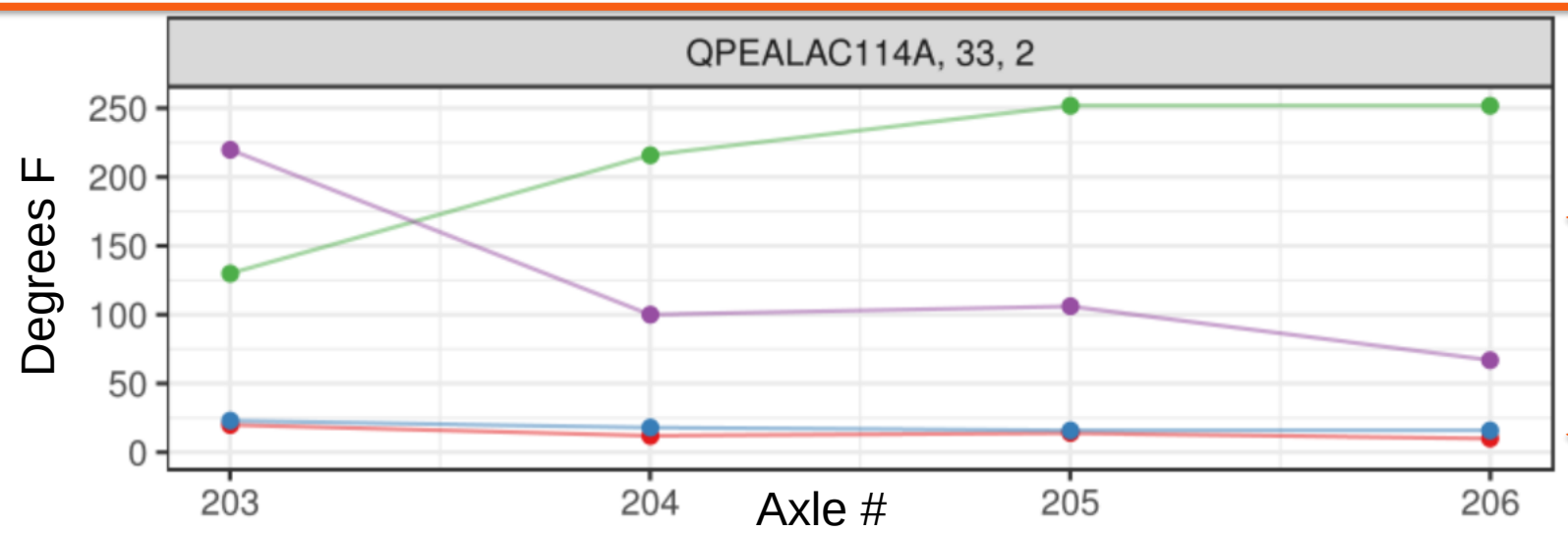
Valve 1



Braking site

Non braking site

Valve 2

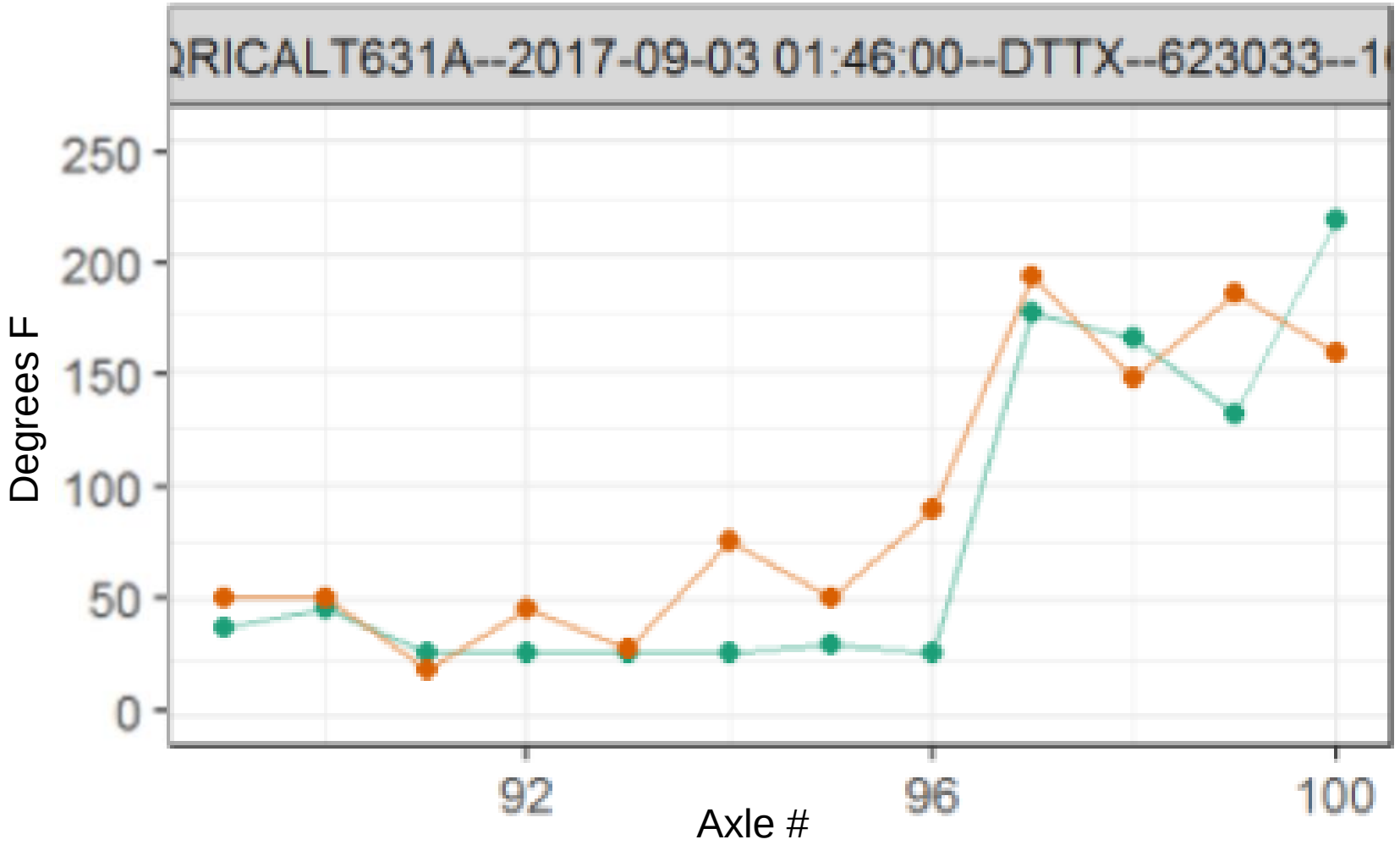


Braking site

Non braking site

Examples of a Flagged Car with Three Valves & Twelve Wheels

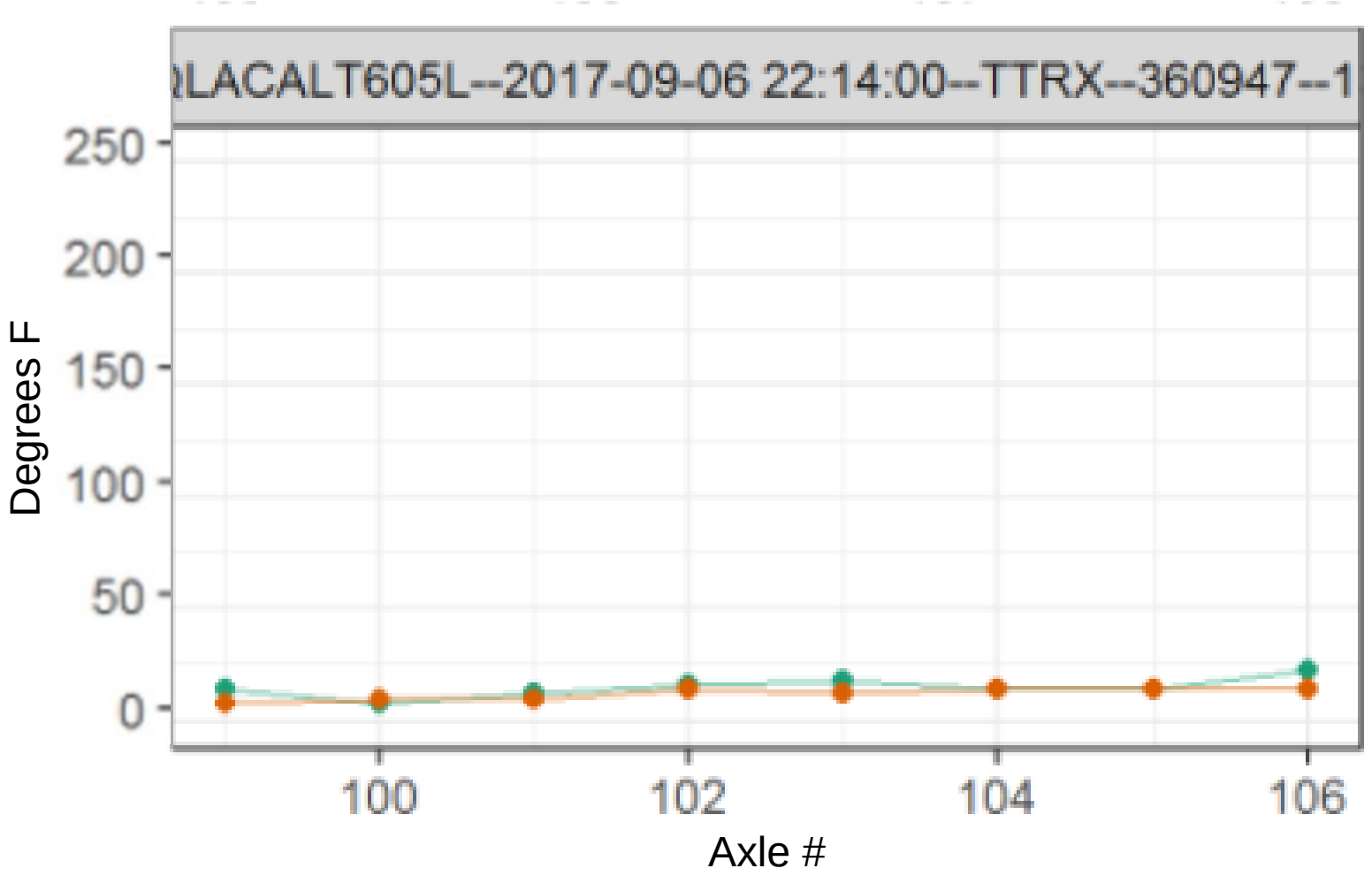
Wheels Hot at Both Sites (Sticking Brakes/Handbrakes)



All wheels on brake valve with elevated temperatures. Indicates sticking brakes or handbrake left on.

Examples of a Single Flagged Car with Eight Axles

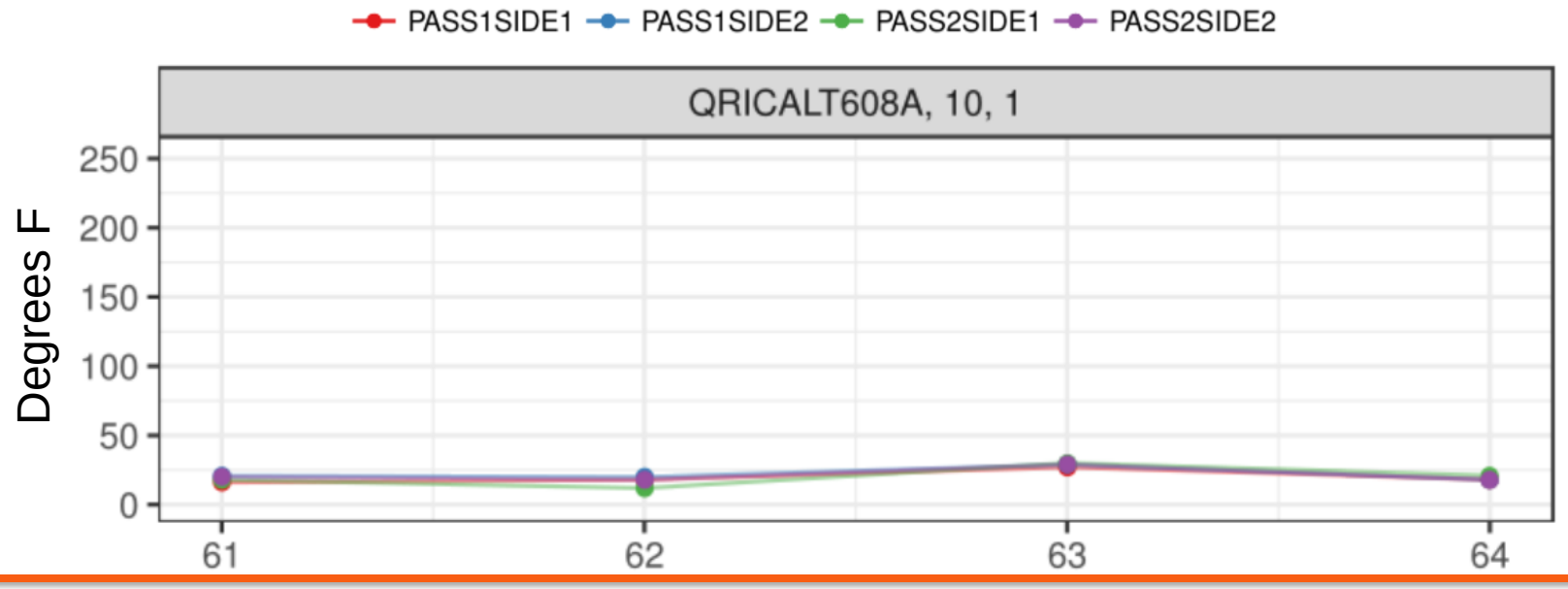
All brake valves suspected ineffective



No change between braking & non-braking site

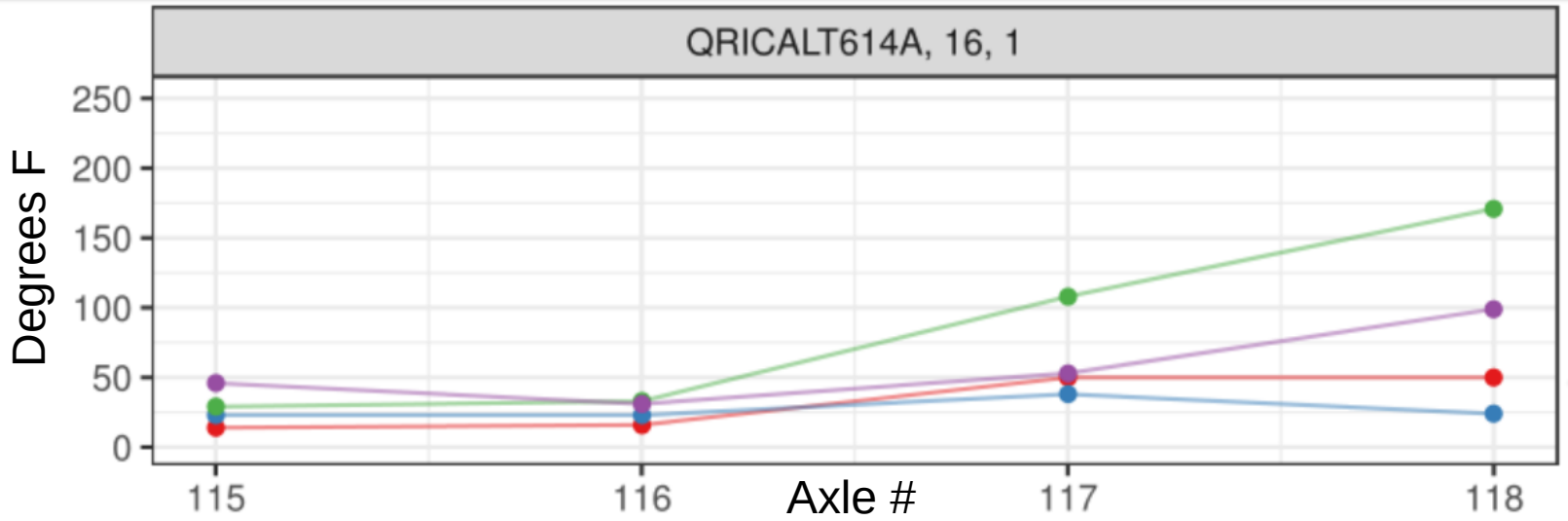
Examples of Failed Valves and Corresponding Wheels

Valve 1



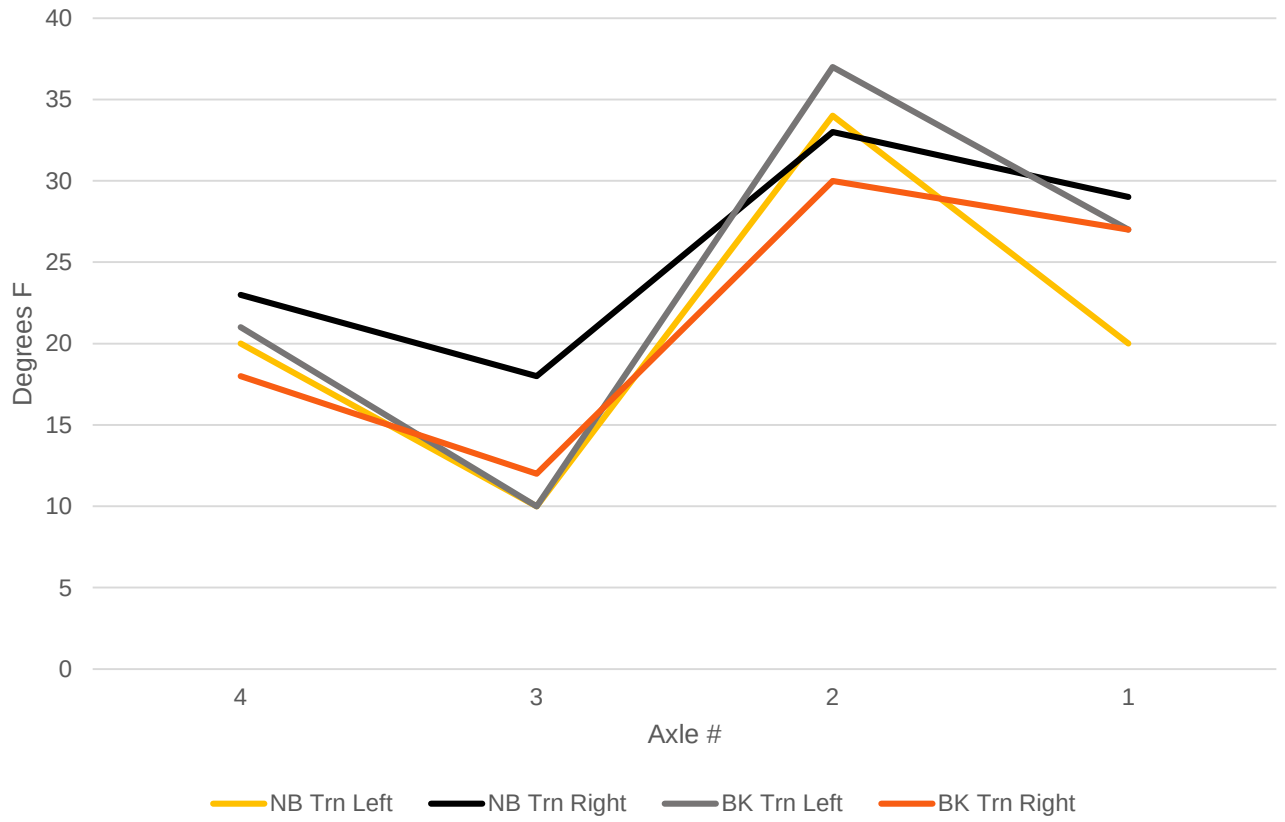
No difference between braking & non-braking sites

Valve 2

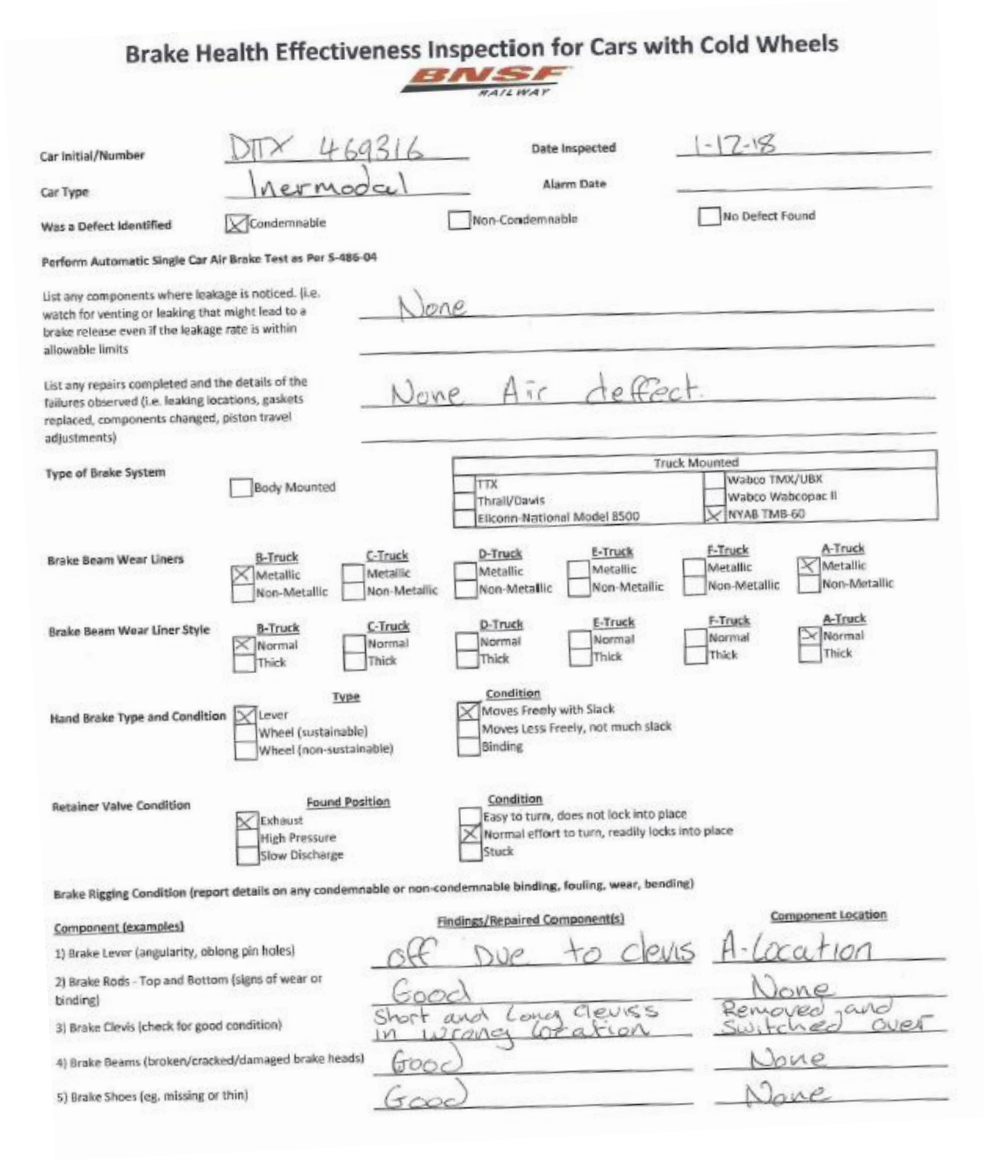


Unable to differentiate sites (below threshold)

Example of Brake Lever Defect – DTTX 469316



1 valve: 2 wheels cold, 2 wheels hot
Indicates brake lever issue – inspection supports finding



Brake Health Effectiveness Inspection for Cars with Cold Wheels

BNSF RAILWAY

Car Initial/Number: DTX 469316 — Date Inspected: 1-12-18

Car Type: Intermodal — Alarm Date:

Was a Defect Identified: [X] Condemnable [ ] Non-Condemnable [ ] No Defect Found

Perform Automatic Single Car Air Brake Test as Per S-486-04

List any components where leakage is noticed. (i.e. watch for venting or leaking that might lead to a brake release even if the leakage rate is within allowable limits: None

List any repairs completed and the details of the failures observed (i.e. leaking locations, gaskets replaced, components changed, piston travel adjustments): None Air deffect.

Type of Brake System: [ ] Body Mounted; Truck Mounted: [ ] TTX [ ] Thrall/Dawis [ ] Elconn-National Model B500 [ ] Wabco TMX/UBX [ ] Wabco Wabcopac II [X] NYAB TMB-60

Brake Beam Wear Liners: B-Truck [X] Metallic [ ] Non-Metallic; C-Truck [ ] Metallic [ ] Non-Metallic; D-Truck [ ] Metallic [ ] Non-Metallic; E-Truck [ ] Metallic [ ] Non-Metallic; F-Truck [ ] Metallic [ ] Non-Metallic; A-Truck [X] Metallic [ ] Non-Metallic

Brake Beam Wear Liner Style: B-Truck [X] Normal [ ] Thick; C-Truck [ ] Normal [ ] Thick; D-Truck [X] Normal [ ] Thick; E-Truck [ ] Normal [ ] Thick; F-Truck [ ] Normal [ ] Thick; A-Truck [X] Normal [ ] Thick

Hand Brake Type and Condition — Type: [X] Lever [ ] Wheel (sustainable) [ ] Wheel (non-sustainable); Condition: [X] Moves Freely with Slack [ ] Moves Less Freely, not much slack [ ] Binding

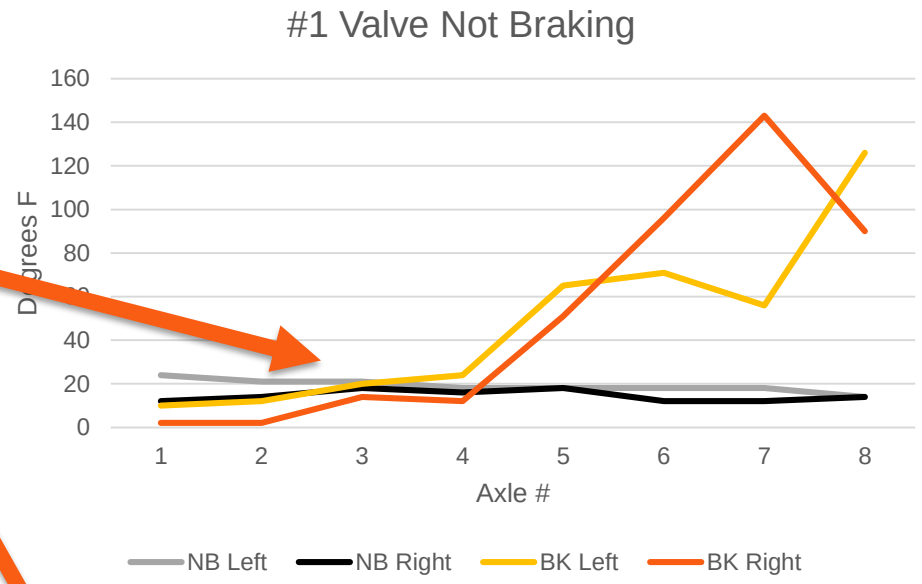
Retainer Valve Condition — Found Position: [X] Exhaust [ ] High Pressure [ ] Slow Discharge; Condition: [ ] Easy to turn, does not lock into place [X] Normal effort to turn, readily locks into place [ ] Stuck

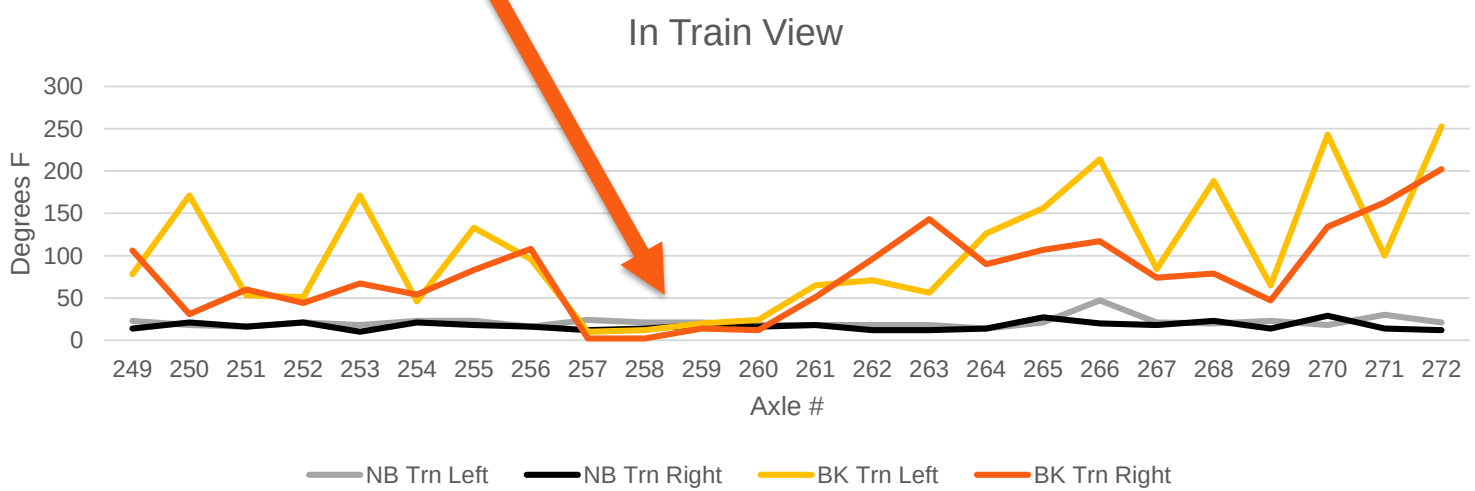
Brake Rigging Condition (report details on any condemnable or non-condemnable binding, fouling, wear, bending)

Component (examples)	Findings/Repaired Component(s)	Component Location
1) Brake Lever (angularity, oblong pin holes)	off Due to clevis	A-Location
2) Brake Rods - Top and Bottom (signs of wear or binding)	Good	None
3) Brake Clevis (check for good condition)	Short and Long clevis in Wrong location	Removed and Switched over
4) Brake Beams (broken/cracked/damaged brake heads)	Good	None
5) Brake Shoes (eg. missing or thin)	Good	None

Examples of Failed Valve – DTTX 728322

No temperature increase from all four wheels of brake valve





Brake Health Effectiveness Inspection for Cars with Cold Wheels

BNSF RAILWAY

Car Initial/Number	DTTX 728322	Date Inspected	12- -17
Car Type	QU 3	Alarm Date	12-13

Was a Defect Identified: ☒ Condemnable ☐ Non-Condemnable ☐ No Defect Found

Perform Automatic Single Car Air Brake Test as Per S-486-04

List any components where leakage is noticed. (i.e. watch for venting or leaking that might lead to a brake release even if the leakage rate is within allowable limits: Service Portion, wafer plate, and "B" piston

List any repairs completed and the details of the failures observed (i.e. leaking locations, gaskets replaced, components changed, piston travel adjustments): Changed service, gaskets, and piston at number one and "B" locations

Type of Brake System: ☐ Body Mounted

Truck Mounted: ☐ TTX ☐ Thrall/Davis ☐ Elconn-National Mod 8500 ☒ Wabco TMX/UBX ☐ Wabco Wabcopac II ☐ NYAB TMB-60

Brake Beam Wear Liners

B-Truck	C-Truck	D-Truck	E-Truck	F-Truck	A-Truck
☒ Metallic ☐ Non-Metallic	☒ Metallic ☐ Non-Metallic	☒ Metallic ☐ Non-Metallic	☒ Metallic ☐ Non-Metallic	☒ Metallic ☐ Non-Metallic	☒ Metallic ☐ Non-Metallic

Brake Beam Wear Liner Style

B-Truck	C-Truck	D-Truck	E-Truck	F-Truck	A-Truck
☒ Normal ☐ Thick	☒ Normal ☐ Thick	☒ Normal ☐ Thick	☐ Normal ☐ Thick	☐ Normal ☐ Thick	☒ Normal ☐ Thick

Hand Brake Type and Condition

Type	Condition
☐ Lever	☒ Moves Freely with Slack
☒ Wheel (sustainable)	☐ Moves Less Freely, n
☐ Wheel (non-sustainable)	☐ Binding

Retainer Valve Condition

Found Position	Condition
☒ Exhaust	☐ Easy to turn, does no
☐ High Pressure	☒ Normal effort to turn
☐ Slow Discharge	☐ Stuck

Brake Rigging Condition (report details on any condemnable or non-condemnable binding, fouling, wear, bending)

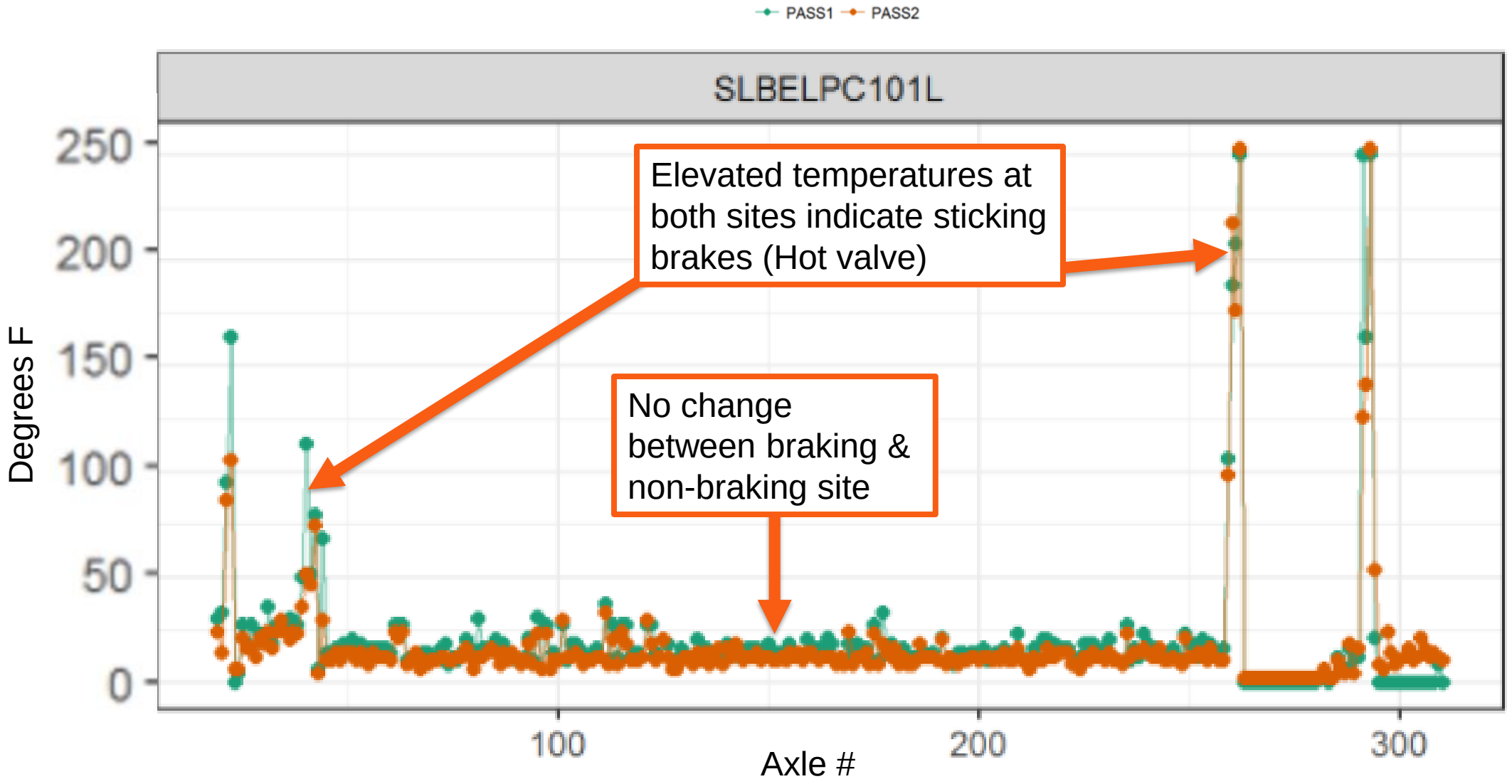
Component (examples)	Findings/Repaired Component(s)	Component Location
1) Brake Lever (angularity, oblong pin holes)	Normal	
2) Brake Rods - Top and Bottom (signs of wear or binding)	Normal	
3) Brake Clevis (check for good condition)	Normal	
4) Brake Beams (broken/cracked/damaged brake heads)	Some Wear (non-condemnable)	
5) Brake Shoes (eg. missing or thin)	Changed 5 shoes	"B" and "C" trucks

Failed service portion

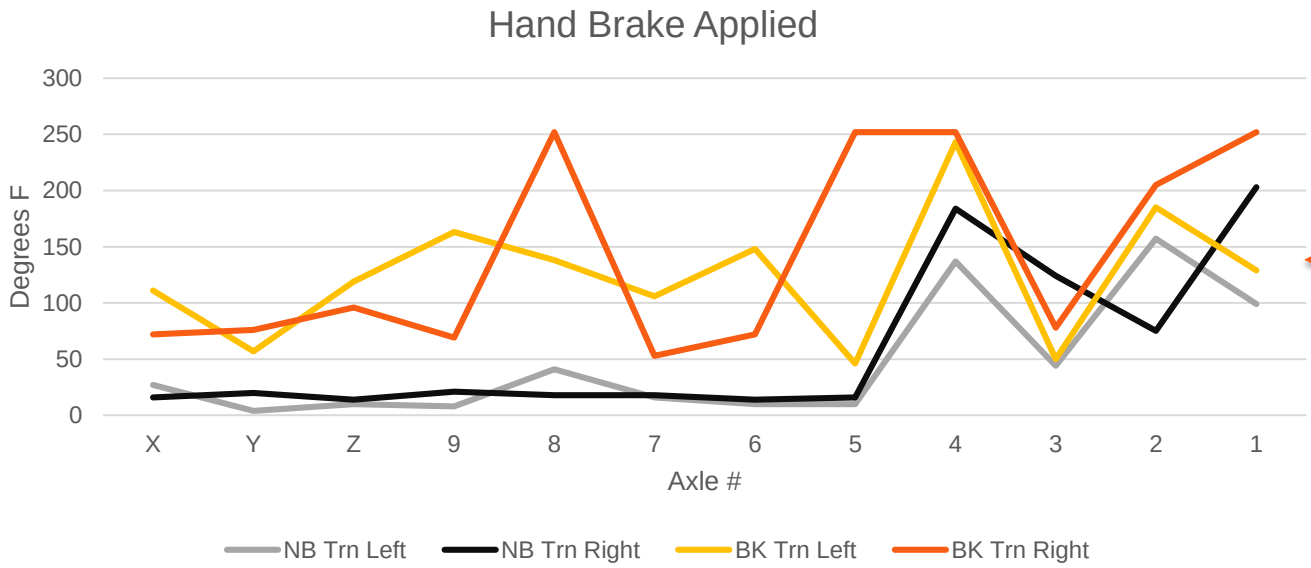
Identification of Sticking Brakes / Hand Brakes Left On

- In cases where a car had a valve with the brakes applied at both the baseline & braking sites, a different alert is applied
  - The algorithm can not correctly interpret the performance of the brakes
    - The measurements may be similar or different at each site on a car with sticking brakes
  - If the average temperature of the wheels is greater than 50ºF at the baseline site, the valve is identified as a “Hot valve”
  - Hot valves will be considered ineffective in the percentage of good valves
  - Hot valves will be inspected for sticking brakes or applied hand brakes

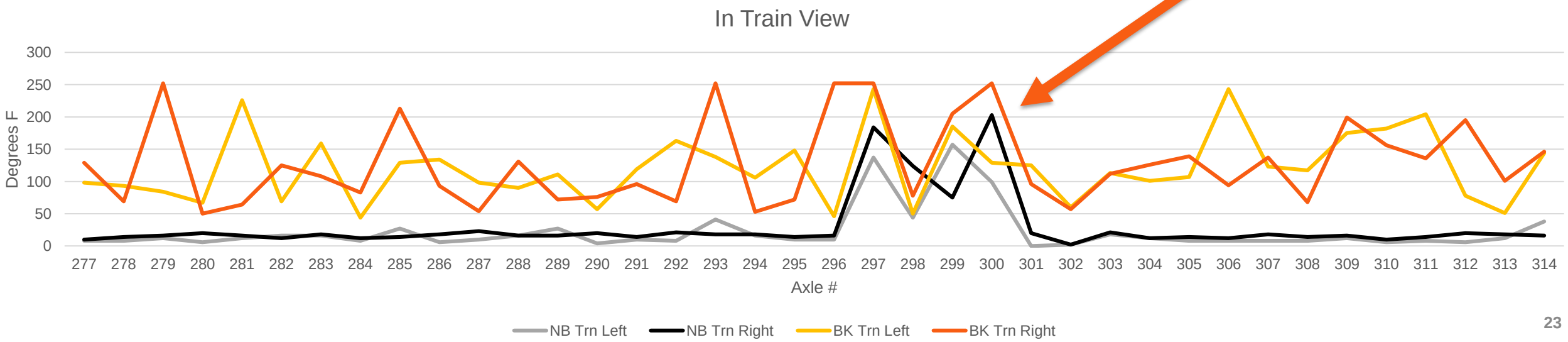
Examples Non-Braking Train with Sticking Brakes



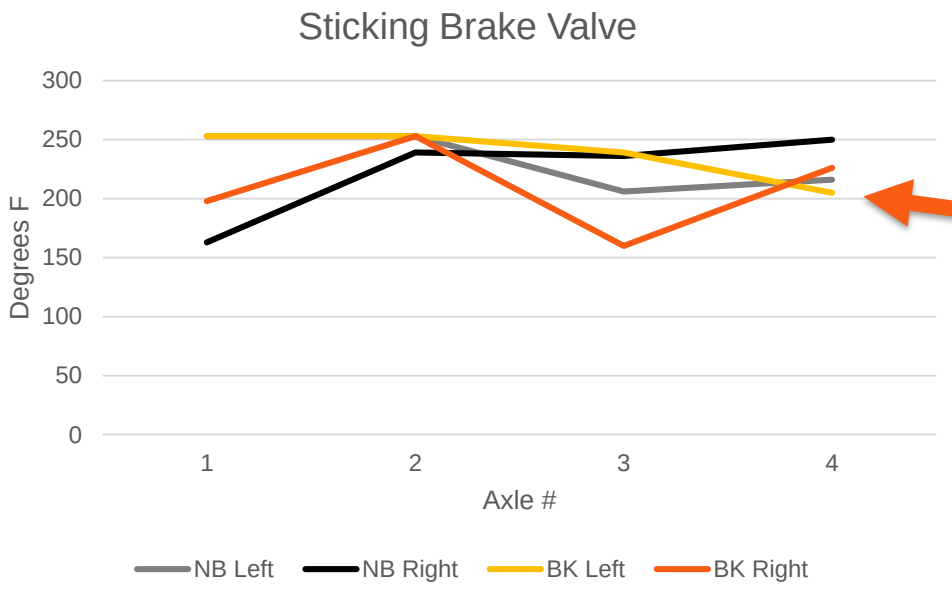
Example of Hand Brake Left On



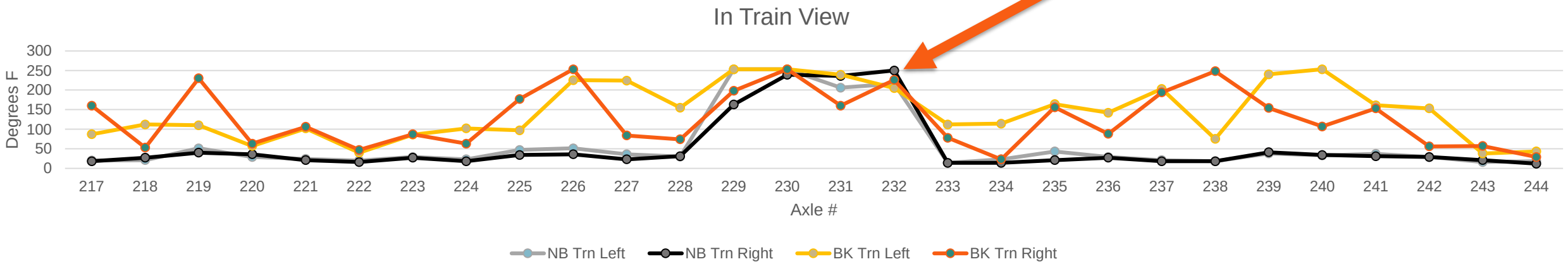
Elevated temperatures at both sites at A end of car indicates handbrake applied (Hot valve alarm)



Example of a Sticking Brake Valve



Elevated temperatures at both sites indicates sticking brakes (Hot valve alarm)



Train and Car Level Performance Test

From the valve level analysis results the train braking performance is evaluated:

- If ***less than 75%*** of the valves pass, the train is deemed as “not braking”
  - I.e. brakes were not set according to the Form C

  Result → “***Not Tested***” & Intermediate Inspection

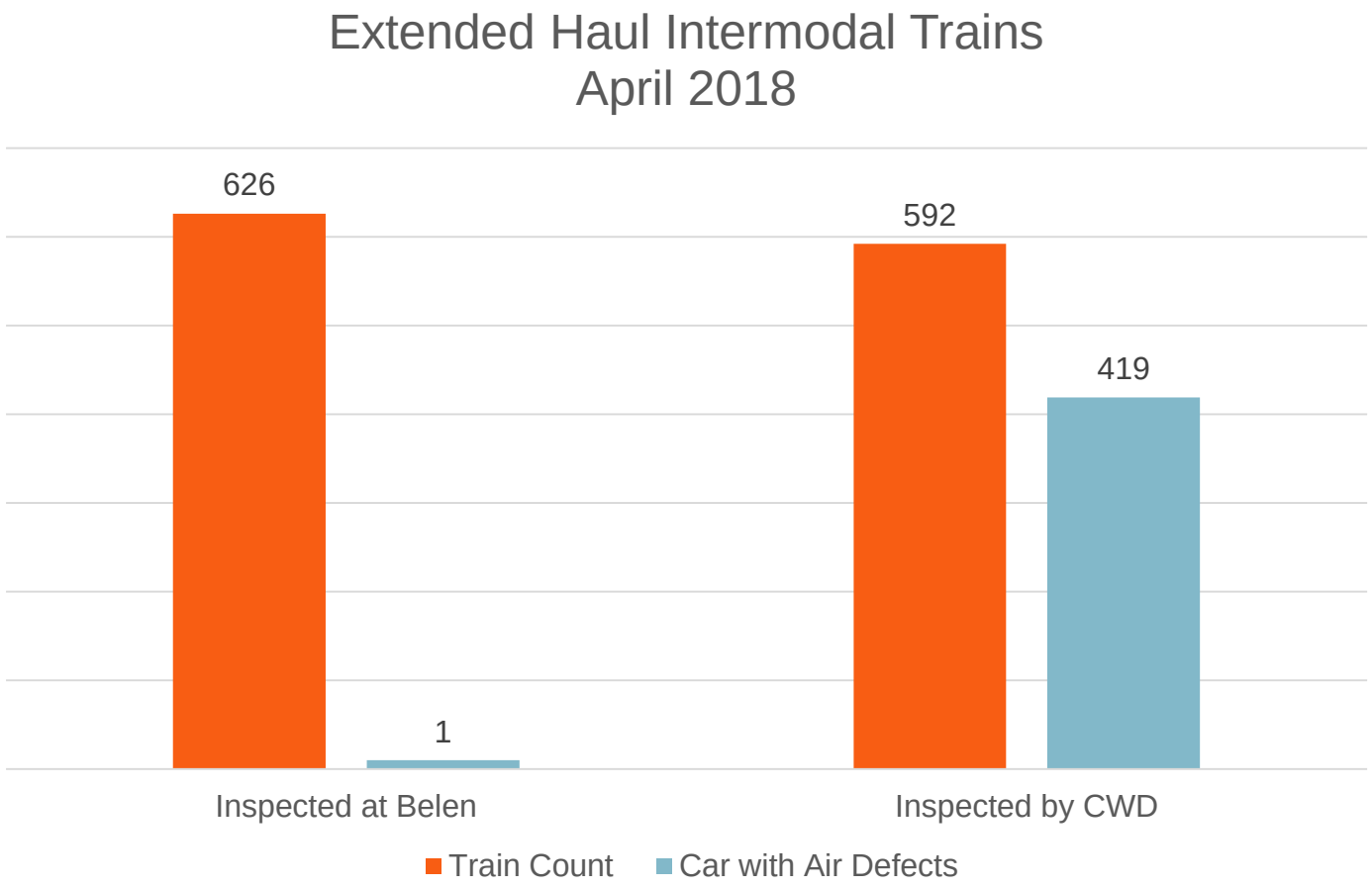
- If ***between 75% and 95%*** of the valves are braking, train failed the BHE test
  - Cars with suspected ineffective valves will be identified and inspected
    - If car passes the 1500 mile inspection, the cars will be flagged to receive an ASCAT at destination
  - Cars with no failing valves are marked as passed

  Result → ***Failed Test*** & Intermediate Inspection

- If ***greater than 95%*** of the valves pass, the train passes the BHE test
  - Any car with a suspected ineffective valve will be flagged to receive an ASCAT at destination

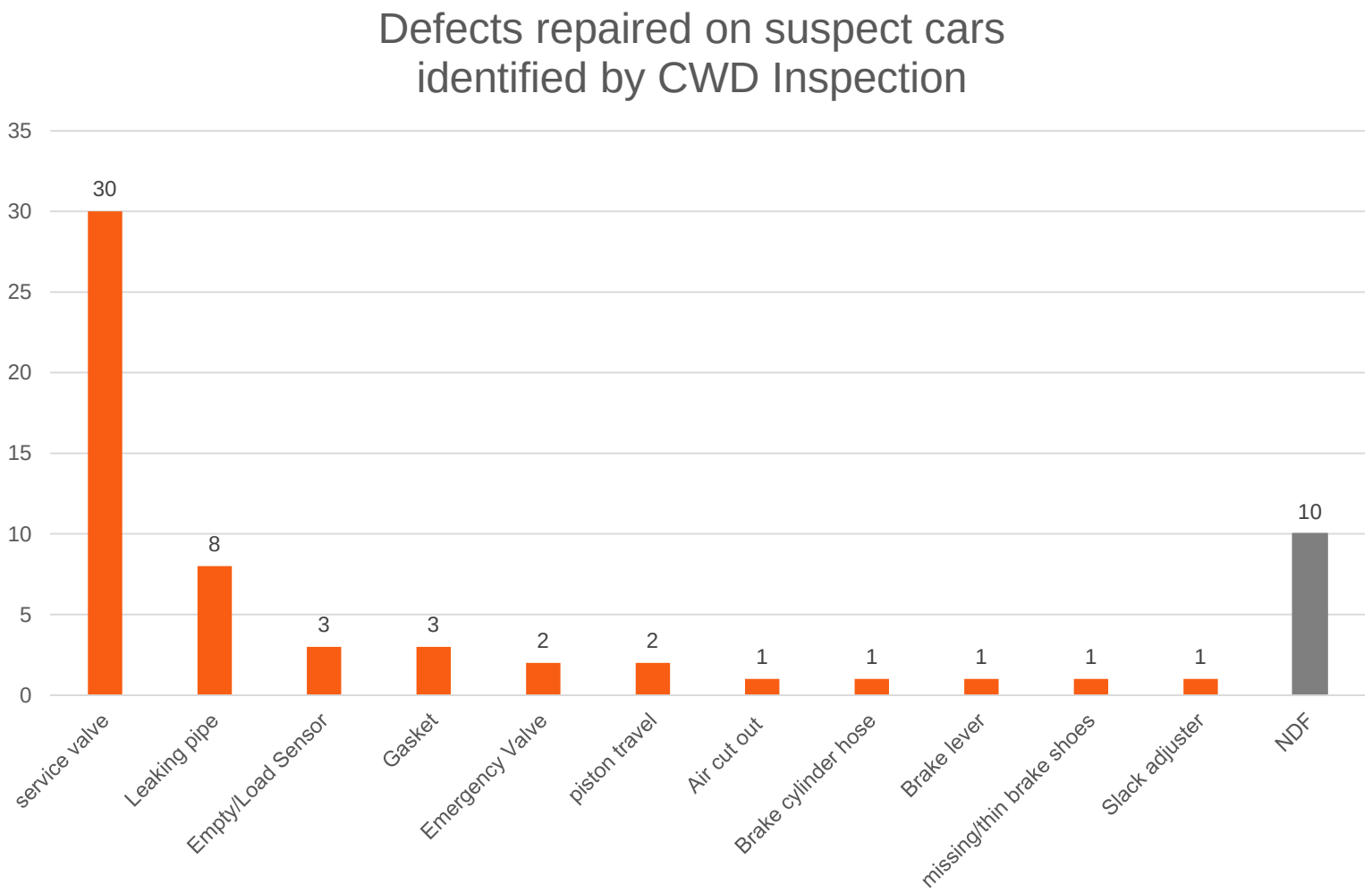
  Result → ***Passed Test*** & Inspection Bypassed

Preliminary BHE Defect Identification Rates



- Current visual inspection not a strong indicator of brake effectiveness
- Wheel temperature based inspections identify more brake system issues
- Fleet statistics show cars in service with ineffective brakes that have not measurably impacted safety
- High confidence that bypassing intermediate inspections with CWD process and repairing cars at destination will not be detrimental to air brake health
- Identifying and repairing cars with ineffective brakes at destination will increase the overall health of the fleet

Preliminary BHE Inspection Findings



Total Defects: 53 Grand Total: 63

- All cars received originating and intermediate inspection with no air related defects found
- Cars identified through CWD process and marked for inspection at destination
- ASCAT and BHE work scope completed at destination with positive results
- Defects found and repaired on cars identified with CWD
- Leading failure modes include bad service valves and air leaks which appeared to operate correctly based on visual inspection

Summary of No Defects Found

10 cars reported “No Defect Found” after ASCAT

- 1 inspected to verify there was no braking issue
  - 2 wheels did not increase in temperature
  - Validated this signature is not an ineffective brake
- 1 reported “N/A” for the ASCAT, assumed manual inspection was performed
- 1 re-failed after returning to service
  - Car flagged to re-inspect
- 4 had non-condemnable defects and thin brake shoes
- 3 found no issues and have not passed a CWD since return to service

Note: test is designed to catch all valves with ineffective brakes but may flag some valves as ineffective when differences are questionable

- Goal: inspect some false positives and create no false negatives

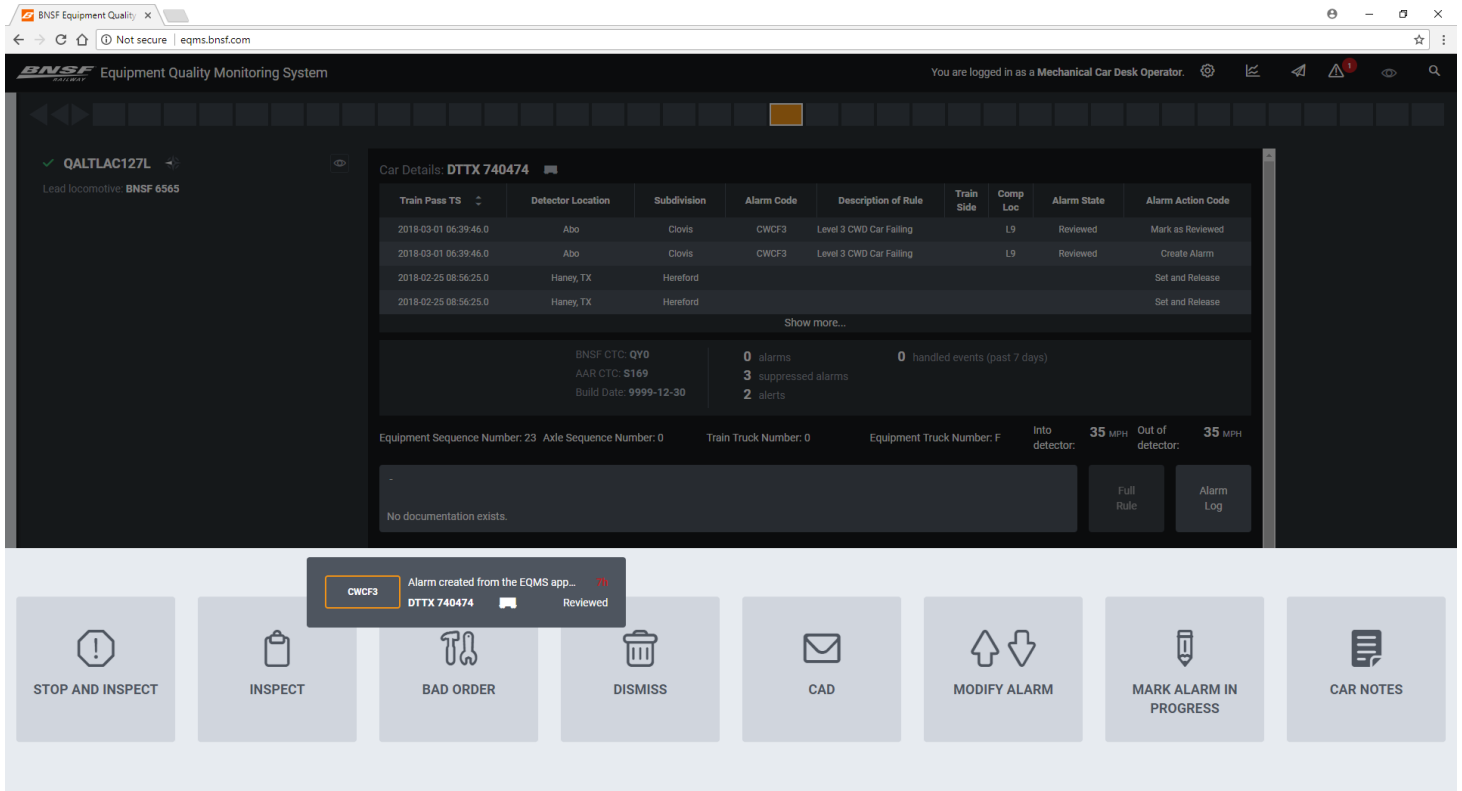
BHE Process Validation Using Passing ASCAT Cars

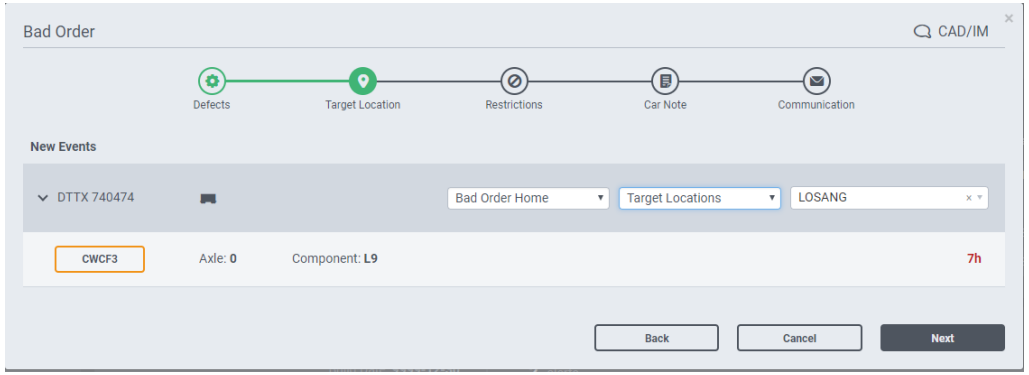
Compared cars that received and passed an ASCAT to readings from a CWD site on a previous train trip

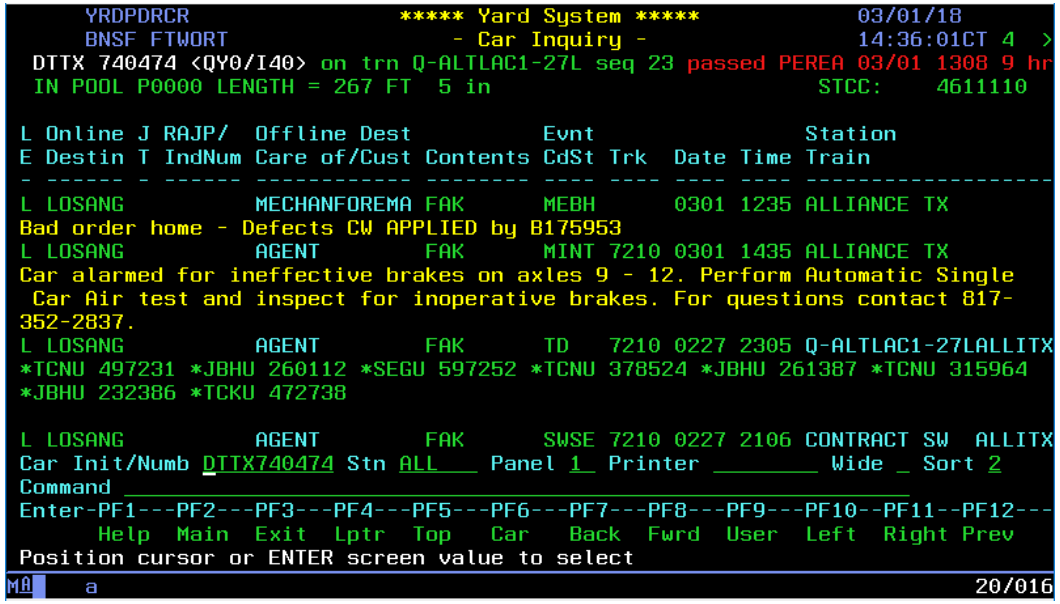
- 20 cars were reviewed that had no defects after an ASCAT
  - 19 cars also passed the BHE test
  - 1 car failed the BHE test prior to ASCAT
- Supports the finding from the inspected cars with suspect ineffective brakes
  - Low false positive rate from suspect cars
  - Low false positive rate off of known cars with good brakes

Notification Process

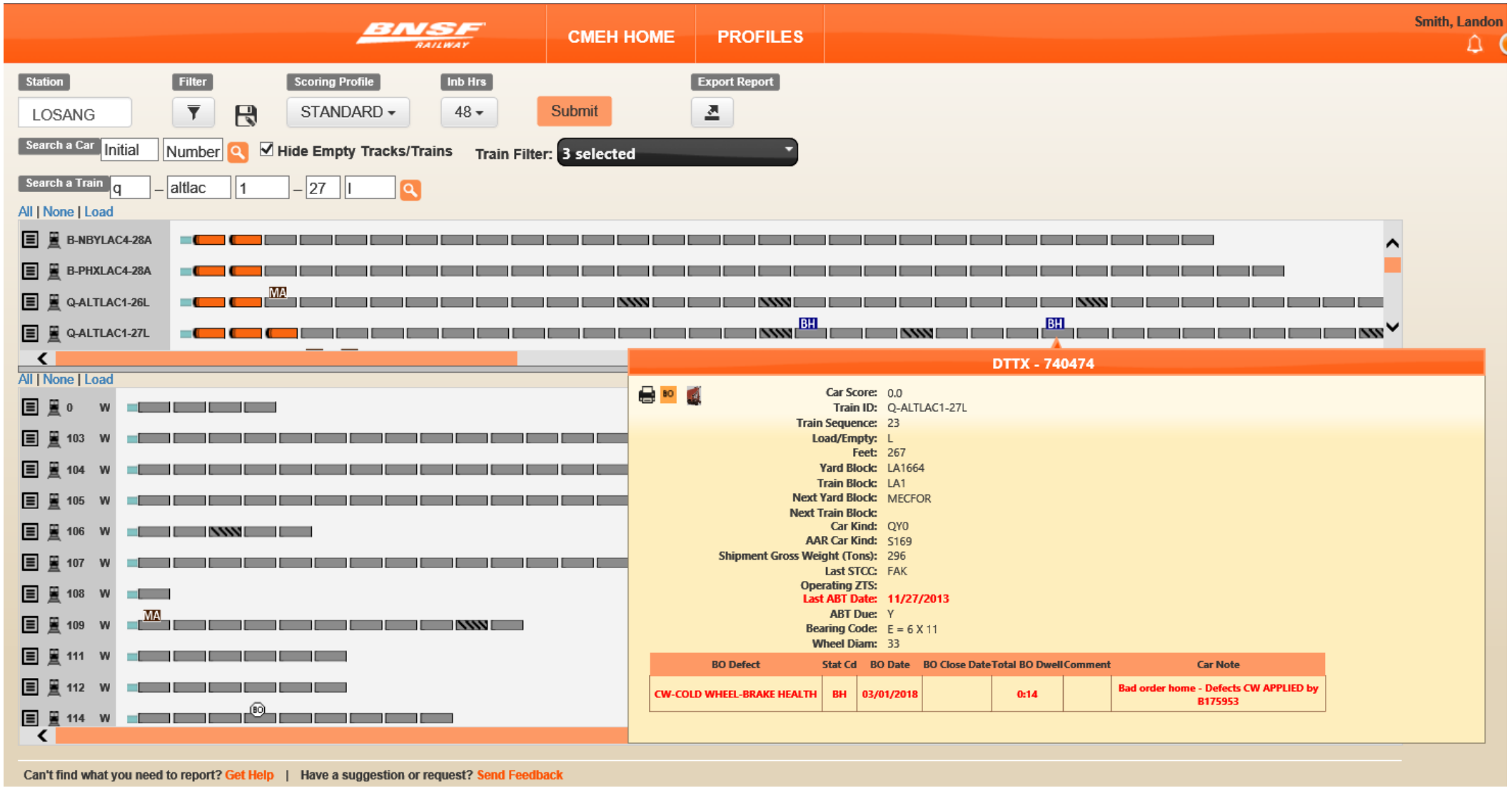
- Alert is bad ordered in Detector Desk UI
- Bad order is reflected in our TSS Mainframe







Notification Process



Supporting Technologies

- Detector Network
  - BNSF has extensive network of detectors in addition to BHE system to identify safety related defects
- Detector Health
  - Detector health is remotely monitored, tracked, and maintained
- PTC Implementation & Performance
  - PTC provides an additional layer of safety for train operations
  - BHE improvements will further confidence in PTC's braking algorithm

Detector Coverage Along Pilot Route

- Route is populated by more than 200 detectors
- Detector sites supplement manual inspections currently and provide redundancy in car health validation
- BHE pilot would not introduce changes to existing detector network
- 24/7 detector desk monitors, alerts, & advises about detector results
- Operating practices require appropriate response to detector alarms

Detector Technology	Systems
Hot Box Detector (HBD)	143
Hot Wheel Detector (HWD)	34
Wheel Impact Load Detector (WILD)	4
Acoustic Bearing Detector (ABD)	4
Truck Hunting Detector (THD)	2
Truck Performance Detector (TPD)	3
Truck Geometry Detector (TGD)	2
Cracked Wheel and Axle Detector (CWAD)	1
Machine Vision – Brake Shoe Detector (BSD)	4
Machine Vision – Coupler Cross Key (CCK)	2
Machine Vision – Coupler Carrier Plate (CCP)	2
Machine Vision – Low Air Hose (LAH)	1
Machine Vision – Spring and Wedge Detector (SWD)	2
Machine Vision – Wheel Tread Detector (WTD)	1
Machine Vision – Wheel Profile Detector (WPD)	2

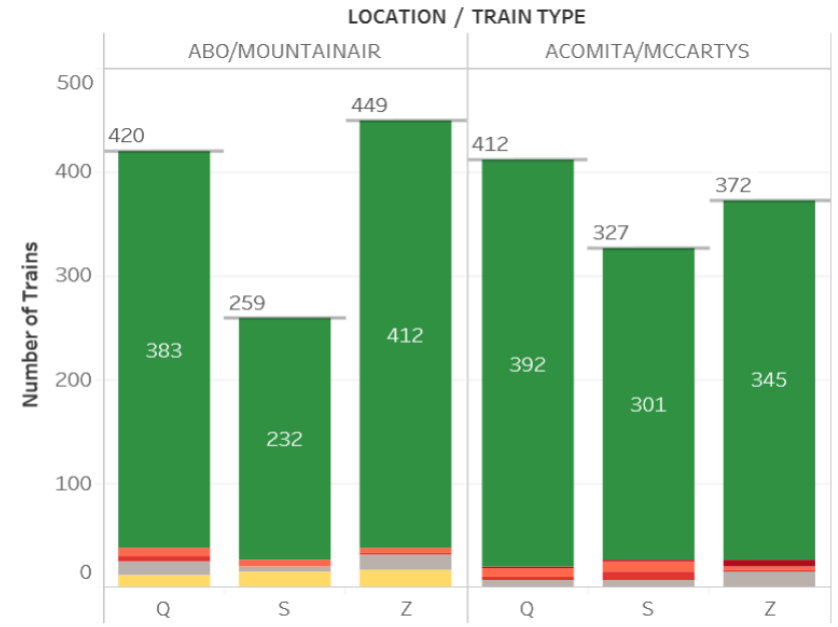
Detector Health

Detector Health Dashboard

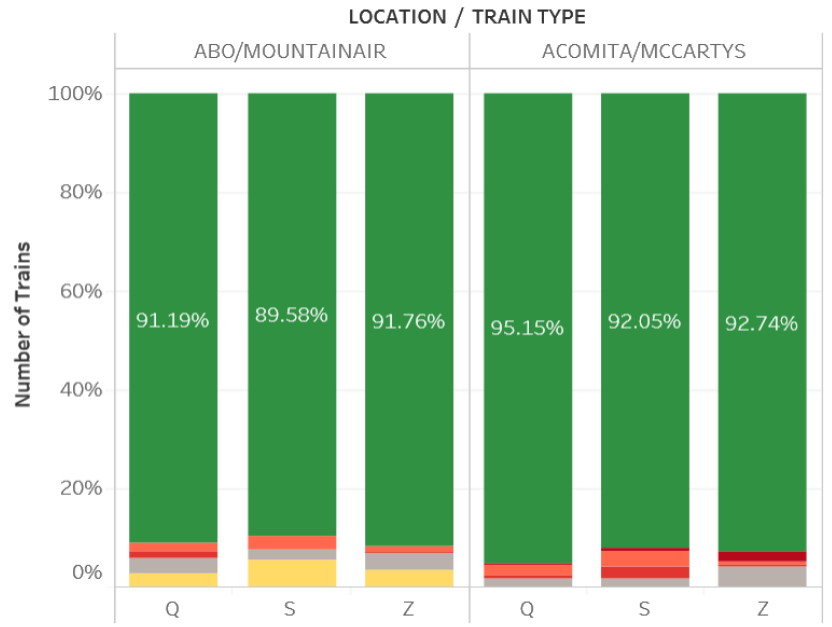
- Shows the performance of detector reporting
- Ability to understand why messages were not received
  - Passed on opposite main
  - Switched mains between sites
  - One or both sites did not report, or error occurred with message processing

SUMMARY
- BOTH_MATCH
- BOTH_MISSING
- BRK_MISSING
- NBRK_MISSING
- NO_CWD
- SWITCH

CWD Message Analysis



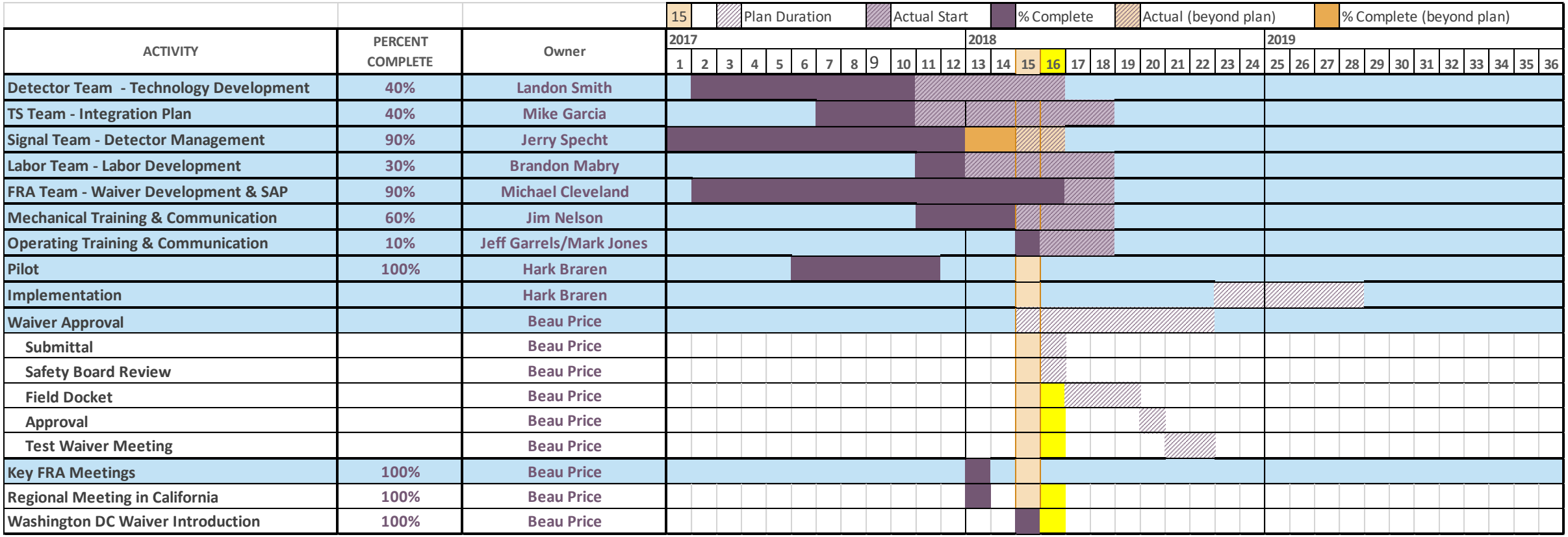
CWD Message Analysis %



Summary

LOCATION	TRAINS	SUMMARY	
ABO/MOUNTAINAIR	Q, S, Z	BOTH_MATCH	91.05%
		BRK_MISSING	1.68%
		NBRK_MISSING	0.53%
		NO_CWD	3.01%
		SWITCH	3.72%
ACOMITA/MCCARTYS	Q, S, Z	BOTH_MATCH	93.43%
		BOTH_MISSING	1.08%
		BRK_MISSING	1.80%
		NBRK_MISSING	1.08%
		NO_CWD	2.61%

Project Plan



ACTIVITY	PERCENT COMPLETE	Owner
Detector Team - Technology Development	40%	Landon Smith
TS Team - Integration Plan	40%	Mike Garcia
Signal Team - Detector Management	90%	Jerry Specht
Labor Team - Labor Development	30%	Brandon Mabry
FRA Team - Waiver Development & SAP	90%	Michael Cleveland
Mechanical Training & Communication	60%	Jim Nelson
Operating Training & Communication	10%	Jeff Garrels/Mark Jones
Pilot	100%	Hark Braren
Implementation		Hark Braren
Waiver Approval		Beau Price
Submittal		Beau Price
Safety Board Review		Beau Price
Field Docket		Beau Price
Approval		Beau Price
Test Waiver Meeting		Beau Price
Key FRA Meetings	100%	Beau Price
Regional Meeting in California	100%	Beau Price
Washington DC Waiver Introduction	100%	Beau Price

Team Make Up

Cross functional team from multiple groups:

- Regulatory & Project Management
  - Beau Price
  - Michael Cleveland
- Detector
  - Matt Baldwin
  - Hark Braren
  - Landon Smith
  - April Kuo
  - Roochi Mishra
- Technology Services
  - Asim Ghanchi
  - Larry Sutton
- Signal
  - Jerry Specht
  - Joe Schnell
- Operating Practices
  - Jeff Garrels
  - Mark Jones
- Field Mechanical & Labor Communication
  - Brandon Mabry
  - Jim Nelson
  - Mitch Mantz – General Manager TTX
  - Mike Hansen – General Manager TTX
- Service Design
  - Michelle Flanery

Appendix

Form C – SAP Appendix C

Released October 2017:

“FOR THE PURPOSES OF TESTING BRAKE HEALTH EFFECTIVENESS, ALL LOADED INTERMODAL TRAINS (EXCLUDING “V” SYMBOLS) OPERATING WESTBOUND ON MAIN TRACK TWO ARE REQUIRED TO MAKE AT LEAST A 10 LB. RUNNING AIR BRAKE SET AT MP 859 AND MUST HOLD SET UNTIL REAR OF TRAIN HAS CLEARED TRACK-SIDE WARNING DETECTOR AT MP 860. STRETCH BRAKING, IF REQUIRED, IS PERMITTED WHILE PERFORMING THIS RUNNING AIR BRAKE SET. PLEASE ADDRESS ANY QUESTONS YOU MAY HAVE TO YOUR ROAD FOREMAN OF ENGINES.”

Speed Analysis for Test Site (Acomita)