Comparison of Predicted and Actual Rail Temperature

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ENSCO Rail
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Executive Summary

A rail temperature **prediction** system was deployed by ENSCO within a program supported by the FRA Office of Research, Development and Technology, CSX, and Amtrak.

The system predicts rail temperatures 12 hours in advance for the entire continental USA.

The system was validated against **actual** rail temperature measurements from wayside systems.

Background

Rail experiences longitudinal stress caused by thermal expansion contraction.

“Neutral Rail Temperature” is the temperature at which rail stress is zero.

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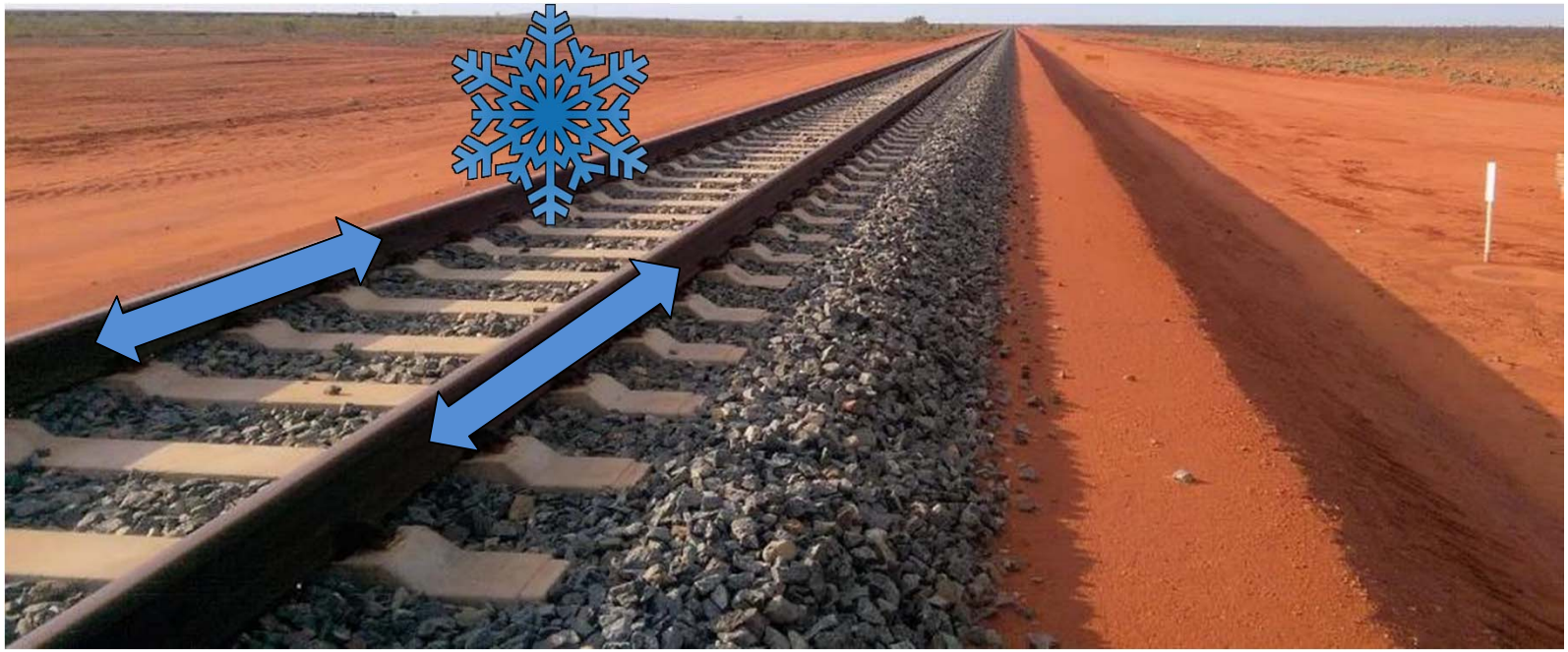

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Background

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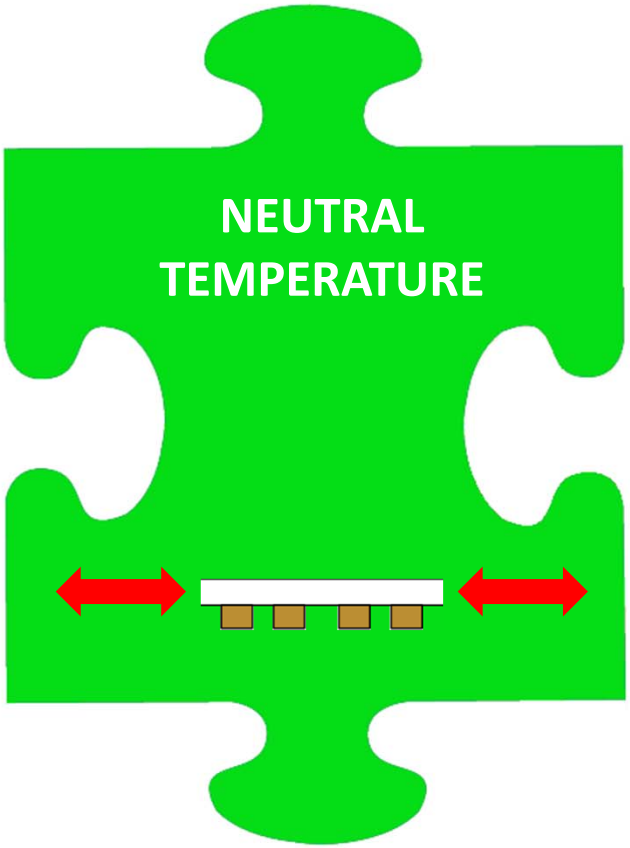
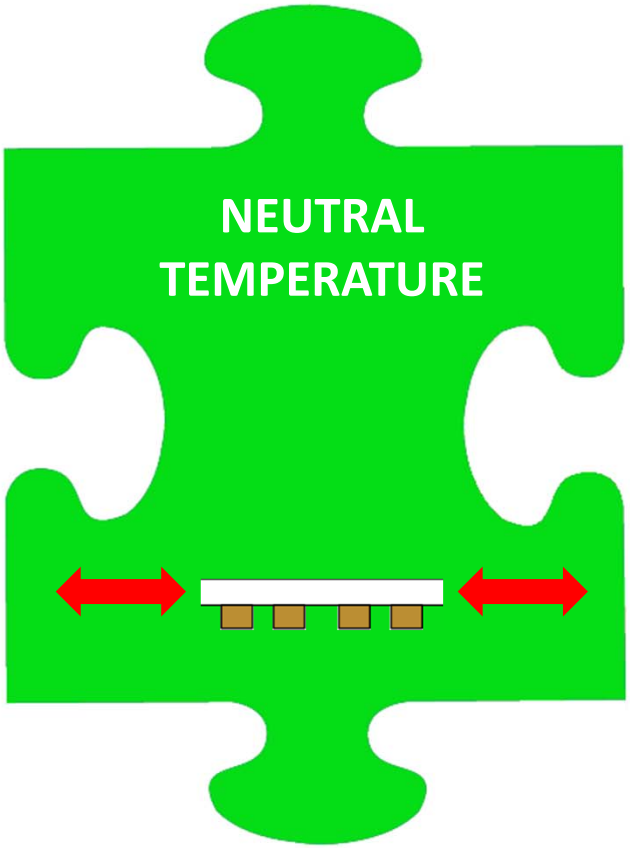
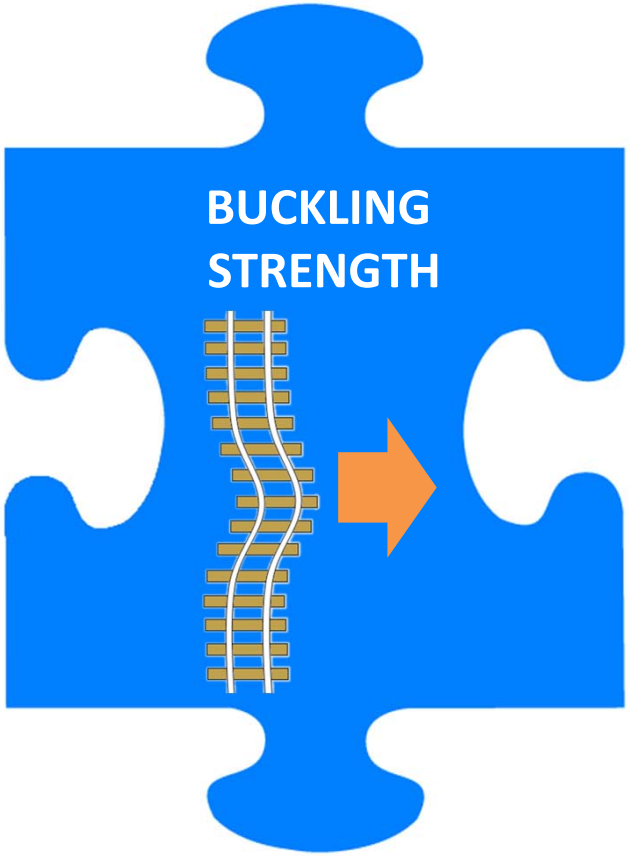
Background

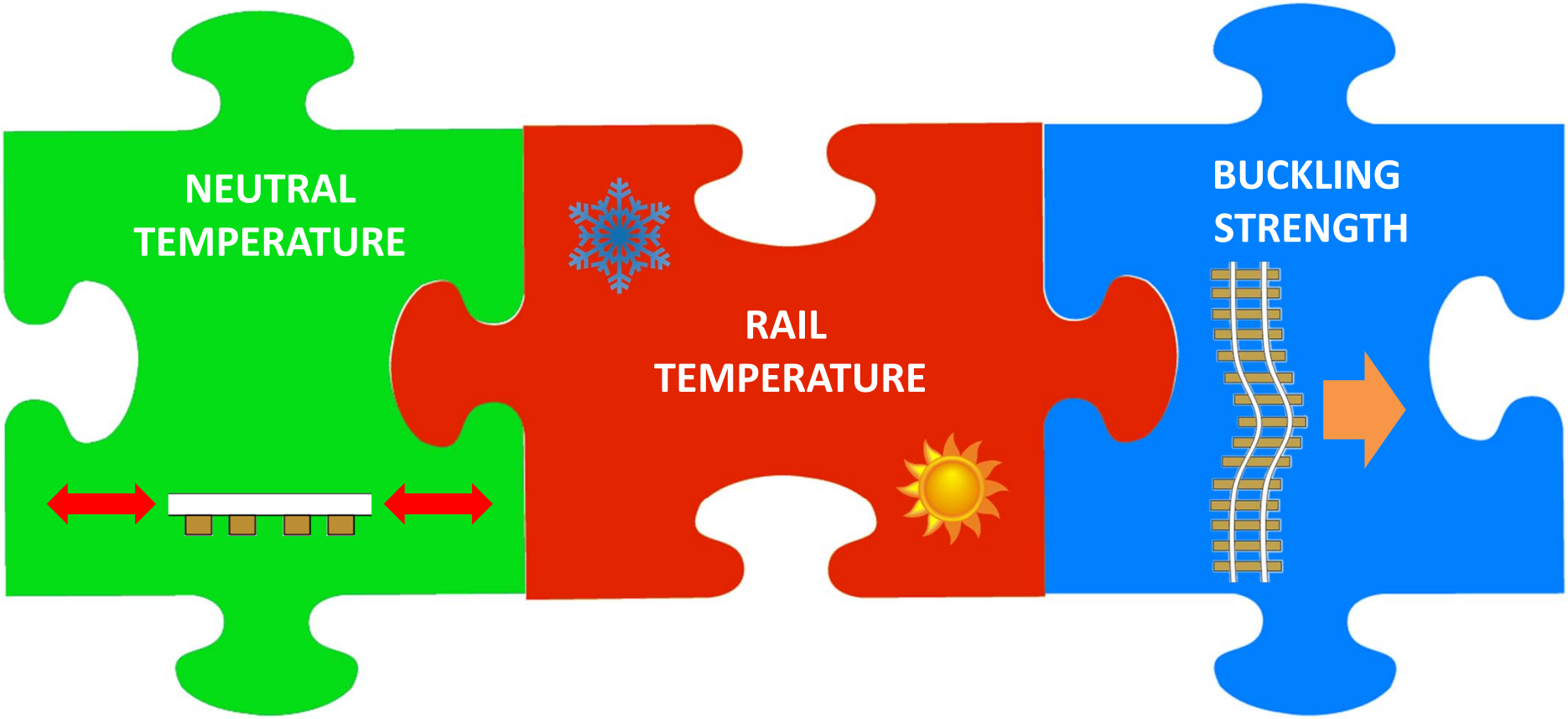
"Pull Apart" broken rail in the winter

"Track Buckles" in the summer.


NEUTRAL
TEMPERATURE

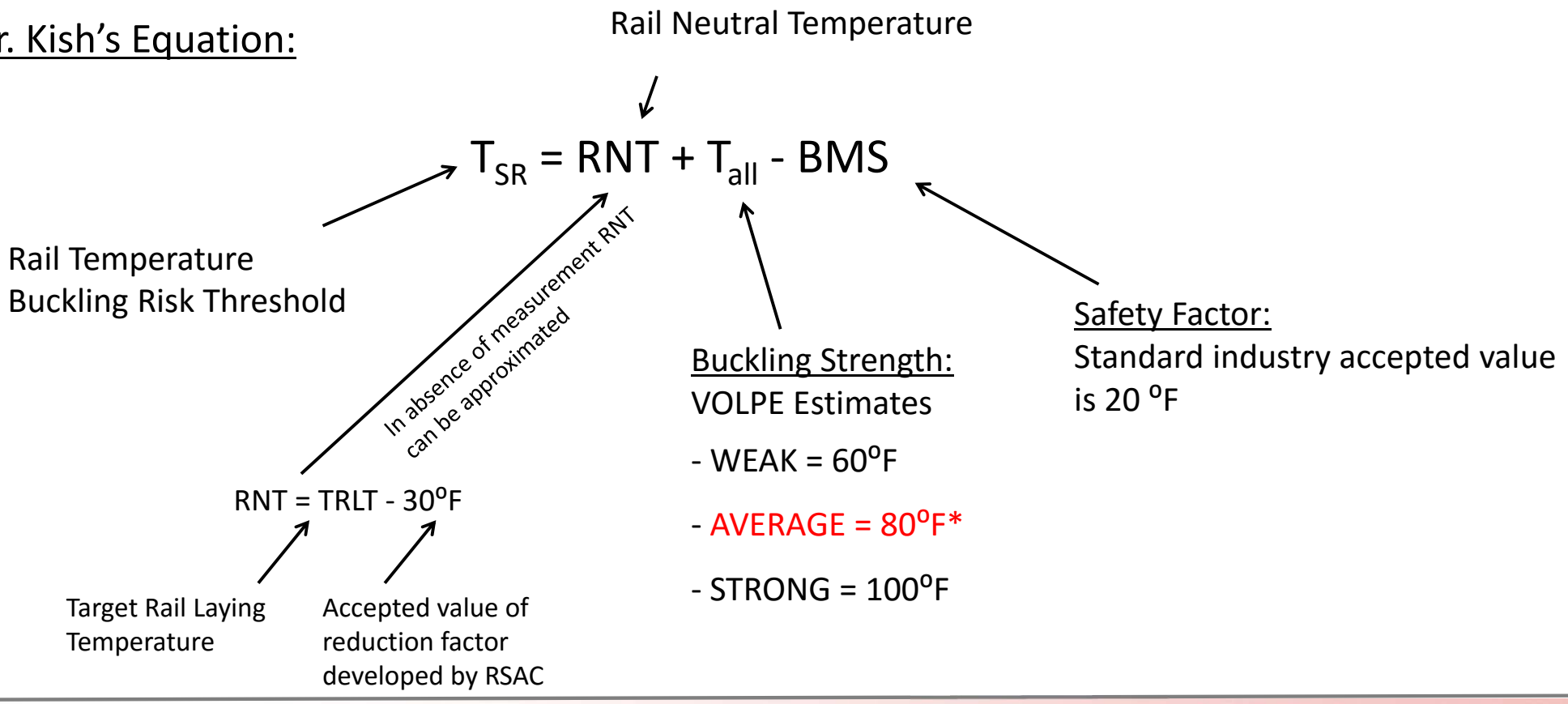

NEUTRAL
TEMPERATURE


BUCKLING
STRENGTH


NEUTRAL
TEMPERATURE
RAIL
TEMPERATURE
BUCKLING
STRENGTH

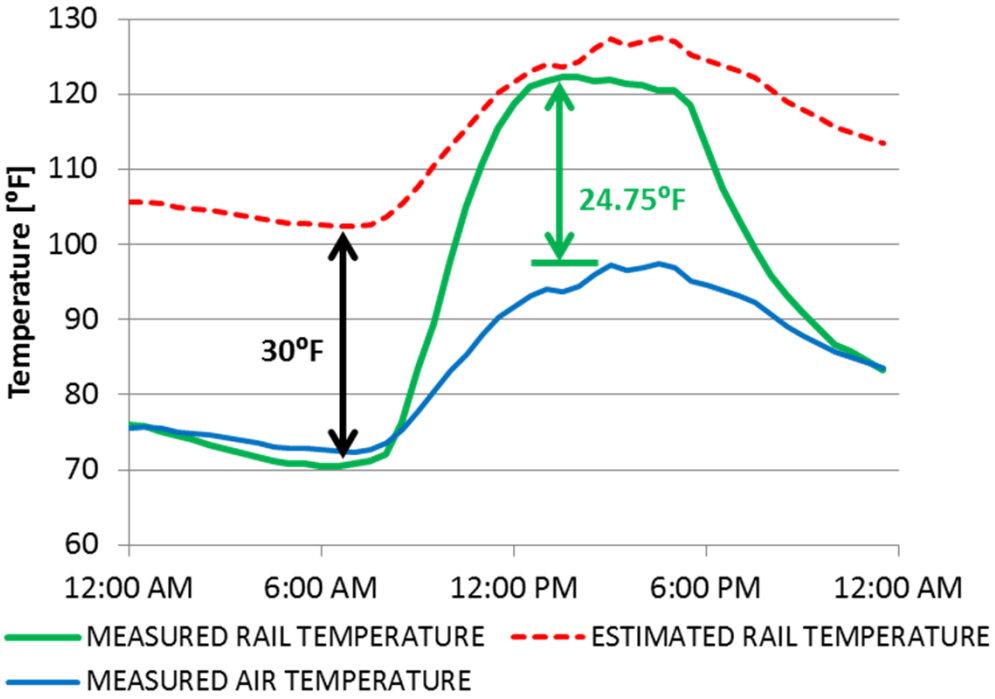
Determining RT Threshold

Dr. Kish's Equation:



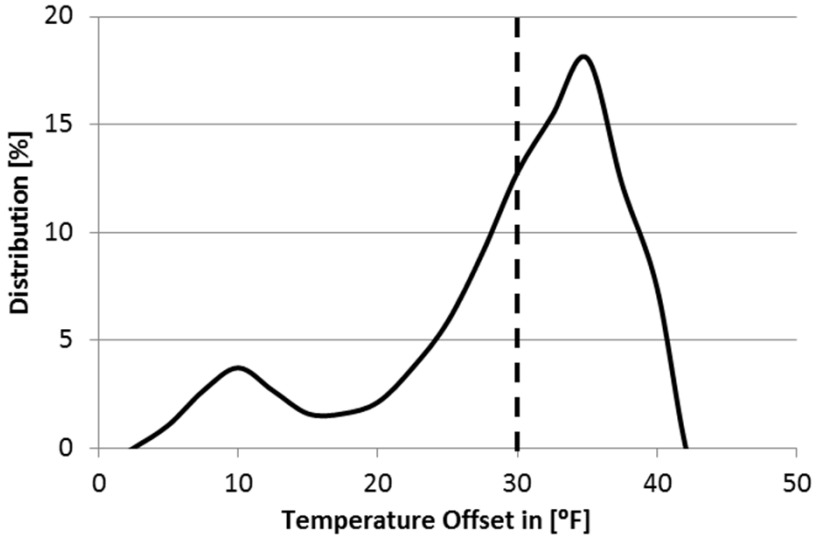
Current Approach

Add Offset to Maximum Predicted Air Temperature (30 or 25 ^{o}F)



In reality, the offset is not a constant.

Using a single constant can lead to errors.

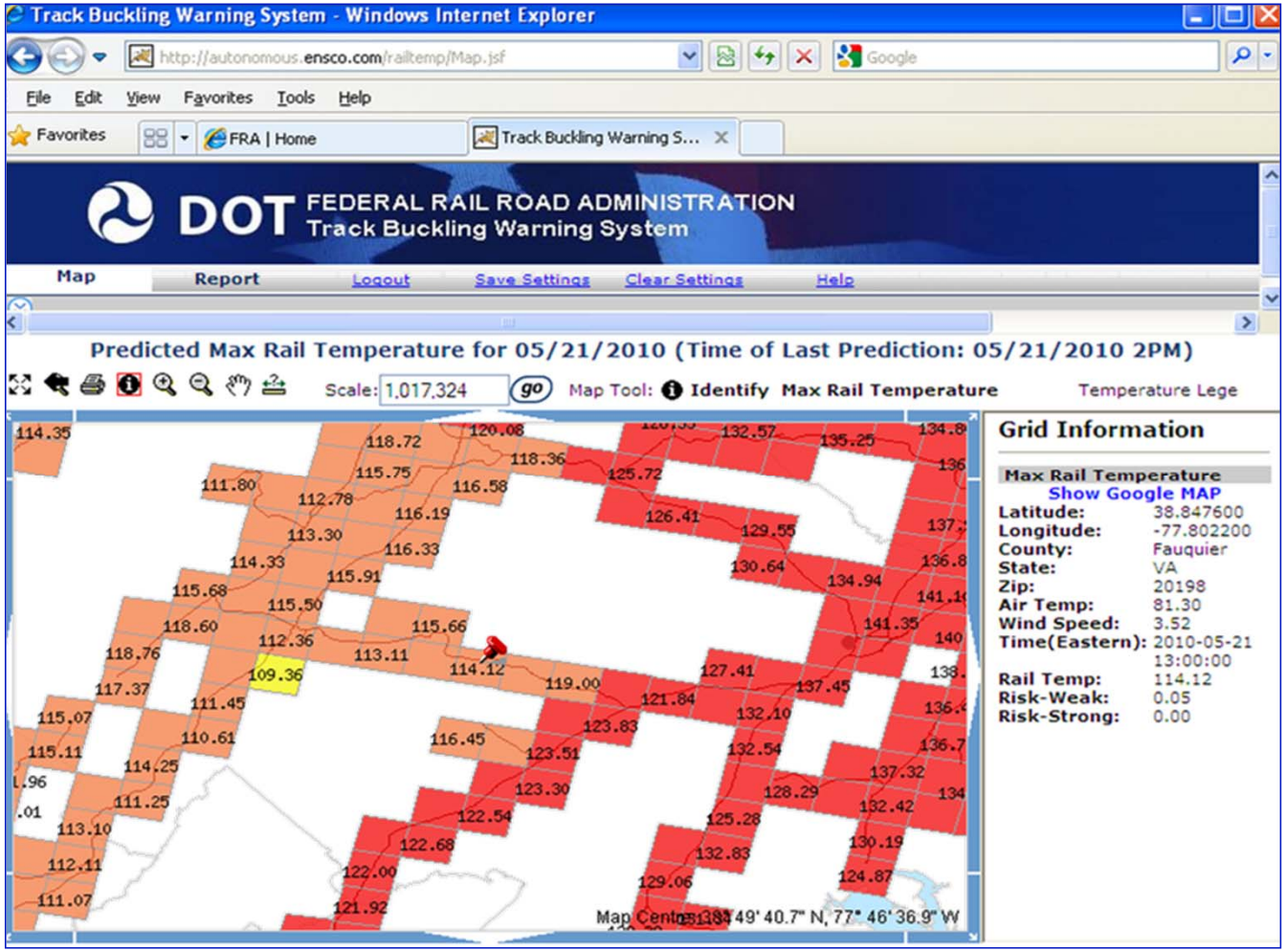


Rail Temperature Prediction Model

- Uses Weather Data Model from the ENSCO Aerospace Division

- Used parameters:
  - Air Temperature
  - Intensity of solar radiation
  - Solar angle
  - Wind speed
  - Sky temperature
  - Heat absorptivity and emissivity of rail

- Predictions are continuous and granular
  - 9x9 km grids converted to subdivision/milepost
  - 30-minute time increments
  - 12 hours ahead


Track Buckling Warning System - Windows Internet Explorer
http://autonomous.ensco.com/railtemp/Map.jsf
File Edit View Favorites Tools Help
Favorites
FRA | Home
Track Buckling Warning S...
DOT FEDERAL RAIL ROAD ADMINISTRATION
Track Buckling Warning System
Map
Report
Logout
Save Settings
Clear Settings
Help
Predicted Max Rail Temperature for 05/21/2010 (Time of Last Prediction: 05/21/2010 2PM)
Scale: 1,017,324
go
Map Tool: Identify Max Rail Temperature
Temperature Lege
Grid Information
Max Rail Temperature
Show Google MAP
Latitude: 38.847600
Longitude: -77.802200
County: Fauquier
State: VA
Zip: 20198
Air Temp: 81.30
Wind Speed: 3.52
Time(Eastern): 2010-05-21 13:00:00
Rail Temp: 114.12
Risk-Weak: 0.05
Risk-Strong: 0.00
Map Cente 49' 40.7" N, 77° 46' 36.9" W

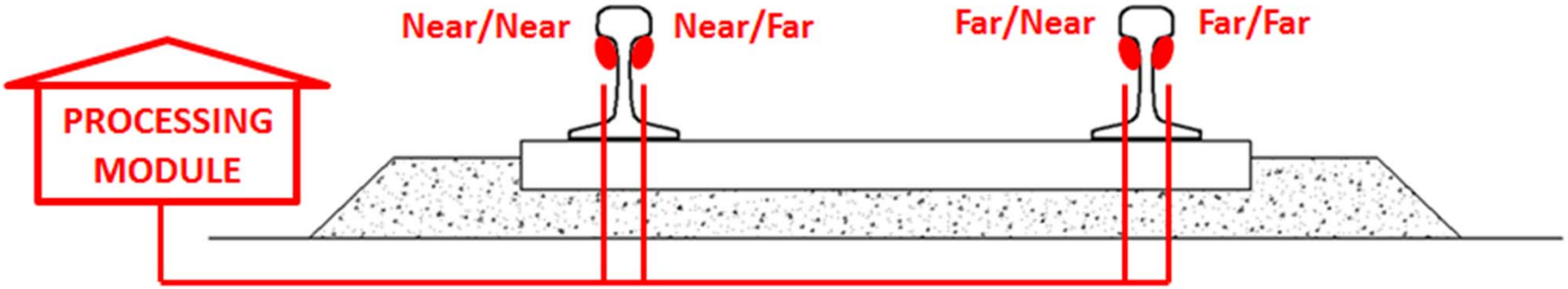
Model Validation

CSX 23 Wayside Sites

Amtrak 21 Wayside Sites

Actual measured rail temperature was used to benchmark and validate the rail temperature prediction model.

Model Validation



The CSX wayside sites had 4 temperature sensors under the rail heads

The Amtrak wayside sites have 2 temperature sensors (one per rail) on the rail base

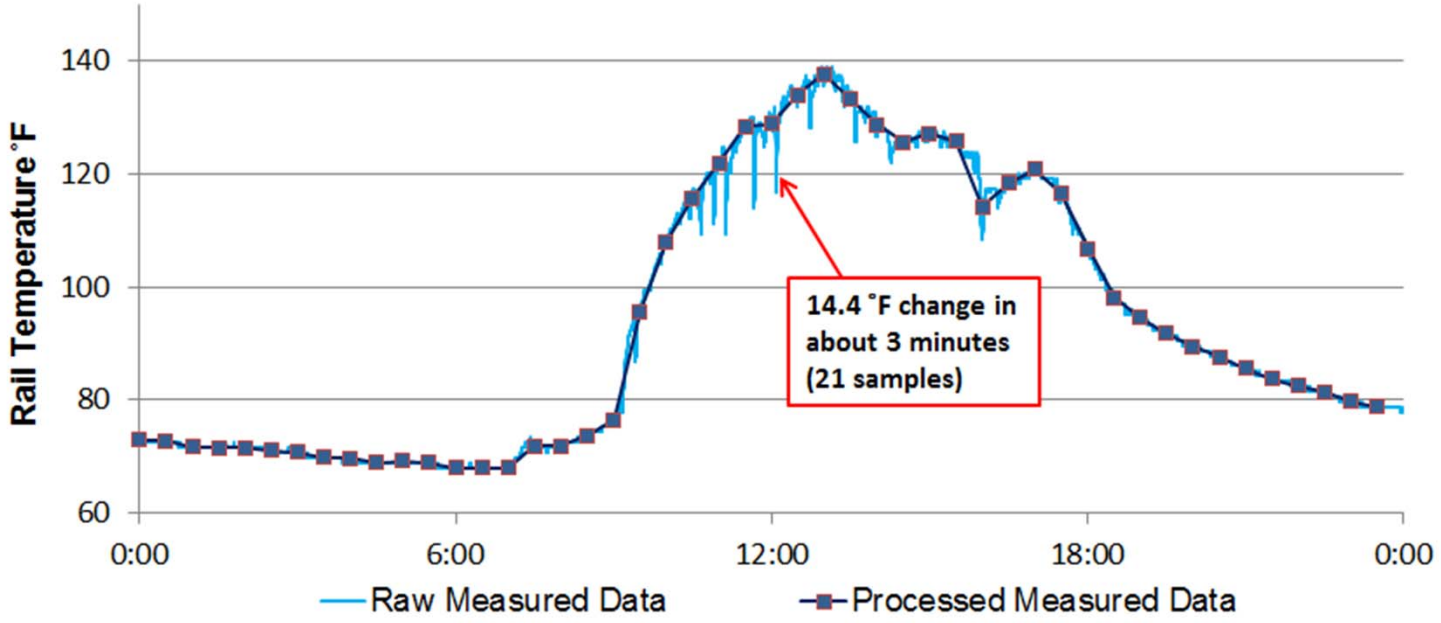
CSX data was downloaded manually for analysis

Amtrak data is automatically transferred from the wayside sites

Model Validation

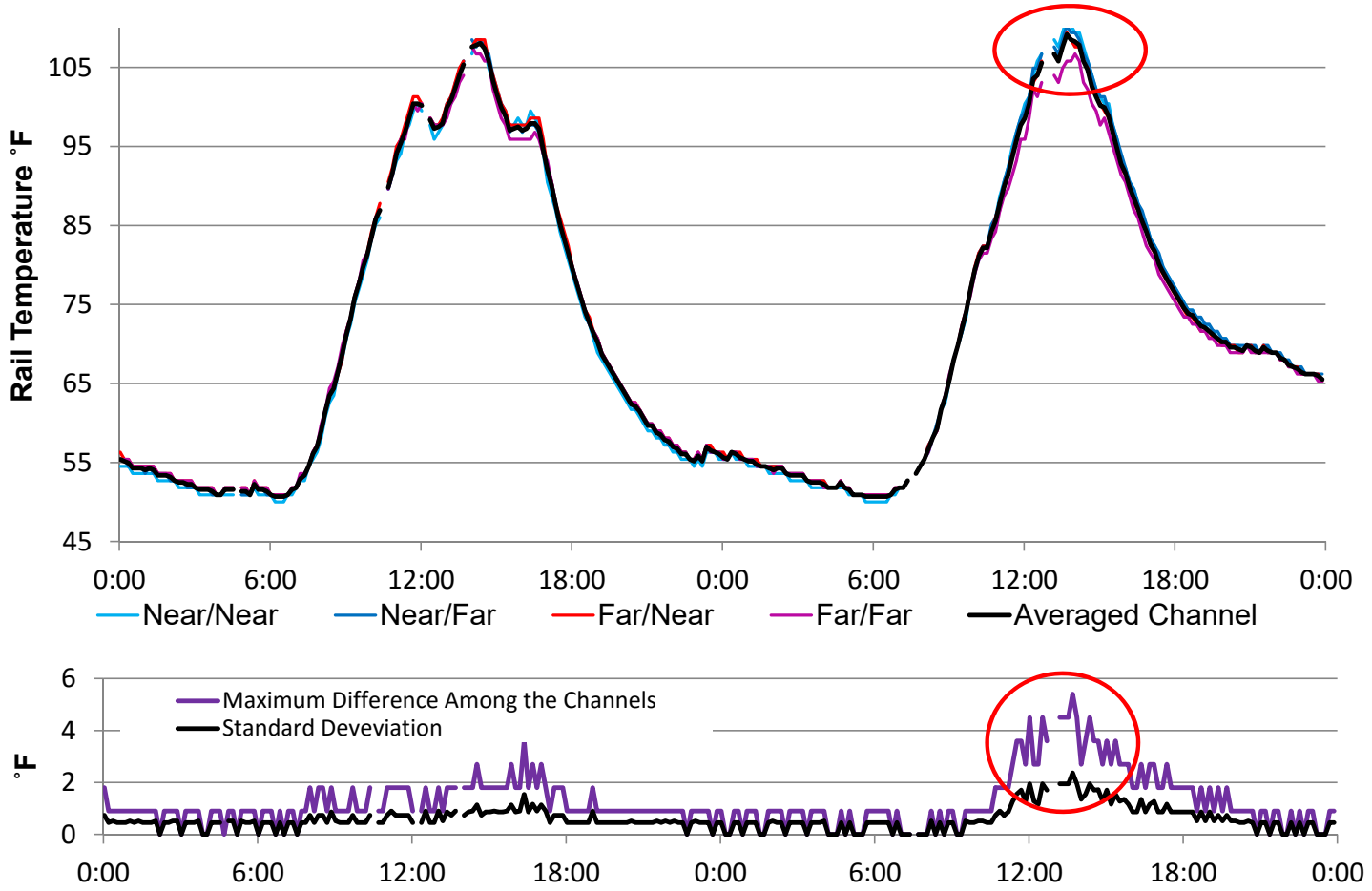
Raw measured rail temperature data was noisy

Filtering was required to smooth the data



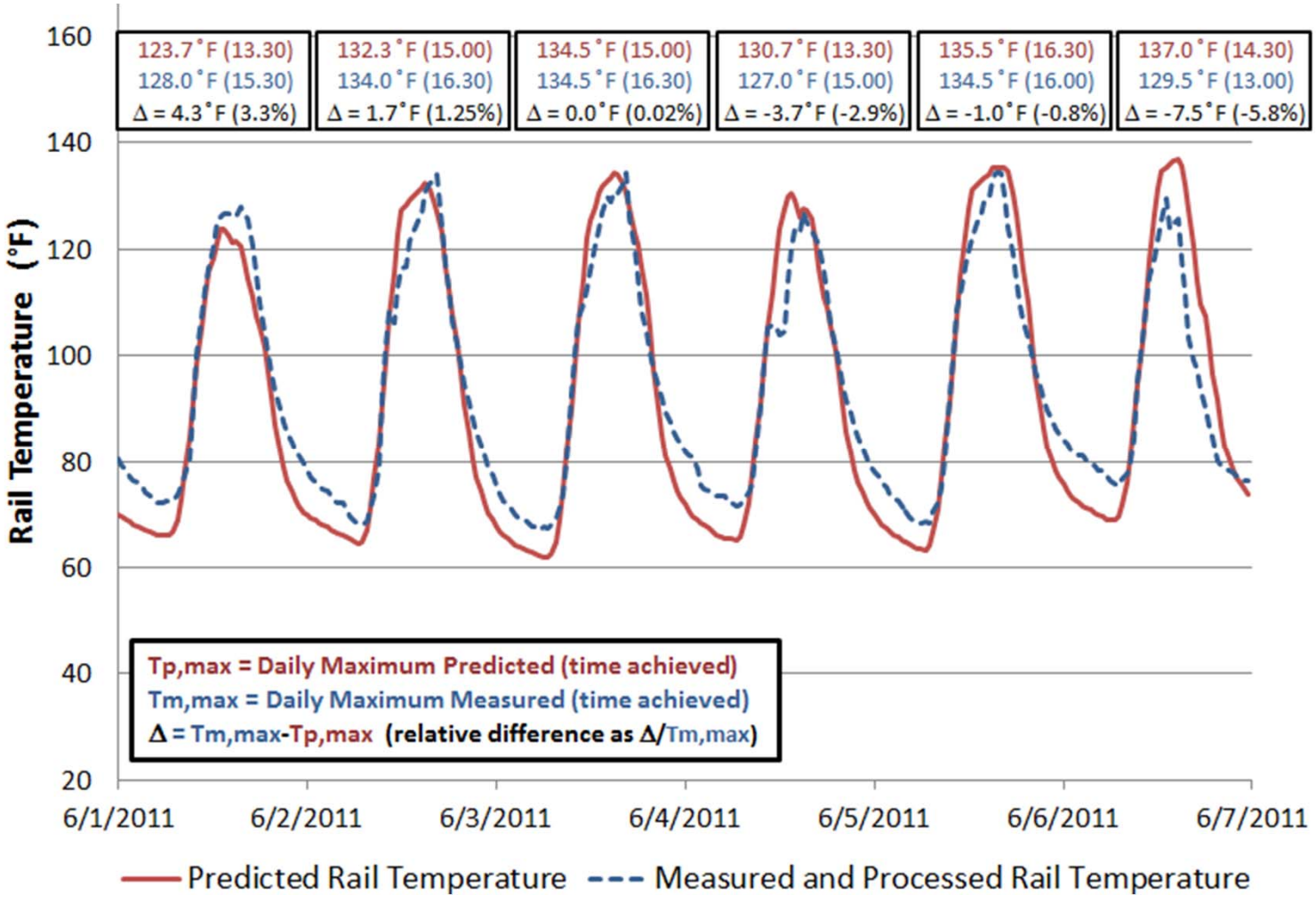
Model Validation

- Differences between the 4 sensors was observed.
- An average channel was created.
- Error ranged 1 to 5 ^{o}F.



Predicted Rail Temperature

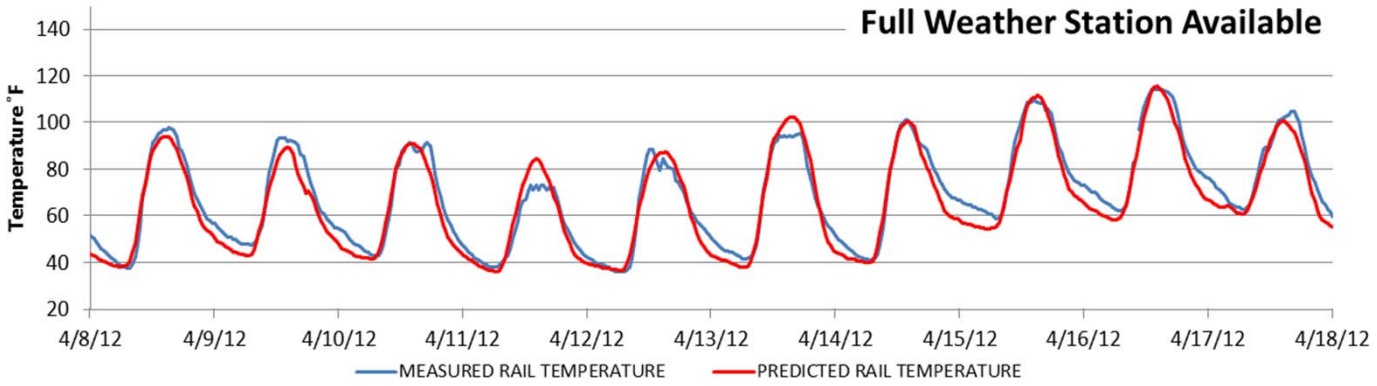
Measured Rail Temperature



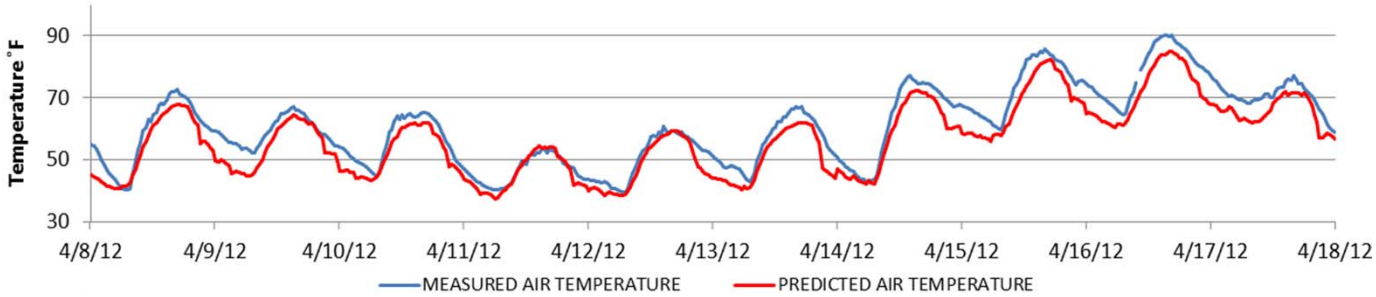
Predicted Rail Temperature

Measured Rail Temperature

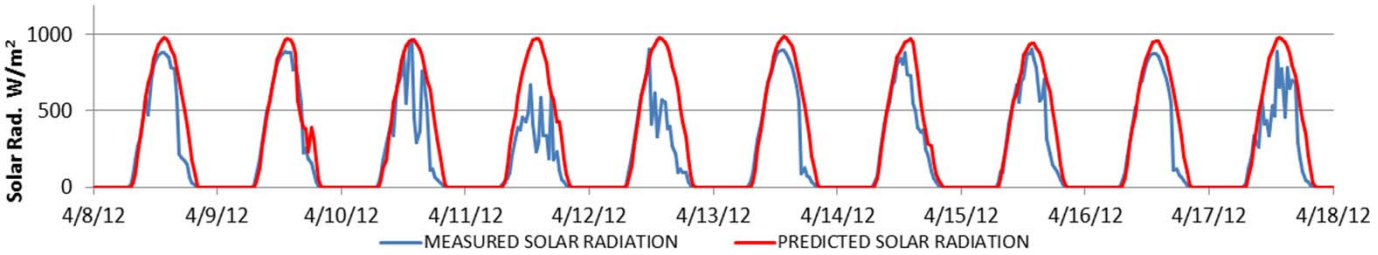
Rail Temperature



Air Temperature



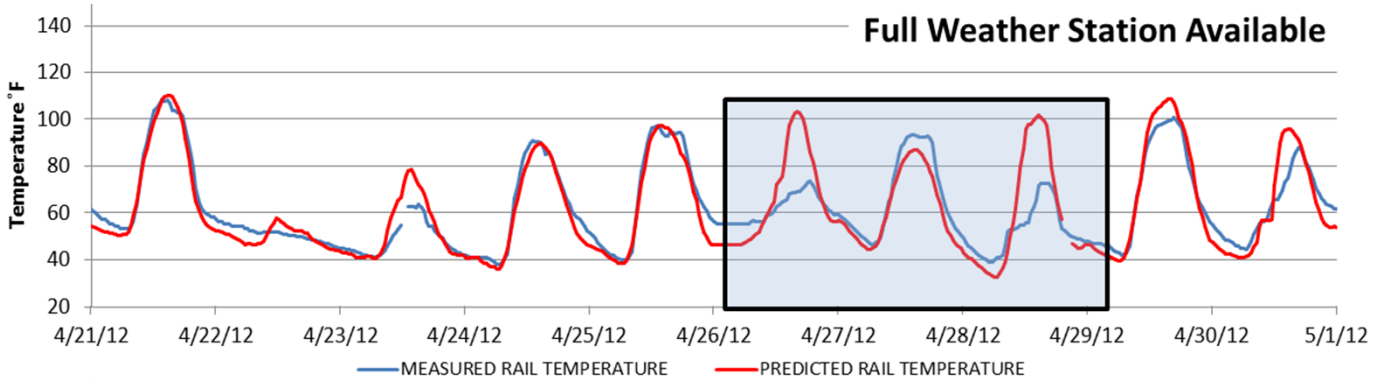
Solar Radiation



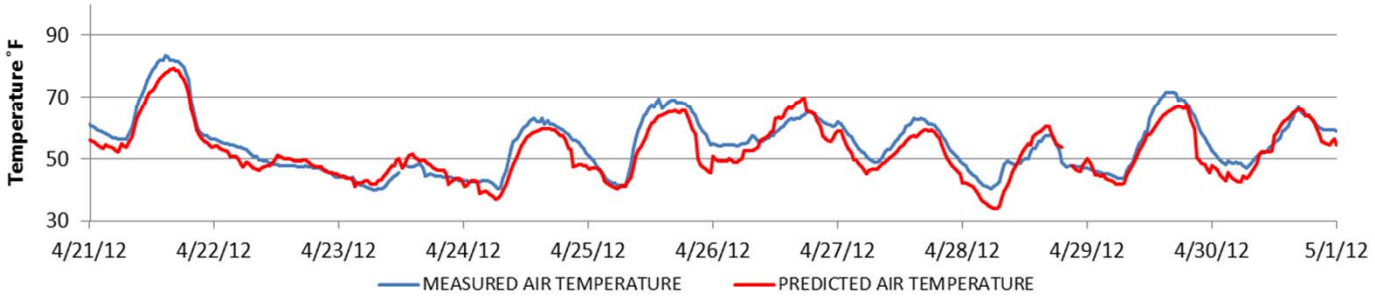
Predicted Rail Temperature

Measured Rail Temperature

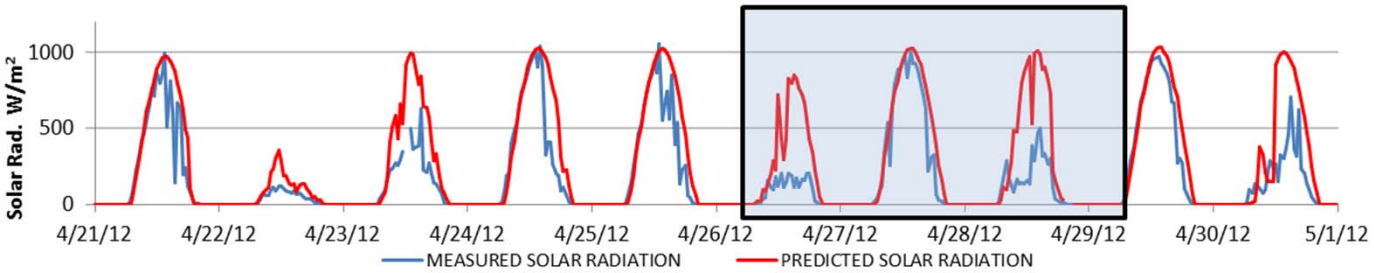
Rail Temperature



Air Temperature



Solar Radiation



Model Validation

Key Observations:

1. Model was found to be on average within 5 ^{o}F compared to the measured rail temperature for peak daily temperatures.

2. Days of over predicted maximum temperatures were associated with inaccurate solar radiation prediction data.

    - Further analysis is needed, but this may be attributed to scattered storms/cloud cover.

3. The model under predicted the minimum temperature, which required the model to be adjusted.

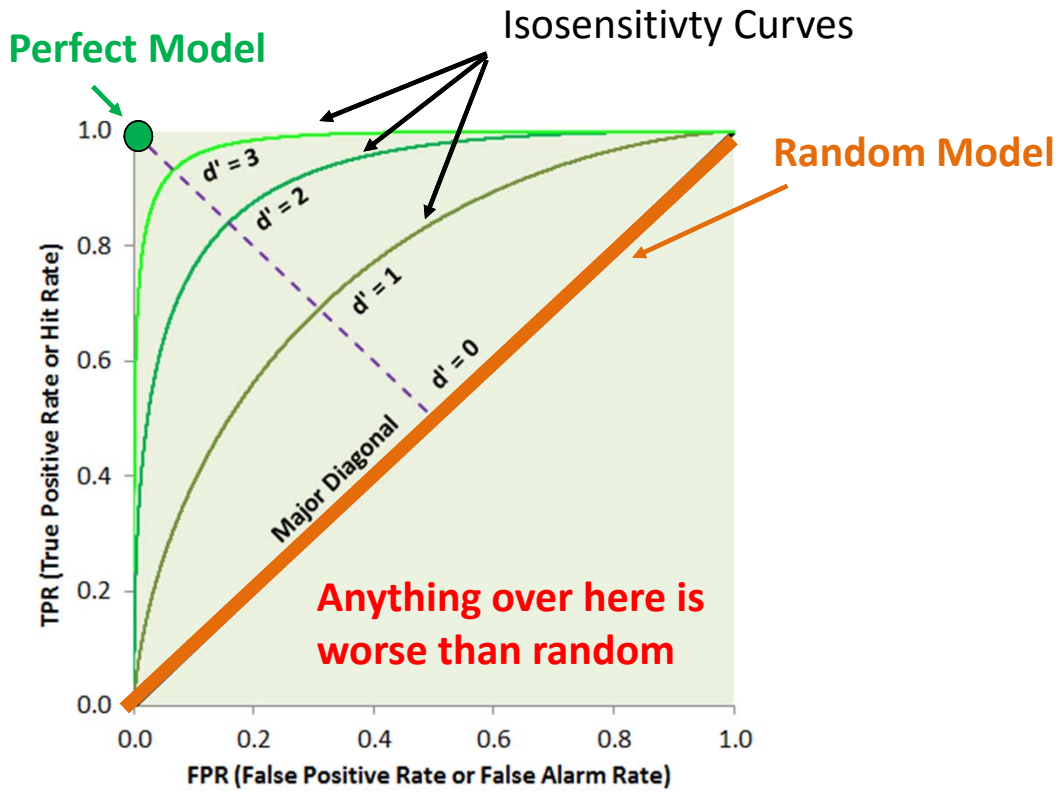
Threshold Analysis

- Evaluated how accurate alerts would be generated at given thresholds.
- Used measured rail temperature as ground truth
- Evaluated the Prediction Model and the +25 ^{o}F Air Temp Model
- Used the signal detection theory “Receiver Operating Characteristics” (ROC)
- Built 2x2 contingency tables (also known as confusion matrix)
- False Positive Rate and True Positive Rates are calculated from the contingency tables.

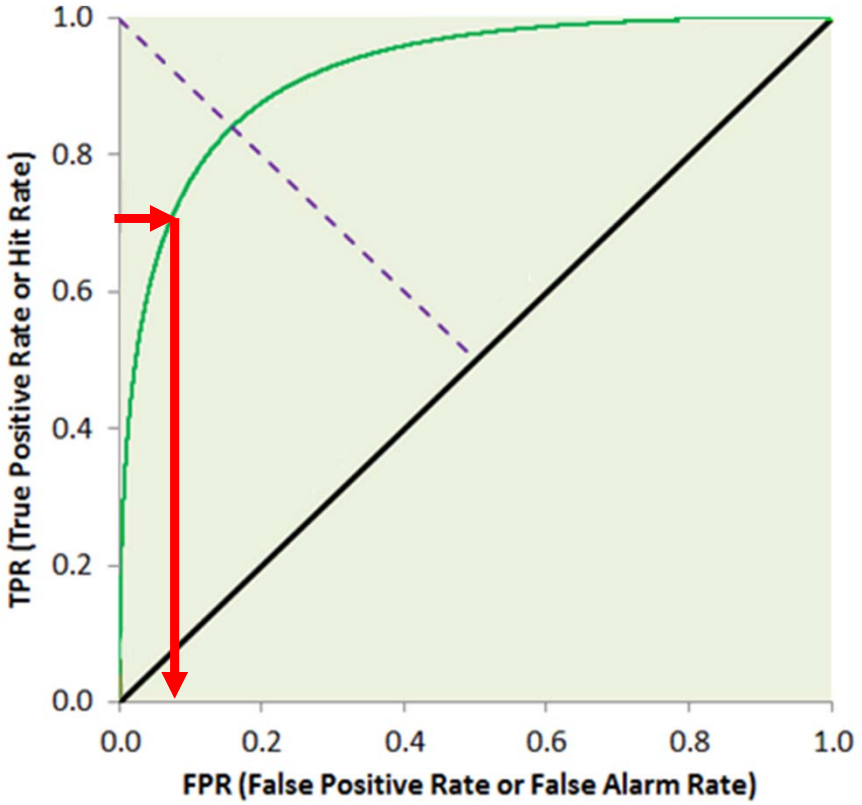
		Predicted	
		Alert	No Alert
Ground Truth	Alert	True Positives	False Negatives
	No Alert	False Positives	True Negatives

ROC Space Plot

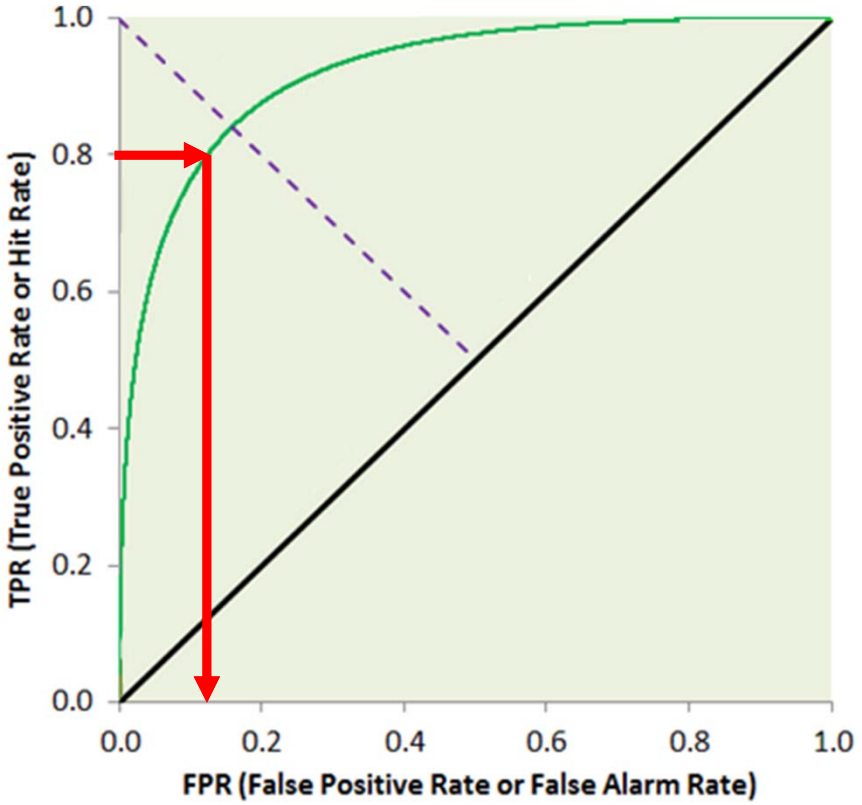
- By plotting the data, you build an “isosensitivity curve”.
- Each model has its own isosensitivty curve
- The shape of the curve shows how accurate the model is.



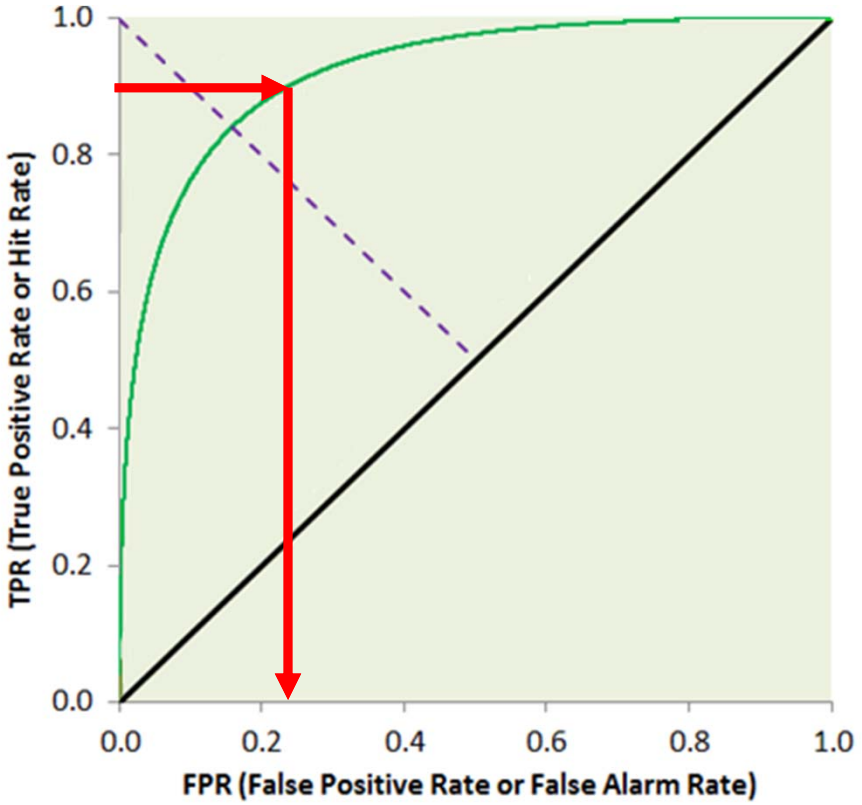
ROC Space Plot



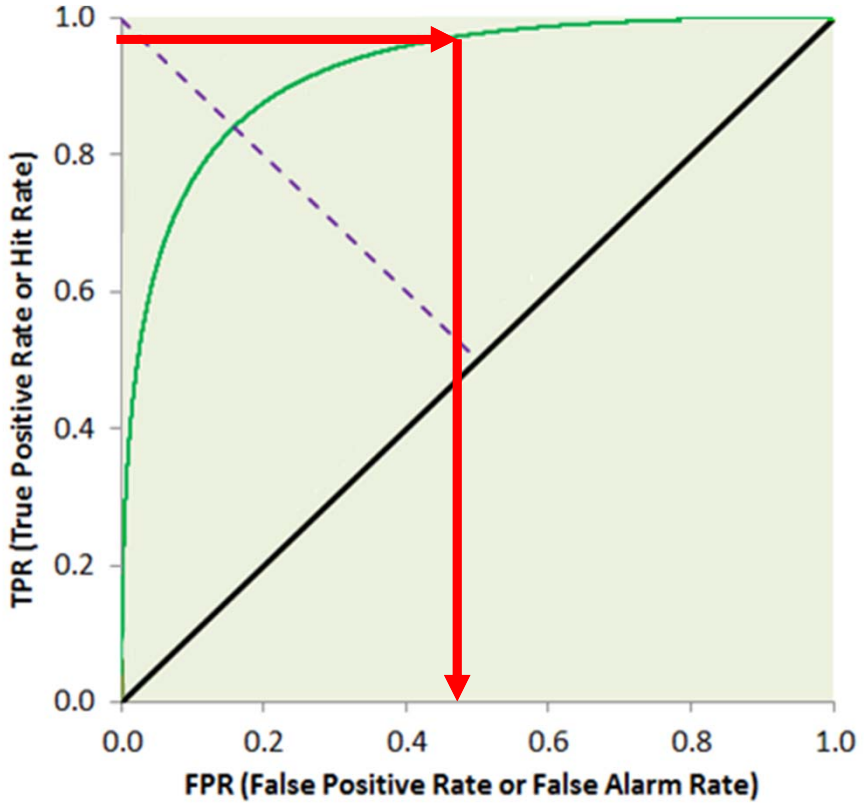
ROC Space Plot



ROC Space Plot

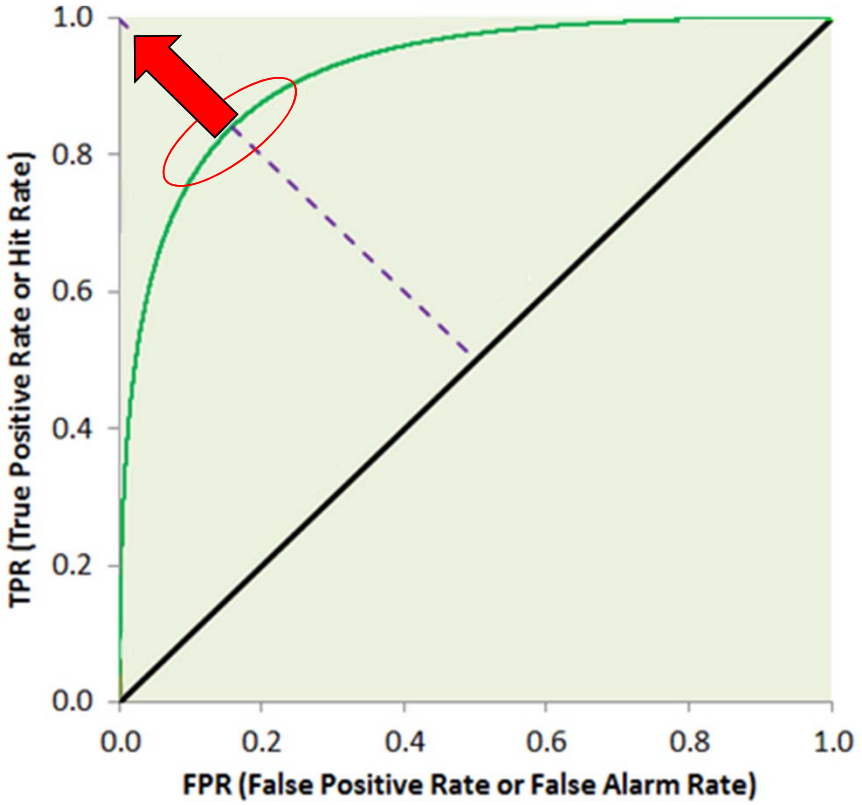


ROC Space Plot



ROC Space Plot

The “Sweet Spot” is a balance of the True Positive Rate and the False Positive Rate and having the isosensitivity curve be as close to the corner as possible.

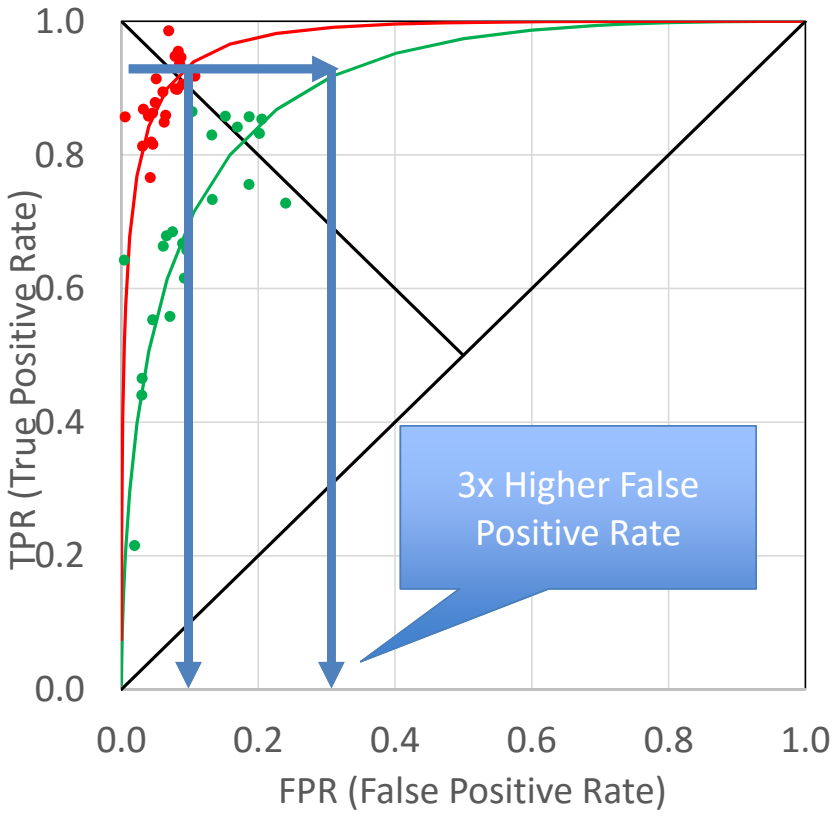


Effectiveness of the Model

Plot of individual wayside sites alarm rates.

Built corresponding isosensitivity curves

Results indicate that the Prediction Model out performs the current method of an offset from the air temperature.



Prediction Model

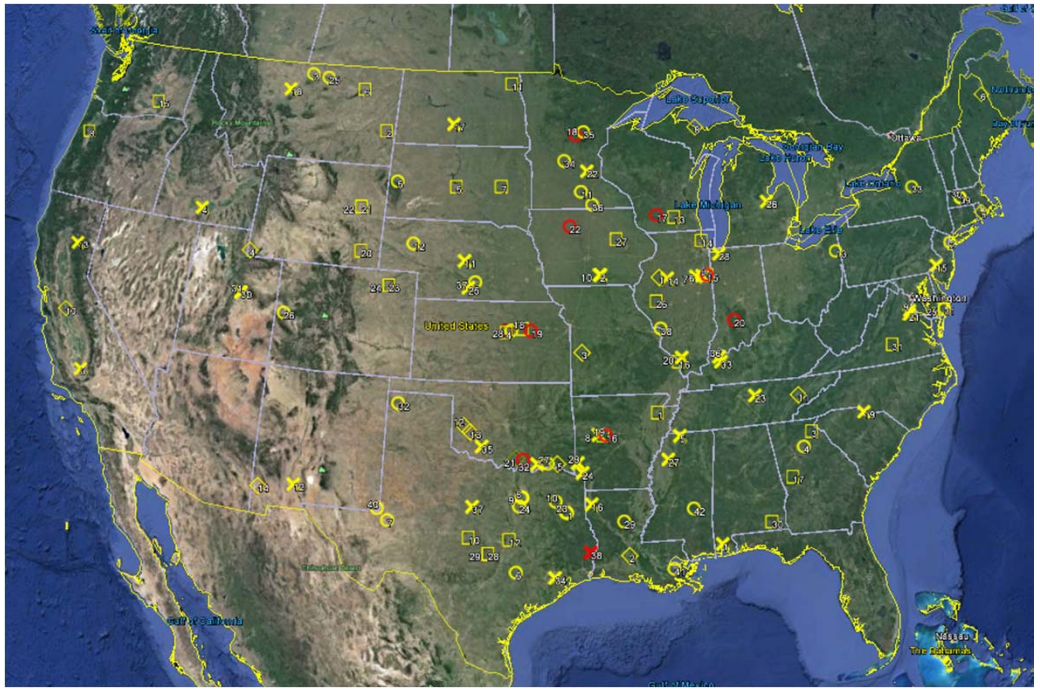
+25 ^{0}F Air Temp Model

Derailment Analysis

Derailment Analysis

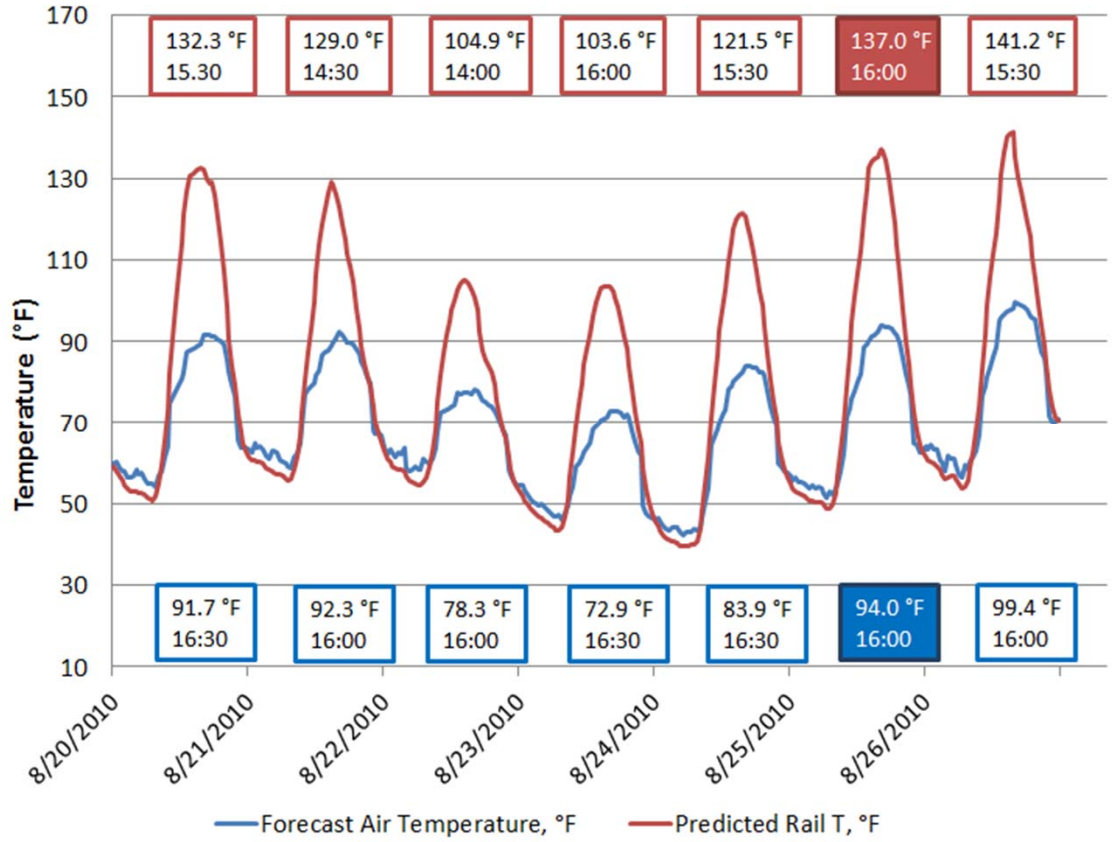
Investigated 115 Track Buckle Derailments (FRA Cause Code T109)

Pulled historical rail temperature data leading up to the derailment



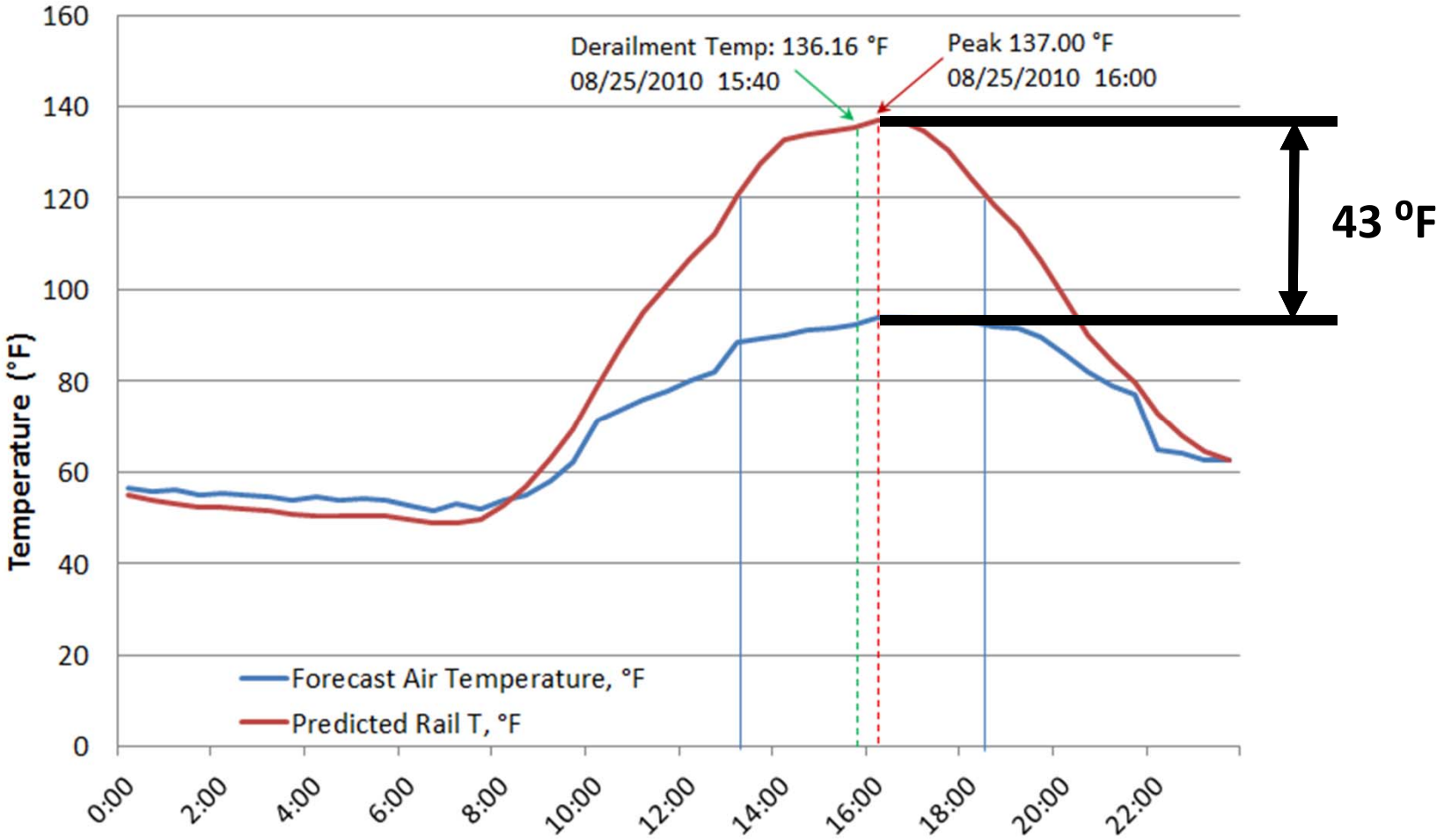
X – 2010 ANALYZED LOCATIONS
X – 2010 LOCATIONS WITHOUT AVAILABLE WEATHER DATA
O – 2011 ANALYZED LOCATIONS
O – 2011 LOCATIONS WITHOUT AVAILABLE WEATHER DATA
□ – 2012 ANALYZED LOCATIONS
– 2012 LOCATIONS WITHOUT AVAILABLE WEATHER DATA
◇ – 2013 ANALYZED LOCATIONS

Rail and Air Temperatures at Example T109 Derailment

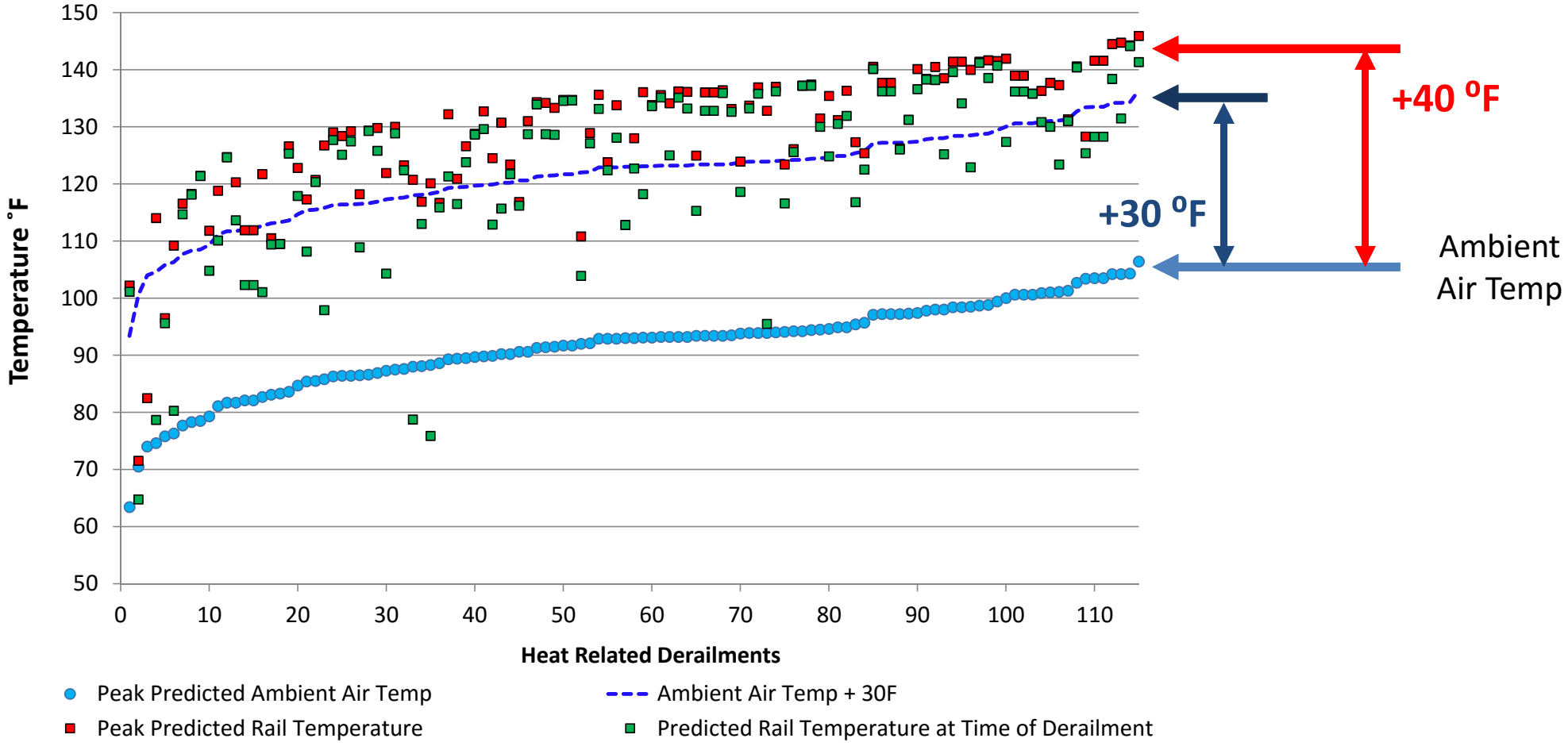


Predicted Rail Temp ^{O}F

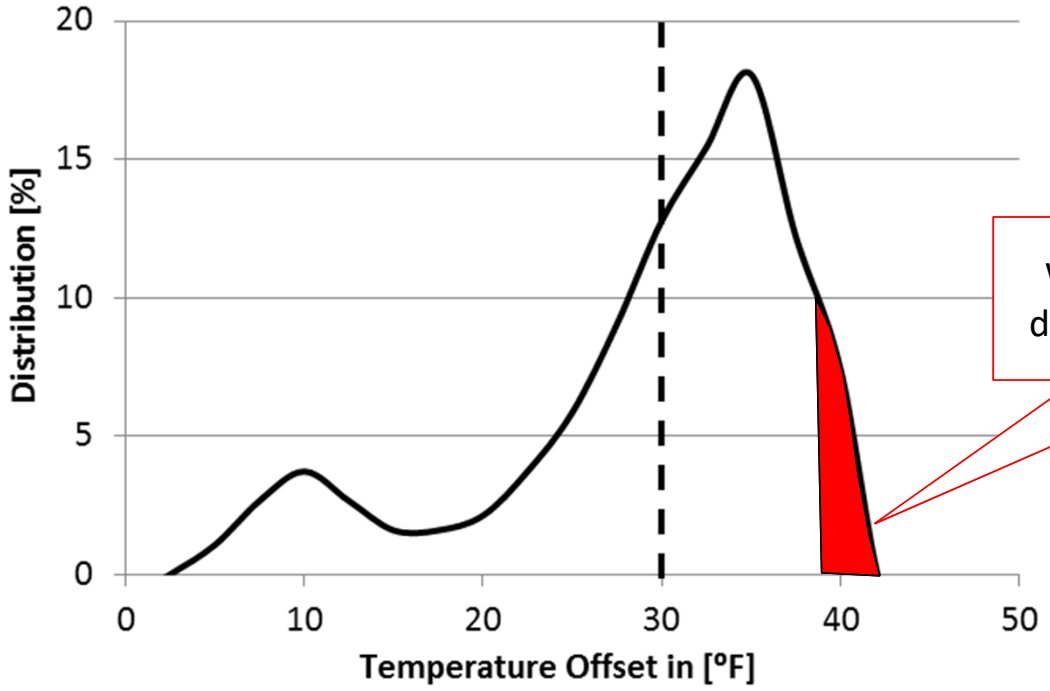
Forecast Air Temp ^{O}F


Derailment Temp: 136.16 °F
08/25/2010 15:40
Peak 137.00 °F
08/25/2010 16:00
43 °F
Temperature (°F)
160
140
120
100
80
60
40
20
0
Forecast Air Temperature, °F
Predicted Rail T, °F
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00

T109 Derailments Rail and Air Temperatures (Ranked Lowest to Highest Temps)



Distribution of Offset Value for Ambient Air Temp to Rail Temp



Where many of the T109 derailments are happening

Slow Order Analysis

Slow Order Analysis

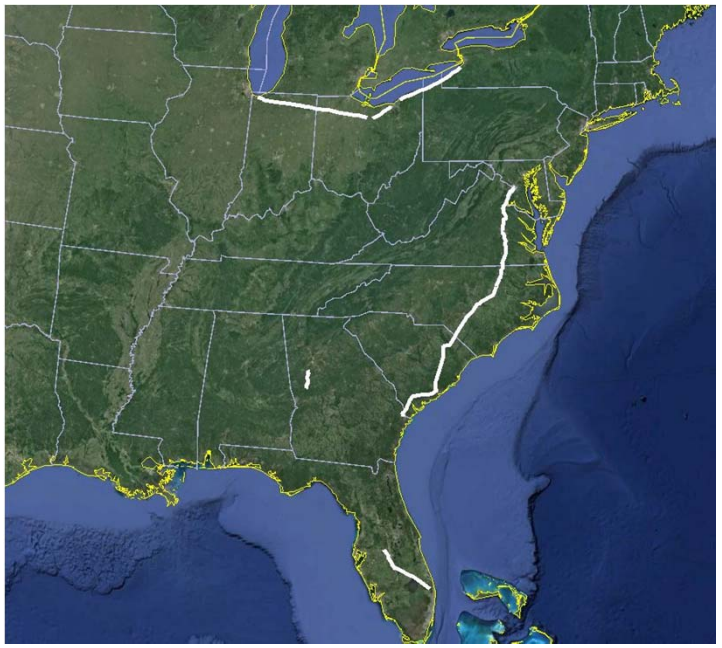
Pulled historical rail temperature data around actual heat slow orders

Hypothetical slow orders were created using the Predicted Rail Temperature System

Actual and Hypothetical slow orders were compared

Findings Using the Predicted Rail Temperature System for Slow Orders:

- Easier implementation of seasonal thresholding
- Less false positive alerts
- Shorter duration and length slow orders
- Overall results in 33% reduction of slow order Mile*Hours

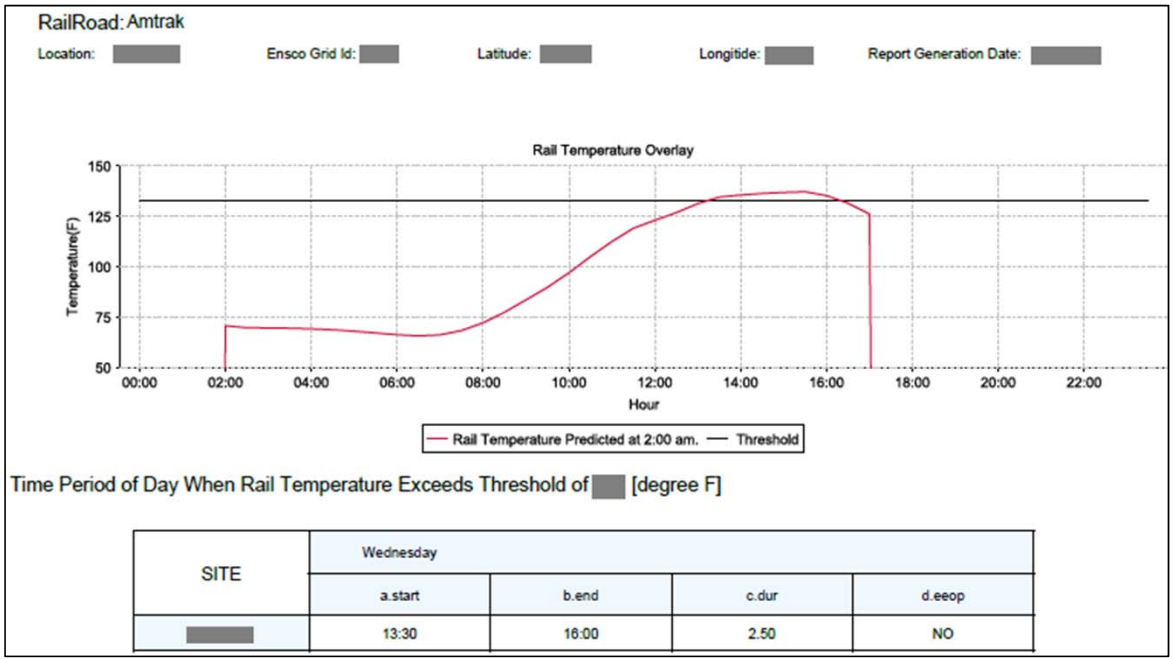


Slow Order and Heat Inspection Application Example

Application Example

- Amtrak is the first to use the Prediction Model for resource planning associated with slow orders and heat inspections.
- Amtrak is currently using a hybrid approach with 30 wayside temperature sites and the Prediction Model working together.
- The Rail Prediction model provides daily 5AM email reports.
- Throughout the day, updated reports are provided.
- Prediction Model is used as a back up if a wayside site malfunctions.

Example Daily 5AM Email Report:



SITE	Wednesday			
	a.start	b.end	c.dur	d.eeop
	13:30	16:00	2.50	NO

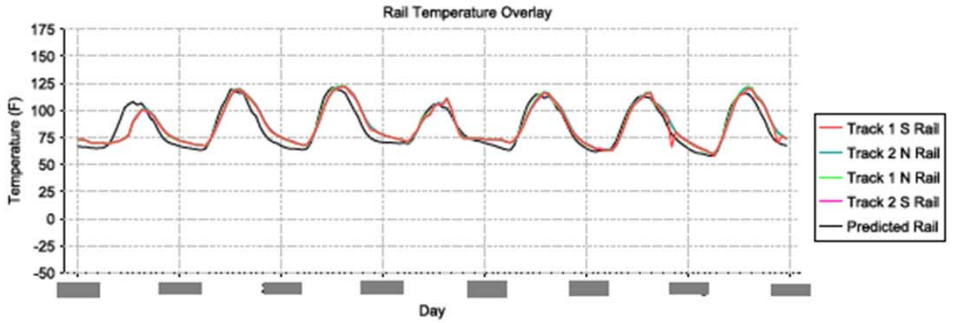
Application Example

- Weekly summary email reports are also generated.
- Weekly Reports compare the measured and predicted rail temperatures for the past week.

Example Weekly Summary Report:

RailRoad: Amtrak

Location: [redacted] Ensco Grid Id [redacted] Latitude: [redacted] Longitide: [redacted] Report Generation Date: [redacted]



Overall Correlation Results:

Tracks	a. Mean [degree F]	b. Stdev [degree F]	c. Max Delta [degree F]	d. Min Delta [degree F]
Track 1 N Rail	5.54	4.14	29.56 Mon	0.05 Sun
Track 1 S Rail	5.6	4.33	29.56 Mon	0.02 Sun
Track 2 N Rail	5.83	4.28	29.56 Mon	-0.14 Sun
Track 2 S Rail	5.69	4.15	29.56 Mon	0.11 Thu

Summary of Temperatures Exceeding Threshold : [redacted] [degree F] for the week of [redacted] - [redacted]

Conclusions

Results:

- On average, within **5 ºF** of directly measured rail temperature.
- More accurate than current method of adding offset to ambient air temperature.
- Can better identify high rail temperatures associated with past T109 derailments.
- Has potential to reduce heat slow orders by **33% Mile*Hours**.
- System is only software. No installed hardware on track. Full USA coverage.

References

R. Bruzek, L. Biess, L. Al-Nazer, “Development of Rail Temperature Predictions to Minimize Risk of Track Buckle Derailments”, *Proceedings of the 2013 Joint Rail Conference,* 2013

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R. Bruzek, M. Trosino, L. Kreisel, L. Al-Nazer, “Rail Temperature Approximation and Heat Slow Order Best Practices”, *Proceedings of the 2015 Joint Rail Conference,* 2015

Special Thanks

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Mike Trosino

Questions?