Comparison of Predicted and Actual Rail Temperature

Matthew Dick, P.E.
Radim Bruzek
ENSCO Rail
May 5, 2016
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.
Background

Rail experiences longitudinal stress caused by thermal expansion contraction.

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

Rail experiences longitudinal stress caused by thermal expansion contraction.

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

Rail experiences longitudinal stress caused by thermal expansion contraction.

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

“Pull Apart” broken rail in the winter

“Track Buckles” in the summer.
NEUTRAL TEMPERATURE
Determining RT Threshold

Dr. Kish’s Equation:

\[ T_{SR} = RNT + T_{all} - BMS \]

- **Rail Temperature**
- **Buckling Risk Threshold**

**Rail Neutral Temperature**

- **Target Rail Laying Temperature**
- **Accepted value of reduction factor developed by RSAC**

**In absence of measurement RNT can be approximated**

**Buckling Strength:**
- **VOLPE Estimates**
  - **WEAK = 60°F**
  - **AVERAGE = 80°F**
  - **STRONG = 100°F**

**Safety Factor:**
- Standard industry accepted value is 20 °F
Current Approach

Add Offset to Maximum Predicted Air Temperature (30 or 25 °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
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 °F.
Predicted Rail Temperature

Measured Rail Temperature

\[ T_{p,\text{max}} = \text{Daily Maximum Predicted (time achieved)} \]
\[ T_{m,\text{max}} = \text{Daily Maximum Measured (time achieved)} \]
\[ \Delta = T_{m,\text{max}} - T_{p,\text{max}} \quad \text{(relative difference as } \Delta/T_{m,\text{max}}) \]
Model Validation

Key Observations:
1. Model was found to be on average within 5 °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 °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.

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alert</td>
<td>No Alert</td>
</tr>
<tr>
<td>Ground Truth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alert</td>
<td>True Positives</td>
<td>False Negatives</td>
</tr>
<tr>
<td>No Alert</td>
<td>False Positives</td>
<td>True Negatives</td>
</tr>
</tbody>
</table>
ROC Space Plot

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

Perfect Model

Isosensitivity Curves

Random Model

Anything over here is worse than random
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 outperforms the current method of an offset from the air temperature.

Prediction Model
+25 °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
Rail and Air Temperatures at Example T109 Derailment

Predicted Rail Temp °F
Forecast Air Temp °F
Derailment Temp: 136.16 °F
08/25/2010 15:40
Peak 137.00 °F
08/25/2010 16:00

43 °F
T109 Derailments Rail and Air Temperatures (Ranked Lowest to Highest Temps)

- **Temperature °F**
- **Heat Related Derailments**
- **Peak Predicted Ambient Air Temp**
- **Ambient Air Temp + 30°F**
- **Peak Predicted Rail Temperature**
- **Predicted Rail Temperature at Time of Derailment**

**Legend**:
- Leaf predicted ambient air temp
- Ambient air temp + 30°f
- Leaf predicted rail temperature
- Predicted rail temperature at time of derailment

**Ambient Air Temp**
- +40 °F
- +30 °F
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:
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:
Conclusions

Results:

• On average, within 5 °F 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


Special Thanks

Gary Carr
Robert Wilson
Leith Al-Nazer

Leo Kreisel
Larry Biess
Mike Trosino
Questions?