ABSTRACT

Track buckling due to excessive rail temperature may cause derailments with serious consequences. To minimize the risk of derailments, slow orders are typically issued on sections of track in areas where an elevated rail temperature is expected and risk of track buckling is increased. The Federal Railroad Administration’s (FRA’s) Office of Research and Development (ORD) has sponsored the development of a model for predicting rail temperatures using weather forecast data and predefined track parameters. The rail temperature prediction process was validated by comparing the model’s output to rail temperatures measured at 23 sites throughout the CSX Transportation (CSXT) network between March 2012 and October 2012. Detection theory was used to evaluate the model’s ability to correctly identify rail temperatures elevated above a wide range of thresholds in comparison to the current railroad practice of estimating rail temperature based on constant offsets above predicted peak ambient air temperature. The results are very favorable. Analysis indicates that use of the model offers advantages over the current practices in terms of identifying elevated rail temperatures with the potential for track buckling and that the implementation of the model as a heat slow order management tool would lead to improvements in safety without a negative economic impact on railroad operations since heat slow orders would be issued in more effective and targeted way. The model was also used to determine rail temperatures reached during past track buckle related derailments and showed that the railroad would benefit from implementation of flexible thresholds for elevated rail temperatures to identify buckling concerns.
1. INTRODUCTION

Track buckling caused by high compressive forces in the rail due to thermal expansion of steel may result in derailment with serious consequences. Track buckling derailments when they do occur tend to be very costly. For example, there were 249 FRA-reportable derailments between 2005 and 2013 resulting in nearly $84 million in damages.

The main factors affecting track buckling are Neutral Rail Temperature (NRT), lateral track stability and the actual rail temperature. Continuously welded rail (CWR) is typically installed with the goal of achieving a desired NRT (a temperature at which the rail is in a zero stress state). Its value is typically chosen somewhere in the range of temperatures that the rail is expected to experience in order to minimize the risk of heat related track buckles during hot weather months and “pull-aparts” during cold weather months. In current practice, the industry tends to choose the rail laying temperature at the higher end of the rail temperature range, especially at regions with wide temperature swings as NRT tends to deteriorate (decrease) over time. Also, railroads rely on track circuits and other mechanisms to detect “pull-aparts” prior to incidents. Furthermore, “pull-aparts” are not as likely to result in a derailment when compared to track buckles.

Track with higher lateral resistance can withstand higher compressive stresses and therefore higher rail temperatures before it buckles. Therefore, NRT and track lateral strength govern and define the rail temperature threshold above which the risk of track buckle exists. This threshold is a function of track conditions, maintenance practices and accepted bias towards the buckle or pull-apart failure mode as established by the initial selection of stress-free temperature. The threshold is not a constant since the two parameters (NRT and lateral strength) tend to change gradually with time. The rail temperature threshold can change abruptly only when discrete activities such as track maintenance or track disturbances occur. Curve breathing, track maintenance efforts and rail repair can cause NRT to deteriorate. Specifically, when proper procedures for cutting and adding rail during cold months are not followed, decreases in NRT can be significant. Additional factors having an effect on NRT, and therefore on buckling risk, are initial geometry conditions (especially alinement), traffic patterns, train breaking and proximity to fixed assets such as bridge ends, switches and grade crossings.

It is also important to note that even though track buckling is mostly associated with CWR it can occur on jointed rail as well.

2. CURRENT APPROACH TO HEAT SLOW ORDER MANAGEMENT

Track is at an increased buckling risk when the actual rail temperature is elevated above the buckling risk temperature threshold. The actual rail temperature fluctuates widely from day to night and day to day with varying weather conditions.

To minimize the risk and consequences of derailments on a day to day basis, slow orders are typically placed on track where the rail temperature is expected to be elevated above a given threshold. These slow orders, known as “heat slow orders”, are an important preventive safety measure. Slow orders are, however, also costly as they disrupt timetables and may affect time-sensitive shipments. Two predominant approaches that govern the issuance the heat related slow orders are:

- Advance slow orders
- Real time slow orders

Advance slow orders are issued when predicted daily ambient temperatures reach a pre-determined level. This procedure, adopted by the majority of the railroad industry, including CSXT, assumes that the rail temperature is constantly offset from the ambient air temperature. This method is aimed at approximating the daily maximum rail temperature. During early morning, rail temperature is cooled down to a level very close to the surrounding ambient air temperature. After sunrise, the radiation energy received from sun causes the rail temperature to gradually rise above the ambient air temperature until it peaks, most often in mid-afternoon, and begins to decrease again. During night time, the rail temperature decreases back to levels close to the ambient air temperature. In reality, the offset between the rail and ambient air temperature is not constant, and the exact progression of the rail temperature during the day is not adequately approximated using this method. Therefore, a heat slow order is triggered when the maximum daily ambient air temperature is expected to peak above a given air temperature threshold and issued for a predefined period of a day when rail temperatures are presumed to be elevated - for example from 1 p.m. to 7 p.m.. This value can differ from railroad to railroad and even from region to region within a single railroad. This type of heat slow order is also usually issued at a subdivision level and is applied to a full or a large section of the subdivision or territory even when the risk is localized. The main advantage of this method is that it is a fairly simple procedure with limited or no cost of equipment which provides an advanced warning with ample time to
adjust train movements for a particular day. On the other hand, the method is not precise and results in slow orders that are not targeted, affect large areas and remain in effect for prolonged predefined periods of time.

The second approach is the issuance of real time slow orders that are based on real time rail temperature monitoring utilizing wayside temperature sensors. The real time slow orders are issued for specific milepost ranges based on sensor density and remain in effect only at times when the measured rail temperatures are elevated. This method is very accurate, but it does not provide warning times to the operators to adjust timetables and train movements. As a matter of fact, the slow orders lag slightly behind actual risk as there is a 15-20 minute delay associated data processing and dispatcher response. Also, the installation and maintenance efforts required to keep sensors operational can be very costly, especially for large networks.

Sometimes railroads use a combination of those two methods where rail temperature is estimated by a constant offset from an ambient air temperature measured by a network of wayside weather station to avoid maintenance issues associated with sensors placed directly on the rail.

3. RAIL TEMPERATURE MODEL

The FRA’s rail temperature prediction model was developed with the motivation to arrive at more accurate actual daily rail temperatures while keeping ample warning time to issue heat slow orders in advance to allow the operators to adjust train movements and also to enable more efficient targeted time-of-day and milepost-specific heat slow orders without the need to install and maintain a network of wayside sensors. This way the model is intended to take advantage of the benefits of each of the currently used methods. The model uses National Weather Service (NWS) data as weather forecast inputs and is therefore a completely virtual system. The rail temperature prediction process utilizes several additional weather and material parameters in addition to the traditional approach based solely ambient air temperature:

- Intensity of solar radiation
- Solar angle
- Wind speed
- Sky temperature
- Heat absorptivity and emissivity of rail

The model is based on heat transfer principles and calculates rail temperature based on the amount of energy absorbed from the sun and emitted via radiation and convection. Energy absorbed and emitted via conduction on the rail-tie-ballast interface is not considered. Detailed descriptions of the technical approach can be found in [1] and [2]. The predictions are granular; output is provided in 9x9 km grids which allow slow orders to be issued for specific milepost ranges, and continuous rail temperatures are generated in 30-minute increments updated every three hours, allowing for issuance of time-of-day specific slow orders. Currently, the rail temperature prediction is available 12 hours in advance for the 48 contiguous U.S. states. The predictions can be, however, expanded to 48 hours in advance or geographically to anywhere on the globe at any time with increased computation power.

A web based application is also available for users to access current and historical prediction data.

4. ACCURACY OF THE RAIL TEMPERATURE PREDICTIONS

There are two sources of error in the model outputs. First, as with any model, the rail temperature prediction model is an idealization and does not represent the multitude of complex processes occurring in real life. For example, the model does not take into account conduction between the rail and ties. The second and more significant source of model errors is due to inaccuracies in the weather forecast inputs, especially in the solar radiation. These inaccuracies are subsequently inherited by the rail temperature prediction model.

To establish the level of accuracy of the rail temperature predictions generated by the model at wide variety of geographic and climatic conditions, a wide ranging error analysis study was performed in cooperation with CSXT by comparing the model’s outputs with rail temperatures measured at 23 wayside sites across its entire rail network, see Error! Reference source not found.. Ground truth rail temperature measurements were collected from March 2012 to October 2012 using two sensors located directly on each rail, set up in a configuration to minimize the effect of direct sunlight on the measurements. Analysis also revealed that there may be significant variations between the 4 individual rail temperature measurements at each site. These variations are the highest during daylight hours when the rail temperature is elevated; the differences can reach up to 8°F on a warm day. Differences in rail temperature due to local conditions, such as shadows resulting from trees and foliage, and any differences in accuracy and precision of the individual sensors and their calibration have to be taken into account in order to have reasonable
expectations for the accuracy of the model’s predictions, which are generalized for an area of 9x9 km. Details of the wayside sensor configuration and example overlays of raw measured data can found in [3].

![Figure 1: Locations of Wayside Sensor Sites on CSXT Rail Network](image)

The results on the data combined from all the individual sites, creating a sample of almost 80,000 hours of rail temperature measurements, show that during nighttime hours the model consistently tends to under predict the rail temperature (mean error 3.8°F) and over predict the rail temperature during the daytime hours. The model predicts the daily maximums with very good accuracy and precision (mean error 7.5°F). The model is configured to err on the side of caution in order to maintain a level of safety when used as an indicator of increased risk of rail buckle during daytime and as an indicator of increased risk of cold weather rail breaks, or “pull-aparts”, during nighttime and early morning hours. The model performs slightly worse at predicting the daily maximum temperatures because during nighttime hours, the daily minimum rail temperature is mostly dependent only on the ambient air temperature while during daytime hours additional factors such as solar radiation and wind speed play a major role in predictions and, therefore, there is a higher chance of inheriting an error from the weather forecast. This tendency of the model to under predict during the night and over predict during the day also means that analysis of errors in 24-hour periods may be misleading as the potential for error cancelation exists. Instead, the error analysis was performed on data samples extracted between 9:30 a.m. and 8:00 p.m. each day, when the accuracy of the model is the most important in order to issue accurate time-specific heat slow orders. In this time segment, the model performs in a similar ways as when predicting the daily maximums, with a tendency to over predict. The average absolute error in this case is 8.2°F. The error is affected by the presence of a limited number of large scale over-predictions (above 30°F) related to inaccurate solar radiation prediction due unexpected cloud cover. Such errors do not pose a safety risk as they lead to “false alarm” heat orders rather than false negatives. The individual sites perform consistently and in a similar way as the dataset obtained by combining all of the sites together.
Figure 2: Example Rail Temperature Overlays

Figure 2 presents an example of measured and predicted rail temperature overlay illustrating a typical performance of the model including days with excellent correlation as well as days in which the model results in under and over predictions.

A similar error analysis study was conducted in coordination with the National Railroad Passenger Corporation (Amtrak) with comparably favorable results. Details were reported in [4].

5. APPLICATION OF DETECTION THEORY

Detection theory, whose theoretical background can be found in literature [5], may be applied to the rail temperature datasets in order to evaluate the ability to detect temperatures elevated above a particular given threshold. In our case, using the rail temperature measurements as ground truth, detection theory was applied to both rail temperature predicted by the model and rail temperature estimated by the constant offset from ambient air temperature. This way the model can be evaluated and compared to the current method predominantly used by the industry in terms of effectiveness as a heat slow order management tool by quantifying their ability to correctly place heat slow orders at times when rail temperatures are elevated to levels posing a track buckling risk.

The rail temperature threshold defining the buckling risk can differ based on geographical location even within one railroad operator (see Section 2). In addition, the threshold can be relaxed as the hot season progresses - lower in the spring and early summer and higher towards late summer. Therefore, the effectiveness of the model compared to the current method using several most commonly used values of constant offsets from ambient air temperature was evaluated for a wide variety of rail temperature thresholds - 110°F to 130°F in 5°F increments.

Figure 3 illustrates the detection theory results at the lowest evaluated threshold of 110°F and offset of 25°F for all individual sites except for one. There the instrumentation malfunctioned early in the season and the amount of measured data is very low, mostly from March and April when the rail temperatures are not significantly elevated resulting in dataset too limited for viable application of the detection theory. The results of the current empirical method based on ambient air temperature only are scattered mostly because of large variations in decision bias but also because of differences in sensitivity. The current method is outperformed at all the sites by the model which maintains higher sensitivity and also more consistent and neutral decision bias, This leads to more favorable and consistent true positive rates, also referred to as hit rate (TPR), with comparable or improved false alarm rates (FPR).
When all the sites are combined together the model outperforms the current approach by 18 percentage points in TPR and 5 percentage points in FPR, see Figure 4.
In a similar manner, all the selected thresholds can be evaluated while the model can be compared to current methods using different offsets. Figure 5 summarizes the results for the model and current method using offsets of 25°F, 30°F, and 32°F. The rail temperature prediction model has a higher sensitivity as a detection method than the currently used empirical methods. The sensitivity of the current methods increases with higher offsets from ambient air temperature but it does not reach the level of the model even when a higher offset from ambient air temperature such as 32°F is used.

Figure 5: Measurements Sites Combined; Various Thresholds and Offsets

It can be also noted that results for all different detection thresholds for one system lay on one isosensitivity curve, therefore changing the detection threshold does alter the sensitivity but it has a significant effect on decision bias. Higher offset also leads to a shift in decision bias towards saying “YES” to a slow order. In general, at higher detection thresholds, such as 125°F and 130°F, the current methods have a bias heavily skewed towards saying “NO” which leads to a low TPR. Therefore, the current methods are not effective for detection of rail temperatures above those thresholds. On the other hand, the current methods have bias skewed towards saying “YES” for lower thresholds such as 110°F and 115°F, therefore they are able to detect most of the rail temperatures elevated above those lower thresholds, especially for offsets 30°F and 32°F; this is achieved, however, at a cost of very large number of false alarms. One could ask why a higher offset from ambient air temperature i.e. 40°F is not used to achieve even higher sensitivity and detection rates. The observed trend in bias shift towards “YES” with increasing offset would make this cost prohibitive. It is important to realize that an increased offset between the rail and air temperature will call for much larger amount of slow orders in general. For example, when using the current method trying to detect rail temperatures above 120°F slow orders would be placed on days when ambient air is expected to peak above 95°F when 25°F offset is assumed; if 40°F offset is assumed then slow orders would have to be issued on all days with ambient air temperatures peaking above 80°F. Due to the larger number of false alarms, in combination with the costs associated issuing heat slow orders, a higher offset is not desirable.

The model maintains a more consistent near neutral decision bias for all thresholds which, together with a higher value of sensitivity, leads to very favorable detection rates with low false alarm rates. This shows that the model can be a more effective tool to issue advanced heat slow orders compared to the currently used methods across a wide range of detection thresholds.

6. IMPACT OF MODEL IMPLEMENTATION ON CSXT OPERATIONS

The previously discussed results show the model in favorable light and suggest that a railroad using the current method of issuing advanced slow orders based on ambient air temperature forecast would benefit from
implementing the rail temperature prediction model as a heat slow order management tool. To confirm and quantify improvements in slow order management using the rail temperature model, additional analysis was conducted in cooperation with CSXT. CSXT currently employs the empirical approach to issue advance heat slow orders based on an offset from ambient air temperature. The advanced heat slow orders are issued when a forecasted ambient air temperature exceeds defined ambient air thresholds varied for particular geographic regions based on latitude. Lower thresholds are used in the northern portion of the network and higher thresholds are employed in the southern portion of the rail network. These thresholds may also be relaxed in later summer months as the majority of the NRT outliers resulting from maintenance and rail repair efforts in winter months are expected to be removed and the risk of buckling decreases.

Ten subdivisions were selected by CSXT and complete records of heat slow orders issued by the railroad in 2012 were provided to ENSCO for comparisons with slow orders that would have been generated by the rail temperature prediction model. The selected subdivisions are of varying lengths and are located in different geographical regions both in the northern and southern parts of the CSXT rail network.

The detection rates for rail temperature thresholds of $120^\circ F$ and above are very low when the current method is used as indicated in Chapter 5. The initial analysis also revealed that the rail temperature model would call for a larger amount of slow orders if the thresholds used by the current practice were followed. This is due to the much higher true positive rates achieved by the model at levels that couldn’t be compensated by the improvements in false alarm rates. On the other hand the same detection rates could be achieved with the model using smaller amount of slow orders. This configuration, although economically compelling, would not result in any improvements in safety. Therefore a different approach was taken in order to evaluate whether the model could be used to improve the safety level without a negative economic impact on railroad operations. In other words, whether the model could distribute available resources, in this case the number of slow order hours issued by CSXT in 2012, more effectively.

For all subdivisions except one where there were no heat slow orders issued by CSXT in 2012 a rail temperature threshold was identified which, if used by the model constantly throughout the season, would lead to the same number of heat slow orders as issued by CSXT in 2012. This “equalizing threshold” ranges between $116^\circ F$ and $121^\circ F$ for the analyzed subdivisions. Detection theory was then applied in order to evaluate the effectiveness of the actual slow orders compared to the orders generated by the model at the particular equalizing threshold by comparing hit rates for both methods using rail temperatures measured by wayside sensors as ground truth. The results are summarized in Figure 6.

![Figure 6: Improvement in Effectiveness of Heat Slow Orders](image)

The implementation of the model would lead to improvement in the hit rate at all 9 subdivisions where the analysis was performed. The improvement ranges between 14%-75% except for one subdivision where the hit rate almost triples. Subdivision #4 is very long and the potential for the savings when the targeted milepost specific heat
slow orders generated by the model are used is considerably greater. This results in lower equalizing threshold of $116^\circ$F. Such a low equalizing threshold leads to lower assumed offset between the ambient air and rail temperatures. That, as discussed above (see Figure 5), leads to much lower sensitivity and non-neutral decision bias of the empirical method. Therefore the hit rate of the current approach utilized by CSX in 2012 for subdivision #4 at this particular threshold was very low to begin with, leaving a lot of room for improvement.

In can be concluded, that the model uses the same slow order hour resources in a much more targeted and effective way, leading to improvement in level of safety without a negative economic impact on railroad operation. In general, the model tends to issue slow orders on more individual days but these orders are shorter in duration and also affect shorter portions of individual subdivisions.

7. ANALYSIS OF PAST TRACK BUCKLE RELATED DERAILMENTS

The rail temperature prediction model can not only be used as a slow order management tool but also as a means to obtain rail temperatures reached during past track buckle related derailments. In recent years, FRA has tasked ENSCO with detailed analysis of incidents reported in the FRA Office of Safety database [6] in 2010, 2011, 2012 and 2013 as related to track buckles and/or sun kinks (cause code T109). There are 125 such T109 derailments recorded for all railroads combined. Their geographical locations are shown in Figure 7.

![Figure 7: Geographical Location of T109 Derailments in Years 2010-2013](image_url)

Analysis focused on several aspects including geographical location, month of year, track class, type of territory, rail temperature and proximity to fixed track structures in order to identify possible trends and assess factor having significant impact on risk of this type of derailments. Only several result highlights related to topic discussed previously in this paper are presented. Complete results are reported in [7].

It has been generally accepted by the industry that locations in proximity to fixed track structures may be at increased risk of track buckling as NRT can deteriorate at significantly higher rate and track also may be laterally weaker than in open track. Figure 8 shows that between 2010 and 2013, T109 derailments did indeed tend to occur more often at closer proximity to track structures.
Almost half of all the T109 derailments occurred within 400 feet of the fixed track structures, while over 37% occurred even closer – within 200 feet. Almost 80% of the derailments occurred within 1,000 feet of fixed track structures. Most commonly the derailments occurred in proximity to grade crossings - over half of the cases, followed by bridges and switches. See Figure 9.

In the majority of the cases (almost 70%) the train was traveling in a direction towards the nearest fixed track structure. Also, the majority of T109 derailments occurred in tangent (again almost 70%) followed by spiral and curves in equal proportions. This leads one to believe that locations close to a fixed track structures are at an increased risk of track buckling incident. FRA is currently conducting research to gain more insight on NRT deterioration near fixed track structures compared to open track.

Another topic related to track buckling risk mentioned earlier in this paper is the procedure used by some
railroads allowing relaxation of a specified rail or air temperature threshold used to trigger heat related slow orders as the hot season progresses. The relaxation is based on expectation that the risk of heat related track buckle is higher at the beginning of the warm season. Especially in spring and early summer higher uncertainty in NRT exists, caused by a large number of outliers in NRT as a result of NRT decay over the winter months, as well as rail repair and maintenance work that are typically performed during cold weather. As the summer progresses, the risk of track buckle diminishes as the NRT stabilizes; outliers are removed, temporary rail plugs welded, rail distressed, etc. Past track buckle related derailments should statistically tend to occur often in the beginning of the warm season and at lower rail temperatures than in late summer if this assumption is correct.

Figure 10 shows the distribution of the incidents by month. June and July are the two months with the largest number of T109 derailments, together accounting for two thirds of incidents. Number of T109 derailments decreases sharply in August, even though it generally a warmer month than June. T109 derailments were rare in September and October while 11 incidents occurred in May.

![Figure 10: Distribution of T109 Derailments by Month.](image)

The model was used to obtain rail temperatures reached on 115 days out of the 125 incidents reported in the FRA Office of Safety database as there for 10 incidents the historical weather forecast data necessary as input for the rail temperature prediction model was not readily available. Mean rail temperatures reached on days of T109 derailments, in particular months between May and August, along with the variation in each month sample are presented in Figure 11.
A clear trend in increasing rail temperatures reached both at the time of the T109 incident and the maximum peak rail temperatures on the day of the derailment as the warm season progresses can be observed. The variations in the reached rail temperatures are also much higher in May and June suggesting higher proportion of RNT outliers in spring and early summer. A statistical T-test was conducted to confirm a statistically significant difference between May and August samples; subsequent months are not statistically different due to large variation in the samples. The results indicate that, statistically, the risk of heat related track buckle incidents is indeed higher early in the warm weather season and does diminish as the summer progresses confirming the validity of implementing flexible rail temperature threshold in order to maximize the effectiveness of the slow order management process.

8. CONCLUSIONS

The rail temperature prediction model was developed to provide more accurate actual daily rail temperatures ahead of time based on National Weather Service weather forecasts. Currently the model predicts rail temperatures 12 hours ahead of time in 30-minute increments for the 48 contiguous U.S. states in 9x9 km grids.

In cooperation with CSXT ground truth actual rail temperatures were measured at 23 wayside sensor sites between late March and mid-October of 2012. This data, totaling almost 80,000 hours of measurements, was used to assess the accuracy of the model’s outputs and evaluate the effectiveness of the model as a slow order management tool in terms of detection theory. Strong correlations between wayside rail temperature measurements and the model’s predictions were found with an average overall error of approximately 5-8°F. It was also shown the implementation of the model as a slow order management tool would lead to an improvement in safety without a negative economic impact on railroad operations by allowing for issuing of advance heat slow orders in more accurate, effective and targeted way.

Investigation of past heat related track buckle derailments also confirmed industry observations of increased heat track buckle risk at locations in close proximity to fixed track structures and at the start of warm weather season pointing towards flexible rail temperature thresholds that are relaxed as the summer progresses in order to maximize the effectiveness of the heat related slow orders. The model is extremely suitable for implementation of such flexible rail temperature thresholds as it maintains favorable detection rates of elevated rail temperatures over a wide range of thresholds. Flexible thresholds would lead to the most economical heat slow order management process.

9. ACKNOWLEDGEMENTS

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10. REFERENCE


Figure Captions:

Figure 1: Locations of Wayside Sensor Sites on CSXT Rail Network
Figure 2: Example Rail Temperature Overlays
Figure 3: Individual Measurements Sites; Threshold 110°F; Offset 25°F
Figure 4: Measurements Sites Combined; Threshold 110°F; Offset 25°F
Figure 5: Measurements Sites Combined; Various Thresholds and Offsets
Figure 6: Improvement in Effectiveness of Heat Slow Orders
Figure 7: Geographical Location of T109 Derailments in Years 2010-2013
Figure 8: Proximity of T109 Derailments to Fixed Track Structures.
Figure 9: Type of Nearest Fixed Track Structures.
Figure 10: Distribution of T109 Derailments by Month.
Figure 11: Monthly Rail Temperature Trends for T109 Derailments.
Brief Biography – Radim Bruzek

Mr. Radim Bruzek is a staff engineer at ENSCO, Inc. located in Springfield, Virginia. He has been involved in various R&D projects including evaluation of track conditions, track strength and rail temperature predictions. Before joining ENSCO in 2011, Radim worked as a senior structural engineer with Top Con Servis in the Czech Republic, focusing on railroad bridges and bridge foundations. In addition, he held positions as researcher and college lecturer at Czech Technical University in Prague. Mr. Bruzek holds a Bachelor of Science and Master of Science degree in Civil and Structural engineering.

Brief Biography – Leith Al-Nazer

Mr. Leith Al-Nazer is a general engineer in the Track Research Division at the Federal Railroad Administration, a position he has held for seven years. Prior to joining the FRA, Leith was a patent examiner at the Patent and Trademark Office. He holds a Bachelor’s of Science degree in electrical engineering from the University of Virginia.

Brief Biography – Larry Biess

Mr. Larry Biess is Director – Business Intelligence for CSX Transportation, headquartered in Jacksonville, Florida. He joined CSX in 1997 after working as a Nuclear Engineer for the US Navy. He has held positions in Mechanical, Engineering, Advanced Engineering, and Technology. He holds a BS in Marine Engineering from Kings Point, and an MBA from University of North Florida.

Brief Biography – Leo Kreisel

Mr. Leo Kreisel is Director of Track Testing for CSX Transportation, headquartered in Jacksonville, Florida. He joined CSXT in 2008 following a career in the US Navy. He has held positions in both Engineering and Procurement & Supply Chain. He holds an MBA from Brenau University.
Rail Temperature Prediction Model as a Tool to Issue Advance Heat Slow Orders

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CSX Transportation
**Background**

**Track Buckling**
- Formation of lateral misalignments caused by thermal expansion of rail
- Most common in continuous welded rail (CWR)
- Can occur on jointed territory as well
- Several factors influence risk of buckling:
  - Rail Neutral Temperature (RNT)/rail stress management → cutting/adding rail during cold months
  - Lateral stability/resistance of track

**Example**
- Actual rail temperature

**Background**

**Current Practice**

1) **Advance Slow Orders**
- Email an offset from predicted ambient air temperature every (typical method)
- Triggered for predefined period of day when ambient air temperature exceeded to peak over given threshold
- Can "lag" behind actual risk
- In effect for prolonged periods
- Inaccurate
- Not targeted
- Affect entire subdivisions
- Costly installation especially for large networks
- Maintenance of sensor network

2) **Real Time Slow Orders**
- Based on measured rail temperature
- Triggered only at times when rail temperature elevated
- Very accurate
- Targeted
- Economical use of slow orders
- Not economical

**Approximation of Rail Temperature**

- Distribution of measured difference between max. air and max. rail temperature
- Differences may vary between 0°F and over 40°F

**Rail Temperature Prediction Model**

- FRA developed the model to:
  - Be more accurate
  - Allow targeted slow orders
  - Keep advance warning
  - No network of sensors on rail
- Uses National Weather Service data
- Uses additional parameters to ambient 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
  - 30-minute time increments
  - 12 hours ahead
- Web based application available for users to access current and historical prediction data

**Model Validation and Accuracy**

- Rail temperature measured March-October 2012
- Almost 80,000 hours of measurements available
- Average error: 5°F
Effectiveness of the Model

Threshold: 110°F; OFFSET for EMPIRICAL METHOD: 25 °F

Impact on Railroad Operations

- Heat orders issued based on the model predictions more effective
- Coverage of instances with elevated rail temperature improved with the same amount of slow order hours
- Some heat order coverage can be maintained with fewer slow order hours

Flexible Thresholds

Distribution of T109 Derailments by Month

- No of T109 derailments decreases in August, even though warmer than June
- Trend of increasing avg. rail temperature achieved at T109 derailments as warm season progresses
- More uncertainty and outliers in RNT as warm season begins (RNT decay, rail repair, maintenance issues during winter months); suggests use of flexible thresholds to issue slow orders

Concluding Remarks

- Rail temperature model allows issuing of targeted heat slow orders 12 hours in advance
- No equipment installation on rail necessary - virtual system;
- Advance heat orders issued using the model are more accurate and effective than when issued by current empirical approach based on offset from air temperature;
- Heat slow order management process can be even more effective with flexible thresholds based on month of year.
- Stricter thresholds in the spring, relaxed thresholds as the summer progresses
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