U.S. Department
Of Transportation

**Federal Railroad
Administration**

Research
Results

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Development of Rail Temperature Prediction Model

SUMMARY

Preventing track buckling is important to the railroad industry's goal of operational safety. It is a common practice for railroads to impose slow orders during hot weather when the risk of track buckling is high. Numerous factors affect track buckling, but the instantaneous rail temperatures and stress-free (neutral) rail temperatures are the most critical factors. Unfortunately, neither of these two temperatures is easily obtainable. Decisions for slow orders are often based on an arbitrary, ambient temperature limit. The Federal Railroad Administration (FRA) Office of Research and Development has initiated a research project to develop a model for predicting rail temperatures based on real-time meteorological forecast data.

The rail temperature prediction model is based on the heat transfer process of a rail exposed to the sun. In developing such a model, a rail-weather station was established, composed of a portable weather station and a short segment of rail track with temperature sensors installed on both rails. The model has proven to be able to predict the maximum rail temperature within a few degrees and within 30 minutes of the actual time when the maximum rail temperature occurs during the day. The model is being validated for three locations where real-time weather data and rail temperature are collected. A prototype web-based software application has been developed, as is shown in Figure 1. The application is also being tested by Amtrak.

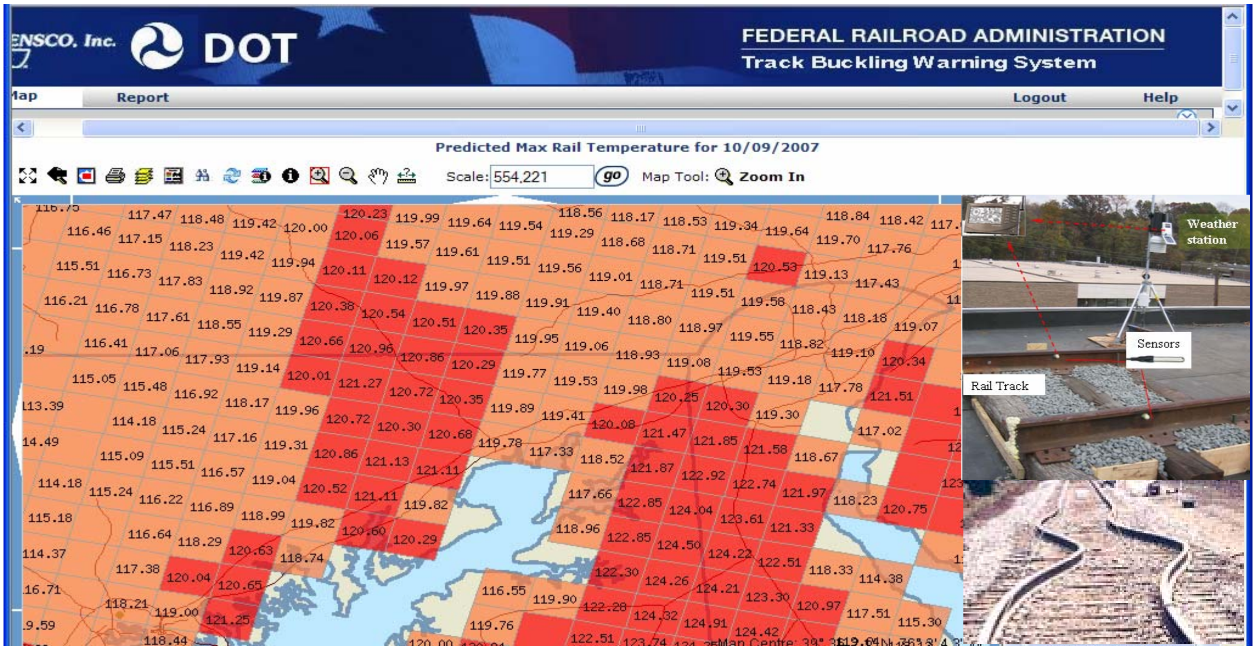

Figure 1. Prototype Web-Based Software Application for Rail Temperature Prediction

BACKGROUND

Track buckling related derailments are very costly to the railroad industry. In 2006, there were 50 track-buckling related derailments with $13M reportable damages, and in 2007 the reportable damages rose to $14M with 34 track-buckling related derailments occurring that year. To prevent track buckling derailments, many railroads issue slow orders when daily ambient temperatures reach a certain level. This practice does not capture all potential buckling risks. On the other hand, excessive slow orders cost the railroad industry millions of dollars each year.

The most effective method of issuing slow orders with respect to both safety and economy would probably be based on accurate instant rail temperature and rail neutral temperature. Unfortunately, neither of the two temperatures is easily obtainable. Accurately measuring rail temperature is limited by numerous factors including resources, time of the day, rail orientation, location of the measuring points, measuring device, etc. Determining rail neutral temperature is even more difficult. Complicating the issue further is that the original rail neutral temperature, which is set when rails are installed, changes continuously due to operational and environmental parameters. In practice, decisions for slow orders are often based on an arbitrary ambient temperature limit.

The FRA's rail temperature prediction model which is currently being developed can improve the slow order decision-making process by providing reasonable rail temperature predictions. The objective is to predict rail temperatures based on real-time, meteorological forecast data obtainable from various commercial weather services. Such a system should lead to significant savings in operations costs while promoting safety and mobility in the nation's railroad systems.

MODEL APPROACH

Track buckling is the result of a combination of factors, as detailed by Zhang, et al (2007). Rail temperature, perhaps, is the most important single influencing factor. There have been efforts to monitor rail temperatures and to correlate ambient temperature with rail temperature. A linear regression technique is commonly used in quantifying the relationship between ambient and rail temperature. The correlation often focuses on the maximum daily ambient and measured rail temperatures for a specific period of time.

Since ambient temperature is only one of many weather parameters that cause rail temperature to change, a linear relationship has proven inappropriate for quantifying rail temperature.

The FRA approach is to quantify the rail heating process in the open sun. The rail temperature model makes use of real-time weather data and track related information as the basis for rail temperature prediction. The model is depicted in Figure 2. The rail temperature is derived by modeling transient heat transfer of a floating body representing a finite rail element. The energy equilibrium for the rail element is of the following form:

$$\dot{E}_{in} - \dot{E}_{out} = \dot{E}_{st} = \frac{dE_{st}}{dt} \quad (1)$$

Where:

$\dot{E}in$ – Rate of energy absorbed by the rail from the Sun and atmospheric irradiation,

$\dot{E}out$ – Rate of energy emitted from the rail through conduction, convection and radiation.

$\dot{E}st$ – Rate of energy stored.

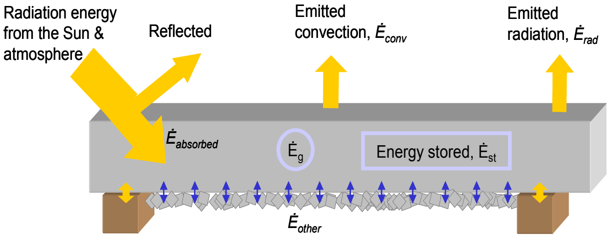

Figure 2. Transient Heat Transfer of a Rail

The energy balance is affected by weather conditions, rail metallurgical properties, rail size and shape, and environmental parameters.

During development of the model, different parameters influencing each energy component were investigated. The energy exchange at the bottom of the rail is currently ignored since the heat conductivity of wooden ties and rock ballast particles are far lower than that of steel. The net energy loss/gain at the interface of the bottom of the rail is considered minimal. The model effectively treats the materials beneath the rails as an isolation layer.

For model development and calibration, a local experimental station was established. The station consists of a mobile weather station with an integrated sensor suite, rail temperature sensors, two short segments of 119 lb/yd rails that are installed on three wooden ties, and crushed rock ballast filling between ties and under the rails. The temperature sensors are installed in the web of the rails, collecting rail temperature at 1-minute intervals. The portable weather station next to rail track collects comprehensive weather data at the same 1-minute intervals. A third temperature sensor was installed on a segment of 140 lb/yd rail to measure rail temperatures for different rail orientations and at different points of the rail.

The collected data is transmitted wirelessly to a data console with an embedded data logger. The data console uploads data to a development computer hourly for model development and data analysis.

PRELIMINARY RESULTS

The rail temperature model algorithm in the form of Equation (1) was implemented in a computer routine. The meteorological data collected by the weather station was entered into the program for predicting rail temperatures at 30-minute intervals.

Figure 3 shows how the predicted rail temperatures compare with measured values for a 5-day period in the summer of 2006. The results indicate that the selected model is appropriate for predicting rail temperatures using weather data. In general, the predictions appear to be reasonable. However, the model can be improved by better dealing with the effects of wind and heat radiation from the rail to the sky.

The ambient temperature on July 31, 2006, was the highest. However, the highest rail temperature was observed on July 27, 2006, which reached 34.7° F above the maximum ambient temperature. This underscores the fact that maximum ambient temperature alone cannot predict the rail heating process.

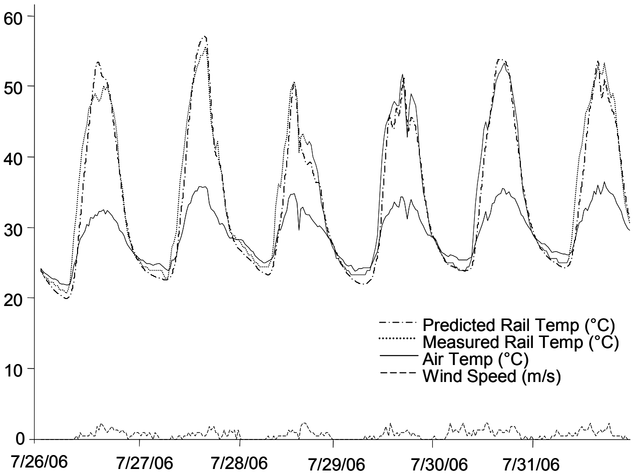

Figure 3. Predicted vs. Measured Rail Temperatures

The predicted daily maximum rail temperatures and measured values, from February 1 to May 31, 2007, are shown in the scatter plot in Figure 4. It can be seen that the predicted rail temperatures agree reasonably well with measured values. The model accurately predicted the peak rail temperatures for most of the days. However, the model also overestimates or underestimates the peak rail temperature for some days. One of the reasons for this is that the model currently assumes a constant difference between ambient temperature and sky temperature in computing energy radiated from the rail to the sky. In reality, the sky temperature can be 60° C below ambient temperature for clear sky or close to

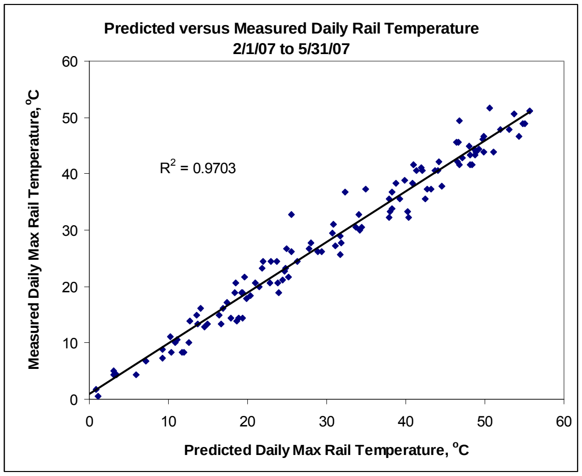

Figure 4. Predicted vs. Measured Daily Maximum Rail Temperatures

ambient temperature for overcast and rainy weather. The difference between the two temperatures also varies with latitude and time-of-year due to the earth's axis being tilted at different angles, with respect to the sun. An extensive literature survey was unable to identify models or procedures to quantify the sky temperature under different sky and weather conditions.

Other major factors affecting model accuracy include weather data updating intervals, wind speed and direction, and rail surface emissivity. Dealing more extensively with these parameters should improve the model accuracy.

REAL-WORLD APPLICATION

For practical application, the model uses real-time weather forecast data for prediction of future rail temperature. Currently, the model receives weather forecast data decimated in 30 minutes intervals. The real-time weather data is transmitted into a fileserver. A data processor will process the weather data into a database. A web-based application provides interfaces for users to view the rail-weather map and query the application to produce reports.

In addition to the station established for model development, two additional validation stations were established on Amtrak. Each station consists of a local weather station and rail temperature sensors. The measured weather data and rail temperatures from these stations were used to verify the accuracy of the model predictions.

The system has been deployed on Amtrak for pilot application. The model produces up to 10 hours rail temperature forecast. Longer periods of forecast are possible, but the level of confidence will diminish along with the weather forecast.

The current research effort is focused on evaluating the model performance using real-time weather data. Parametric analyses will be conducted to investigate if additional parameters will improve the model performance. Further refinements of the model based on data analysis were being continued at the time this information update was written.

CONCLUSIONS

To overcome the deficiency of the industry's current practice of slow order issuance, the FRA is developing a rail temperature prediction model. The model is based on the transient heat transfer phenomenon of a rail exposed in the open sun. The algorithm was verified using locally measured weather and rail temperature data. The preliminary model results indicated that it is able to predict rail temperature within an acceptable range of a few degrees in most cases, provided the weather data is accurate.

The rail temperature prediction model will inevitably inherit the uncertainties from the weather forecasts. Short weather forecast intervals are deemed important for the rail temperature prediction model. Better dealing with key weather parameters should result in a more accurate rail temperature predictions. Other factors, such as rail orientation, rail surface conditions and rail shape factor, and temperature gradient within rail cross sections are also of interest to this project, although the current research points to minor effects on rail temperatures.

The rail temperature predictions from such a system are expected to provide quantitative information for operation mangers, train dispatchers and maintenance mangers in slow order decision making process.

REFERENCES

Zhang, Y.J., Clemenzi, J., Kesler, K. and Lee, S. (2007) "Real Time Prediction of Rail Temperature." AREAM Annual Conference, September 9-12, 2007, Chicago, IL.

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