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Rail Defect Prediction Model Evaluation

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Summary

In a demonstration project, a team of TTCI engineers and researchers from the State University of New Jersey (Rutgers University) successfully modeled rail defect occurrences from a revenue service site using an existing Association of American Railroads (AAR) rail defect prediction model called HALTRACK. Using advanced calibration techniques, the project team tuned HALTRACK for evaluating the current mainline rail operating and maintenance environment.

The project team used rail defect records from a revenue service mainline rail segment. The segment was chosen due to the availability of defect records extending back to the 1990s and a population of rails installed during the same period. HALTRACK was developed in the 1980s and 1990s, and it uses typically available track and operations data to calculate railhead stresses and to predict fatigue defect occurrences.

Data from a portion of the mainline rail was used to calibrate the model. The calibrated HALTRACK model was then used to predict rail defects on the remaining line segments. The initial calibration produced a model incapable of accurately predicting rail defect occurrence. This is believed to be due to changes in rail maintenance practices and rail steels properties since the model was built. The Rutgers researchers then used piecewise linear regression to calibrate the model, which resulted in a successful data set.

Prediction of rail defects is essential to optimal management of the rail asset in track. Of particular interest to railway maintenance planners is the ability to determine the optimal time to replace older rails in track. The rails from the 1980s and prior generally do not have the same strength and metallurgical cleanliness as rails being installed today. They also may not have benefitted, at least initially in their service lives, from the same running surface profile and friction control measures that are commonly used today.

The exercise also highlighted the need to update the capabilities to predict rail failures for current rail steels and operations. Follow-up work will address this need.

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INTRODUCTION

Using advanced calibration techniques, TTCI engineers and Rutgers University researchers successfully demonstrated the capability of an existing AAR rail defect prediction model, HALTRACK to predict the presence of rail defects in mainline rails in track today.

Rail steels and rail performance in track have improved tremendously over the last 30 years due to major industry efforts at improving rail steels, rail maintenance practices, and reductions in dynamic loading due to freight car conditions. As these efforts were implemented, the distribution of failure modes of rail in mainline freight service have changed. The number of rail replacements due to internal fatigue defects has generally decreased as the proportion of running surface fatigue and wear failure modes have generally increased.

BACKGROUND

HALTRACK was developed in 1990 by the AAR Affiliated Laboratory at the Massachusetts Institute of Technology (MIT) in collaboration with the researchers at the AAR’s Research and Test Department, predecessor of TTCI.[1] HALTRACK begins with another model previously developed by the AAR for rail defect studies, called PHOENIX.[2] In order to accomplish the task of developing a rail life-cycle costing model based on the fatigue life, a matrix, consisting of 1,080 sets of conditions, was developed from hundreds of PHOENIX runs that could be used as the basis for interpolation in order to get results for any particular route segment.

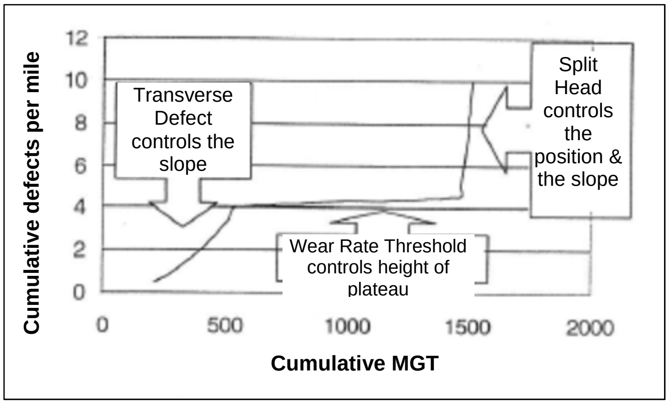
By simulating the mechanical processes leading to the initiation and growth of fatigue defects, PHOENIX can estimate the cumulative MGT by which “X” percent of rails will fail as a function of wheel loads, rail types, wear rates, foundation modulus, and wheel sizes.[3] The accuracy of the model is discussed in detail in Steele and Joerms[4] in which they show results from the PHOENIX model were in agreement with the observations being made at the Facility for Accelerated Service Testing (FAST) at that time.

It was observed in the 1980s that two types of rail defects often occur in mainline rails:

- Transverse defects can occur early in the life of the rail due to concentration of stresses in the railhead
- Split head defects occur later in rail life due to metal flow and plastic deformation. The loss of section combined with increased dynamic loading due to variations in section loss can shorten fatigue life.

In addition, the research team determined that the wear rate (i.e., natural wear plus material removed due to grinding) was a critical factor in the fatigue life of the rail; increased wear rates reduced the number of transverse defects and shifted the defect limits to the split head regime at a much higher cumulative tonnage (MGT). Fatigue life due to transverse defect failure increases as wear rate increases, whereas split head life decreases as wear rate increases.

Figure 1 illustrates the two types of defect occurrence regimes seen in the 1980s. A quiescent period, controlled by the Wear Rate Threshold in Figure 1, is often observed during the transition from transverse defects to split heads. In this period, wear rate is high enough to suppress most transverse defect type flaws, while split head defects do not yet occur due to insufficient loss of railhead section.



Source: Martland and Massot[2]

Figure 1. Structure of the HALTRACK Rail Fatigue Model Output/Results

CASE STUDY

For this study, a heavy haul mainline subdivision was selected due to the fact that (1) this line has a wheel impact load detector (WILD) which would allow for easy access to accurate tonnage information and (2) given the prominence of older rail installed very near when the records of rail defects were first kept (i.e., 1993). The specific data requested for this study was as follows:

- Information on the rail installation: rail grade, section size, installation date(s), and mileposts
- Information on natural rail wear (if possible) as well as grinding date and estimated material removed
- List of detected defects and service failures, including date and milepost
- Recent track charts of the area selected for this study

The model was calibrated to rail performance on a portion of line segments on this line. Then, rail defect occurrence was predicted for the rest of the line segments. Figure 2 shows the results. The model is conservative in the transverse defect regime and un-conservative in the split head regime. The field data also suggests that the rail defect occurrence pattern assumed by the model (i.e., a transverse defect regime, a wear rate threshold regime, and a split head regime) may not always be appropriate for modern rail steels, rail maintenance and train operations. While railroad records are accurate as to when and where rail defects occur, they are less consistent about the defect type. This is especially true for service failures, which are identified by local personnel.

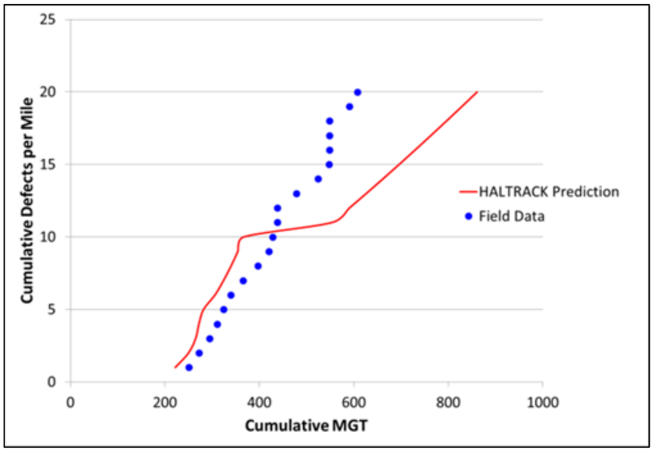


Figure 2. Rail Defect Prediction Results from Calibrated HALTRACK Model

It should be kept in mind that transverse defects, which are partly caused by contact stresses, can and do occur throughout the life of the rail. Split heads, which are associated with the structural strength of the rail, are more likely to occur in the latter portion of the rail's service life when the rail head is worn.

EXISTING MODEL IMPROVEMENT

The Rutgers team was able to improve the predictive power of the existing model by decomposing the model into its three constitutive fatigue regimes and creating a calibration of each. This piecewise regression calibration is quite successful for improving the predictive capabilities of the model for segments of track where the rail has a long defect history (i.e., the service life of the rail is well advanced). Figures 3–5 show results for three separate specific segments of the same line segment using a piecewise regression for each. The vertical red lines were the break points of the piecewise regressions.

The variation in performance of the rail in these segments needs to be noted here. In the three examples presented, one (Figure 4) shows the defect occurrence regime envisioned with clearly identified transverse defect and split head zones. The other two examples show a less clear demarcation of these two failure modes. Although, there is an increase in the defect occurrence rate in the third time period for all line segments studied. It is likely that the combination of railroad operations (i.e., dynamic loading), rail steels properties, and track maintenance practices (e.g., increased use of fasteners that provide more rail roll resistance) may be altering the thresholds of the two fatigue failure modes.

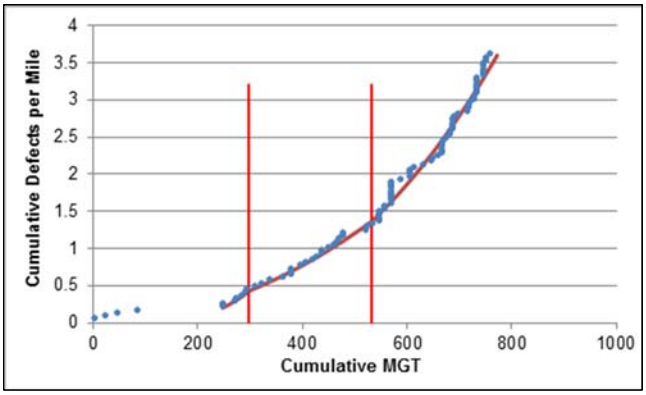


Figure 3. Results of Piecewise Regression Calibration of HALTRACK for a Portion of the Line

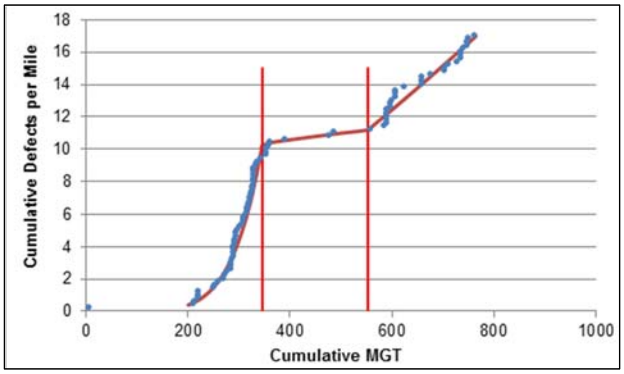


Figure 4. Results of Piecewise Regression Calibration of HALTRACK for a Portion of the Line

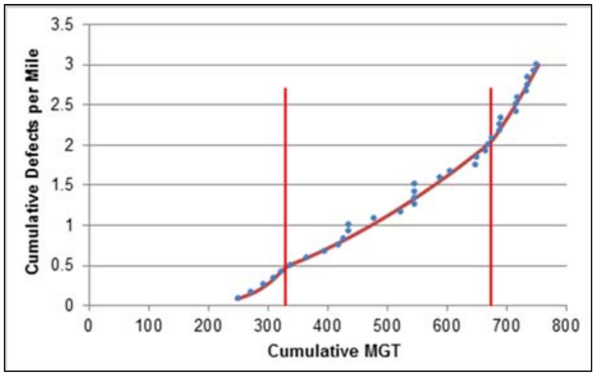


Figure 5. Results of Piecewise Regression Calibration of HALTRACK for a Portion of the Line

SUMMARY

The demonstration project has shown that the rail defect prediction HALTRACK model should be upgraded to account for currently used rail steels, maintenance practices, and operating conditions. The harder and stronger rail steels available today will likely have different break points between transverse defects, wear rate threshold, and split head regimes.

In the same way, the refinement of rail grinding practices has led to a general reduction in the magnitude and/or number of cycles of rolling contact stresses at any given point of the railhead for the same loading as per conditions of the 1980s. This can extend the number of load cycles before rolling contact fatigue (RCF) related defects develop. It is also likely that these maintenance and materials changes are responsible for a shift in the origin of fatigue defects towards the rail surface. Thus, the proportion of rail removed for "internal" (i.e., subsurface) fatigue has generally decreased while the proportion of rail removed due to "RCF" (i.e., surface and near surface) fatigue has increased.

Friction control methods have also improved significantly since the 1990s. Curve rail lubrication is more effective due to improved materials and applicators. Additionally, top of rail friction control has reduced wear rates and allows the rail to carry more load without excessive deformation.

These factors cannot be adequately accounted for in the current model, which is built from a parametric study of 1980s rails and practices. The rail maintenance practices of today have led to a near optimized balance of wear and fatigue accumulation that has greatly lengthened rail service life. But, due to the model's lack of accounting for running surface fatigue, the rates and failure modes of defects predicted may not match actual railroad experience.

FUTURE Model Improvement

The next step of this research could be accounting for a set of variables (e.g., rail hardness, wear rate, maintenance history, traffic volume and mixture of wheel loads, curvature, grade, rail age) from multiple routes/locations to better understand rail defect occurrence processes under different circumstances. The expanded, multivariate model can ultimately be implemented into a forecasting tool to predict segment-specific number of rail defects. To this end, the following technical roadmap is suggested (Figure 6).

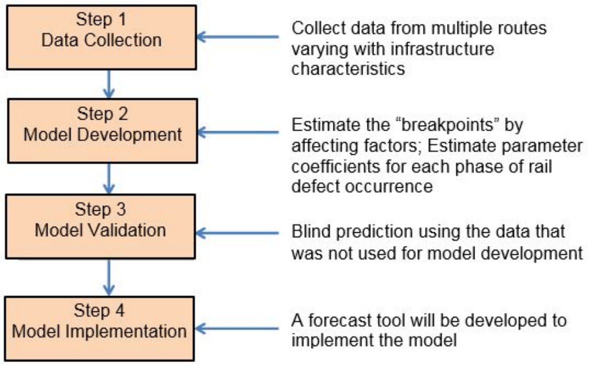


Figure 6. Roadmap for developing a Rail Defect Statistical Prediction Tool

Step 1: Data collection. Collect data from multiple routes/locations that vary with curvature, rail hardness, traffic, axle load, wear rate, and other possible affecting factors.

Step 2: Model development. Apply piecewise regression to calibrate parameter coefficients in the HALTRACK rail fatigue model that was described in Martland and Massot.[2] A portion of the data can be used for model development (e.g., 80 percent of raw data). The "breakpoints" in the piecewise regression might be affected by rail hardness, traffic, axle load, wear rate, and other factors. Regression models can be developed to predict "breakpoints" by influencing factors. This will improve the Martland and Massot approach in two aspects:

- Instead of using simulation data from PHOENIX, field data will be used for model development.
- The "breakpoints" that characterize different rail defect occurrence phases will be estimated based on a set of influencing factors. This provides insights into when a certain phase of rail defect may shift to another, given specified infrastructure conditions.

Step 3: Model validation. The remaining data that were not used for model development will be used for model validation. The Coefficient of Determination (R^2) will be used to evaluate how well the blind prediction matches the observe data.

Step 4: Model implementation. Implement the statistical model into a forecasting tool to predict future rail defects. For example, given input variables such as axle load, rail hardness, wear rate or additional factors, the "breakpoints" will firstly be estimated. Next, in each phase (transverse defect, wear rate threshold, or split head), the relationship between cumulative defects and cumulative MGT will be predicted.

References

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