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Benefits of Ballast Shoulder Cleaning

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The research described was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Key Findings:

- Results showed that ballast degradation rate increases with increasing fine level. This suggests fine-filled ballast will degrade at a faster rate than clean ballast.
- An analysis of two 15-mile sections of revenue service track showed that ballast shoulder cleaning reduced the ballast degradation rate compared to track that had no maintenance performed.
- Ballast degradation rates measured by ground penetrating radar can be used to develop a forecasting model that will project future ballast degradation for various types of production maintenance interventions (e.g., no interventions, shoulder cleaning, or undercutting).

TTCI analyzed the benefits of ballast shoulder cleaning (BSC) on ballast degradation in revenue service. BSC is a production ballast maintenance technique used by North American railroads to improve the drainage in fine-filled ballast track. This work was part of the Association of American Railroads (AAR) Strategic Research Initiative (SRI) Program.

Unlike undercutting (UC), which replaces the entire ballast section underneath the track, BSC removes and replaces the ballast shoulders with reclaimed or clean ballast. By focusing on just the shoulders, BSC has a higher production rate than UC so either more track length can be cleaned or less track time is expended. However, the specific benefits of BSC are not well quantified and may vary widely based on the condition of the ballast.

Theoretically, BSC should remove shoulder fines and help the drainage in the ballast section. This process allows excess moisture to drain at a quicker rate. A ballast section with improved drainage should experience less deformation; thus, better performance.[1] The improved drainage/decreased deformation should reduce track geometry degradation and its damage to track components. Shoulder cleaning has also been theorized to wash away some of the fines in the center track, which would help clean the entire ballast layer but is yet to be proven.

In order to quantify the benefits of shoulder cleaning on ballast fine levels, especially at the track center, TTCI used ground penetrating radar (GPR) data provided by a Class I railroad collected over three years from two 15-mile sections of track. In addition, the results of the study were used to develop a framework for a ballast degradation forecasting model.

TRACK AND GPR DATA

The project used GPR data gathered from two 15-mile sections of revenue service track running through the same subdivision over three years (2015 to 2017). The subdivision is a highly trafficked route in the Midwest, and the track contained fines. The first 15-mile section (Section 1) is located on single track and no production ballast maintenance was conducted between the 2015 and 2016 GPR data collections, but ballast shoulder cleaning operations did occur between the 2016 and 2017 data collections. BSC and surfacing were conducted for the entire 15 miles.

Section 2 is located in double-track territory and had GPR runs in 2015 and 2017 only. Between those two data collection runs, no maintenance was implemented on

4 miles of track, and BSC and surfacing were performed on the remaining 11 miles.

The GPR output analyzed for the study is called the Ballast Fouling Index (BFI). The BFI is calculated using the GPR waves emitted into the ballast, and the data is typically grouped into five categories based on Selig's Fouling Index (FI). The categories are as follows: clean (FI=0–4), moderately clean (FI=5–9), moderately fouled (FI=10–19), fouled (FI = 20–39), and highly fouled (FI=40+). The GPR outputs BFI values at the track center and both shoulders every 15 feet. Only the center BFI was used for this analysis.

DATA PROCESSING

Data analysis included four main steps to ensure data quality.

The first step involved cleaning and aligning the data.

The second step involved removing data within 0.1 mile (528 feet) from any fixed asset (bridges, road crossings, and turnouts) because production BSC will avoid fixed assets. The fixed assets could be identified initially from the track charts, and the exact location was then refined by looking at the BFI data. The 0.1-mile buffer ensures the data representing the fixed asset and any transition effects were removed.

The third step involved removing any obvious spot maintenance locations (spot undercutting, for example) in order to isolate the effect of the production BSC. There were a few locations in each data set in which a section with a BFI above 15 (moderately fouled category or higher) was reduced to 5 or below (clean ballast category) in sections of track 45 feet or longer. This reduction in BFI likely indicates spot undercutting; the inclusion of these undercut locations would lower the average BFI and not truly represent ballast degradation. Therefore, regions that were judged to be undercut were removed from the data set. Similar criteria were used for data removal and the amount of data removed from each 15-mile track section were about the same.

The fourth step involved aggregating the data into 0.05-mile (264-foot) block intervals. This involved averaging about 17 sets of 15-foot GPR data over the 0.05-mile section. This aggregation was done for multiple reasons: 1) railroads often aggregate GPR data for production maintenance planning, which considers long stretches of track instead of isolated locations that can be fixed by spot maintenance; and 2) previous GPR calibration efforts suggest that the GPR accuracy can vary for a single data point (15 feet), but the accuracy averages out over stretches of track.^{2}

It should be noted that both aggregated and non-aggregated methods were examined, and the general results and trends were very similar.

BSC VERSUS NO BSC RESULTS

The first task of the analysis involved comparing the change in the center BFI over either a one-year period (Section 1) or a two-year period (Section 2). These sections were separated for comparison based on whether they did or did not experience BSC. The data was broken down according to the Selig's FI levels; which determined how the center BFI changed from the initial BFI levels.

Figure 1 shows the change in the average BFI for Section 1 (a) and Section 2 (b). The x-axis categorization was based on the initial BFI data (e.g., 2015); the change in BFI is the difference between the two years (e.g., 2015 subtracted from 2016).

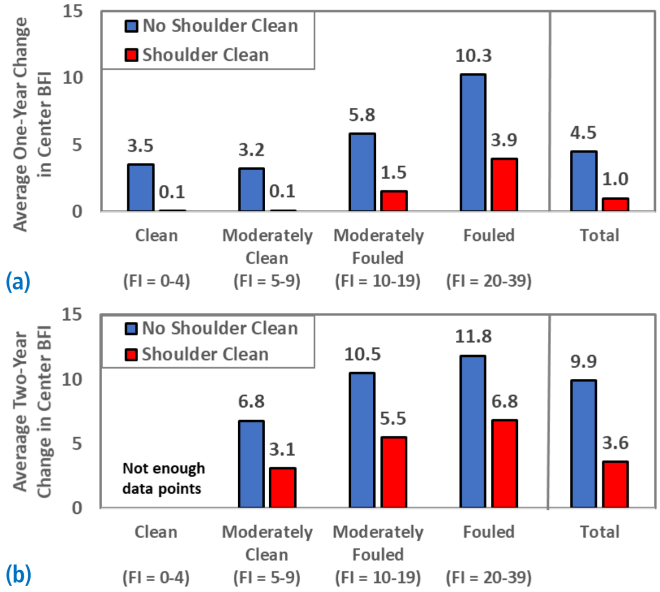


Figure 1. Average change in center BFI for (a) Section 1 and (b) Section 2 plotted against various initial BFI categories

The results for both sections and all FI categories showed that the BSC sections had a lower increase in BFI than the non-BSC sections. These results suggest that BSC does not necessarily "clean" the center ballast section (lower BFI) but does reduce ballast degradation. As such, the BSC led to the benefit of reduced ballast degradation in the track, probably due to improved drainage and fine migration paths as a result of clean ballast in the shoulders. In addition, the change in BFI increases with the increase in initial BFI. This means that ballast degradation rates will likely accelerate with time (or tonnage) and ballast will degrade faster for fine-filled ballast compared to clean ballast.

Figure 2 shows the same data set as Figure 1, but as a box and whisker plot where the bottom and top of the box plot represent the first and third quartile (25 percent of data passing and 75 percent of data passing), the middle line represents the median, and the top and bottom whiskers represent the maximum and minimum, respectively. The results show similar trends to Figure 1 but emphasize the distribution of data. The results also suggest the distribution range increases with increasing BFI. It is unclear how much of this is physical and how much of this result is an artifact of the accuracy of the inspection system.

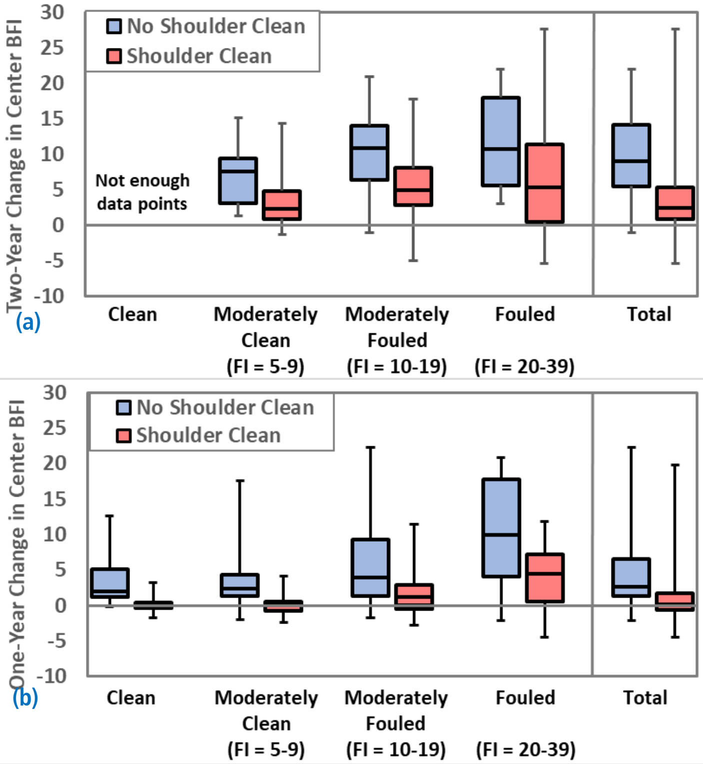


Figure 2. Box and Whisker plot showing changes in center BFI for (a) Section 1 and (b) Section 2 distributed by BFI category

As more data is collected and analyzed, it is anticipated that the results from this study will be refined. In addition, until different locations are studied, it is unclear how site-specific the results are and how fine type, climate, and tonnage may affect these results.

FORECASTING MODELS

The GPR data was also used in the development of forecasting models used to project the BFI levels or ballast degradation, depending on ballast maintenance intervention. These forecasting models would be site-specific and assume the railroad line would experience similar rainfall, drainage, and traffic levels year-to-year. This forecasting model can be useful when comparing the pros and cons of using different ballast maintenance techniques, or as input data for a more advanced track geometry degradation model.

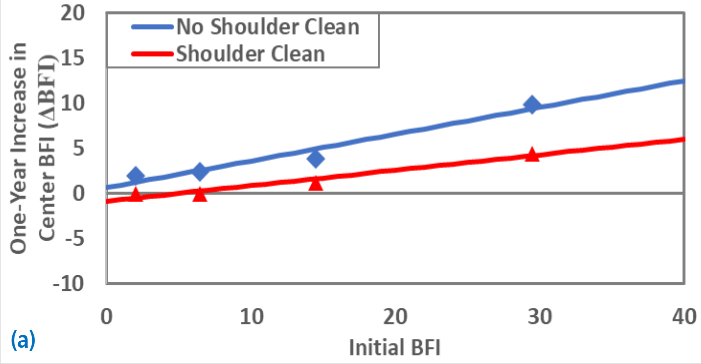
Model Development

The first step of creating a forecasting model is to develop the initial underlying equation. Since the model input will be the BFI, the underlying equation for projecting the next year's BFI is a fitted linear regressive equation. With additional data, this equation may be modified to a non-linear fit. The linear equation is shown below (Equation 1) where BFI(n) is the current BFI, ∆BFI(n) is the change in the BFI over a one-year period, n is the year, m is the slope of the line, and b is the ∆BFI(n) assuming the (n) is zero.

$$\Delta BFI(n) = m * BFI(n) + b \qquad (1)$$

Figure 3(a) shows a linear fit of the median ballast degradation values with each FI category for Section 1 for the BSC and non-BSC scenarios. Figure 3(b) shows the linear fit for Section 1 that was calculated from Figure 3(a) for the BSC scenario, but also includes uncertainty bands that represent ± 2 times the standard deviation, which should incorporate 95 percent of the measured data. This method assumes a normally distributed data set, but this assumption may be refined with additional data.

Presenting the data in this manner, Figure 3(b) emphasizes that the BFI degradation of a single 0.05-mile track section is statistically distributed over a range of values instead of having one specific outcome (e.g., the median). The variation can be a result of the natural variation in ballast degradation, drainage, and other factors including inspection methods.



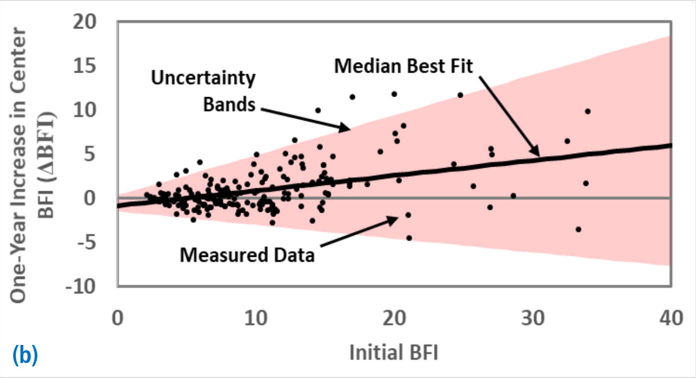


Figure 3. Ballast degradation model using (a) median values and (b) uncertainty bands

Forecasting Model

The second step is forecasting the future BFI by using the underlying equation from the previous section. The forecasting equation (Equation 2) can be in the following form, where BFI(n+1) is next year's BFI.

$$BFI(n+1) = BFI(n) + \Delta BFI(n) \tag{2}$$

Figure 4 shows an example of a theoretical scenario illustrating how this procedure can be utilized. The data prior to Year 0 (black dots) are theoretical data that would be represented by actual data sets. The lines to the right of Year 0 compare the five-year median forecast from three possible maintenance interventions (none, annual SBC, and UC). The results could show significant differences in the center BFI based on the maintenance intervention, so it might be useful as a maintenance planning tool.

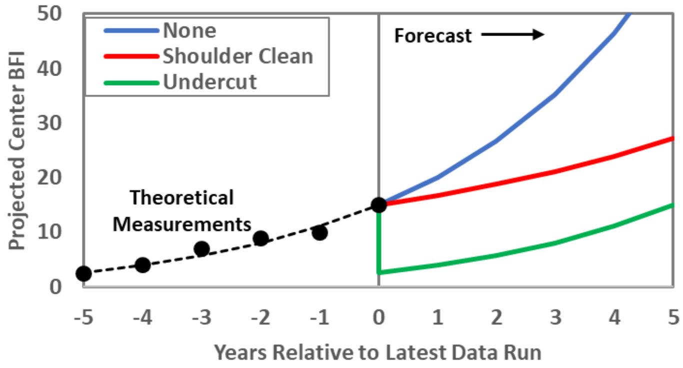


Figure 4. Example of forecasting model that projects center BFI for a 0.05-mile track section using various maintenance intervention assuming median values

Figure 5 shows the same illustrative forecast as Figure 4, but with the inclusion of the uncertainty bands from Figure 3(b). Representing the data in this manner shows the possible range of values for a single 0.05-mile section of track. The graphs in Figure 5 are split by maintenance intervention to prevent clutter.

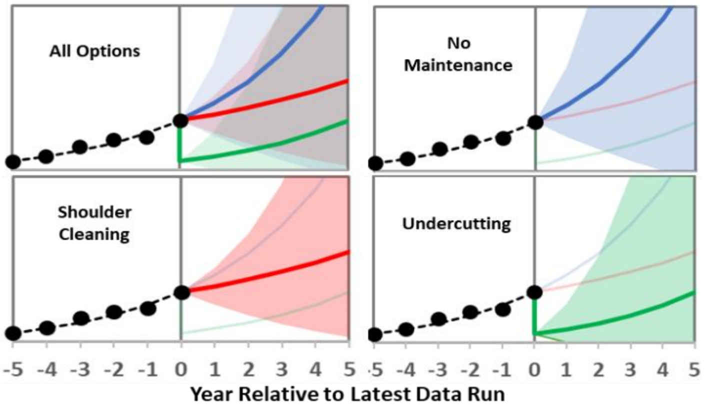


Figure 5. Example of forecasting model for various maintenance interventions displaying uncertainty bands for a single 0.05-mile section of track

One observation of the graph is the high levels of uncertainty of forecasting due to the measured variations from Figure 3(b). This uncertainty suggests that the median values (Figure 4) could be used for analyzing large stretches of track because they would give a single value and the uncertainty (e.g., risk) should average out with enough 0.05-mile track sections.

The forecasts should be updated with each GPR run in order to provide more accurate and up-to-date projections, and/or that different cutoffs (one standard deviation instead of two) can be used to represent uncertainty.

References

1. Wilk, S., and D. Li. October 2019. "Ballast Rainy Section at FAST: Phase 1 Report." *Technology Digest* TD19-022. AAR/TTCI. Pueblo, CO.
2. Bankston, A., M. Wnek, and S. Wilk. September 2019. "Implementation of BNSF Railway's Geometry Car-Based Ground Penetrating Radar Program," Proceedings 2019 AREMA Conference. Minneapolis, MN.

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