

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

Key Findings:

- A procedure was developed to investigate the relationship between track geometry degradation using historical track geometry measurements and ballast condition using ground penetrating radar. The preliminary analysis focused on short track intervals (250 feet) and required identifying scheduled and unscheduled tamping events at each selected location.
- Regions of high track geometry degradation are often localized, repeat over multiple surfacing cycles, associate with higher BFI, and have linear degradation trends.
- A trend between the Ballast Fouling Index (BFI) and track geometry degradation was found, but this trend may vary at different track locations due to ballast maintenance history and other factors.
- For a given location, projections from historical track geometry were slightly more accurate than BFI projections. BFI projections, however, can account for ballast maintenance and changes in the ballast condition over time.

Influence of Ballast Condition on Track Geometry Degradation

Stephen Wilk and Dingqing Li

[TTCI](#) analyzed 30 miles of track-based inspection data collected between 2016 and 2018 from the central United States to investigate the possibility of using both historical track geometry measurements and current ballast condition inspections measured using ground penetrating radar (GPR) to project future track geometry degradation.

Track inspection vehicles (track geometry and GPR) provide valuable information on the current track state, and when the track is inspected at regular intervals, the inspection vehicles can also determine the change in track state over time. This change in behavior can potentially be used to project future track behavior and maintenance needs. Additionally, track inspection vehicle data can establish how the ballast condition affects track geometry degradation and identify which ballast condition parameter, or combination of parameters, best relates to track geometry degradation. This information may help allocate ballast maintenance to locations where it will be most useful, especially if the effect of ballast maintenance on the track state and future track geometry degradation is understood and quantified.

The method selected to project track geometry degradation is based on historical track behavior and ballast condition. Historical track behavior is selected because, assuming no significant loading environment changes or ballast/tie maintenance, track geometry degradation in general is similar before and after surfacing. Therefore, locations that perform poorly historically are often known. From a more technical perspective, track with poor ballast conditions such as high fine levels and excessive moisture is more susceptible to settlement and track geometry degradation.¹⁻³ This *Technology Digest* presents the results and findings from the preliminary research.

DATA SOURCE

This study used three years of track geometry and GPR data collected from two 15-mile segments of track in the same subdivision of a western railroad. The subdivision is located in an area of the central United States that has a wet climate (~30 inches of rainfall per year). The three years' worth of data was used to calculate track geometry degradation rates within at least two surfacing cycles as well as the

ballast condition within those surfacing cycles. This data allows for comparisons between the track geometry degradation results of the first and second surfacing cycle (historical track geometry) and between the track geometry degradation and ballast condition within a single surfacing cycle. The surface profile from the track geometry records, and the Ballast Fouling Index (BFI) from the GPR records were used.

DATA PROCESSING METHOD

The data processing method had multiple steps that are outlined in the subsequent sections.

Track Geometry Representation

The first step involved converting the 62-foot surface profile mid-chord offset data into more manageable representations. The first representation is simply the absolute value of the 62-foot surface profile referenced as surface magnitude (SM). This representation is useful because it directly relates to track geometry exceptions. The second representation is the 200-foot running standard deviation (SD). This parameter represents track roughness, and while not used for track geometry exceptions, it is useful for visualization and could have some maintenance planning implications in the future. In addition, the BFI data is aligned with the track geometry data.

Location Selection

The second step included selecting the data for detailed analysis. Over 100 locations were selected and at each location, the maximum SM, SD, and BFI were determined from about a 250-foot window around each selected location. This window method was selected because it reduced the effect of misaligned data, kept a reasonable distance between the selected locations, and easily accounted for unscheduled maintenance. Transition locations near bridges, road crossings, and turnouts were excluded since those typically represent different behavior than the open track but are planned to be incorporated in future analysis iterations.

Figure 1 shows a sample track record with different track geometry representations (surface profile, SM, and SD) and BFI along with various window locations. The windows were generally selected at regions of higher track geometry degradation but also included low track geometry degradation regions to diversify the dataset.

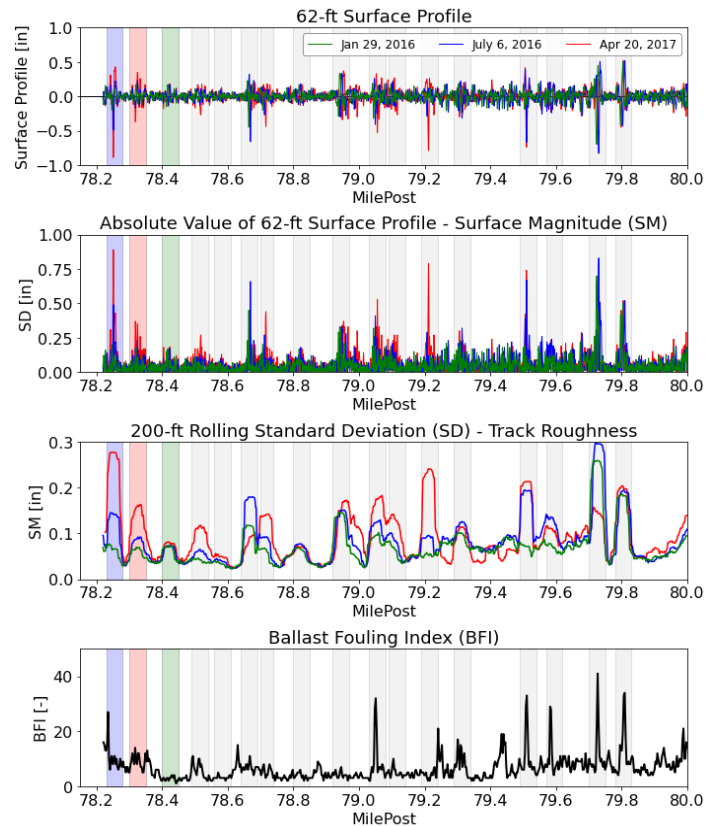


Figure 1. Example track locations showing various track geometry and BFI representations and windows.

Surfacing Window

One of the challenges when calculating an accurate surface profile degradation rate is the unscheduled maintenance that occurs between scheduled maintenance activities. Therefore, for each location, surfacing events had to be identified, and the SM degradation rates (dSM) were calculated within each surfacing cycle. Figure 2 presents three example locations that show tamping events and degradation rate calculations. The SM degradation rate trends generally appeared to be linear, so simple line-fitting techniques were used.

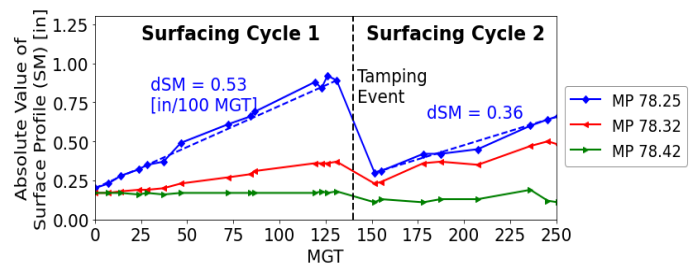


Figure 2. Degradation rate calculation at three selected locations

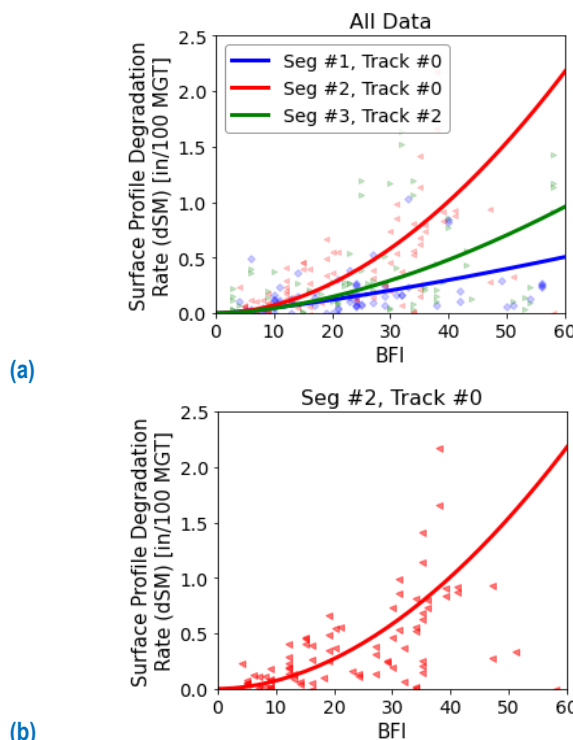
BFI RELATIONSHIPS WITH TRACK GEOMETRY DEGRADATION

At each selected location, relationships between dSM from historical track geometry and BFI were developed. The data was separated into track segments, with the start and end points being mainline turnouts, to determine if differences in behavior existed due to different segments. These differences in behavior could be attributed to varying ballast maintenance histories (new versus degraded ballast), tie type, or even variations in subgrade or drainage.

Figure 3 shows the BFI-dSM relationships with Figure 3a showing all the data split into the three track segments. Track #0 represents single track while Track #2 generally experiences loaded cars on this particular double mainline (Track #1 generally has empty cars). The fitted line is a power law relationship that is created by making a linear fit when the BFI and dSM data is plotted in a log-log scale.

The data in Figure 3a shows that locations with low BFI almost always have low track geometry degradation while locations with high BFI generally have a greater range in degradation behavior. The fit lines show that each of the three track segments have generally similar behavior (i.e., higher BFI leads to higher track geometry degradation), but the exact relationship differs at each location. For example, at a BFI of 40, one can see higher track geometry degradation within Seg #2, Track #0 (red) than within Seg #3, Track #2 (green). This difference has implications on the prioritization of ballast maintenance if BFI is used as a metric. It is unclear why the different relationship exists at different track segments, but it could possibly be due to ballast condition (new versus degraded) or some differences in drainage. For example, Seg #1 (blue) was undercut about two years prior to the study while Seg #2 and Seg #3 have not been undercut within the past five years at least.

Figure 3b emphasizes the data points at Seg #2, Track #0. While the data does fit the curve, there is scatter. This scatter is likely due to other ballast and track parameters that affect track settlement and degradation and cannot be captured only by BFI.¹ A potential example is moisture. Moisture levels have been found to have a significant influence on track geometry degradation with higher moisture levels resulting in higher track geometry degradation rates.²



(a)

(b)

Figure 3. BFI-dSM Relationship for (a) all data and (b) Segment #2, Track #0

PROJECTION ACCURACY

Projection accuracy can be accessed by taking the projection and plotting it against the measured dSM value. The historical track geometry projections take the dSM from the first surfacing cycle and multiply it by 1.25 (y-axis in Figure 4a), the statistical fit that accounts for the increase in track geometry degradation for each surfacing cycle, against the measured dSM of the second surfacing cycle (x-axis in Figure 4a). For the BFI in Figure 4b, the projection calculated from the fitting equation in Figure 3 is plotted against the measured degradation. The plots in Figure 4 are in a log-log scale to better distribute the degradation data and accuracy of projections. Perfect accuracy between the projected and observed values would occur if the data point fell exactly on the center diagonal 1:1 line. The dark shaded region shows data within the 2:1 ratio, and the light shaded region shows data within the 10:1 ratio.

The historical track geometry in Figure 4a shows a good match with about 60 percent of the projections falling within a 2:1 ratio. The main outliers are either at low degradation rates or were at an undercut location (green x). The projected track degradation rates based on BFI in Figure 4b show more scatter

but with about half of the projections within the dark shaded 2:1 ratio region.

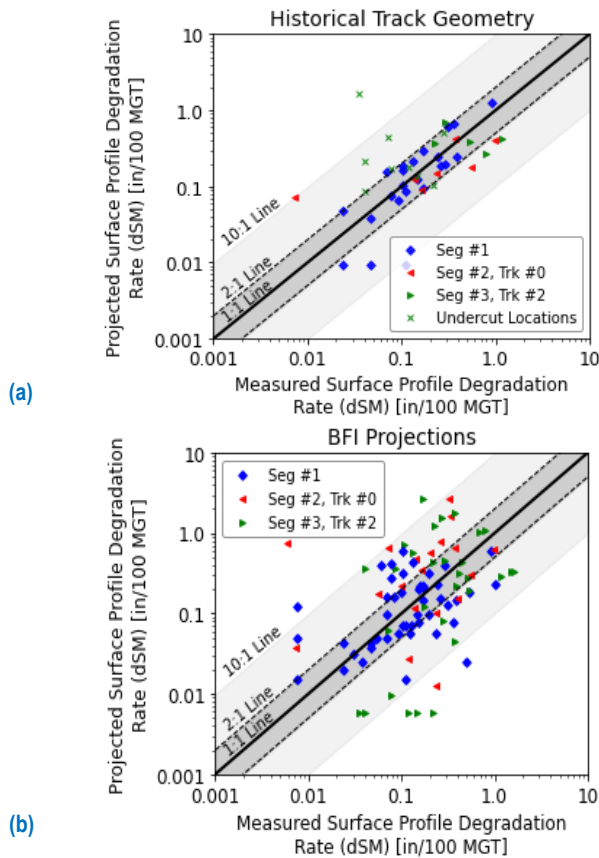


Figure 4. Accuracy of (a) historical track geometry and (b) BFI projections

Figure 5 shows the percentage of projections within the 2:1 ratio. As can be seen, the projections based on historical track geometry are slightly more accurate than the general projections based on the BFI.

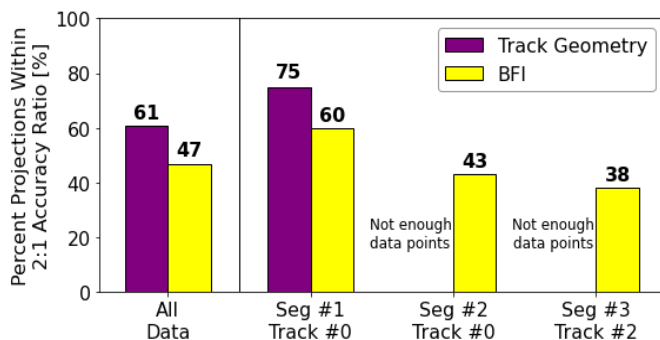


Figure 5. Accuracy of historical BFI projections

The BFI projections (from Figure 4) tend to have more scatter than the historical track geometry projections. There were less

than 10 data points in both Seg #2 and Seg #3 sites for historical track geometry, so those accuracy values were not included due to low sample sizes. There does appear to be variation in accuracy for BFI projections based on track segment data, and the reason is currently unclear.

DISCUSSION

The analysis of three years of track geometry and GPR records show that both historical track geometry and BFI can potentially be useful for projecting track geometry degradation. The ability to use both techniques is important because the two approaches would be used in different situations. Historical geometry would be more useful in situations where few maintenance activities or changes in load environment have occurred while BFI projections can estimate the track geometry behavior after ballast maintenance has occurred. In addition, the current dataset suggests that the same BFI in two different track segments may perform differently.

Further work will consist of additional analyses of track in other geographical regions along with attempts to simplify the analysis by focusing on larger track segments than 250-foot intervals.

References

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