Utilizing surface and subsurface trackbed inspection techniques to help plan and derisk undercutting operations on Amtrak’s Northeast Corridor

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Outline

• Background
• Technology Overview
• Maintenance Planning / Undercutting / Drainage
• Conclusions & Benefits
• Recommendations
Background

• Zetica/BB commissioned by Amtrak to undertake a detailed trackbed inspection survey of a ~84 mile section of the North East Corridor route between East Haven and Kingston Station.

• Aims:
  • To assist in identifying the most appropriate locations for undercutting based on ballast fouling and fouling depth.
  • Help derisk undercutting operations by identifying locations with potentially shallow bedrock.
  • Help derisk undercutting operations by identifying locations with limited clearance.
  • Assist with identification of poor track drainage locations.
Survey platform & measurement systems

• Integrated datasets acquired in a single pass over each track using BB/Zetica’s Railroad Asset Scanning Car (RASC®) system mounted to hy-rail vehicle.
RASC® measurement systems

<table>
<thead>
<tr>
<th>System Deployed</th>
<th>Objective</th>
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<tr>
<td>Ground Penetrating Radar (GPR) 6 channel system:</td>
<td>• Layer interface metrics</td>
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<tr>
<td>• 3 x 2 GHz</td>
<td>• Areas of formation failure / incipient mud spots</td>
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<tr>
<td>• 3 x 400 MHz</td>
<td>• Modelled ballast fouling &amp; fouling depth layer</td>
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<td>• Moisture likelihood estimate</td>
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<td>Trackbed surface imaging</td>
<td>• Surface mud spots</td>
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<td>• Tie quality</td>
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<tr>
<td>Mobile Terrestrial Laser Scanner (MTLS)</td>
<td>• Ballast management</td>
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<td></td>
<td>• Track drainage</td>
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<td></td>
<td>• Clearance analysis of targeted areas for undercutter access</td>
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</table>
Ground penetrating radar (GPR)

- Multi-channel GPR system utilising both high (2 GHz) and low (400 MHz) frequency antennas to achieve resolution & depth.
- 3 antennas per frequency – mounted over left shoulder, track center and right shoulder.

<table>
<thead>
<tr>
<th>GPR – 2 GHz antenna</th>
<th>GPR – 400 MHz antenna</th>
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<tr>
<td>Ballast Fouling</td>
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<td>Ballast thickness</td>
<td>Layer Roughness</td>
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<td>Shallow Mudspots/Wet Beds</td>
<td>Deep Ballast Pockets</td>
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<td>Mapping surface assets</td>
<td>Mud spots / Wet beds</td>
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<td>Buried assets e.g. culverts</td>
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Trackbed surface imaging

- 4 high speed linescan cameras
- Integrated infrared light source
- Image capture triggered by a DMI with along track resolution starting at 0.75mm per pixel
Mobile terrestrial laser scanner (MTLS)

- 360° laser profiling system (with integrated Inertial Measurement Unit)
- High scan rate (max. 200 Hz) for detail – 1 million pixels/second
- Down-track scan interval ~10 cm @ survey speed 50 mph

### Laser Profiler
- Ballast profile
- Ballast volume
- Gauge clearance
- Drainage
- Ground contour mapping
- Mapping assets
Trackbed metrics

- The results of the RASC® survey were summarized as a series of trackbed metrics, derived from the interpreted GPR layer depth information, modelled ballast fouling and interpretation of the linescan camera images and Lidar point clouds.

- Each of the metrics reports a different aspect of the trackbed condition, which together highlight the worst sections of track and help the engineer to plan the most appropriate course of remedial action.

**Sub-Surface Condition Metrics**
- Ballast Fouling Index (BFI)
- Fouling Depth Level (FDL) Index
- Ballast Thickness Index (BTI)
- Layer (Interface) Roughness Index (LRI)
- Moisture Likelihood Index (MLI)
- Surface Mud Spot Index (SMI)

**Surface Condition Metrics**
- Ballast Volume Metric (BVM)
- Ballast Deficit Metric (BDM)
- Surface Mud Spot Index (SMI)
- Track Drainage Index (TDI)
Maintenance planning tool - trackbed condition score (TCS)

- Objective assessment of the overall quality of the trackbed, similar to a TQI commonly used in the assessment of track geometry.
Work order recommendations

- Rules-based system used to help determine most appropriate maintenance method and help define limits of work sites
WOR clustering

- Clustering algorithm identifies minimum length areas that meet WOR criteria, taking account of fixed assets:

  Clusters terminated at fixed assets that can’t be cut, such as road crossings and interlockings.
Undercutting recommendations

- The ballast fouling results were utilized individually and in conjunction with the most recently available track geometry data to identify locations for undercutting.
- Three sets of undercutting work order recommendation (WOR) results were generated based on the following sets of rules:
  - **WOR 1:** Left Shoulder OR Center OR Right Shoulder BFI > 25 (CAT 1 - 2)
  - **WOR 2:** Left Shoulder OR Center OR Right Shoulder BFI >10 (CAT 1 – 3) **AND**
    Track Geometry TGI* >= CAT 2
  - The track geometry (quality) index (TGI) was calculated based on a summation of the standard deviation of Gage, Alignment, Warp and Profile:
    \[
    TGI = 1\sigma \text{ GAGE} + 1\sigma ((\text{LPROF62+RPROF62})/2) + 1\sigma \text{ WARP62} + 1\sigma ((\text{LALIGN62+RALIGN62})/2)
    \]
    1\sigma values were determined over a 100-ft rolling window.
    TGI categorized as Good, Moderate or Poor based on thresholds of 0.25 and 0.4.
High risk shallow bedrock locations

Example BTI exception track chart from Main 1 between MP80.0 and MP150.0 illustrating locations where the interpreted depth to the base of the ballast is less than 10 inches.
RM80 structure clearance analysis

- Lidar point cloud data collected during the RASC survey.
- Clearance analysis of structures within the proposed limits of undercutting identified by the WOR.
- Used to determine whether RM80 could clear the structure with or without track slew.
Work order recommendation (WOR)

Location of proposed undercutting sites on Main 1 based on clustered WOR1 results:

Location of proposed undercutting sites on Main 1 based on clustered WOR2
Workflow

1. Acquire integrated RASC datasets
2. Calculate layer & fouling metrics
3. Calculate trackbed surface profile metrics
4. Lidar point cloud clearance analysis
5. Shallow bedrock identified from BTI
6. Run Work Order Recommendations & calculate Trackbed Condition Score
7. Identify required track slew locations
8. Filter U/C WOR locations
9. List of recommended U/C locations
Amtrak undercutting

- **Block Undercutting**
  - Entire length of track between two interlockings
  - Track out of service for a range of a few weeks to a few months
  - Targets larger drainage issues

- **Spot Undercutting**
  - Smaller locations that can be completed within a Friday-Monday 55-hour track outage
  - Targets mud spots
Recommendations for spot undercutting

• **Method #1**

  1. Pick 5-mile track sections from Trackbed Condition Summary

    • TCS is an analysis of 5 GPR-based metrics: layer roughness, ballast fouling, fouling depth, moisture likelihood, ballast thickness

  2. Reference the BB/Zetica Work Order Recommendations to pick specific locations

    • Based on Ballast Fouling Index and Track Geometry Index (warp, gage, profile, alignment)
Method #1 – trackbed condition summary

Track 1

Track 2
Method #1 – trackbed condition summary
Method #1 – work order recommendation
Method #1 – TCS Plus BFI, FDL, & geometry

1-Mile Report
Track 1
MP 111
Recommendations for spot undercutting

• **Method #2**

  • Pick blocks based on Amtrak geometry exception data

  • Look at the BB 1-mile Type 1 report
    • Narrowed down locations within the block by looking for locations where exceptions occurred and Ballast Fouling Index is high
# Method #2 – Amtrak geometry exceptions

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<th>Level 1’s</th>
<th>Level 3’s</th>
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Method #2 – BB/Zetica 1-mile report
Targeting spot undercutting – interlocking construction

• New interlocking planned
• Recurrent mud spot just west of planned interlocking location
• Knowing that track will be out of service, we want to address drainage issue during construction
Targeting spot undercutting – interlocking construction

1-Mile Report
Type II
Track 2, MP 133
Amtrak drainage planning

- Current methods are not based on data
  - Reactionary based on track inspection observations
  - Ad-hoc spot improvements to known problem areas
  - Supplementary to large construction projects (i.e. tie/rail replacement, undercutting)
- Want to use BB/Zetica data and reports to improve drainage planning
Amtrak drainage planning

- Areas identified as having potentially elevated trackbed moisture levels are commonly observed to occur on both Main 1 and Main 2.

Extracts from MLI track charts for Main 1 & Main 2 between MP80.0 and MP90.0 and MP110.0 to MP120.0
Amtrak drainage planning

- Trackbed drainage was also assessed by comparing the surface profile data obtained from the 2d laser scanner with the Amtrak standard roadbed design profile detailed below.

- The design profile was modified in curves to account for track superelevation (SE) using superelevation data derived from the MTLS’s built in inertial measurement unit (IMU).
Amtrak drainage planning

• Ground contour plots provided on the Type II trackbed condition reports provide a top down view of the trackbed profile out to 32-ft from the track centerline.

• The plots are color-coded such that the design level of the formation is colored green. Areas of track above formation level appear as shades of green / brown enabling locations where off-track drainage is sub-optimal to be quickly identified.
Conclusions and benefits

• Optimize schedule and planning of undercutting, shoulder cleaning, surfacing, drainage work.

• Change from reactive / production based method of maintenance to condition based maintenance.

• Amtrak’s field engineers and Project Manager have started to request trackbed condition data.

• Optimize performance and extend the life of the asset.

• Cost savings / reduce impact on operations
  • Prioritizing work locations.
  • Derisking maintenance operations
  • Repeat visits to locations.
  • Track geometry exceptions
  • Train delays due to slow orders

• Improving passenger experience (ride / comfort).
Recommendations

• Next steps
  • Implement a more regular trackbed inspection program.
  • Monitor change over time “Run on Run” to work towards establishing a predictive time based model of maintenance.
  • QC maintenance work.
  • Implementation of drainage data for planning purposes.