Analysis and Assessment of MBTA Green Line

Light Rail Track System

For:

The Commonwealth of Massachusetts

DEPARTMENT OF PUBLIC UTILITIES (DPU)
TRANSPORTATION OVERSIGHT DIVISION

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Executive Summary

In October 2016, DPU issued a Request for Response (RFR), *Assessment of the Massachusetts Bay Transportation Authority's Green Line Light Rail Track System*, COMMBUYS Bid: BD-17-1033-DPU01-DPU01-10412, Agency Document Number: 17DPURSMY1, to secure the services of a qualified contactor for an analysis and assessment of the (MBTA) light rail, (Green Line) track system. Harsco Rail/Protran Technologies, Consulting Services Division, was the selected consultant for this project.

The assessment specifically requested the following:

- Evaluate Current Condition of Track Structure by Performing Physical Inspections of the Green Line Track Infrastructure.
- Evaluate MBTA's Ability to Maintain Track Structure to an Acceptable Level.
- Review Track Department Records, Procedures, and Maintenance Management Processes.
- Review the Track Department (MOW) Training Program.
- Determine if the MBTA Green Line Track System is Maintained to:
    - MBTA Standards
    - Industry Recommended Practices
    - DPU 220 CMR Section 151.11 and 151.12 Requirements

This report is presented for the assessment and provides the details for the requested review as listed above. The recommendations listed in the Executive Summary are priority recommendations and should be implemented as soon as possible. There are additional recommendations located throughout the body of the report per section and are summarized by subject matter in Appendix A at the end of the report.

Evaluation of the Current Track Structure

The MBTA Green Line track is in need of an aggressive maintenance program due to the fact the track is in need of significant rehabilitation. The MBTA Track Department faces many unique challenges to maintain the Green Line in a non-restrictive operational state due to a variety of problematic foundational issues with the age, design and renewal needs of the track infrastructure. Performing track maintenance work on track components which have exceeded their useful lives or restoring track geometry to the track on a track bed which is unable to hold that geometry creates a challenging environment for maintenance managers and lessens the efficiency of maintenance dollars spent. Due to a variety of factors (i.e. track time, access issues, staging location issues, etc.) Track maintainers on the MBTA Green Line are fundamentally no longer in a maintenance mode but rather in "repair the issue just enough" to return to a restricted service mode. Although this is a widely used technique in Track Maintenance, it is not sustainable in the long run and creates an ever-increasing backlog of issues needing permanent resolution. It is clear by the total number of speed restrictions (58 at the time of this writing) that this is where the MBTA Green Line presently is regarding the condition of the infrastructure. Although it is acknowledged that the Green Line is unique in multiple aspects (heaviest light rail ridership in nation, 100+ years old infrastructure, operating articulating trains with independent rotating wheels), there is no other transit system in North America with this many infrastructure related speed restrictions to the assessment teams' knowledge.

Current MBTA Management has recognized that renewal of the track infrastructure is paramount to the long-term viability and operational efficiency of the Green Line. The MBTA has self-identified the need for infrastructure improvement and has already begun some programs such as Grade Crossing Repairs, CWR Work, Grinding and tie renewal to improve the overall "state" of the infrastructure. Per MBTA comments, due to their renewal efforts during the last year (August 2016 and August 2107) On-Time Performance has risen 37.5 %. However, this reported short-term improvement may not be sustainable as OTP is directly impacted due to track conditions and will continue to be below what it could be if the track infrastructure is not returned to a State of Good Repair. As such, the MBTA must continue to use outside resources and continue to invest in the renewal of the Green Line system if they intend to spend their maintenance dollars efficiently and to reduce the number of delays and issues caused by the track/train interface.

The system needs renewal of its track infrastructure including such things as;

- Subgrade stabilization in mud spot areas,
- Ballast renewal in many areas especially in areas near stations and crossings,
- Crossing renewal,
- Tie renewal,
- Turnout renewal and modernization,
- Track (Rail) renewal and standardization,
- Platform interface with track structure,
- Vegetation Control.

Priority Recommendations

- Hire additional contactors and additional staff to augment the workforce to reduce the number of conditions on the Green Line that cause speed restrictions.
- Analyze the use of "Speed Restrictions" for locations where the "Maximum Authorized Speed (MAS)" may not be set correctly for the physical characteristics of the area. Discontinue the use of "Speed Restrictions" in these areas and adjust the MAS accordingly.
- Investigate the possibility of having extended "single tracking" events to allow additional track time for repairs and rehabilitation.
- Expand current plans for short and long term "diversions" as was successfully demonstrated this year at Commonwealth Ave. Bridge for renewal efforts. Investigate similar successful programs in NYCT, WMATA and CTA.

Evaluation of MBTA's Ability to Maintain the Track Structure to an Acceptable Level

The term "acceptable level" is subjective and not clearly defined but one can surmise that an "acceptable level" would be one where the track is maintained to allow trains to operate at maximum authorized speed (MAS). As such, with the number of track defect based speed restrictions in place, and the frequency of derailments with track infrastructure issues as primary or secondary contributing factors, it is quite apparent that the MBTA cannot maintain the Green Line to an "acceptable level" or even significantly reduce the number of operational speed restrictions without additional resources. At the present time, our analysis concludes that the Green Line is minimally staffed.

The MBTA staff is making a considerable effort to try to up-grade the system and to maintain the system to at least a restricted operational level but their resources are stretched to the limit. With work efforts supplemented by contractors, the MBTA provided the assessment team with a listing of work which has been performed in the last 15 months. This includes the following:

- Replacement of over 25,000 Ln. Ft. of Rail
- Replacement of more than 2,200 Ties.
- Replacement of more than 945 Tie Plates
- Grinding and Gauge Face Angle Correction on over 104,000 Ln. Ft. of Rail.
- Repair of 16 Grade Crossings.

This level of repair and rehabilitation is commendable and clearly demonstrates that the MBTA understands the need to upgrade the system but is not sufficient to return the Green Line to a State of Good Repair and must be increased. Significant investment is required to fully rectify the total number of problems found on the system. Many of these problems are legacy design issues such as outdated and unavailable parts, track alignments, number of road crossings, inaccessible track component locations and clearances. Others are the result of the previous lack of investment in upgrading and modernizing the infrastructure. With the tight track geometry requirements for the No. 8 vehicles, there are simply too many issues that force the managers to move constantly from critical issue to critical issue just to allow continued restricted operation. Succinctly, the system is simply overdue for renewal, and maintenance requirements far exceed capabilities of existing MBTA resources. Per documentation provided by the MBTA, there are efforts underway to fund and execute additional "rehabilitation" efforts which will eliminate some of the areas that require extensive maintenance and allocation of already stretched maintenance resources.

In looking at causal factors regarding derailments and speed restrictions, it becomes quite clear that by having only the minimal amount of resources available, Track Management has to try to maintain a track structure where the track conditions remain at a state near the track standards limits which, for the most part, are not being addressed until they reach "red level" before action is taken. As a result, the frequency of exceeding track standards occurs at a higher level than is acceptable and ultimately results in a high number of derailments due to the sheer number of "red level" conditions and the fact that No. 8 cars are susceptible to minor alignment and geometry deviations which can develop quickly. Because of this, the MBTA must be extremely vigilant to maintain the infrastructure to the Maintenance Standards as described in either their own MBTA Track Maintenance and Safety Standards or to 220 CMR Section 151.11 and 151.12.

The introduction of additional resources, such as a Job Order Contractor (JOC) or hiring additional personnel will and has greatly improve the ability for the MBTA Green Line Track Managers to address track related issues beyond the average of 3 crews per night and 2 crews per day currently being used. Currently, the MBTA is utilizing multiple on-call contactors to supplement MBTA staff to perform track renewal work or support the track renewal effort as self-identified above. Additionally, the MBTA is implementing modern maintenance management software and performing analysis on logistics surrounding the optimum number of contactors and employees who can work in any dedicated work zone.

The acquisition of modern track maintenance equipment will also improve overall performance of the track department. With equipment resources being shared with the entire MOW department,

additional equipment resources are needed for dedication to the Green Line. A maintenance department which is dealing with 58+ operational speed restrictions should not have to share resources with other lines which at times required them to schedule repairs around waiting on available MOW equipment.

Priority Recommendations

- Implement a "Specialized Geometry Assurance" team(s) whose only focus is geometry issues on the railroad.
- Increase training on track/train dynamics for System Repairpersons (Inspectors) to assure a high confidence in monitoring geometry conditions on the Green Line. Document any findings and action taken.
- Determine Critical Parts and Critical Stock levels for track parts.
- Increase Capital Investment for renewing track infrastructure to a state of good repair.
- Increase Capital Investment for modernized track equipment specifically capable of negotiating the Green Line.
- Implement additional inspection processes such as a Portable Track Loading Fixture (PTLF) Program for sections of track where visual inspections are obstructed.

Review of Track Department Records, Procedures, and Maintenance Management Processes

The review of the MBTA Track Department practices and records found that the maintenance practices are relying on a rather loose sub-division level management structure. These practices lead to non-uniform document management, non-uniform maintenance practices, non-compliant maintenance practices and high levels of inefficiency in work execution.

MBTA's records management program primarily uses a paper based system with a newly introduced "work list" program and rudimentary condition monitoring dashboard. The majority of critical asset maintenance information is held at the sub-division level and is reliant on an informal communication and documentation process which has broken down due to recent management changes. Some documentation is not available as required by both MBTA and DPU regulations. As such, critical maintenance information and overall condition of MBTA Green Line track infrastructure information is incomplete and disjointed. This results in incomplete information being funneled to higher levels of the MBTA organization which may affect funding, priority, and access needs.

Currently, efforts are underway by the Engineering and Maintenance Department to address some of these issues stated above. Engineering is in the process of introducing a linear Asset Management Program and current maintenance leadership has implemented some process management and document control reforms. These efforts must be completed to move the MBTA more in line with industry Recommended Practices and MAP-21 Transit Asset Management (TAM) requirements.

Priority Recommendations

- Develop procedures for document management and retention.

- Develop "Maintenance Control Policy".
- Formalize and document all processes utilized within the management framework.
- Identify roles and responsibilities in all processes.
- Modernize Inspection and Work Order processes to efficiently manage any renewal and maintenance program.
- Update all forms used for assessments, work order request, crew assignments, QA/QC review and work order closing.
- Complete implementation of Optram and implement analytics for defect and condition trending,
- Assure that inspection, condition assessment and speed restriction paperwork is integral to MBTA's MAP-21 TAM Performance Reporting requirements for Fixed Guideway "Percentage of track segments with performance restrictions."

Track Department Training

On any rail transit agency, the track and track structure play a key role in the operating viability of the system. It is the job of the Track Department to ensure that the track and track structure is maintained to the proper level of integrity for the speed of track being operated. A loss of track integrity such as pumping, or spike killed ties, low or fouled crib ballast, misaligned track, incorrect super elevation on the curves, high rail wear, incorrect destressing of Continuously Welded Rail and the like, can lead to:

- Loss of component life
- Damage to track structure
- Temporary slow order application
- Spread gage
- Track buckles or pull-aparts
- Derailments

It is of utmost importance that on today's transits, all Track Department employees are aware not only of what they are to do and how to do it, but also the reason the work must be done.

During the initial assessment, the Assessment Team found that the Green Line did not have a Training Department and the MBTA had previously self-identified this issue. The MBTA has informed the Assessment Team that they have now hired a Manager of Training who is presently evaluating training efforts and working with MBTA MOW Managers to determine training needs. Additionally, during this period when there was no formal Training Department in the MOW Department, MOW Managers did utilize consultants to provide required training for Track Inspectors.

The Assessment Team believes the previous training insufficiency is the core of many problems as there was no on-going training needs evaluation, or refresher training for Supervisors, repairers, welders, operators, or laborers.

<u>Current Training</u>

In documentation provided by the MBTA, Laborers are provided a five-day introductory course regarding their responsibilities, tool identification and safety on the track. System Repairpersons are provided a ten-day program to qualify them to inspect track and are then required to be "recertified" every two years. This type of training is compliant with FTA, APTA and DPU requirements and recommended practices for those performing track inspections but lacks some of the recommended specialty training implemented by many transit agencies for their inspectors.

All personnel should be properly trained and retrained at regular intervals. Training needs to be improved by enhancing the existing track standards and creating better procedures and guidelines. Work processes should be clearly defined by a formal Work Procedures process and employees should be trained to these Work Procedures. Management philosophy and a maintenance management plan needs to be fully defined and personnel trained in their roles to execute the maintenance plan.

Priority Recommendations

- Continue having the new Training Manager evaluate the current training needs.
- Update position descriptions to include skills, knowledge, and behavior requirements to meet current organizational needs.
- Hire consultant to develop training requirements to match skills and knowledge requirements for all specific jobs.
- Develop and implement Standard Work Procedures for all track work jobs. Train personnel consistently to these standard work procedures.
- Develop a clear syllabus for each training class that includes learning objectives and pass/fail criteria.
- Develop a step-by-step guide for On-The-Job training.

Is the MBTA Green Line being maintained to Standards?

As indicated above in the maintainability portion of this summary, the MBTA is facing many unique challenges to maintain the system to its own standards and the DPU's standards. It is the conclusion of the assessment team, that although the MBTA's efforts are for the most part meeting the standards as outlined in the 2008 version of the MBTA Track Maintenance and Safety Standards, and 220 CMR Section 151.11 and 151.12, these standards do not fully address the criticality of some issues on the system and do not meet current FTA, APTA or industry recommended practices. Further, the overall track infrastructure condition has deteriorated to a point that trains may at times be operating at/or near potential derailment threshold limits for the No. 8 cars and at times these conditions are only recognized and acted upon by the MBTA after a derailment or near derailment incident occurs. Note: actual No. 8 car derailment threshold limits have not been determined.

It has been recommended by other consultants that MBTA update their Track Standards, but this has not taken place yet. One of the biggest deviations from current industry best practices and both APTA and FTA recommended practices are the lack of Out of Service conditions within the Track Standards. This clearly allows for ambiguity in application of standards and as a result may be one reason for a higher frequency of derailments and speed restrictions per comparison with other similar agencies.

Priority Recommendations

- Update Track Standards to meet current APTA and FTA Recommended Practices.
- Develop a "Black Condition" rating (Out of Service) for critical geometry, wear and fixation conditions which affect the safe passage of trains and equipment.
- Divide Standards Manual into two volumes. One volume is an "Engineering/Office Reference Manual" the other is a Supervisor and Track Inspectors "Pocket-Sized Field Guide".
- Expand the existing QA/QC Department to include internal oversight and quality audits of Engineering and Maintenance functions.

Summary

In any transit operation, there are conflicts between operations and maintenance. The clear desire of train operations management, often supported by senior leadership, is to be customer focused; with emphasis on maximum achievable service levels and a high degree of on-time performance. Care must be taken to assure that appropriate opportunity is afforded to maintenance. In the case of the MBTA Green Line, this balance must continue to be monitored so as to not tip too far, given that on-time performance has been a key measurement of the Green Line's efficiency. Those charged with maintaining track should not see themselves as unable to get their job of inspection and maintenance done without taking operational needs into consideration first. Senior leadership has self-identified this issue and maintains an atmosphere of team building and cooperation between maintenance and operations and both groups exercise their best efforts towards a common task of rebuilding and then ultimately maintaining the system in a state of good repair. It is critical that this effort be closely monitored to assure that it is achieving the anticipated results and that maintenance is afforded the time and access to rehabilitate and return the Green Line to a State of Good Repair. New strategies may be needed to assure adequate work is done, including review of collective bargaining agreements and operational parameters that apparently restrict work to times when the operations are less impacted.

It is the opinion of the Protran Consulting Assessment Team that the MBTA must undertake a systematic renewal of the Green Line track infrastructure. Many of the components within the Green Line system are well beyond their normal useful lifecycles and require replacement. The MBTA must increase its Capital expenditures for infrastructure renewal of the Green Line. If Capital Investment is deferred for too long the following occurs:

- Components fail to operate reliably. As service suffers, MBTA riders will seek alternate transportation, and fewer funds will be available to sustain the system.
- Labor expenses increase as components fail unexpectedly, causing delays. Crews must work longer hours and unscheduled shifts and overall operating costs will rise.
- The poor condition of one component accelerates wear and tear on other components. For example, track conditions affect the operation of revenue trains causing increase wheel and vehicle maintenance. Deteriorated ballast conditions affect the alignment of track which affects the wear of track components.

- Operating costs will escalate, more dollars are diverted from capital needs, and deferral of maintenance continues. The cycle continues to worsen at an increasing rate. Meaningful service enhancements or extensions will be impossible.

The MBTA is already experiencing many of the issues described above as Capital Investment in the Green Line is long overdue. The MBTA must use this opportunity for track renewal to utilize modern track components and to correct long standing alignment issues from legacy systems which cause a maintenance burden beyond normal requirement to the track department. By adjusting and realigning track crossings, utilizing modern removable crossing panels, and by standardizing the infrastructure to one rail size, the MBTA will achieve lower maintenance costs and remove the burden of trying to maintain and match parts within a mixed infrastructure component system. Further, by improving the overall condition of the infrastructure, MBTA will see improved on-time performance and lower operating and maintenance costs.

END OF EXECUTIVE SUMMARY

Background

The Commonwealth of Massachusetts Department of Public Utilities (DPU) located in Boston, Massachusetts, is the designated State Safety Oversight Agency (SSOA) for the Massachusetts Bay Transportation Authority (MBTA) pursuant to M.G.L. c. 161A 3(i) and 49 CFR Part 659. Due to recent mainline derailments on the MBTA's Green Line (light rail) that occurred on revenue track, the Department reviewed data which identified track deficiencies as one of the contributing factors in these derailments.

In an effort to analyze and determine causal factors for track related issues on the MBTA's Green Line, the Department of Public Utilities (DPU) contracted with Protran Consulting Group to perform an analysis and assessment of the MBTA Light Rail, Green Line track system and the MBTA Green Line Track Maintenance program. This assessment and evaluation includes a review of multiple facets of the MBTA's overall Green Line Track Maintenance program including the efficiency of current track standards, the track inspection program, the track maintenance program and the effectiveness and efficiency of employee training for those performing track maintenance and inspection activities.

Scope

The project evaluated the current condition of the Light Rail, Green Line track system based on 220 CMR Section 151.11, 220 CMR Section 151.12, and the Massachusetts Bay Transportation Authority, Maintenance of Way (MOW)Division, Green Line - Light Rail, Track Maintenance and Safety Standards, Edition 2008.1 (7/08).

The assessment specifically requested a review of the following:

- Evaluate Current Condition of Track Structure
- Evaluate MBTA's Ability to Maintain Track Structure to an "Acceptable Level". Review following components of the Green Line Track Maintenance Program:
    - Review Man-Power Resources
    - Policies
    - Procedures
    - Training Programs
    - Record Systems
    - Quality Assurance Programs
    - Maintenance Programs
- Review the following Track Department Records:
    - Inspection Reports
    - Switch Certification
    - UT Reports
    - Geometry Car Data
    - Optical Inspection Data (Rail Profile/Gage Face)
    - Work Order Generating Process
    - Quality Assurance Reports
- Review Track Department (MOW) Training Program including:
    - Training Curriculum and Employee Requirements

    - Employee Training Records
    - Lesson Plans and Support Documents
- Determine if the MBTA Green Line Track System is maintained to:
    - MBTA Standards
    - Industry Recommended Practices
    - DPU 220 CMR Section 151.11 and 151.12 Requirements

Additionally, the assessment included a walking inspection of the track system to evaluate the conditions of revenue service tracks compared to existing standards and to familiarize the Assessment Team with the unique challenges the MBTA faces in performing track maintenance and inspection activities.

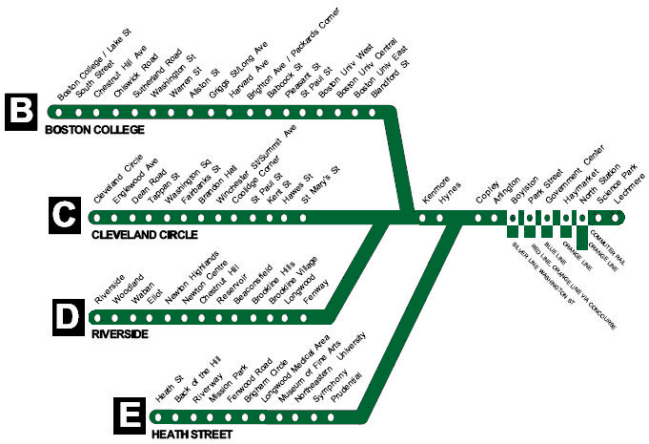
The MBTA Green Line

The MBTA's Green Line is over (100) years old and is part of a legacy property with tunnel sections dating back from 1897, the oldest in America. The Green Line performs over 200,000 trips per weekday which constitutes the nation's busiest light rail line. The Green Line consists of four surface level or above ground branches, routes B, C, D, and E, which includes 66 stations on both privatized right of way and sections that are street running which are shared with automobiles. There are 51 traffic signalized intersection with roadways and pedestrian crossings. These four lines diverge to form the central subway line at Kenmore Station to service the western portion of the greater Boston metropolitan area. Most of the Central Subway sections are in tunnels but does terminate with a short aerial structure to surface level section at Lechmere. The Central Subway runs under downtown Boston and is comprised of (13) service stops over (4) miles of track.

The overall right of way infrastructure consists of 45.8 track miles (Revenue Route Miles X2), 317 turnouts (Yards and Revenue), 131,225 rail ties, and 5 miles of tunnel with [redacted] ventilation shafts and [redacted] ventilation fans. Additionally, the Green Line has 235 miles of overhead catenary power cable, [redacted] power substations and [redacted] wayside signal equipment cases.

Rail car fleet storage and maintenance facilities are located at Riverside, Boston College, and Reservoir yards. Engineering and Maintenance offices are located at Charlestown bus facility and Reservoir rail yard.

The overall system is show below:



The Green Line is of light rail configuration and has the heaviest ridership of any system of its type in the country.

The guideway infrastructure is comprised of multiple fixation type track structure including concrete ties, wooden ties, and direct fixation fasteners. There are multiple types of rail being used on the system including standard Tee Rail section of 115 RE and 85 RE Rail, 149# and 118 girder rail sections. There are also many areas of single-sided and double-sided restraining rail track.

Assessment Methodology

Walking visual inspections were conducted over a two-week period between May 1 and May 12, 2017. This included a complete traversing of the entire 23-mile section of the mainline track on all lines including the B, C, D, E Lines, and the entire Central Subway section (A-Line). The inspectors used a variety of hand tools including tape measures, taper gauges, flange gauges and a RRT-2008 CP Track Gauge and Elevation Level. Additionally, Protran Consulting Services ran two track geometry vehicles over the above ground sections of the Green Line during this period used for internal Protran analysis and referencing. Track component conditions and construction methodologies were evaluated against design specifications, track standards and shop drawings.

The assessment team executed a review of all available documentation to evaluate current standards for two reasons; 1. To determine compliance to industry recommended practices regarding maintenance documentation, track inspection, training requirements and 2. To evaluate the viability/effectiveness in maintaining the existing system.

The assessment included a records review of all available documents associated with track maintenance over a historical period of (24) months prior to the start of the project and continuing up to the start of the project.

The records review included the following documents;

- Track System Reports
- Switch Certification Reports
- Geometry Car Reports
- Work Generating Documents
- Training Documents
- Employee Training Records
- System Repairpersons' Inspection Reports
- Ultrasound (Internal Defect) Reports
- Optical Inspection Reports (Rail Profile/Gage face)
- Quality Assurance Reports
- Training Curriculum and Required Training
- Lesson Plans and Support Documents

Additionally, there was extensive historical documentation review and a document comparison/review between Massachusetts 220 CMR Section 151.11, 220 CMR Section 151.12, and the Massachusetts Bay Transportation Authority, MOW Division, Green Line - Light Rail, Track Maintenance and Safety Standards, Edition 2008.1 (5/08).

Generalized recommendations are listed throughout the document for conditions and issues observed during the inspection and review. Specific recommendations to address primary questions asked in the RFR are listed at the end of the report.

Types of Transit Cars Used on the MBTA Green Line

The passage of the 1990 American with Disabilities Act (ADA) initiated a movement for Transit Agencies to provide equal access to services and facilities to people with disabilities. After a review of alternate means of providing access to people with disabilities, the MBTA made the decision to purchase 100 low floor cars (Breda - No. 8) for the Green Line. Additionally, part of this procurement included modifying the MBTA's existing fleet of (Kinkisharyo – No. 7) cars to be operationally compatible with the new No. 8 cars. During the procurement of these cars numerous issues became known regarding the rail wheel interface.

Figure 1- MBTA Breda Type 8 Car

Figure 2 - MBTA Kinkisharyo Type 7 Car

Currently, these are the only two types of transit cars used on the Green Line.

Historical Context – Known Issues

To fully understand the unique challenges faced by the MBTA to maintain the track structure and provide safe transportation to riders, one must fully understand the historical context regarding the track, vehicle design and track/vehicle interface and the many efforts undertaken over the years to address the derailment issue with the No. 8 cars on the Green Line.

NOTE: The majority of the following information is for background purposes and was used by the Assessment Team to understand the genesis for many of the existing maintenance efforts underway at the agency.

In 1995 MBTA Board of Directors voted to award a contract to Breda Costruczioni Ferroviarie (AnsaldoBreda) for the purchase of 100 wheelchair accessible low-floor No.8 Green Line cars. Soon after the delivery of the first set of prototype cars, the MBTA began to experience derailments and other issues with these cars.

After experiencing four derailments during limited revenue service of the No. 8 cars between April 2000 and July 2000, the No. 8 cars were removed from service and multiple efforts were undertaken by the MBTA to address the derailment issue. The MBTA worked and consulted with Breda, TTCI, APTA and the Commonwealth of Massachusetts Department of Telecommunications and Energy (DTE), (the predecessor agency to the Department of Public Utilities) on this effort.

Below is a summary of findings from testing and investigations into the No. 8 car derailments from those listed above. Each group provided a detailed report but this background section lists only pertinent findings related to the vehicle interactions or conditions/standards of the track structure. Those interested in the full reports are encouraged to read each of the reports for more background and foundational information.

TTCI Report – February 2001, Report P-01-05

In 2001 TTCI was hired to conduct a survey of actual Green Line conditions. In this survey, the listed the following findings and recommendations:

Findings:

- The No. 8 car has a design issue associated with the lack of steering of the center truck. The possibility of wheel-flange-climb coupled with (the initially designed) 63-degree maximum flange angle and a lack of control of the wear angle of the Green-Line track was a major factor contributing to the derailments.
- The No. 8 cars are sensitive to reverse curve (S) track geometry.
- Wide Track Gauge significantly increases derailment risk.
- Derailment potential increases with speeds above [redacted] mph on reverse curves and above [redacted] mph on other track geometries.

Recommendations:

- The MBTA should install restraining rails on all reverse curves with a radius less than 2,000 feet and lengths less than 300 feet.

- Implement new track alignment standards.
- Reduce maximum speeds to [redacted] mph

APTA Peer Review – October 2002, Green Line No.8, Low Floor Light Rail Vehicles

The 2002 APTA Peer Review provided an overall review of the entire issue regarding Green Line No. 8, Low Floor car derailments. As the focus of this peer review was broad and far reaching, there were no specific findings regarding the track or rail/wheel vehicle interface. There were some general observations and recommendations to the MBTA:

General Observation

- The March 2002 APTA Final report states, in part, that "the fundamental problem is that the MBTA under-estimated the technical risk involved in introducing a first of its kind, unique and totally unproven car design on a severely limiting and unforgiving infrastructure such as the Green Line."
- They concluded that the car's center truck as designed, which includes stub axles with independently rotating wheels, combined with the current wheel flange/track contact angle created a situation where these No. 8 cars operated at or near the theoretical limit of derailment when run on the current Green Line track Infrastructure (2001).

Recommendations

- Increase knowledge of what is actually happening at the wheel to rail interface through a carefully designed program of track geometry measurements, instrumented wheel set tests and modeling.
- Develop a standard that can be practically implemented for inspections and maintenance of the Green Line Track.
- Assign clear responsibility for and develop a prioritized Green Line track upgrade program.

Commonwealth of Massachusetts – Feb 16, 2007 Audit Report

In 2007, the Commonwealth of Massachusetts, Auditor of the Commonwealth, initiated audit report No.2004-0583-7A, *Independent State Auditor's Report on Certain Activities of the Massachusetts Bay Transportation Authority Regarding the Purchase of Green Line Cars.* In this report, the Commonwealth made several observations regarding the track structure or vehicle/track interface:

- The MBTA's failure to ensure that the No.8 Low-Floor Green Line Cars were properly designed for the Green Line Infrastructure, namely the lack of providing detailed track information, led to the acceptance of vehicles that have a propensity to derail.
- The MBTA did not adequately plan and test the No.8 Low-Floor cars, thereby contributing to a derailment flaw that caused a significant delay servicing its disabled patrons.
- The MBTA, per the recommendations of its consultants TTCI, HNTB and APTA, performed the following:
    - Implemented track modification work
    - New Track Maintenance Standards

    - Redesigned interim wheel profile on its No. 8 and No. 7 cars to discourage wheel climb by changing from a 63-degree wheel flange angle to a 75-degree wheel flange angle.
- The No. 8 Car Manufacturer was not provided all the correct track layout drawings and received permission to use "San Francisco Line Geometry Data" and worst-case track irregularity data computed using VAMPIRE Rail Vehicle Dynamic Software for dynamic simulation modeling instead of actual track geometry of the Green Line, which was unknown to the MBTA at the time (1991 – 1994). Unfortunately, the VAMPIRE program did not include a model for vehicles such as No. 8 cars, which have independently rotating wheels in the crucial center truck portion of the vehicle.

January 2013 – HNTB Track Inspection Report for MBTA Line Supervisors

In January 2013, HNTB Rail Systems Group provided a detailed inspection report to MBTA for the Blue, Orange, Red and Green Lines under their MOW Division GEC Contract MOWPS04 – Task 2, HNTB Project Number 50907. Per this report, HNTB inspectors conducted detailed inspections of the track structure over a three-month period between October 2012 and December 2012. This report, in regard to the Green Line, listed multiple technical recommendations and one safety recommendation as follows:

- Perform Line Corrective Actions for Track Defects.
- Additional training required by MOW personnel.
- A review of safety in Level 1 areas to enhance daytime track inspections.
- Updating MBTA Track Standards to reflect recent operational changes and demands.

The results of these recommendations were not disclosed to the assessment team.

Track Standards Development

As stated above in the Commonwealth of Massachusetts audit report, a recommendation from the APTA Peer Review was to implement new Track Maintenance and Safety standards. To accomplish this recommendation MBTA contracted with consulting firm, HNTB, to develop MBTA's track standards in 2003, complimentary to the successful running of the No. 8 Transit Car. The current version is Edition 2008.1 (7/08) and has been modified as indicated on the Revision History table located on page 4. It is not known if the standards upgrade recommendation by HNTB has been initiated or planned. However, the manual provided to the assessment team and the one observed being used in the field has not been updated since 2008.

Track Structure Issues

The assessment team performed walking inspections on the entire Green Line Track Right of Way for a two-week period between April 30 and May 12 except for the embedded street running track between Brigham Circle and Heath Street on the E-Line. This embedded track section was visually inspected at random points when it was safe to do so by the assessment team as no vehicular traffic control measures were set up to provide access.

The intent of these walking inspections was to familiarize the assessment team with the physical infrastructure, to observe track conditions, train operating perimeters and to familiarize the assessment team with the unique challenges that the MBTA has in maintaining the Green Line. The walking Track System review did not include a detailed, full assessment with measurements, profiles and documenting of all defects or conditions observed on the system. This effort was for generalized inspection of the track to identify the condition of the track structure. The assessment team utilized the latest geometry, ultrasonic and inspection data provided by the MBTA for full condition analysis. Any defects or conditions which were found to be out of tolerance were brought to the attention of the MBTA personnel assisting in the walking inspection.

The assessment team inspected and recorded track conditions of the mainline track system structure which included horizontal and vertical track alignment defects, surface condition track support (ballast, inverts and embedded), rail fastening assemblies (inclusive of direct fixation fasteners, anchor studs, rail clip studs, rail clips, ties, tie plates, spikes, and screw spikes) and rail conditions with a focus on wear especially within curves and restraining rail areas. Additionally, the team concentrated on observing unusual rail wear patterns throughout the system which would indicate any rail/wheel interface issues. Special track work was also reviewed for wear patterns and other signs of irregular wear or condition. This included assessing and inspecting worn switch points, point gap, condition of stock rails, heel blocks, bolted/welded/bonded joints, gage plates and switch plates, switch rods, connecting rods, switch clips, switch and turnout timbers as well as the complete frog assembly with its accompanying point wear, joint condition, flange-way dimensions, guard rail wear and corresponding "check gage" dimensions, and wing rails and hardware. Further, during this walking inspection the assessment team observed on-going maintenance activities and inspection activities.

The following highlights samples of conditions observed on the roadway that the assessment team found to need corrective measures or maintenance as defined in the MBTA Green Line Track Maintenance and Safety Standards. These conditions are listed just for examples of the issues facing the Track Maintenance Group.

Geometry - Surfacing, Alignment, and Gauge Conditions

The condition of the rail track geometry is an important factor in track /train dynamics. It affects the running behavior of the trains and affects the safety, and riding comfort of the passengers. Poor quality ballast conditions, jointed rail, poor ties, varying roadbed surfaces and thermal forces have resulted in multiple surfacing, alignment, and gauge issues throughout the Green Line. Some of these as indicated in the following photographs:

Figure 3 - Surface Deviation After a Road Crossing

Figure 4 - Surface Deviation on Jointed Rail Area

The majority of the surface deviations observed on the Green Line are either dips or humps which deviate from uniform profile at the mid-ordinate of a 62' cord in various measurements between ¼" to 2". Those shown in Figure 3 and Figure 4 are around 1" - 2" deviations. Figure 3 is a "Yellow" condition and requires a [redacted] MPH speed restriction and require the track for surfacing within 30 days per MBTA Green Line Track Standards. As these areas are adjacent to road crossings with an operational [redacted] mph speed restriction, no "track based" restriction was placed on these defects. However, these conditions have been in place for an extended period and are the result of various factors. Figure 3 illustrates a common issue on the Green Line in which immediately past a road crossing, there are bolted joints directly across from each other. This situation leads to a "pounding" impact condition as solid axle trains leave the roadway crossing and each axle of the train impacts and pounds both joint simultaneously eventually resulting in ballast degradation and a low spot. This condition is highlighted to demonstrate that some issues requiring repeated repairs can be eliminated or minimized with up-dating and modifying track standards to industry and APTA/FTA best practices.

The original design and layout of the Green Line presents a tremendous challenge for maintainers to keep the surface uniform and within tolerances. With 51 signalized road crossings and numerous pedestrian and non-signalized crossings, the track structure is subject to many factors that cause surfacing issues and make it very difficult to maintain due to physical location constraints.

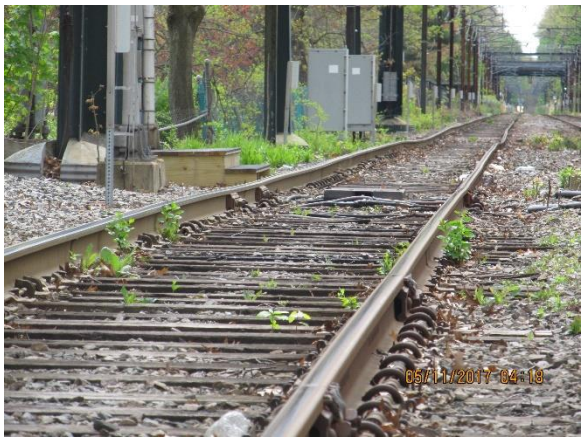


Figure 5 - 2.5" Surface Deviations on Approach to Riverside

Figure 6 - Eastern View of 2.5" Service Deviation at Riverside

The surface deviation shown above (2.5" +) was the most severe alignment deviation observed by the assessment team. The escorting supervisor immediately placed a speed restriction on the area and scheduled a crew for repair. In areas as shown above, with standard running track, a well planned and executed annual or bi-annual surfacing program would eliminate deviations of this extreme. Additionally, well trained inspectors should have noted this condition long before it deteriorated to this level. In areas of repeated settlement, sub-surface and track foundation evaluations should be undertaken.

Green Line crossovers and special trackwork areas also show alignment and surfacing issues. These areas are subject to not only vertical loads but lateral forces as well during crossover moves.

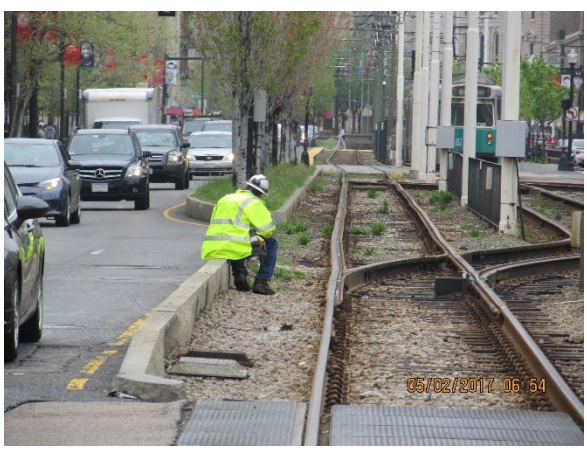


Figure 7 - Alignment Issues on Special Trackwork

Figure 8 - Alignment Issue on Special Trackwork Near Fixed Roadway

Figures 7 and Figure 8 illustrate alignment issues at turnout locations. These two examples, although similar, are completely different from a maintenance perspective. Figure 7 shows a turnout that is located in a very small section of track between two crossings, aligning this area can be achieved by standard maintenance methodology. Figure 8 on the other hand, demonstrates the unique challenges faced by the MBTA due to legacy issues with the right-of-way alignment. To address this correctly, the agency would need to completely align the track crossing the roadway (resulting in vehicular traffic interruption) and realign all three tracks in this area. Conditions of this type present unique challenges for track maintainers who must make maintenance and

installation decisions which at times may appear to conflict with standards but are necessitated by the unique physical characteristics the Green Line legacy track system. Without significant investment and redesign, situations of this type will continue to challenge track managers to assure these areas do not deteriorate beyond the capabilities of the No. 8 vehicles. This condition also requires continuous monitoring on gauge spread as the two rails may spread apart as the stock rail is pushed out during turnout moves.

Figure 9 - 57" Wide Gauge - Green Condition

Figure 10 - Gauge Rod installed due to Wide Gauge

Gauge variations due to track alignment issues are frequently encountered on the Green Line as shown on Figure 9. These areas are easily found by observing alignment issues or installed gauge rods as shown on Figure 10. These conditions are generally the result of defective wood ties at these locations. Although not spelled out in the MBTA Track Standards Manual, gauge rods are only a temporary measure and should only be used in track for a determinate amount of time. These were several areas where during our inspections, the gauge rods that had been installed for an extended period of time and were loose and no longer performing their intended temporary function.

Findings

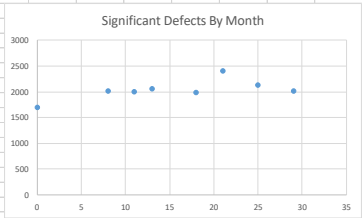
During the normal operations of any railroad or transit system, irregularities in alignment do occur and track maintenance personnel need a good working knowledge of how to deal with such defects. Determining the underlying cause for such alignment defects is paramount to achieving efficient maintenance. Alignment defects do not present themselves without precursor conditions existing. Precursor conditions such as inadequate or deteriorated/contaminated ballast, defective ties, mud spots and other conditions will be discussed in other sections of this report.

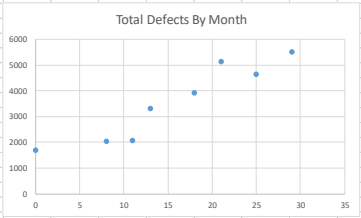
There are a multitude of track alignment conditions and defects (i.e. surface, crosslevel and gauge) throughout the entire Green Line. As indicated by the total amount of defects associated with track geometry there needs to be a focused and concerted effort to restore the track structure to proper alignment. Observations of marginal geometry conditions were observed which indicates maintenance is only being performed at or near the time that the track geometry reaches critical maintenance and safety limits.

These issues are a result of multiple factors including the characteristics of the physical layout of the track and maintenance issues resulting from precursor issues listed above and a lack of a standardized surfacing and alignment maintenance program.

Currently Green Line Management has a contactor performing automated geometry inspections three times per year. An analysis of the geometry inspections defects reported has shown that critical geometry conditions on the Green Line have remained at a relatively high and consistent level over last few years but the total number of all geometry defects has significantly increased over the last few years as shown in the chart below:

Month	Year		Wide Gauge		Narrow Gauge	Twist 31		Align. L		Align R		Profile L		Profile R		Cross Level	Total Significant Defects	Gross Total Defects
			P	U	U	P	U	P	U	P	U	Prifile L	U	Profile R	U	P		
August	2014	0	590	104	50	495	98	190	34	96	34	0	0	0	0	16	1707	1707
April	2015	8	720	107	27	570	119	238	55	119	55	0	0	0	0	20	2030	2030
July	2015	11	627	106	56	567	122	256	62	128	62	1	0	1	0	16	2004	2064
Sept.	2015	13	742	140	37	544	113	238	55	119	55	3	0	3	1	16	2066	3305
Mar	2016	18	636	110	65	524	106	222	44	222	44	0	0	0	0	17	1990	3905
June	2016	21	852	121	20	600	134	260	63	130	63	64	11	64	11	18	2411	5128
Oct.	2016	25	603	106	44	583	117	232	61	116	61	84	17	84	17	19	2144	4638
Feb.	2017	29	714	107	42	534	108	228	50	114	50	31	0	31	0	18	2027	5520





**Significant Defect are those categorized as Urgent or Priority*

The geometry exceptions reported and the quality of the data provided by the contractors must also be evaluated in a more expeditious manner. Per discussions with MBTA personnel, there is a procedure in place to place speed restrictions on geometry defects at the time they are found during the geometry run, however, this procedure could not be validated as no documentation was presented demonstrating this action. Additionally, in review of the other documentation provided, due to the volume of Priority and Urgent exceptions noted on the report, it takes as long as 8 days for the Section Forman to validate the findings. This is inconsistent with industry standards and best practices as recommended by the FTA.

Rail Conditions

The condition of the rails currently installed on the Green Line is an indicator of the overall health of the track infrastructure. The assessment team observed a variety of rail defects throughout the entire Green Line system. These defects, visible to any inspector, are plentiful, spread out throughout each line, and result in increased dynamic interactions between the MBTA's rolling stock and the track with corresponding increase in dynamic wheel-rail forces and resulting rail stresses. These dynamic impact forces can be quite significant and can result in significant damage to both the track structure and the rolling stock.

Increased dynamic wheel-rail forces have a range of consequences that include:

- Shortened rail life,
- Shortened tie and fastener life,
- Shortened surfacing cycles,
- Shortened ballast life,

- Increased wheel/car maintenance,
- Accelerated wear in truck components,
- Increased noise and vibration.

Additionally, not only does the rail have significant defects, there are many areas throughout the Green Line where the track structure is a mix of various types of rail (Girder Rail and Tee Rail) which can be quite challenging for those who must perform maintenance and react to rail failures which impact passenger service.

The following photographs are examples of the rail defects that were observed by the assessment team:

Figure 11 - Engine Burn with flattened rail head.

Figure 12 - Engine Burn Fracture

Figure 13 - Spalling Rail

Figure 14 - Shelling Rail, Gauge Face Defect

Figure 15 - Rail End Batter, Girder Rail, Poor Weld Repair

Figure 16 - Rail End Batter, Tee Rail

Figure 17 - Squat Defect

Figure 18 – Minor Rail Corrosion

Figure 19 – Severe Rail Corrosion

Figure 20 – Rail End Mismatch causing flattening of rail

Figure 21 - Worn/Flattened Rail with Shelf

Figure 22 - Worn Rail on Gauge Face creating Shelf

Figure 23 – Micro-Cracking on Rail Head

Figure 24 - Corrugation

Figure 25 - Base Corrosion

Figure 26 - Severe Base Corrosion, Most of Base Missing

Figure 27 - Transverse Crack, Worn Rail

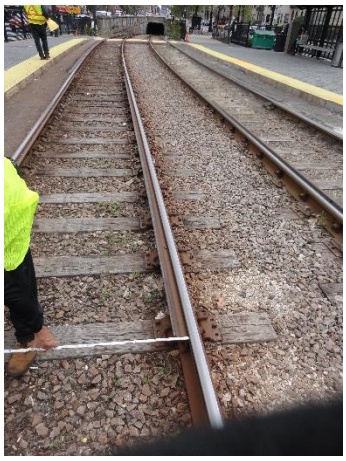


Figure 28 - Mismatched Types of Rail, Tee Rail then small section of Girder Rail

Findings

The overall condition of the rail on the Green Line runs the entire spectrum between newly installed rail and very old rail. Most of the older rail is moderately to severely worn, exhibiting RCF (rolling contact fatigue) defects, corrosion, corrugations, and damage. The age and degradation of the rails raises concerns about its long-term viability regarding its ability to perform satisfactory without service interruptions due to rail breaks and issues with the vehicle interface (i.e. derailments, wheel damage).

As the rail condition is a direct indicator of the overall health of the track structure, one can determine that the MBTA Green Line track is in need of an aggressive maintenance program due to the fact the track is in need of significant rehabilitation.

Observations of ½" to ¾" side wear were observed in several locations, and gauge face angles of > 20° which indicates maintenance is being performed at or near the time that a component reaches the critical maintenance and safety limits.

Restraining Rail Issues

Restraining rails are usually installed inside the low rail on curves. This is done to reduce the lateral forces on the outside rail by dividing the force between the two contact areas (generally, force distribution should be 60% to the outside rail and 40% to the restraining rail). If this distribution is not maintained as in wide gauge or tight restraining rail flangeway gaps, the results will be accelerated restraining rail wear and broken restraining rail bolts. MBTA also utilizes double restraining rails in multiple locations[1]. The restraining face of the restraining rail is toward the gauge side of the inside and outside running rail and when properly adjusted provides for proper restraint for both wheels as trains travel through curves.

[1] It should be noted here that the FTA only recommends the use of double restraining rails in curves less than 125 foot radius.

The following photographs are examples of the restraining rail issues that were observed by the assessment team:

Figure 29 - Severely worn restraining rail indicating considerable contact with back of wheel flange.

Figure 30 – 5/8" side wear in double restrained area indicating gauge deviation and worn restraining rail.

Figure 31 - 2" Flangeway of new installation. This is a Red condition per LRT213.116.

Restraining Rail Findings

Although conditions observed on restraining rail were widely scattered, the wear patterns on the restraining rail face indicates a wide variation in friction and lateral forces being produced by MBTA light rail cars even at low speed. It is apparent the gauge variations between the running rails are contributing to the amount of wear on the restraining rail as the angle of attack of the wheels increases as gauge increases.

The MBTA Track Maintenance and Safety Standards addresses restraining rail flangeway width in section LRT213.116, Restraining Rail. There is an apparent lack of maintenance on these areas as flangeway widths vary between 1 ¾" to 2 ¼". This may be the result of a lack of inventory and the Track Department trying to match tee rail restraining rails with girder rails.

Special Trackwork

As part of the "guideway" system of the Green Line, special trackwork components are inspected with the rail and roadway during routine and special inspections. Additionally, per MBTA Track Standards and Track Standards outlined within DPU 220 CMR 151.11, special trackwork switches require additional and focused inspections and certifications. Special trackwork components such as frogs and switches require additional maintenance as the components are subject to an interaction of forces, accelerations and motion between the vehicle and the track. These forces tend to be especially intense during diverging moves.

The following photographs are examples of the special trackwork issues that were observed by the assessment team:

Figure 32- Worn flangeway and indications of impact from hollow tread wheels.

Figure 33- Worn Flangeway and Impact Damage to Frog from Hollow Tread Wheels.

Figure 34 - Loose Wedges, Allowing Stock Rail Movement

Figure 35 - Consecutive Wedges Loose, Allowing Stock Rail Movement and Gauge Widening

Figure 36 - Severe Flangeway Wear - Red Condition at 5/16"

Figure 37 - Severe Flangeway and Tread Wear on Frog with Gauge Corner Spalling

Figure 38 - Plate Cut Wedge Plate - Allowing Movement of Stock Rail

Figure 39 - Severely Worn Frog Point - 9/16" - Red Condition Frog Requires Replacement or Rewelding.

Switch Points

Figure 40 - Chipped Switch Point, Approx. 10" back from Point

Figure 41 - Chipped Point at Undercut Location.

Figure 42 - Severely Chipped Switch Point

Figure 43 - Same Switch Point Showing total extent of chipping and wear.

Figure 44 - Severely Worn Switch Point

Figure 45 - Worn and Chipped Switch Point

Special Track Work and Switch Point Findings

Moderate to Severe frog wear, stock rail anchorage/wedge tightness and switch point chipping and wear were identified during inspections. Many areas were observed to have loose joint bolts and loose spikes holding frogs in position. Many alignment errors were also observed in turnout locations.

The MBTA Track Maintenance and Safety Standards contain specific requirements for the inspection of track and turnout components. Specifically, frog wear criteria is spelled out in section LRT213.137 and stock rail anchorage requirements are identified in section LRT213.135.

Switch Point condition on the Green Line is non-compliant to standards at best and unsafe in some instances. According to the regulations for worn or broken switch points; section LRT213.135 states: "Unusually or excessively chipped/worn switch points shall be repaired or replaced". Specific requirements for "Schedule of Switch Point Maintenance Criteria" are clearly spelled out on page 26 of the Maintenance and Safety Standards.

Field observations show that these criteria is not being followed as required. As shown in the photos above, there are multiple switch points in the system that is past this replacement criteria.

Tie Issues

Ties are designed to distribute the loads transmitted through the rails to the roadbed. One of the most challenging jobs in track inspection is determining the overall conditions of the ties. On the Green Line, this is especially difficult due to the abundance of debris (i.e. leaves, sand, and ballast) that prevent a clear look at tie condition in some areas.

The MBTA Green Line Track and Safety Standards Manual clearly outlines the requirements for defective maintenance thresholds for ties, however it is difficult to be assured these standards are being followed due the issues identified above, as well as the number of vehicular road crossings on the Green Line.

The following photographs are examples of the tie defects that were observed by the assessment team:

Wood Ties

Figure 46 - Split Through Tie, No Fastener

Figure 47 - Plate Cut Tie with spike kill.

Figure 48 - Split Through, Spike Killed Tie

Figure 49 - Skewed Tie, Indications of movement

Figure 50 - Through Cracked Tie

Figure 51 - Deteriorated Tie Under Debris

Concrete Ties

Figure 52 - Cracked Concrete Tie with Shoulder Casting Missing

Figure 53 - Cracked Damaged Concrete Tie

Figure 54 - Center Bound Tie

Figure 55 - Concrete Tie End showing corrosion on tension cables.

Tie Maintenance and Inspection Issues

The assessment team observed several maintenance and inspection issues with ties along the Green Line right-of-way. The following photographs show the areas of concern:

Figure 56- Due to coverage over ties - Conditions cannot be seen until there is a gauge issue.

Figure 57 - Gauge Rod Installed in area where issue was only discovered after a gauge issue.

Figure 58 - Crossings Prevent Any Inspection of Ties

Figure 59 - Tie and Fastener Condition Under Removed Crossing.

Figure 60 - Mixed Concrete and Wood Ties, Requiring Different Surfacing Maintenance

Figure 61 - Five Defective Ties in Row. Requiring a Speed Restriction.

Tie Assessment Findings

Tie conditions on the Green Line are generally good to fair with some pockets of poor ties. Some areas appear to have had several passes of tie replacement in selective areas. However, overall tie components are aging and fast approaching the end of their useful service life. This is critical to the MBTA as a Tie Replacement Program is required. Additionally, this further highlights the requirement for the removal of any ballast, sand or debris on tie areas which are not under crossings. Tie conditions under crossings can generally be assumed to be in the same condition as the tie areas immediately adjacent to these areas.

The challenging issue for the Green Line Track Maintenance personnel is to determine which ties are clearly defective, as visual inspections are non-existent in certain areas. Note: This comment is focused on areas which are not part of embedded track (which is covered under section LRT213.334) but areas which are obstructed by dirt, debris, vegetation, sand, and other materials. This situation must be fully documented and other methodology put in place for accurate inspections. Currently, this situation is non-compliant to inspection requirements as the areas are not being inspected to the standards as required by both MBTA, and DPU requirements.

Per the MBTA Track Maintenance and Safety Standards, there are clear standards for ties in section LRT213.109. However, the assessment team found the standards to be lacking in regard to what is an allowable amount of non-effective tie plates on otherwise good ties. Section LRT213.123 states there must be plates on at least "9 out of 10 consecutive ties", however there is no mention of distance between effective fasteners. The plates can be there but not secured or have missing hardware. (Note: This may have been a contributing factor in a recent derailment FY17-02675 on the B-Line.)

Roadbed and Ballast Issues

The roadbed is comprised of sub-grade materials (soils) for where the sub-ballast and ballast is placed for the purpose of providing drainage, stability and support of the ties and rail. Ballast is an integral part of the track system and the ballast provides the physical support for holding the track in proper surface, grade, alignment, and cross level. The functions of ballast are:

- To distribute the traffic load from the tie to the sub-grade with overloading the subgrade.
- To permit free drainage of the track area.
- To prevent lateral movement of the track.
- To prevent longitudinal movement of the track.
- To afford a convenient medium for the maintenance of proper track geometry.
- To provide dynamic resiliency to the track structure.
- To inhibit growth of vegetation.

Specifically, for track maintenance groups to maintain quality track, ballast must be of sufficient quantity and quality to withstand static and dynamic loads in all three directions (vertical, lateral, and longitudinal) and to provide for free drainage of water. Vehicular and Pedestrian Crossings on the roadbed affect the ability for the track maintenance group to efficiently maintain the roadbed as well. This will be discussed in the Crossings section of this report.

The following photographs are examples of the roadbed defects that were observed by the assessment team:

Figure 62 – Severely Fouled Ballast with Fine Soil Preventing Drainage

Figure 63 - Moderately Fouled Ballast.

Figure 64 - Fouled Ballast at Joint. Note Unsuccessful Attempt to Tamp.

Figure 65 - Severely Fouled Ballast.

Figure 66 - Excessive Ballast in Crib and Shoulder Areas.

Figure 67 - Excessive Ballast in Shoulder Area.

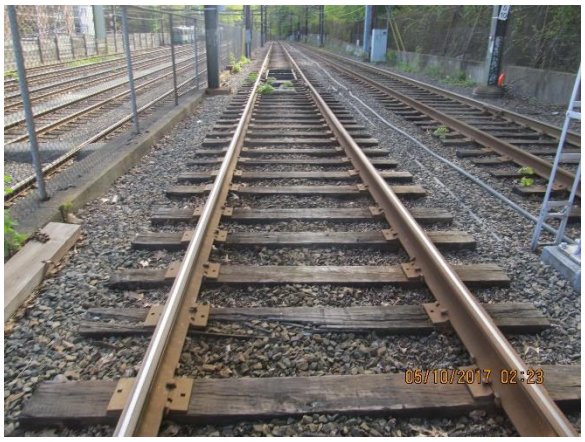


Figure 68 - Skeletonized Track - Low Ballast

Figure 69 - Insufficient Shoulder Ballast - Buckling Potential.

Figure 70 - Severely Fouled Ballast Indicating Lateral Movement of Track.

Figure 71 - Severely Fouled Ballast Indicating both Lateral and Longitudinal Movement.

Figure 72 - Fouled Ballast, Saturated Subgrade - Mud Pumping

Figure 73 - Fouled Ballast, Poor Subgrade - Mud Pumping. This is on a bridge Deck.

Figure 74 - Unstable Trackbed - Subgrade is liquefied. Track is pumping and moving laterally, longitudinally, and vertically.

Figure 75 - Fouled Trackbed Area with dried mud. Area is subject to repeat runoff from overhead structure.

Figure 76 - Vegetation growth in fairly good ballasted area. This can be controlled by spraying.

Figure 77 - Vegetation growth in severely contaminated ballast area. This ballast needs to be replaced.

Figure 78 - Severely Contaminated Ballasted Area with Vegetation.

Figure 79 - Vegetation Growth Adjacent to Track which may impact sight lines for Track Workers.

Figure 80 - Direct Fixation Fastener on Concrete Invert – No Concrete Trackbed Defects Observed.

Figure 81 – Koln Egg Fastener - No Invert Defects Observed.

Roadbed and Ballast Findings

Per MBTA Green Line Maintenance and Safety Standards, the ballast and roadway conditions are inspected during regular inspection cycles. The overall condition of the trackbed and ballast sections are in marginal shape for the most part, especially in the older sections of the Green Line.

Additionally, the functions of the ballast addressed in section T213.103 of the standards are unobtainable in most of the areas shown in the pictures above. The severely deteriorated and contaminated ballast locations are spread out throughout the Green Line with the most concentration being near station areas, crossings and overhead bridge structures. However, these areas are also found in tunnel sections near water leaks and mud spots. These areas cannot support the track structure for proper performance in regard to maintaining alignment, surface and crosslevel.

The mud spots observed in several locations also indicate a deterioration of the sub-grade materials in these locations. These will be a challenge to correct but can be done with the right specialty contractor.

The best quality ballast sections observed were on the "D-Line" and are out towards Riverside Yard; however, these areas also show that the Maintenance Department does not follow Roadbed Track Standard LRT213.31. There are multiple areas with skeletonized track, low shoulders, insufficient ballast as well as an overabundance of ballast.

Vegetation issues are abundant throughout the entire Green Line. Although the assessment team found only one area on the D-Line where safety may be impacted by vegetation growth as shown in Figure 79, this situation must be monitored to prevent a reduction in sight lines for employees and train operators. The majority of the vegetation within the dynamic envelope of the roadway is a result of the deteriorated and contaminated ballast. The Track Maintenance Group should investigate the use of a specialty contractor to apply approved herbicides to control the growth. The majority of transit systems and railroads within North America have vegetation control programs which include both pre-emergence and cutting programs.

As a problematic situation, the overall condition of the ballast, combined with the number of vehicle and pedestrian crossings on the Green Line present significant challenges to the Track Maintenance Group to be able to maintain surface, crosslevel and alignment along the Green Line. It is very apparent that given the quality of the trackbed and ballast sections that a robust surfacing and aligning program would not be capable to restore the geometry effectively or for any lengthy period of time due to the marginal quality of the trackbed. However, due to the susceptibility of No. 8 cars reacting adversely to out-of-tolerance geometry conditions, these efforts must be undertaken on a regular basis.

Miscellaneous Issues on Roadway

Throughout the inspection of the roadway by the assessment team, numerous items were observed which indicates either a physical challenge for the Track Department to maintain to standards or indicates a lack of funding, inventory control, or understanding by MBTA staff to maintain to proper standards. Although most of these issues are not safety related and would not in themselves cause train derailments or impacts to service, they are issues that indicates the overall condition of the infrastructure and maintenance management plan.

The following photographs are examples of the miscellaneous items that were observed by the assessment team:

Crossings:

Figure 82 - Crossing with both rubber and asphalted covering.

Figure 83 - Rubber Crossing.

Figure 84 - Pedestrian Crossing with 4+" of heave from Top of Rail. Tripping Hazard and impedes Track Maint and Insp.

Figure 85 - Deteriorated Crossing and Platform ADA Edge that impedes Track Maint and Insp.

The MBTA has recognized and identified that road salt and electrolytic reactions are the primary cause of deterioration of trackway located at road crossings. As such, the MBTA has self-addressed this issue and has established an initial grade crossing program to address 27 crossings and has repaired 16 grade crossings in the last two years. Additionally, the MBTA has initiated another grade crossing program to bid in 2018.

The maintenance and inspection requirements for grade crossing areas are limited in the MBTA Green Line Track Maintenance and Safety Standards. Section LRT213.334 requires inspectors to look for signs of movement only but there is no surface inspection or crossing durability requirement. Currently, it appears that the MBTA tends to replace rubberized crossings with asphalt crossings. This restricts the ability for track maintainers to remove sections of the crossings to determine conditions underneath. It is recommended that the MBTA investigate and analyze the use of

modern removable ADA gap and crossing panels which will allow the maintenance and inspection of the track components they cover.

Current Trackbed Cleaning Efforts

Per Green Line Management, they have engaged the services of a specialty contractor to remove all the excess sand and debris from the roadway areas at station platforms. This effort will greatly assist inspections and maintenance of this area. Shown below is an example of a before/after effort at Southerland Station:

Figure 86 - Southerland Station before Clean-up

Figure 87 - Southerland Station after Clean-up.

Figure 88 – Close-up view of crib area after cleaning.

Figure 89 - Close-up showing corrosion which was hidden by sand and debris.

This effort will greatly increase the ability of inspections and maintenance in these areas as well as the overall life of the components in these areas. Although the assessment team has only observed this effort being undertaken at station platform areas, it is necessary to also expand this effort to areas within 15 to 20 feet from each roadway crossing. Further, this effort clearly shows the MOW

Management Team understands the inspection requirements for all track areas and are making efforts to assure proper inspection and maintenance.

Rail Lubricators

Figure 90 – Non-Functioning Rail Lubricator In Tunnel Area

Figure 91 - Non-Functioning Rail Lubricator on Surface Track

Rail lubricators prevent wear which is a result of friction between the wheels and rails. Gauge side wear on the high rails of sharper curves is a common problem. Wear affects the life and performance of rails and wheels. The influential wear factors are: axle loads, lateral forces, longitudinal force, creepage, curve radius, gradient of the track, cant/superelevation, track gauge, surface conditions of the wheels and the rails, train speed, train length, frequency and type of trains, rolling stock performance, and operational and environmental issues.

Currently, there are no operational automatic wayside lubricators working on the Green Line. Per Track Engineering personnel, all lubrication is being performed by hand. Observations by the assessment team indicate that lubrication is occurring in areas designated by Track Engineering. MBTA is in the process of replacing all the wayside lubricators on the system. Below are the installation locations:

1	Green_Line A	GR[redacted], AC, Double Rail	WB	AC	Double*	[redacted] (Park)
2	Green Line A	GR[redacted] AC Double Rail	EB	AC	Double*	[redacted] (Boyston)
3	Green Line A	GR1[redacted], AC Double Rail	WB	AC	Double*	[redacted] (Boyston)
4	Green Line A	GR[redacted], AC Double Rail	WB	AC	Double*	[redacted](Gov.)
5	Green Line A	GR[redacted], AC Double Rail	WB	AC	Double*	[redacted](North/Science)
6	Green Line A	GR[redacted], AC	EB	AC	Single	[redacted](North)
7	Green Line A	GR[redacted], AC	EB	AC	Single	[redacted] (Park/Gov.)
12	Green Line A	GR[redacted], AC	EB	AC	Single	[redacted] (Park)
23	Green Line A	GR[redacted], AC	EB	AC	Single	[redacted] (Kenmore/Hynes)
24	Green Line A	GR[redacted], AC	EB	AC	Single	[redacted](Kenmore/Hynes)
26	Green Line A	GR[redacted], AC	WB	AC	Single	[redacted](Hay.)
39	Green Line A	GR[redacted], AC	EB	AC	Single	[redacted](North/Science)
41	Green Line A	GR[redacted], AC	WB	AC	Single	[redacted] (Science)
31	Green Line B	GRB[redacted], AC	EB	AC	Single	[redacted] (Kenmore)

45	Green Line B	GRB[redacted] Solar DC	EB	DC	Single	[redacted]	(Packards)
46	Green Line B	GRB[redacted], Solar DC	EB	DC	Single	[redacted]	(Griggs)
47	Green Line B	GRB[redacted], Solar DC	EB	DC	Single	[redacted]	(Allston)
51	Green Line B	GRB[redacted], Solar DC	WB	DC	Single	[redacted]	(Warren)
52	Green Line B	GRB[redacted], Solar DC	WB	DC	Single	[redacted]	(Allston)
32	Green Line D	GRD[redacted], AC	WB	AC	Single	[redacted]	(Kenmore/Fenway)
33	Green Line D	GRD[redacted], AC	WB	AC	Single	[redacted]	(Kemore/Fenway)
34	Green Line D	GRD[redacted], AC	WB	AC	Single	[redacted]	(Kemore)

Currently, Vehicle Maintenance is endeavoring to install solid stick lubricators on all vehicles. It is the assessment teams' opinion that these car borne lubricators do not replace the need for wayside lubricators.

Further, the assessment team recommends that all wayside lubricators be installed with double blades (lubricating both rails).

Non-Staggered Joints

Figure 92 – Non-Staggered Joint on Concrete Tie Area

Figure 93 - Non-Staggered Joints on Wood Tie Area

Joint stagger is especially important in areas where there is poor ballast and sub-surface conditions. As a solid axle train passes over these locations they receive the full impact of both wheel loads on the axle. This causes surface pounding and eventually surface deviations at the joint locations. There are no joint stagger requirements in the MBTA Track Maintenance and Safety Standards, section LRT213.121. It is recommended that a minimum of 2' or one tie spacing, whichever is larger, for joint stagger requirements.

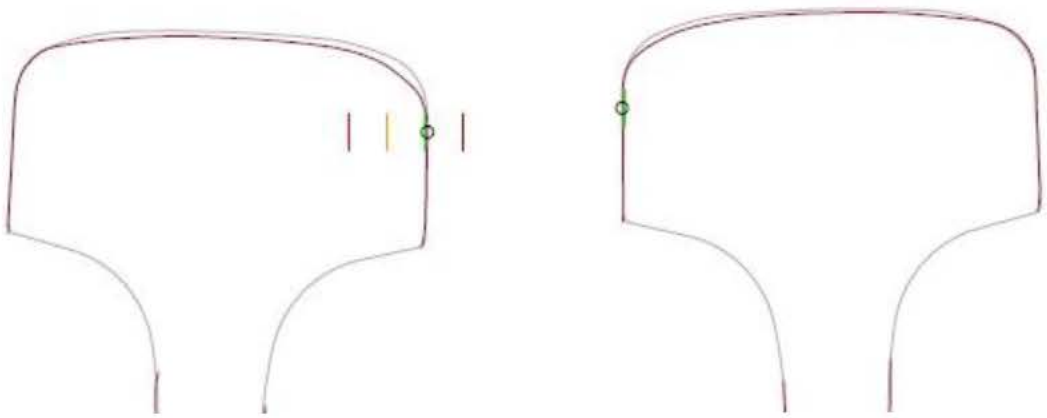
Wheel/Rail Interactions

Wheel/Rail interactions are at times primary factors in derailments. As the RFR requires a thorough review of the track structure to assure all phases of track maintenance are efficient and complaint to standards as well as looking at causal factors of recent derailments, a review of historical research on the No. 8 car derailments and maintenance practices was undertaken. This review included a review of current grinding practices, rail wear behavior and wheel wear and truing practices.

Unfortunately, the assessment team was not able to get the current wheel cutting profile, but did receive information on wheel wear.

The following is a review of the rail wear. From the rail profiles obtained from MBTA, the rails wear over time based on its location in the track.

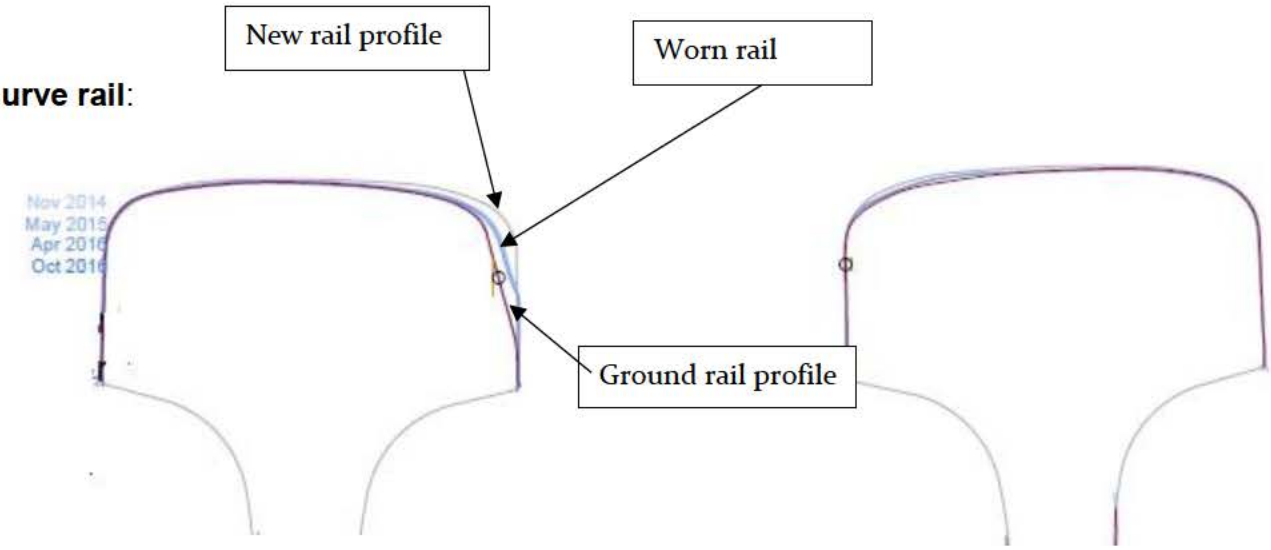
Tangent Rail:



Left Rail Right Rail

The top of rail wears down with time and traffic showing a bit more wear near the gauge corner than on the field side.

Curve rail:

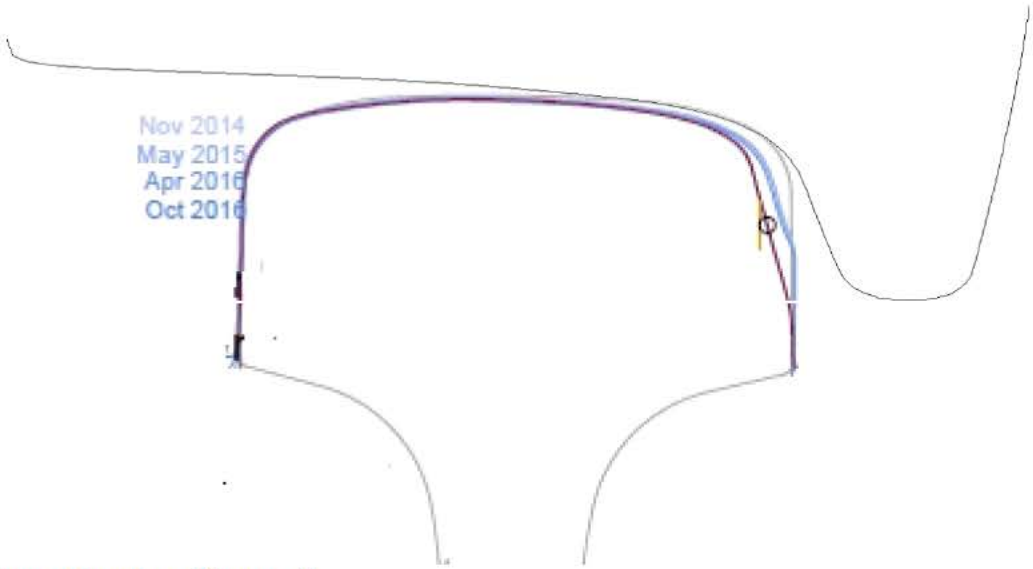


High Rail Low rail

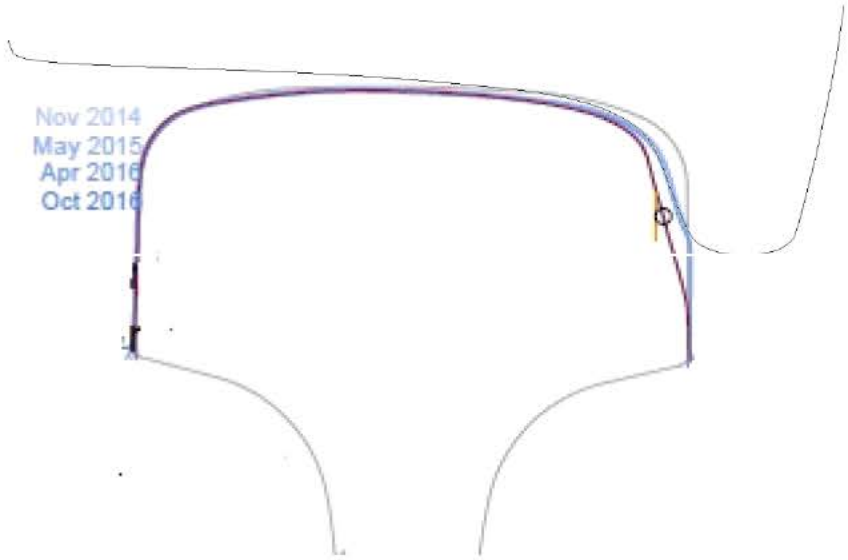
The high rail in a curve will wear mostly off the gauge corner. This type of wear will form a shelf at a location between ½ to ¾ inch down from the top of rail. The low rail tends to wear more off the top of rail with no gauge face wear.

By matching wheel and rail profiles, the wheel/rail contact points can be identified. It is these contact points that influence the location of wear on both the wheels and the rails.

Curved Track High Rail:

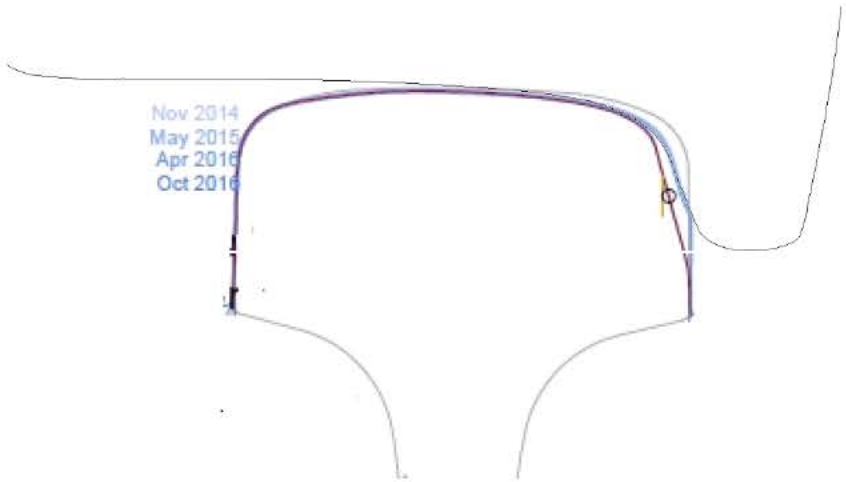


New wheel on New rail

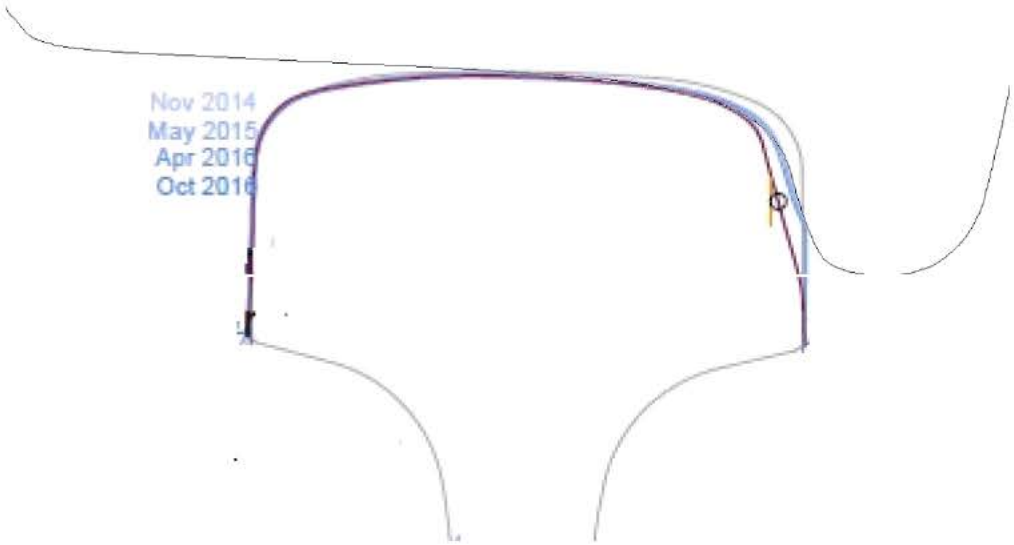


New wheel on worn rail

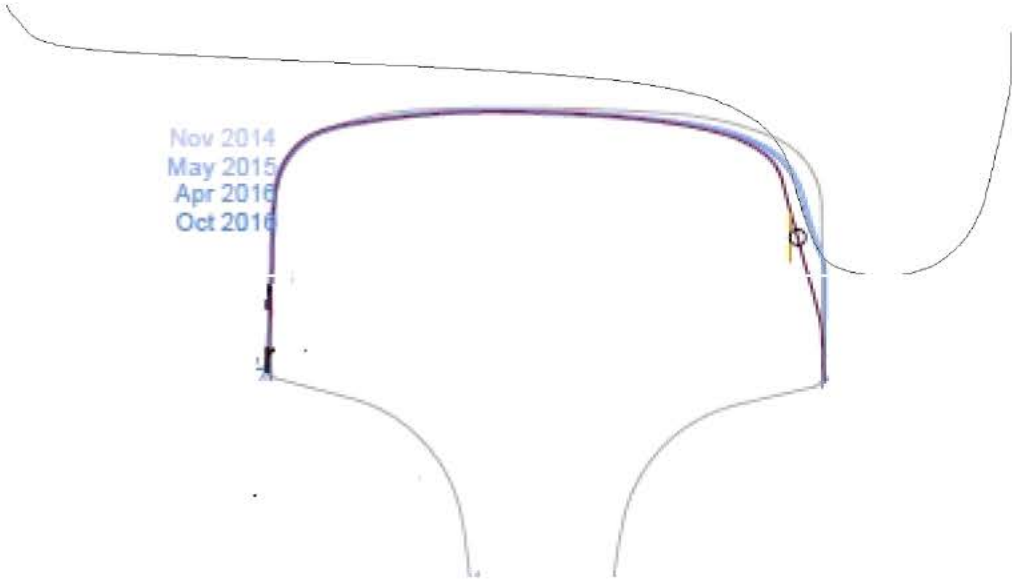
(Note, in a curve with increased angle of attack. The contact point of wheel on rail shifts up which results in the formation of the shelf being cut into the rail gauge face)



Worn wheel on worn rail (perfect match with worn rail profile)



Worn rail with center wheel



Center wheel being unloaded, tends to climb onto the rail shelf

The development of the high rail gauge face shelf is a result of wheels skewing in a curve and increasing the angle of attack the wheel flange makes with the gauge face of the rail. The angle of attack also increases with the increase in track gauge. This means that as the track gauge is allowed to increase over standard gauge, the amount of skewing of the wheel sets is also allowed to increase which results in a wheel contact higher up the rail gauge face, increased lateral forces and a quicker and deeper ledge in the rail gauge face is allowed to form. With a higher and deeper shelf formation in the high rail, the center truck wheels (with virtual axles and lower weight) climb up onto the shelf and ride the shelf reducing the amount of flange contact being made with the rail. At this point, a small amount of track twist (variation in crosslevel) or rail surface change would be enough to allow the wheel to jump up and off the rail.

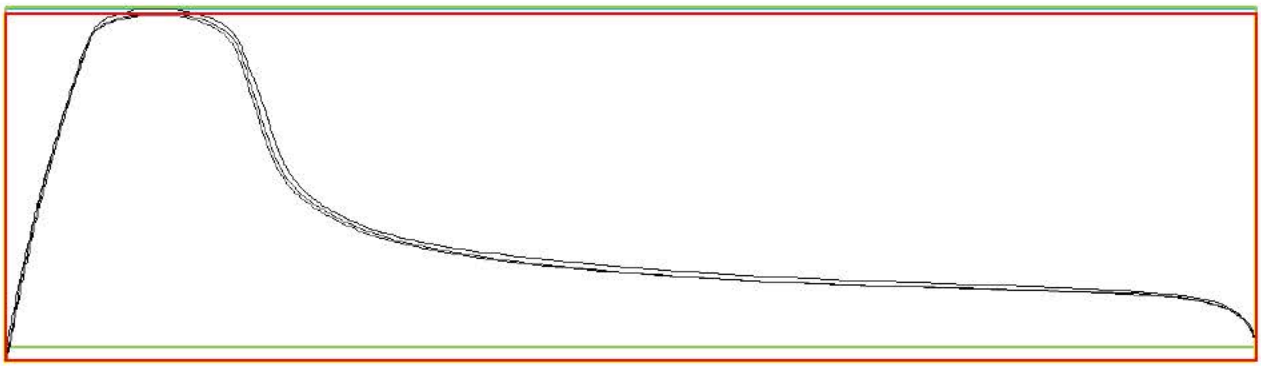
This type of action can be mitigated by ensuring the restraining rail remains tight to the back of flange of the wheel set and that track gauge is kept in check (e.g. not allowing the wheel sets with solid axles to skew and cut into the high rail forming the shelf).

This same action also explains the observed wheel wear patterns seen on the MBTA No.8 vehicles as shown below.

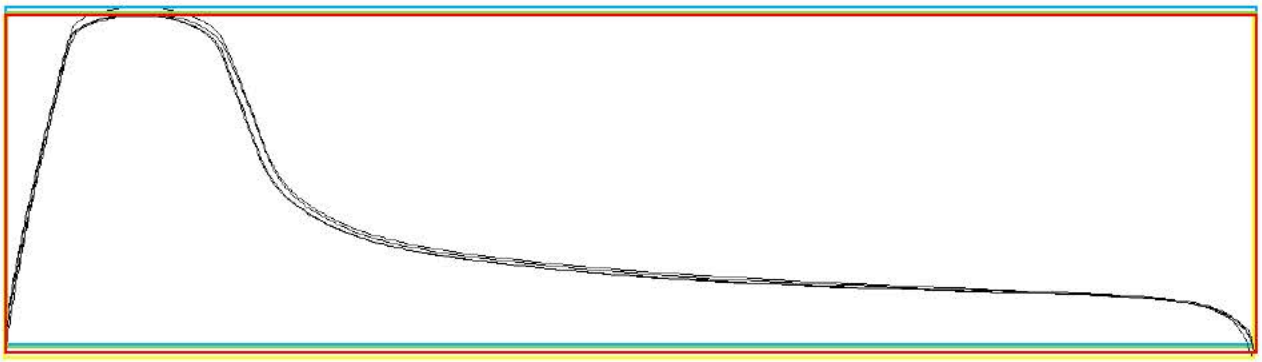
Vehicle # 3800 IL 9-9-16 BLUE, 12-6-16 GREEN, 3=6=17 YELLOW, 5-31-17 RED

NOTE: Back to Back for all wheel sets is 54 3/16 inches

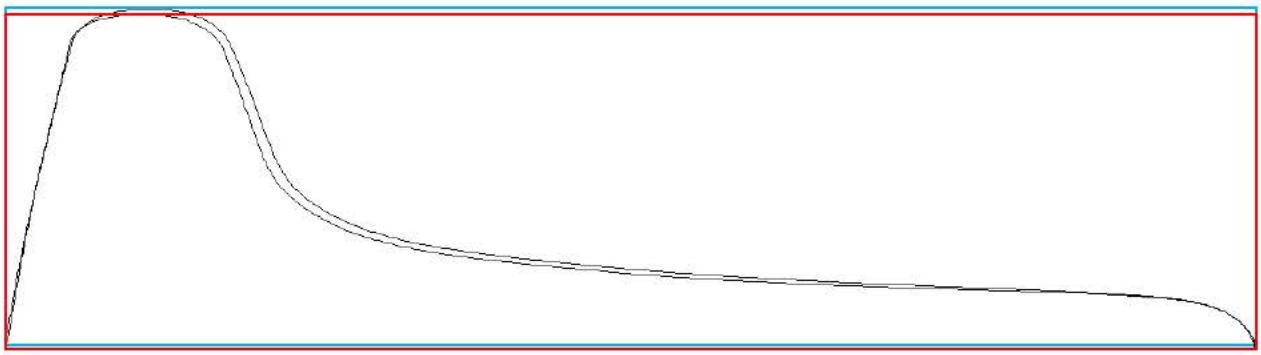
The following miniprof profiles were taken by MBTA Car shop personnel off Vehicle # 3800 over a period of 8 months in service. It can be seen that most of the wheels are being worn on the side of flange and the tip of flange more than anywhere else except for the B truck that had additional wear on the tread portion of the wheel making the wheel take a hollow tread profile.



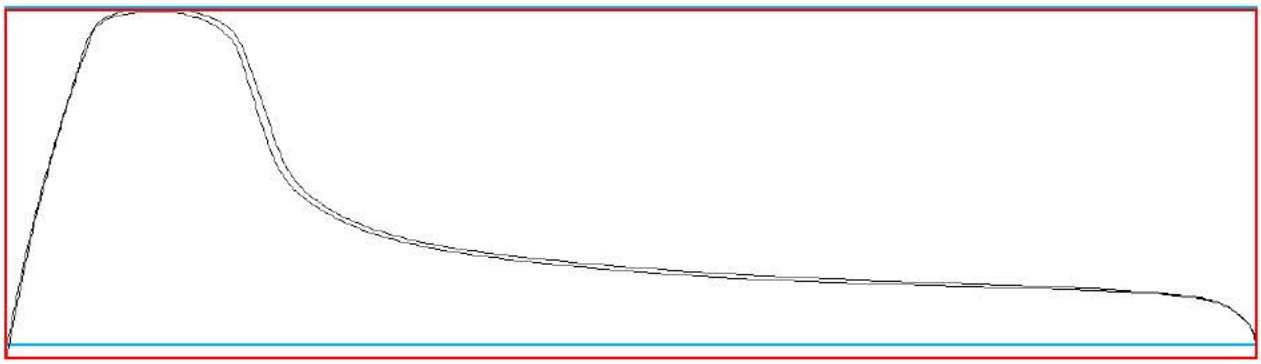
Vehicle # [redacted] IR 9-9-16 BLUE, 12-6-16 GREEN, 3=6=17 YELLOW, 5-31-17 RED



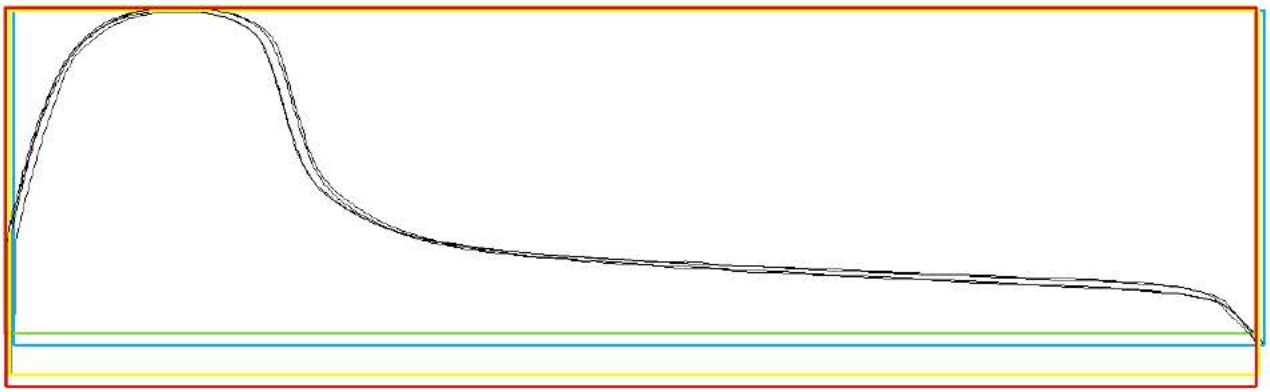
Vehicle # [redacted] 2L 9-9-16 BLUE, 5-31-17 RED



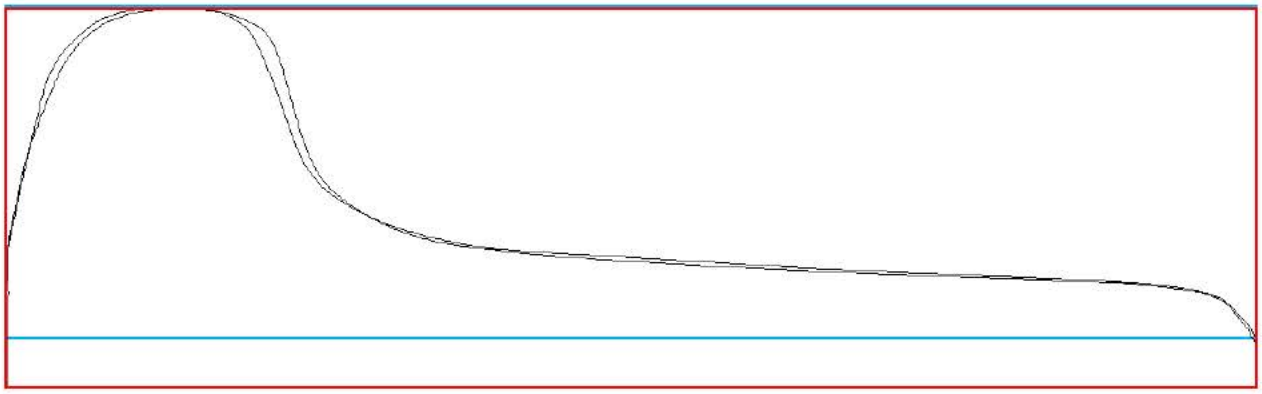
Vehicle # [redacted] 2R 9-9-16 BLUE, 5-31-17 RED



Vehicle # [redacted] 3L 9-9-16 BLUE, 12-6-16 GREEN, 3=6=17 YELLOW, 5-31-17 RED

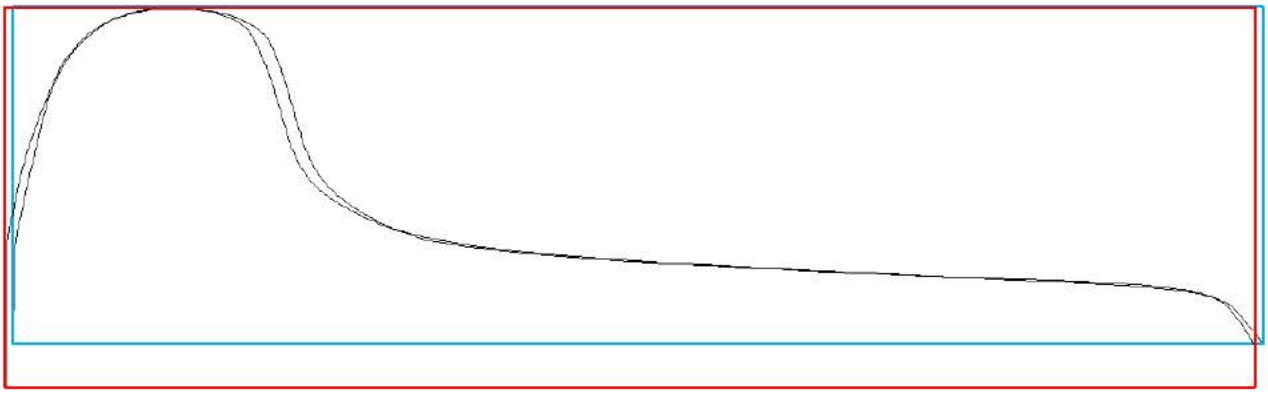


Vehicle # [redacted] 3R 9-9-16 BLUE, 5-31-17 RED

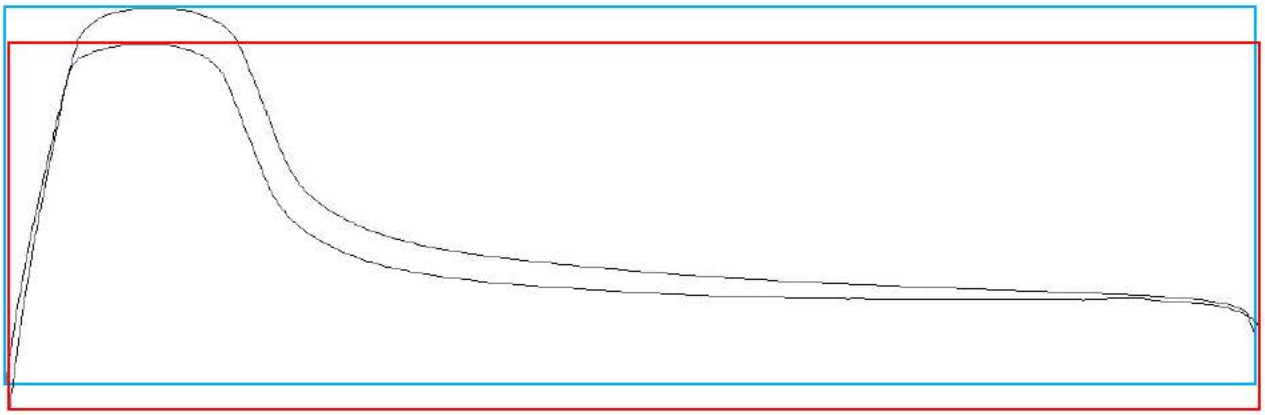


Vehicle # [redacted] 4R 9-9-16 BLUE, 12-6-16 GREEN, 3=6=17 YELLOW, 5-31-17 RED

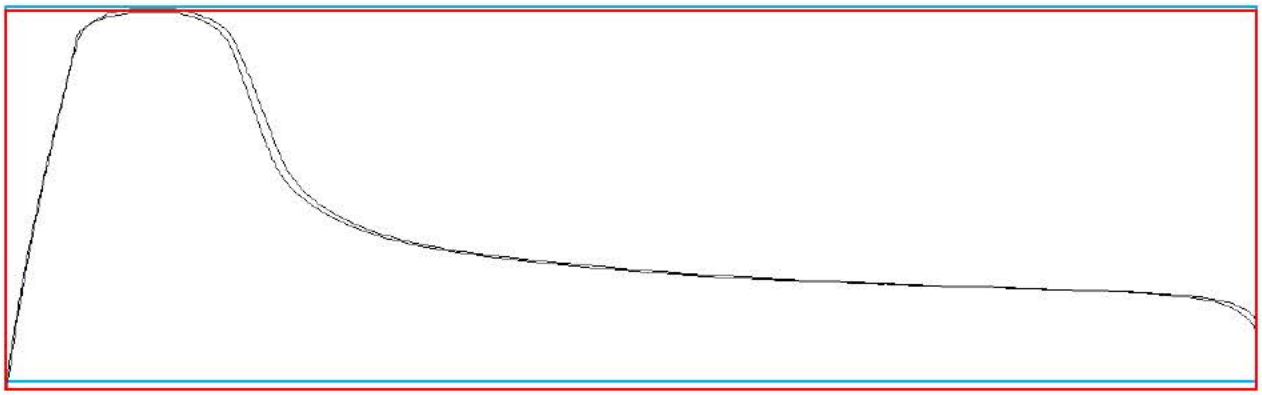
Vehicle # [redacted] 4L 9-9-16 BLUE, 5-31-17 RED



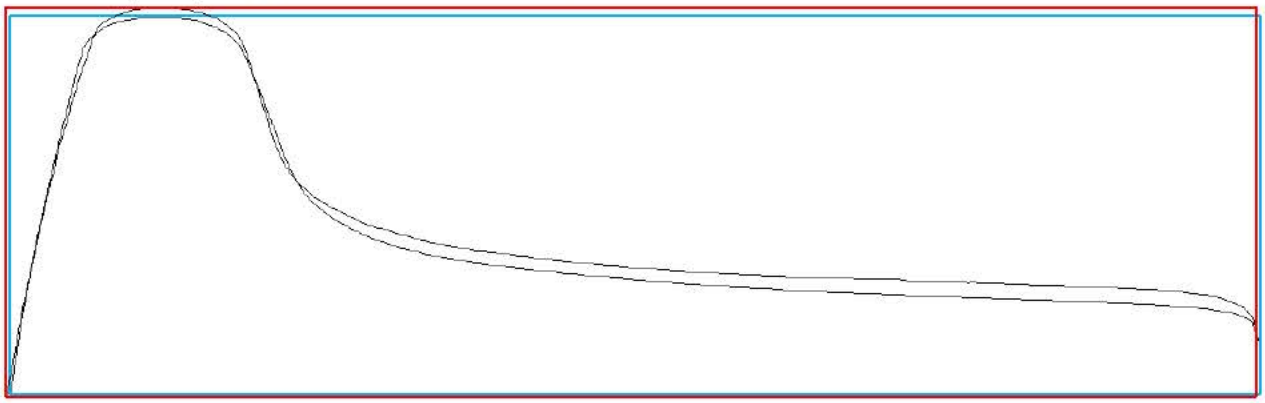
Vehicle # [redacted] 5L 9-9-16 (blue), 6-9-17 (red)



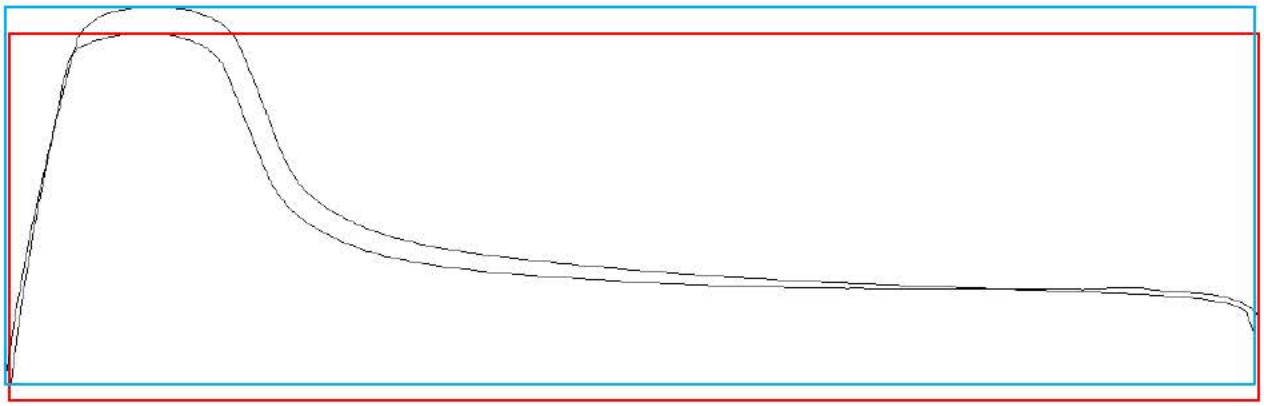
Vehicle # [redacted] 5R 9-9-16 (blue), 6-9-17 (red)



Vehicle # [redacted] 6R 9-9-16 (blue), 6-9-17 (red)



Vehicle # [redacted] 6L 9-9-16 (blue), 6-9-17 (red)



In review of wheel/rail interactions and the cause of the recent up-tick in derailments, the assessment team has concluded that the efforts undertaken by Vehicle Engineering and Vehicle Maintenance have significantly reduced the wheel/rail interface issues. Continuation of the recommended practices from TTCI, HNTB, and others, will suffice as long as the track conditions are maintained to existing standards and the Green Line is returned to a State of Good Repair.

Additionally, although not part of this assessment, the assessment team has identified two other wheel/truck design issues that have not been addressed that do have impact on the stability of the No.8 vehicles regarding their susceptibility for derailment on marginal track conditions. These issues are discussed below:

1. The center trucks have 26-inch wheel diameters. The smaller wheel diameter reduces the amount of flange contact being made with the rail. Since the lateral load is increased due to the individually rotating wheels of the center truck, it is important to have as much flange

contact as possible in order to hold the wheel against the rail and to distribute the load. With a reduction in flange contact, the pressure of flange against rail increases which allows the wheel to gouge into the rail. Also, with a reduction in flange surface area contact, the angle of attack between rail and flange also is allowed to increase which sets up a walk off situation. In addition, on transit vehicles, the wheel diameter variation on wheelsets, bogies, and between bogies fitted to vehicles shall be as per the limits specified the TPRC and AAR, Section 2.5, Wheel Diameter in One Car and in the Railways of Australia (ROA) Manual of Engineering Standards and Practices, section 24.2.1.3 (e), (f), (g), as stated below:

- Maximum permissible variation in wheel tread diameter 0.5mm per axle (new or re-turned)
- Maximum permissible variation in wheel tread diameter 1mm per axle (in service)
- Maximum permissible variation in wheel tread diameter per bogie 25mm

2. The use of a ¾ inch flange height also increases the potential for wheel climb derailment since the wheel does not have to climb too high before the flange is above the gauge face of the rail. To increase stability at the wheel/rail interface, a 1-inch flange height would be a much-improved profile to use.

The assessment team, in discussions with MBTA management and vehicle engineering, recommended that a consultant be retained to analyze the possibility of changing the center truck wheel size and flange to be the same size as the powered trucks, however, the MBTA responded that this has already been done and is not feasible.

Rail Grinding

The assessment team did not receive any information on either the current wheel grinding profiles or the rail grinding profile templates. As mentioned in other sections of this report, rail grinding was initially recommended to remove the shelf that is produced on the gauge side of the rail by passing flanges with a large angle of attack. This is needed to reduce the possibility of the center trucks of the No. 8 vehicle from climbing up the gauge face of the outside rail of a curve and being prone to walk off derailment. Additionally, grinding is also used to prevent a 90° edge or "knife-like" edge on tongue switches to prevent wheel climb.

Figure 94 - Newly Profiled Rail

Figure 95 - Heavy Gouge Marks due to grinding.

Figure 96 - New Rail Grinding showing multi-pass to re-profile rail head.

Figure 97 - Running Bead on newly profiled rail.

During the grinding cycle, not only is the gauge face of the rail is being ground, but also the top of the rail head is ground to produce a profile that was recommended in the past to reduce the flattened railhead and leave a crowned railhead. This crowning of the railhead profile was determined to be a better fit with the new wheel profile to reduce detrimental wheel/rail interaction. However, in order to produce this railhead crowning profile, there is a requirement to remove a great deal of metal off the top of the rail due to "flattening" of the rail head that is prevalent on older rail. Metal removal depends on a number of factors: the power of the grinding motor, the number of motors being used by the grinder, the number of passes used by the grinder and the coarseness of the grinding stone. Unfortunately, the grinder being used by the MBTA Contractor has only 16 grinding stones (8 per rail). This leaves a very wide cut on the top of the rail for each stone and thereby wide facets are also left on the top of rail as seen in the photographs above. This multifaceted profile is detrimental to the life of both wheels and rails and should be made smoother using extra stones, more passes, or less coarse stones.

The gauge face "shelf" that is created by the short wheel flange on severely worn rail cannot be removed with the current grinder that the MBTA employs. It is recommended that any rail where the "shelf" is created by wheel flanges be removed and replaced with new rail.

Rail/Wheel Interactions – Findings

Although a review of the wheel profiles and rail grinding was not a part of this assessment, a review of wear patterns, wheel cutting parameters and rail grinding profiles was undertaken to determine if there is any influence on the track conditions. The following is a list of findings:

- Flanges of the center truck different from the flanges of the wheels on the A or B end of the car.
- The left-side wheels are more tread wearing than the right-side wheels. This may be an indication of improper wheel truing. Additional information needed.
- KLD Wheelscan technology is installed at Copley Station to assist Rail Car Engineering in determining wheel tread issues (i.e. Hollow Tread, Flat Spots, etc.), it is not functional and requires repair.
- Many wheels show side of flange wear and edge of flange wear, which may indicate these wheels are responsible for cutting the shelves in the high rail of curves. However, addition modeling and studying is needed to validate this observation.

- There is a considerable amount of rail in the system that is worn beyond any chance of saving the rail by rail profiling.

Documentation and Maintenance Management Review

MBTA Green Line Track Standards – Edition 2008.1 (7/08)

The Department of Public Utilities regulations 220 CMR Section 151.11 - Track Inspection and 220 CMR Section 151.12 - Track Maintenance require that the transit agency has specific standards to which the track is inspected and maintained.

MBTA Green Line Track Maintenance and Safety Standards, dated July 15, 2008, is a collection of civil engineering and management criteria regarding track maintenance strategies, inspection requirements, employee competency levels, documentation requirements, and inspection/maintenance thresholds and parameters. The purpose of these standards is to meet the requirements of DPU 220 CMR Section 151.11 and 151.12 and outline the minimum requirements for maintaining the Green Line track structure in a manner that will maximize the safety, usefulness, and cost effectiveness of this infrastructure, as well as, ensuring the safety of the riding public and the employees of the MBTA.

The current MBTA Track Maintenance and Safety Standards Manual is a very good foundational document to build upon to address current needs of the organization and the current condition of the track infrastructure. The format of the document is adequate but is cumbersome to read and is not organized to provide personnel quick references for any found track defect nor to serve as a document which provides detailed maintenance standards for some components on the existing track structure system.

A Track Maintenance and Safety Standards Manual should provide system maintainers with comprehensive guidance, procedures, and the necessary technical references to efficiently inspect and maintain the track structures and all ancillary equipment maintained by the Track Maintenance group. The Standards Manual should be a dynamic document that is written to be easily understood. It must be organized in a manner so that Track personnel can readily locate necessary information and so that it can be easily modified to reflect changes to the track system operation and maintenance.

In the MBTA Management Plan, section 3.2.2, Engineering and Maintenance, it states "E&M activities follow federal, state, local, and industry safety regulations, codes, standards, and recommendations (e.g., NTSB, industry best practices)." The assessment team's analysis of the existing MBTA Track Maintenance and Safety Standards Manual has determined that the MBTA document is compliant to meet DPU 220 CMR Sections 151.11 and 151.12 requirements as well as the MBTA's Management Plan Section 3.2.2. For the most part, these standards have some components which reflect industry "best practices" as defined by the Federal Transit Administration (FTA), 2011 "*Compilation of Rail Transit Industry Best Practices for Track Inspection and Maintenance*" or APTA's RT-FS-S-002-02, Rev. 1, *"Rail Transit Track Inspection and Maintenance"* but it does require further updating and revision to be fully compliant.

To be fully compliant with industry "best practices", the MBTA Track Maintenance and Safety Standards Manual should be updated as described below. Some of the recommendations for improvement include:

- Develop a "Black Condition" rating (Out of Service) for critical geometry, wear and fixation conditions which affect the safe passage of trains and equipment.
- Rewrite section LRT213.1 Scope and remove statements on combination of conditions. Add a section to the manual to specifically address "Combination of Conditions". When a combination of conditions at a given location exists, but none individually requires action, a qualified person (as designated in LRT213.7 and 220 CMR 151.11(4)) must evaluate the condition for protection and take appropriate action. Train dynamics, track geometry and track design, location of the track, maximum speeds over the area, and any other factors that could negatively influence the severity of the conditions found must be taken into consideration when evaluating the proper action(s) to be taken, particularly in special work and curved locations. A few of the major transit properties have adopted a rule on "Combinations of Conditions" (in compliance with FTA Best Practices) and have added a section to their manual that simply states the following:

  "*In the case of the inspector finding more than one defect at the same location, the degree of severity and therefore the speed limit may be affected. Should a combination of three or more defects occur at any one location, under the discretion of the inspector or track supervisor the severity level can be dropped a minimum of one classification for any combination of defects. For example, if three Yellow defects affecting three different parameters, are discovered at any one location, the Severity Level should be dropped to a Red Level. Please note, the defects must occur in three different parameters, that is, three yellow wide gauge defects shall be counted as one defect, however, a yellow gauge, with a yellow tie condition and a yellow cross level condition will be cause to drop the location to a Red Level. In addition, these defects must occur within a track length which matches the axle to axle spacing on a single truck.*"

- Develop reference section for maintenance criteria which will assist track workers on proper maintenance activities such as torque values for joint bar bolts, torque values for fasteners, screw spike and cut spike installation patterns for tangent and curved rail.
- Develop criteria for Minimum distance between of "unsecured tie plates" or "fasteners" for both inspection findings and maintenance work. (Note: In section LRT213.109 Crossties, there is a table for "Maximum Distance Between Non-Defective Ties (CTR to CTR)" but there is no reference in the manual for maintenance if the ties are still good but the fastening has either been removed for maintenance or the spike have been deteriorated and ties are still performing. This leads to ambiguous situations that could and have resulted in derailments.
- Develop criteria for the use of temporary measures such as gauge rods and cheater bolts (i.e. duration of use and installation).
- Develop a section on what is explicitly expected for both Maintenance and Inspection if an area of the track is obscured by either temporary issues (Sand, Vegetation) or permanent issues (road crossings and platform edges).
- Expand Part F – Inspection, to include as specific section on Automated Inspections by Contractors (i.e. Geometry, Ultrasonic, GRMS, Rail Profile, etc.). Include requirements for

data analysis, immediate Red Condition validation, maintenance response, documentation of actions taken and marking of such defects.

- Expand the specific criteria for the inspection of the obstructed areas including embedded track (Section 213.334). With 51 crossings and several miles of embedded track, this section should have specific criteria for evaluation and restrictions, especially for surfacing and runoff.
- Include forms and examples of how they are to be filled out consistently. Additionally, if the MBTA is migrating to a computerized system where defect codes and component codes will be used for a computerized MMS such as OPTRAM. Include defect codes and component codes in a quick reference table.

Additionally, it is becoming increasingly common in the transit industry to have two versions of the Track Maintenance and Inspection Manual. One version is an "Engineering/Office Reference Manual", the other is a Supervisor and Track Inspectors "Pocket-Sized Field Guide". They are usually split up in the following manner:

Engineering/Office Reference Manual which is used by engineers and managers to plan work, establish the maintenance process, location information, work instructions, roles and responsibilities and other pertinent management information. Usually this version will contain the following items:

- Maintenance Philosophy
- Roles and Responsibilities
- Reference Drawings
- Route Drawings
- General Notes
- Types of Inspections and Cyclic Requirements
    - Walking
    - Geometry
    - GRMS Inspections
    - UT Inspections
    - Special Inspections
    - Inspections of Work Performed by Others
- Standard Work Procedures for all Track Maintenance Tasks
    - Work Production Standard
    - Engineering Standards
    - Quality Standards
    - Job Hazard Assessment
    - Crew Size
    - Material Listing
    - Step by Step Instructions on how to perform the task.
- The Reporting Forms and Inspection Reports
- Maintenance Forms and Reports
- Rail Inspection Section
- Cross Tie/Invert/Plinth Pad Section
- Rail Fastening Systems and Anchor Inspection Requirements
- Roadbed Requirements

- Turnout, and Special Trackwork Section
- Miscellaneous Track Inspection Items
- Track Geometry Maintenance and Inspection Requirements
- Track Appliances and Devices
- Heat Countermeasure Program Requirements
- Glossary of Terms

Track Maintenance and Inspection Field Guide is a pocket-sized guide with quick reference tables, remedial action requirements and short explanations with the following items:

- General Information including:
    - Qualified Persons Definition
    - Safety Information while on Track
    - Job Briefing Details
    - Responsibilities when work is done by others
- Combinations of Conditions
- Forms, Component, and Defect Codes, to be used.
- Types of Inspections and Cyclic Requirements
- Classes of Track
- Condition Prioritization with guidance on how and when to use them.
    - Black
    - Red
    - Yellow
    - Green
- Reference Tables with Measurement Criteria
    - Rail Inspection
        - Rail Wear Tables
        - Rail Surface Inspections
        - Rail Surface Fatigue
        - Internal Rail Defects
    - Rail Joints
        - Joint Bars on Defective Rails
        - Insulated Joints
        - Joint and Weld Stagger Requirements
    - Rail End Standards
    - Rail End Mismatch
    - Battered Welds
    - Rail End Inspections
    - Web Defects
    - Rail Defects
    - Rail Defect Inspection Frequency
    - Internal Rail Defects
    - Rail Defect Remedial Table
    - Defects within Switch Points
    - General Rail Maintenance Criteria
    - Inspection of CWR
    - CWR Remediation Action Needed

- Joint Inspection in CWR
- Restraining Rail Threshold Limits
- Restraining Rail Bolts
- Cross Tie Inspection
  - Wooden Ties
  - Concrete Ties
- Yard Trackage/Embedded Trackage
- Group/Plinth Pads
- Rail Fastener Inspections
- Rail Anchors
- Roadway Inspections
- Ballast Requirements
  - Wood Ties
  - Concrete Ties
- Vegetation Inspections
- High Water Inspections
- Special Track Work Inspections
  - Chipped Point Width Limits
  - Chipped Point Depth Limits
  - Worn Point Limits
  - Switch Rod Limits
  - Frog Requirements
- Diamond Maintenance Limits
- Grade Crossing (Vehicle and Pedestrian)
- Track Lubricators
- Platform Area Requirements
- Fences and Access Points
- Signage
- Tunnel Lights
- Storage of Equipment and Materials Requirements
- Track Geometry Inspections
  - Gauge Min/Max Tolerances
  - Variation in Gauge
  - Track Surface Limits
  - Super Elevation
  - Super Elevation Runoff
  - Horizontal Curve Data
  - Alignment Min/Max Tolerances
  - Unbalance Charts (3" and 4")
- Track Appliances
  - Derails
  - Switch Heaters
  - Cable Leads
- Power
  - 3rd Rail

- Catenary
  - Street Running Track Work
    - Roadbed
    - Gauge
    - Track Flangeway Tolerances
    - Track Structure
    - Rail

As part of the RFR requirement to determine compliance to DPU regulations, the assessment team has performed a section by section review of the MBTA's Green Line Track Maintenance and Safety Standards, dated July 15, 2008, and the Department of Public Utilities regulations 220 CMR 151.11 Track Inspection and 220 CMR 151.12. As such, the assessment team has determined that the DPU regulation requirements are being met or exceeded by the MBTA. The section by section comparison will be included as Appendix A to this report.

Derailment Report Review

As part of the RFR, the assessment team reviewed derailments reports from 2015 to present as part of the document review and overall analysis of track maintenance performance. Per DPU, this review effort concentrated on derailments caused by track conditions or where track conditions significantly contributed to the derailment. Derailments from other causes were not part of this assessment.

Derailment Review Material

Report No.: #D15-16
Date: Monday July 7, 2015
Location: B Line, 35 feet passed the intersection of Colborne Rd and Commonwealth Ave, eastbound
Train Number, location in train: Center truck HPCU of Vehicle #[redacted].

Reported Cause: Track conditions: Track conditions at the location of the incident were in a "Yellow condition," as defined by MBTA Maintenance of Way track maintenance Light Rail Transit standards, and should have been restricted to [redacted] miles per hour at the location of the derailment.

Track Defects reported by Geometry car on April 16, 2015 and not repaired.

1.) Eight foot (8') section of track with a maximum twist of two inches (-2"), requiring a speed restriction of [redacted] mph, and necessitating repair within seventy two (72) hours.

2.) Two foot (2') section of track with a maximum gage of 57 ⅜", requiring a speed restriction of [redacted] mph, and necessitating repair within thirty (30) days.

3.) Six foot (6') section of track with a maximum cross level deviation of 1 ½", requiring a speed restriction of [redacted] mph, and necessitating repair within thirty (30) days.

4.) Six foot (6') section of track with a twist of 1 ¼", requiring a speed restriction of [redacted] mph, and necessitating repair within thirty (30) days.

5.) Eight foot (8') section of track with a maximum gage of 57 ½", requiring a speed restriction of [redacted] mph, and necessitating repair within seventy two (72) hours.

6.) Forty four foot (44') section of track (leading up to and running through the point of derailment) with a maximum gage of 57 ⅜", requiring a speed restriction of [redacted] mph hour, and necessitating repair within thirty (30) days.

Report No.: #D15-17
Date: Monday July 12, 2015
Location: D Line, Eastbound track approaching Longwood Station
Train Number, location in train: The #3L wheel on the C truck of Vehicle #[redacted] derailed.

Reported Cause: Track conditions: Track conditions at the location of the incident were in a "Yellow condition," as defined by MBTA Maintenance of Way track maintenance Light Rail Track standards.

Track Defects reported by Geometry car on April 15, 2015 and not repaired.

1.) A two (2) foot section of track with a twist of 1 ¼" measured through a thirty one foot (31') section of track.

2.) The defect was measured to be approximately nineteen feet (19') west of the location of the derailment. This defect necessitated a speed restriction of [redacted] miles per hour based on MBTA MOW track maintenance Light Rail Track standards.

3.) The defect is also required to be mitigated within [redacted] days of identification.

4.) MBTA MOW did not produce any Quality Assurance/Quality Control (QA/QC) reports to verify the track deficiencies identified by the geometry car report in April 2015 were addressed and repaired

Report No.: #D15-18
Date: Monday July 29, 2015
Location: Derailment at Switch # L4 - Lechmere Yard
Train Number, location in train: The C Truck of Train 3664 climbed the tongue of switch #L4.

Reported Cause: Track conditions: Axles #3 and #4 (C Truck) of Train #[redacted] climbed a "knife edge" switch point of switch #L4 which was very dry and proceeded onto the outer loop.

Report No.: #D15-20
Date: Monday August 17, 2015
Location: Line B, intersection of University Road and Commonwealth Avenue fifty-seven feet (57') past the intersection, the #3R wheel on the C-truck of Vehicle #[redacted] climbed onto the head of the rail, causing #4R wheel to climb also. Both dropped off the rail.

Train Number, location in train: The C Truck of Train #[redacted] climbed the tongue of switch #L4.

Reported Cause: Track conditions: Track conditions at the location of the incident were in a "Yellow condition," as defined by MBTA Maintenance of Way track maintenance Light Rail Transit standards, and should have been restricted to [redacted] miles per hour at the location of the derailment, but were not.

Track defects found following derailment:

1.) The track area was inspected by Maintenance of Way engineers following the incident. Static measurements of the track taken after the derailment identified a section of rail at the point of derailment with a gage of 57 3/8". Based on this defect, a speed restriction of [redacted] mph should have been implemented in the incident area in accordance with the MBTA MOW track maintenance LRT standards.

2.) MBTA Safety reviewed all open and closed speed restrictions on the Green Line for the previous six (6) months. MBTA Safety did not identify any speed restrictions placed in the incident area prior to the derailment.

3.) Post-incident inspection of the track revealed indications of significant side-wear on the inside of the rail head of the right-hand rail.

Report No.: #16-1074
Date: Monday March 19, 2016
Location: D line, Between Hynes Convention Center Station and Copley Station.
Train Number, location in train: Track Marker 26+40, the 3R (right wheel on the third axle) wheel on the center truck of Vehicle #[redacted] climbed onto the right running rail.

Reported Cause: The primary cause of the incident was determined to be Train #3[redacted] travelling at speed in excess of the posted speed in the curve.

Contributory Causes:

1.) Gage variation within the curve that was not within acceptable track standards.

3.) Degraded center truck suspension components on Vehicle #[redacted]

4.) Lack of a speed restriction of [redacted] miles per hour as warranted by the track conditions in the curve.

Report No.: #16-1881
Date: Sunday, May 13, 2016
Location: Switch #70, westbound track approaching Park Street Station
Train Number, location in train: #5R wheel on the B-end truck of Vehicle #[redacted] moved over Switch #[redacted] and dropped between the switch points.

Reported Cause: The primary cause of the incident was wear at the switch point of Switch #[redacted] which caused the gage at the switch point to be outside of specification (58").

Report No.: #16-3180
Date: August 1, 2016
Location: Between Switch #[redacted] and westbound wall track, Park Street Station
Train Number, location in train: #6L wheel (leading Vehicle #[redacted] climbed the right-hand running rail in a left-hand curve.

Reported Cause: The primary cause of the incident was a high level of friction on the rail.

Report No.: #16-4153
Date: October 3, 2016
Location: Westbound track approaching Copley Station

Train Number, location in train: Train #[redacted]-[redacted] was travelling westbound between Arlington Station and Copley Station. As the train departed Arlington Station, the center truck of the trailing vehicle derailed to the right of the track.

Reported Cause: The probable cause of the incident was determined to be excessive speed of Train #[redacted]-[redacted] The train was travelling at approximately [redacted] miles per hour at the time of the derailment, in an area with a designated speed limit of [redacted] miles per hour.

Contributing Causes:

1.) The condition of Vehicle #[redacted] An inspection of vehicle components determined several components of the suspension were worn. Although several parts were worn, each worn part individually would not cause the derailment, the summation of worn parts may have been a possible contributory cause.

2.) High friction on the gage-face of the rail. The rail had been recently re-profiled, leaving a rough finish. The rough finish may have increased the level of friction on the gage side of the rail at the incident area.

3.) Short wavelength combination geometry defects (alignment, cross level, gauge and gauge rate of change) were present in the track.

Report No.: #16-4885
Date: November 16, 2016
Location: Approaching Boston College Station westbound
Train Number, location in train: Train #[redacted]-[redacted] was travelling westbound between South Street Station and Boston College Station. As the train approached Boston College Station on the westbound track, the trailing truck (A Truck) of lead Vehicle #[redacted] derailed to the right of the track.

Reported Cause: The probable cause of the incident was determined to be a pre-existing defect in the web of the running rail which, over time, propagated approximately ten (10) feet. This ten-foot crack caused approximately 16 inches of rail head to separate from the remainder of the rail, resulting in a gap in the right hand running rail. Without an appropriate running surface, the wheels of the A truck on Vehicle #[redacted] departed the running rail as it passed over the discrepant area causing the derailment.

Report No.: #FY17-02675 (Official Report was not received at the time of this assessment.)
Date: June 14, 2017
Location: 1500 Comm Ave. (After old Summit Street Stop) East Bound
Train Number, location in train: Train 3674-3824 was traveling eastbound on the B Line when trailing car 3824 derailed crossing through a MOW work sited located at the intersection of Summit and Commonwealth Ave. The train was traveling at approximately [redacted] mph through the work site when it derailed.

Reported Cause: The track department was in the process of replacing severely deteriorated tie plates on the right-hand rail. At the time the derailment occurred, the right rail had eight (8) consecutive ties with unsecured tie plates. Per the photos observed by the assessment team, this was a combination of 5 plates had been replaced but had yet to be secured and 3 additional plates that were severely corroded and had no spikes in place.

Derailment Report Review Findings

Of all the derailments reported that involved the No. 8 cars, 9 were caused by MOW failure to follow their own Track Standards or correcting the defects found by the Geometry car runs, and 1 was caused by improper track maintenance during revenue train operations.

This leads us to the following significant findings:

- Derailments of the No. 8 vehicles do not seem to be a systemic issue now as they have been in the past. Corrections to the wheel profiles and rail profiles appear to have reduced the derailment issue substantially.
- Increased emphasis on track geometry, switch point condition and adherence to speed restrictions once installed will further reduce the potential for track infrastructure based derailments.

However, as there are still track condition caused derailments there remains several track standard issues:

1.) Track geometry does not get sufficient emphasis. The track is not being maintained to a level that is compatible with the requirements of the No. 8 series cars. Even though the information on track defects is available through the track geometry car runs, it is either not being looked at or not being believed. Slow orders that should be placed based on the defects found by the track geometry cars are not being issued and have resulted in several derailments because of it.

2.) Even if the track was being maintained to the existing track standards, the track standards that are being used for the Green line do not appear to be strict enough for the tight tolerances required by the low floor cars. Gauge, variation in gauge, alignment, crosslevel and warp requirements do not emulate the requirements of the FTA Best Practices for Transit Track Operations.

3.) Supervisors and employees require additional training on track maintenance standards to understand track/train dynamics and track performance during maintenance operations. Detailed work instructions should be developed which clearly define when it is appropriate to allow trains to pass over "in-situ" trackwork or during broken rail conditions.

Maintenance of Way Organizational Structure

Per the MBTA Maintenance Management Plan, the MOW Division is responsible for the maintenance and repair of all track and fixed guideway structures and performs landscaping, facilities cleaning, rubbish pick-up, and snow removal at various locations throughout the system. The department is staffed by 300 employees, which includes a Director, Deputy Director, Superintendents, Supervisors, Forepersons, Line Repairers, Trackpersons, and Laborers.

Areas of Responsibilities:

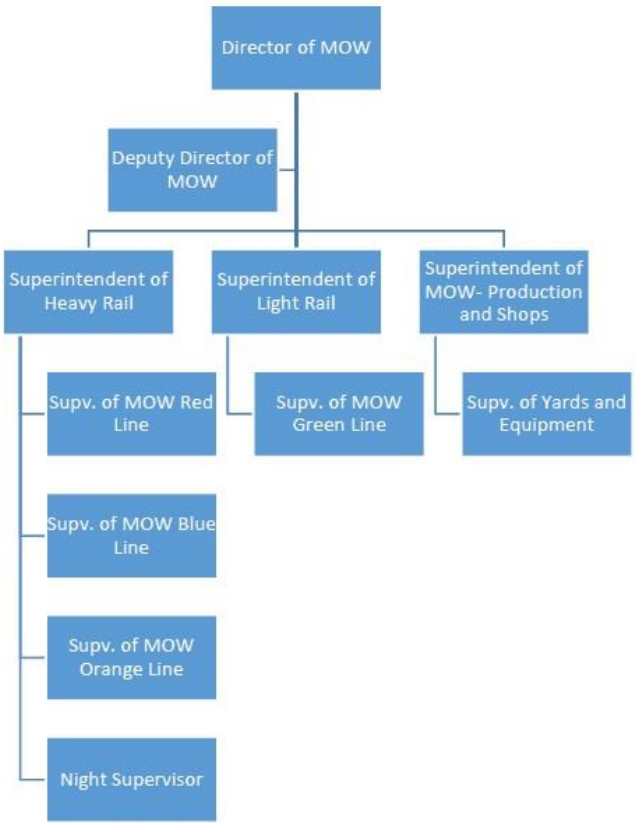
The MOW Division is responsible for the maintenance and repair of all track and fixed guideway structures except for those maintained by Power, Signals, and Communications. The collective focus of MOW is to support all transportation modes to achieve and retain "service grade condition," whereby revenue service operates efficiently and without restrictions. The MOW

Division is responsible for the inspection and maintenance of over 183 miles of rapid transit and surface line track. Additional functions include landscaping, facilities cleaning, rubbish pick-up, and snow removal at various locations throughout the system.

Budget

The current MOW Division budget is $39,800,000 which includes an operating budget of $22,000,000 and a capital budget of $17,800,000. This budget is shared between all MOW divisions, including those maintaining both light rail (Green Line) and heavy rail (Red, Orange and Blue Lines.)

MOW Overall Organizational Structure



The breakdown of the overall rail sections maintained by the MOW Departments are shown below and are provided to demonstrate the offices which draw from the budget listed above:

<u>Light Rail System (Green Line)</u>

The Green Line has a total of 46 revenue track miles. Although the track type varies throughout the Green Line, the majority of the line is a wood tie and ballast unit with some monoblock concrete tie track as well. The running rail on the line consists of both "T" rail and girder rail. The entire line is powered by overhead catenary wire. Since portions of the Green Line are at street level and cross automobile traffic, there are 64 grade crossings along the Green Line and other crossings within the maintenance facilities. Streetcar grade crossings have a useful life ranging from 12 to 15 years.

Heavy Rail System (Red, Orange and Blue Lines)

The Red Line operates over 45 miles of revenue track. Types of track construction vary from standard wood tie track to concrete floating slab, with variations of the two. The line includes timber tie track, concrete dual block tie track, direct fixation, and concrete floating slab track. The entire line is powered by third rail. The 6-mile long Mattapan-Ashmont Trolley segment of the Red Line is powered by overhead catenary wire.

The Orange Line operates over 22 miles of revenue track. The type of track construction varies. The track consists of timber tie track, direct fixation, and concrete floating slab track. The entire line is powered by third rail.

The Blue Line operates over 12 miles of revenue track. The type of track construction is primarily timber tie; however, sections of the track are monoblack concrete tie track. Throughout the Blue Line a combination of overhead catenary wires and third rail power the line.

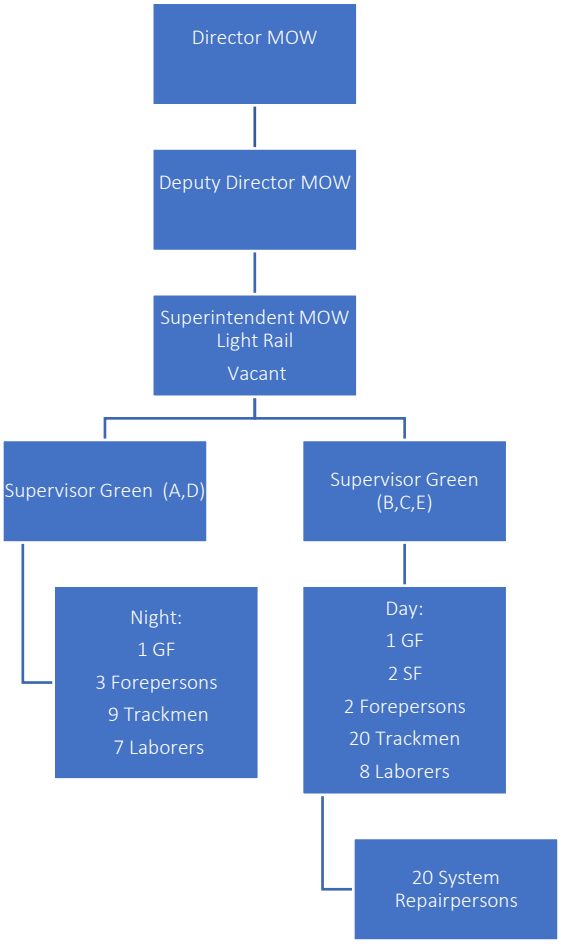
The subway fleets operate over 1 million feet of mainline-ballasted track and over 400,000 feet of yard ballasted track. The MBTA has approximately 560 mainline turnouts (sections of track which "turn out" from the main line), which have useful lives ranging from 4 to 25 years. There are 675 total yard turnouts, whose useful lives range from 8 to 25 years.

Furthermore, all MOW departments share MOW equipment and other tools and resources. For maintenance control documentation, MOW utilizes the Engineering & Maintenance Mgmt. Plan, Maintenance of Way Division Annex, dated July 11, 2016, and the following documents:

Document ID	Subject	Date	Revision Number
EM-SOP-2011-02	Standard Operating Procedure for Idling Engineering and Maintenance Vehicles During Normal Working Conditions	4/6/2011	0
EM-SOP-2011-03	Standard Operating Procedure for Daily Pre-Work Review	4/29/2011	0
EM-SOP-2011-05	Standard Operating Procedure for Pettibone Movement Policy	5/16/2011	0
EM-SOP-2012-02	Standard Operating Procedure for Engineering and Maintenance Procurement Process	6/26/2012	0
EM-SOP-2012-09	Standard Operating Procedure for Reporting Field Visit Reports	10/23/2014	0
EM-SOP-2012-10	Standard Operating Procedure for Logging Into, Assigning Work, Closing, and Creating Work Order Reports on MCRS Blue Zone	12/12/2012	0
EM-SOP-2013-01	Standard Operating Procedure for Planning and Scheduling Work on the Right of Way During Revenue Hours	11/29/2012	0
EM-SOP-2011-22	Standard Operating Procedure for Internal Auditing of Engineering and Maintenance Activities	11/18/2012	0

Green Line MOW Division

The MBTA Green Line Organization Structure was presented to the assessment team as shown below:



The number of organizational levels in a track maintenance department is directly proportional to the size of the department and the size of the physical property. For the MBTA Green Line, a line maintenance organization as shown above is suitable for 45 to 60 workers and three or four Supervisors reporting to a lead maintenance manager, in this case the Superintendent of MOW Light Rail. The positions above Superintendent, the Director and Deputy Director are executive level positions with multi-line responsibilities, so their focus is solely not on the Green Line.

Additionally, there are approximately 7 engineers in the Engineering and Maintenance Department (E&M) that directly support the track program. These engineers support the track function in various ways including the review and support of the automated track geometry inspection efforts.

Green Line Maintenance Personnel Resources

Although there are many factors which influence the number of personnel that a maintenance department needs and it is very difficult to determine adequate resource allocations requirements without detailed time/motion analysis, for general comparison purposes, the assessment team looked at other agencies for an employee/inspector per mile of track to see where the MBTA Green

Line staff level is. Included in this comparison chart is the number of operational speed restrictions currently applied to each system. This reflects the overall condition of the track infrastructure. Below are some comparisons:

COMPARISON OF PERSONNEL AND SPEED RESTRICTIONS						
Agency	**Total Miles**	**Total Maint. Personnel**	**Total Inspection Personnel**	**Total Miles Inspected per Person**	**Track Miles Maintained per Person**	**Operational Speed Restrictions**
Cleveland	57.8	32	4	14.45	1.8	24***
Sound Transit	41	12*	0	3.4	3.4	1
LA Metro	200	51	12	16.6	3.9	3
WMATA	234	252	52	4.5	.9	2
Valley Metro	19.5	0**	7	2.7	N/A	1
NYCT	682	827	94	7.2	.8	0
MBTA – GL	**46**	**44**	**20**	**2.3**	**1.04**	**58**

*Perform both maintenance and inspection duties. Not a separate job class.
** All Maintenance is contracted to 3rd party.
*** Mixture of Short Term and Long-Term Rehabilitation Areas.

The agencies listed above are either relatively new and have robust maintenance programs, or have substantial Capital Programs aimed at renewing the track infrastructure and have supplemented their internal workforce with contractors. This information is very basic and does not take into consideration unique challenges the MBTA faces in maintaining their track structure. It is simply offered to allow comparison to other agencies.

In reviewing the organizational chart for the Green Line, and looking at like similar transit agencies, the total number of track maintenance employees appears to be adequate to maintain the Green Line in a State of Good Repair **IF** the Green Line was renewed to a "like new" condition or significantly supplemented by contract personnel. A detailed time/motion study (which takes into consideration, train frequency, operational hours, access hours, infrastructure needs, cyclic maintenance requirements, etc.) would be needed to determine if staffing levels meet maintenance needs. Even though it appears they have adequate personnel to both inspect and maintain their track if it were in a "good state of repair", it is obvious from the extreme number of speed restrictions, that they are not and should not be in a maintenance mode. The system should be in a rehabilitation mode requiring both additional operating and Capital dollars, and personnel (whether in house or outside contractors) to bring the system back to where it can be maintained with the personnel they have.

Current Personnel Distribution – Shift Activities

Of the 64 personnel directly involved in the maintenance and inspection of this line they are broken up into crews who work dayshift and nightshift.

Day Shift - The [redacted] System Repairers perform inspections on all 44 miles of track 3 times per week, and perform all the preventative maintenance work. Additionally, [redacted] Trackmen and Laborers are broken up into crews of [redacted] to perform switch repair and cleaning. The remaining personnel are divided into crews to perform other track work jobs and paving work.

Night Shift - The [redacted] Trackmen and [redacted] Laborers on night shift perform a variety of track maintenance work. On average [redacted] crews are deployed per night.

Findings – Personnel Resources

Given the Green Line's current condition, this level of personnel is inadequate to maintain the Green Line to its fully functional capacity without operational restrictions or to reduce the number of operational restrictions on the rail road. Years of deferred maintenance, limited access and lack of resources has created a backlog of maintenance and rehabilitation requirements. Sending a total of [redacted] to [redacted] crews out during the day and an average of [redacted] crews per night will never provide enough effort to catch up and reduce the backlog of maintenance needs.

Presently, most of the employee and managers' time is spent chasing critical issues and trying to prevent service disruptions due to substandard or marginal track infrastructure conditions. This is clearly evident in the number of track infrastructure based Speed Restrictions that are currently on the railroad.

By FTA and Industry recommended practices, the term "State of Good Repair" has no universal definition, for track assets the term is generally applied as the track system is in a "State of Good Repair" when there are no or only short term operational restrictions due to track conditions.

On May 31, 2017, the assessment team was provided a list of then current speed restrictions due to track infrastructure defects and track infrastructure conditions which indicated there were 64 track infrastructure based restrictions on the railroad at that time. On July 3, 2017, the assessment team was provided an updated list of Speed Restrictions and the number was reduced to 58. Some of these restrictions have been in place for many years and the track condition requiring the speed restrictions will take major rehabilitation to resolve. This is clearly a barometer of the overall health of the Green Line and the efficiency of the resources that are deployed to maintain the infrastructure.

Some track conditions on the Green Line are far beyond the scope of normal maintenance and will require specialized contractors to resolve. As an example, due to the condition of the subgrade in areas where there are mud spots which lead to repetitive maintenance issues for surfacing and alignment, these "maintenance issues" will never be permanently corrected until the underlying subgrade and drainage issues are resolved. Until these underlying issues are addressed, the frequency of these types of problems will increase and the severity of their effect on safe operations will increase.

Per the MBTA, they have been working with a contractor since October 2016 to develop a track renewal plan to address the Green Line Infrastructure needs and have begun to develop a five-year plan to return the Green Line to a State of Good Repair. Additionally, they report that they have had an on-call contractor on the property to address priority issues system-wide with much of the work focused on larger Green-Line issues.

Based on the field observation by the assessment team, it is recommended that this program be accelerated with additional resources being committed and focused solely on the Green Line.

Maintenance Management Record Review

Maintenance Record Management is a fundamental function of any maintenance department. Proper documentation and record retention is a principal step in any good transit track maintenance program. Documentation provides a thorough knowledge of the history and present status of the operational railroad. It provides the Track Maintenance Manager with a clear snapshot of the conditions (i.e. Wide Gage, Surface, Cross level, alignment, etc.) and the condition of the components that make up the track structure whose degradations and failures, create the above mention conditions. Thus, it provides a basis of where resources should be focused in the present, what resources (i.e. personnel, equipment, funding, access) are required for planning purposes and what activities will be needed in the future to assure a high level of operational readiness and what improvements can be made in the track maintenance management process.

Additionally, record thoroughness and record retention not only assists maintenance management personnel in their maintenance functions but also is required for other agency issues such as risk management, legal responses to lawsuits and regulatory requirements.

The following is a breakdown of the records which were provided to the assessment team to review per the RFR requirements.

Condition Assessment Records (Inspection Reports, Geometry Reports, Rail Profiles, UT Reports)

<u>Contract Inspection Records</u>

Contractor produced geometry reports, rail profiles and UT reports were reviewed by the assessment team and found to be compliant to industry recommended practices.

In performance of Track Geometry, Rail Profile and Ultrasonic (UT) rail inspections, these contractors produce standard exception reports which are submitted to the Green Line Managers immediately after inspection runs and in electronic format. These reports are analyzed and verified by E&M Engineers. The maintenance managers use these reports to prioritize their work efforts, validate walking inspection thoroughness and should be using them to address any immediate issues which impact or threaten the safe movement of trains on the railroad.

The retention of these records for the time period prescribed in the Track Maintenance and Safety Standards Manual appears to be compliant with section LRT213.237. The assessment team was not provided enough information to determine if there is a “designated location” for storage of these records as required by the standard.

To validate accuracy from the MBTA contractors, the assessment team ran inspection vehicles on some portions of the Green Line to compare geometry findings. The analysis between the records produced by the contractor and the output of the Protran vehicles demonstrated that the data being produced by the contractor vehicles is fairly accurate but can have considerable amount of "drift" in exact locations of exceptions. This means that chainage information can be as much as several hundred feet off in identifying exception location. This is not unusual and many transits struggle with this issue and require the contractor to analyze and "scrub" data for accuracy. Below are examples of the data:

[redacted]

Geometry defect data taken from Mermec report on the Green Line B East Bound run. The wide gauge reported at chainage [redacted].

From the Calisto run on the same track, the wide gauge was also found as shown below on the Calisto Defect report, to be at chainage [redacted] to [redacted]

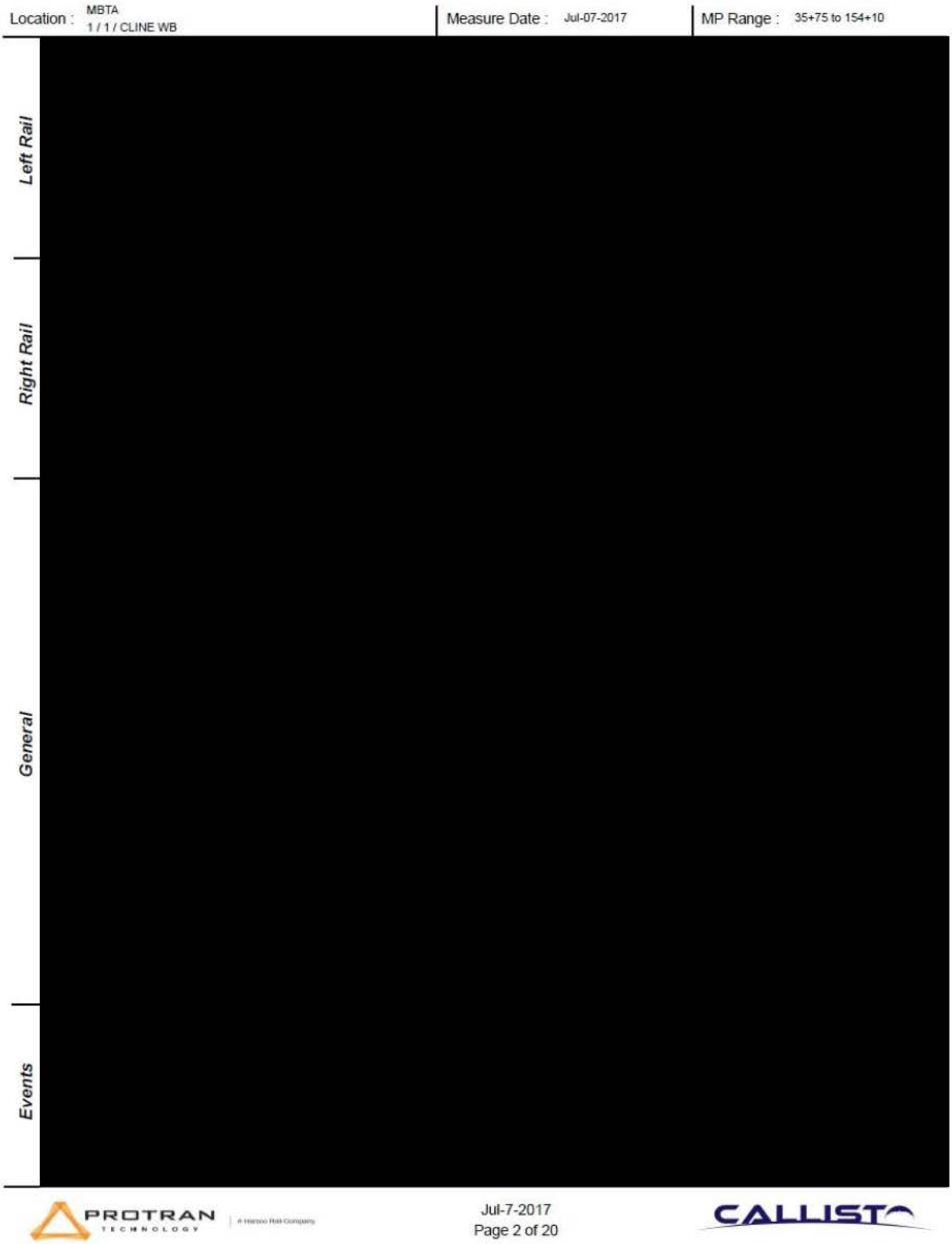
[redacted]

From the pencharts (seen below) of both systems, location problems can also be seen.

It can be seen that the penchart traces are very similar with just a few minor exceptions which is a good indication of the relative accuracy of both systems.

[redacted]

The Mermec systems identifies the wide gauge defect at chainage [redacted]



Calisto identifies the wide gauge defect at chainage 48+75, a difference of 100 feet.

[redacted]

Mermec identifies the middle of the first curve to be at chainage [redacted]

Location : MBTA 1 / 1 / CLINE WB | Measure Date : Jul-07-2017 | MP Range : 35+75 to 154+10

Left Rail

Right Rail

General

Events

[redacted]

PROTRAN TECHNOLOGY | A Harsco Rail Company

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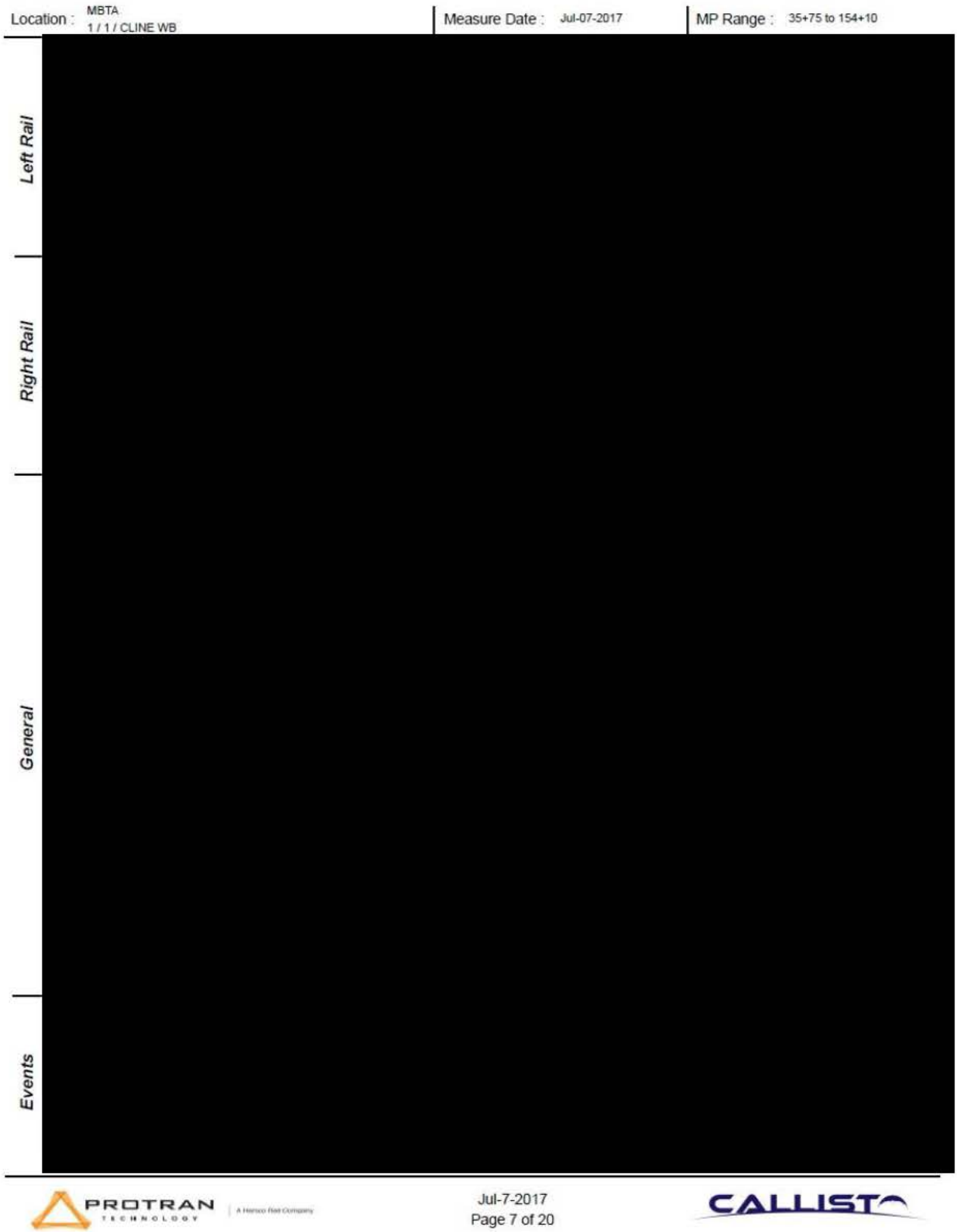
CALLISTO

Calisto identifies the middle of the first curve to be at Chainage [redacted] a difference of 110 feet.

[redacted]

Mermec wide gauge defect located at chainage [redacted]



Calisto wide gauge defect recorded at Chainage [redacted], a difference of 145 feet

The above shown data demonstrates the "drift" that can occur on geometry runs. Other data compared to the Mermec data showed that the results obtained from running the Protran track geometry vehicle

(Calisto) emulated the results given by the Mermec vehicle (once the location was adjusted) except for a few twist readings. There was a discrepancy in twist31 and twist62. This was field verified so it is critical that inspectors and engineers are aware of techniques, such as string lining, to validate these exceptions as well. Overall, most of the geometry exceptions reported by the Mermec system were found to be valid.

Protran Technologies operated their ASIV (Automated Switch Inspection Vehicle) over portions of the Green line in order to obtain rail profiles and to verify track geometry readings obtained by the Calisto Vehicle. The geometry readings duplicated one another for those locations where the two vehicles ran in tandem and both had mimicked the Mermec data as well (as noted in above section of this report).

Rail profile data also shows the wear patterns on the rail and was very similar to the profile data obtained by the Mermec TGV. In curved track, the outside rail showed wearing on the gauge corner of the rail and the formation of the shelf on the gauge corner ½ to 5/8 inches down from the top of ball. The inside rail also showed rail wear on the top of rail closer to the gauge corner. This type of wear can be reduced with the use of rail lubrication.

Example rail profile views from the ASIV System are in Appendix C of this report.

Walking Inspection Records

For walking, on-foot inspections, there are two standard track inspection report forms; Daily Track Inspection Report, and Turnout Inspection Report, which were provided to the assessment team for review.

The Daily Track Inspection Report form provides for a considerable amount of information to be passed from the Track Repairperson to the Section Foreperson and Supervisor. It contains, to and from locations, direction, starting and ending marker locations, defect and component codes, and remedial actions taken. There is also a text box for detailed description of defects. This form is a good foundational document for the agency to start inputting defects and assessment information into Optram and Trapeze when they get those systems operational.

Retention of these documents is subject to requirements as outlined in section LRT213.241 Inspection Records. This section states that "A written record of each track and/or rail inspection required will be kept on file." The requirement states for a period of 1 year after the inspection. This requirement is not being followed and there are no formal document management processes being used in the field. Document retention is left up to the individual supervisor and does not have any uniformity or similarities between supervisors. This needs to be rectified for full compliance to this requirement.

In review of the Daily Track Inspection Report demonstrates that there are personnel who are performing inspections that either lack knowledge or have not been properly taught how to provide quality assessment information. Some forms lack basic information when a defect is described. As an example, there are several reports stating chipped switch points, dips in rail or side wear but there are no measurements to provide for the manager or engineer to evaluate the condition of the defect. This is inconsistent with best industry practices for complete documentation of defects observed.

One additional concern that the assessment team has with the daily inspection process is the lack of documentation regarding "non-inspectable" areas. No inspection reports provided by the MBTA had any references to areas where physical obstructions were preventing a proper assessment of track components. Note: This comment is focused on areas which are not part of embedded track (which is covered under section LRT213.334) but areas which are obstructed by dirt, debris, vegetation, sand, and other materials. This situation must be fully documented and other methodology put in place for accurate inspections. Currently, this situation is non-compliant to inspection requirements as the areas are not being inspected to the standards as required by both MBTA, and DPU requirements.

The Turnout Inspection Report is a standard form that is used to perform "Switch Certification" per Section LRT213.235. These forms are inadequate for documenting all the defects that an inspector could find during a detailed inspection of a turnout. Additionally, the form provided to the Assessment Team is for Green Line Tee Rail only. No Turnout Inspection Forms or documentation for girder rail or tongue and mate turnouts was provided, however, Section LRT213.235 states "This process directs that <u>all</u> revenue service turnouts are thoroughly inspected on a quarterly basis." It is unknown to the assessment team if the other turnout types are inspected as required.

Of the forms that were provided to the assessment team there are detailed "actual measurements" but the information is minimal, and the form lacks critical information that most transits collect during detailed Turnout and Switch Inspections. The following is additional information that is normally collected during a detailed inspection but is not collected on the Green Line form:

- General Switch Information
    - Surface (Ballast, Concrete, Bridge)
    - Configuration
    - Size
    - Point Length
    - Point Type
    - Rail Type
- Switch Point Gaps
- Guard Face Gauge
- House Top Information
- Heel Block Bolt Information
- Track Geometry Crosslevel and Surface Information at specific points such as:
    - Heel of Switch Point (Turnout and Straight Side)
    - Point of Frog (Turnout and Straight Side
    - Rail Wear and Frog Flangeway Wear Information

The information collected above will need to be acquired for the FTA TAM requirements and for analytic data capabilities of Optram. It is recommended that the Turnout Inspection Report be updated to include the additional information listed above.

In addition, Turnout Forms for girder rail and tongue and mate switches should be developed if non-existent.

Work Generating Documents (Work Orders, Foreman Reports, Supervisor Records)

The Green Line MOW Management has implemented a basic "closed loop" maintenance process that demonstrates an understanding of the importance to having a work plan for the life cycle of track components. Engineering and Maintenance senior leaders have begun to build the foundation of this system with their plans to implement Optram as a linear asset management and analysis tool, a work order system (Work Bank), and a maintenance managers' "Dashboard" for monitoring the conditions in their area of responsibility.

A series of communications is necessary to convert an assessment record to a work request and then into a completed job. The first line of communication is between the maintenance Section Foreman to the Supervisor who must then pass the work request to the General Foremen to execute.

This is further advanced by the aggregate collection of the entire work force details in the General Foreperson's Daily Work Assignment Roster.

Currently, the Section Forepersons are using the MOW Division QA/QC Program Work Request and Acceptance Report form as a consolidated work request, track work tracking and quality control document. This process is cumbersome at best and leads to incomplete documentation of the work and hampers the ability of the agency to track defects from discovery to closure. Additionally, this consolidated form requires a regimented and systematic exchange of multiple pieces of paper to track a work effort. This process is in its infancy, is not clearly defined and needs to be further developed.

To track all the work, the MBTA has recently started tracking all defects that result in QA/QC report in a spreadsheet database that provides the Line Supervisor with an on-screen Dashboard to monitor the condition of the section of the Green Line they are responsible for. This is a good improvement but still needs further development.

Quality Assurance Reports

As defined in the Engineering and Maintenance, Management Plan, Quality Assurance is defined as follows:

Quality Assurance and Quality Control establishes the processes and procedures that are to be followed to ensure that all materials used by E&M and the work performed by departmental personnel meets the required standards of acceptability set by senior management. Quality Assurance refers to the adoption of policies and procedures to govern the process. Quality Control refers to the execution and documentation of the adopted policies and procedures.

E&M has developed its own QA/QC manual that guides the materials procurement process and the work activities performed across the Directorate. The manual is based largely upon the standards developed by the Authority's Quality Assurance/Quality Control department which works within the Design and Construction Directorate. These standards were developed to govern procurement of material and work activity associated with construction projects but many of the principles apply to E&M activities as well. QA/QC lacks the resources to perform quality control procedures outside the realm of construction work. Therefore E&M is responsible for the execution of its own quality control processes.

The E&M QA/QC plan includes an internal audit process that is designed to foster a culture of continuous monitoring, feedback, and improvement of work practices throughout the directorate. The process provides an independent examination of work practices with the involvement of the operating division. The QA/QC plan contains a detailed Standard Operating Procedure that detail the auditing process.

The assessment team was not provided a copy of the E&M's QA/QC Manual nor any documentation that any Quality Assurance activities are being undertaken. As such we are unable to determine the level of Quality Assurance built into any process within the Track Maintenance Management processes. Further, the assessment team saw no records which indicated any independent examination of work practices.

For Quality Control, the Track Maintenance group utilizes the above-mentioned QA/QC report as a part of the quality control process. When a Line Supervisor is notified either by completed work report or by his General Foreperson that work is complete, he then notifies his Section Foreman to provide a quality inspection of the work activity or repair job. This is a quality control process but it lacks formality of process and only reviews the finished product by visual means. There are no incremental or "in process" quality checks. This process leaves many questions about quality during the actual installation or work process. For Instance, if a piece of rail is replaced in an embedded track section, and the Section Foreman returns to the locations to perform a "post work" inspection, there is no possible way for his to determine if installation and fastening standards were correct below the covered track section.

Maintenance Management Records Review - Findings

The assessment team requested multiple documents for the last 24 months on maintenance activities as required by the RFR. In response, the assessment team was provided some documentation for the entire 24 month requested period, namely the documentation for automated inspections but the remaining documentation on day to day inspection and track work were not available after searches by the Track Maintenance team. However, it must be noted, the current Line Supervisor appears to understand the need of a standardized filing system and had all documents requested for the last 9 months. This is a good start but this process is also informal and does not follow any institutional procedure.

The agency needs a formal document control process and modernization in data collection. There are many commercially available programs on the open market for this. All the reports, other than outputs from automatic inspection contractors, are hand written. Inspectors, Supervisors, and Managers need to be supplied computers and software to document their efforts. The Engineering and Maintenance, Management Plan states that E&M uses Trapeze and Optram to track their assets and maintenance program. The assessment team did not see any use of these programs by the Green Line Supervisors or Managers but these were discussed as "planned" future management practices.

Currently, compliance to inspection cycles is a manual process which is not tracked or documented consistently as outlined in MBTA Policy, MOW-POL 2015-01, Section 8 – Reporting and Documentation Policy for Track Inspection.

Document retention is sloppy and needs to be clearly defined. There are lots of duplicate and incomplete documents. This places the agency at risk legally and out of compliance for not only MBTA Management Plan documentation requirements and DPU requirements and industry best practices.

Assessment team was told that it was the System Repairpersons who are trained to inspect track, however, the Daily Track Inspection Report form has a signature line for a Track Repairperson which can cause confusion on who is supposed to be doing inspections. Forms should be modified to reflect the correct title of the inspector.

Documents beyond 9 months ago are not available for review. They are possibly located in boxes in a shed or shipping container at Reservoir Yard MOW Building.

One of the primary findings relating to documentation is the lack of documentation regarding the immediate actions taken by the MBTA when "Red" conditions are found during automated, contractor supplied, geometry and UT inspection.

In interviews, the assessment team was informed by the MBTA that they have a draft procedure, EM-MOW-SOP 2017-02.00, that addresses this process, however, a review of the draft procedure does not provide for any immediate action to be documented for compliance to this policy. Further, the assessment team was not provided any documentation from previous inspections that this process was followed or implemented. Documentation provided showed that it took up to 8 days from the inspection for the Section Foreman to validate the findings of the inspections.

It is recommended that the MBTA immediately implement a policy that requires that any time a "Red" condition is flagged on an inspection vehicle, it is required that the vehicle stop, and a qualified person validates the finding and implements immediate corrective action or operational restriction to assure the safe passage of trains. Once immediate correction action is taken, this action is documented and archived. This type of policy is consistent with industry best practices.

Maintenance Management Process

The MBTA Engineering and Maintenance, Management Plan, states:

Engineering and Maintenance Vision Statement- Our vison is to provide best in class maintenance, engineering, customer service, and support by listening to and supporting our employees and customers. We will accomplish this by providing proper direction, honest and frequent communication, support, tools, positive feedback, and above all a safe work environment.

Engineering and Maintenance Mission Statement- Our mission is to provide world class, effective and efficient design, construction, and maintenance of the MBTA's infrastructure, through excellence in service. We will create a safe environment that facilitates growth, reflects the diversity of our customers, embrace Mass DOT principles, is honest, open and collectively supports and exceeds all of our employee's and customer's expectations.

For the two above Vision and Mission statements to be achieved, the Maintenance Management philosophy must be led and encouraged by the leadership of the MBTA. Management's dedication to a successful and well-focused maintenance program should be evident to the organization.

Maintenance efforts should be linked to the business goals of the MBTA which is to move passengers throughout the Boston area effectively and safely.

There are many positive signs that senior leadership as well as both Engineering and MOW Management are attempting to work closely together to achieve the framework to move to a more organized and fully effectual maintenance management organization to help fulfill the business objectives of the MBTA. However, there are many obstacles in the way which currently prevent the agency from moving from a "reactionary" mode to a "predictive" model or a world class in maintenance organization. It is critical to the management structure that both engineering and maintenance management partner with each other to clearly understand the issues at hand.

The current MOW Management team is attempting to implement a maintenance program that roughly follows a "Closed-Loop" asset management process where assets are inspected on a cyclic basis, conditions are evaluated, work is prioritized, and work is executed to return the asset to a pre-established standard for operation. This very basic Maintenance Management philosophy has many subcomponents and factors which determine its overall effectiveness. There are some activities underway that will ultimately assist the MBTA in being in a better position to address track infrastructure issues in a more expedient and efficient manner than they currently have. The following are four key area that are critical to the foundation of maintenance management and must be fully functional so that the management team and personnel can effectively perform their roles. These four key elements are:

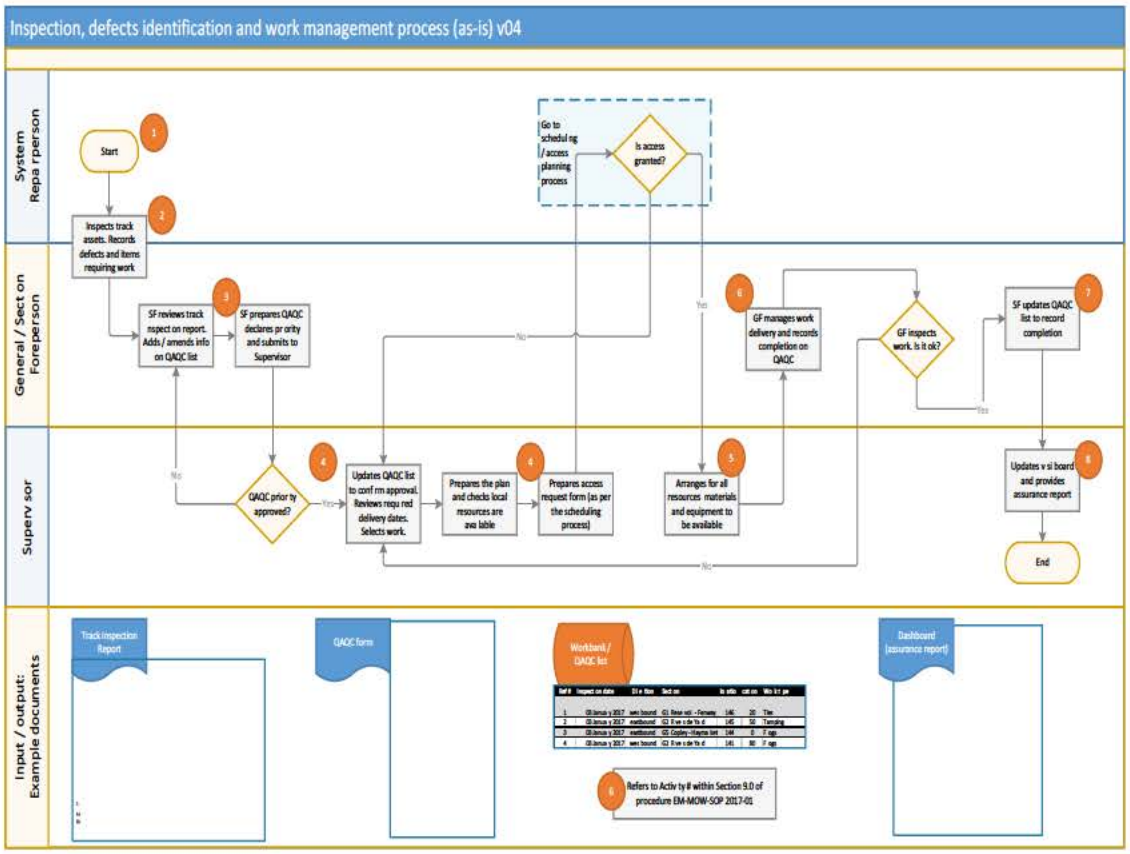
- Process Management
- Inventory Management
- Engineering Support
- Quality MIS System

These elements are discussed below:

Process Management

Understanding what is required for maintenance and the processes required for effective maintenance management is critical to being able to identify inefficiencies and subsequent corrective actions for improvement. The Engineering team along with Maintenance leadership is starting to formalize processes so there is uniform application across the department. This will allow these processes to be institutionalized and will clarify roles and responsibilities. It is recommended that a specific MOW/Track Department "Maintenance Control Policy" manual be developed. This manual should include all the processes, and policies regarding such things as inventory control, quality control policy, purchasing policy, configuration control, process control, life-cycle planning, inter-office coordination policies, and hazard management policies.

The assessment team was provided only one process control document. This document outlines the maintenance management process as shown below:



This process diagram is a good start to develop clear and concise procedures for all MOW activities and graphically outlines roles and responsibilities and anticipated outputs. It should be expanded to include the storage and archiving of the data and documents. It is clear, easy to understand and provides a true means to identify and reconcile any discrepancies should the process not be completed.

As the development of procedure documentation can be extensive, time consuming and multi-layered in an agency as large as MBTA, it is recommended that the agency prioritize all maintenance processes and then develop standardized procedures by priority level for all activities and functions within the MOW Division.

Inventory Control

In maintenance material planning, overlooking the smallest, most inexpensive part can shut down or interrupt very costly revenue operations. As such, having specific focus on inventory and the resources applied to assist maintenance managers in inventory are critical to a maintenance organization. This is especially critical in an operation like the Green line as they have both new and legacy systems.

One of the most consistent comments expressed by Maintenance Managers and Supervisors was the lack of parts and an inventory control process. This situation leads to managers and repairers using 'what is available" and sometimes incorrect parts. As a result, managers are frustrated with the time it takes for inventory to be specified, procured, and delivered. It is an impediment to effective maintenance to have a substandard inventory and parts process. This issue should be fully evaluated to address the impact on the efficiency of the maintenance function. Here are a couple

of examples where incorrect parts are being used out of necessity and "types" of components are mixed to maintain operations:

Figure 98 - Fabricated Weld-Mate Bar. Out of Standard. Used due to lack of parts.

Figure 99 - Example of both too short and too long bolts being used

Figure 100 - Two types of Girder Rail being used leading to mismatch.

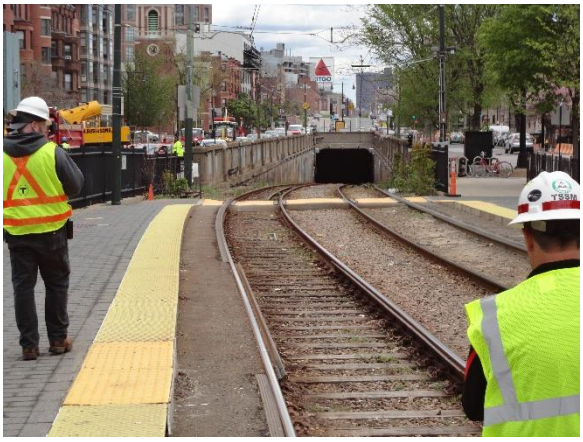


Figure 101 - Small section of girder rail mixed with tee rail.

As the MBTA makes efforts to be more efficient and to modernize their track infrastructure, it will be even more critical for maintenance inventory to be available and correctly specified. The assessment team would recommend that Maintenance team, led my MOW Engineering, determine where there are critical shortages in stock and what measures are necessary to assure that correct spare parts are available.

Engineering Support

The support of the engineering function for maintenance cannot be overstated. It is a critical function which must occur. Maintenance Engineering in most railroads and transit agencies have responsibility for standards, including design, materials, and maintenance and inspection standards. They are also instrumental in the development, monitoring and continuous improvement of the agencies preventive maintenance program and long-range planning. In review of other transit agencies, the maintenance engineering function has a partnership with the maintenance department which has the responsibility to execute the "engineered" program on a

day to day basis. It is not clear to the assessment team as to how involved engineering personnel are in the day to day maintenance operations.

In mature and well-functioning transit agencies, the maintenance engineer typically will have all or some of the following responsibilities:

- Ensures that track related equipment is properly designed, selected, and installed based on anticipated life cycle, maintainability, availability, and functionality.
- Ensures that equipment is performing effectively and efficiently through analysis collected through maintenance, inspection, and performance records.
- Establishes and monitors routine maintenance programs for rail replacement, fastener replacement, and other track components through work order analysis and other condition monitoring techniques.
- Provides analytical support for long range planning for system rehabilitation and upgrade.
- Reviews deficiencies noted during corrective maintenance.
- Provide technical guidance for Computerized Maintenance Management System (CMMS), Standards Manuals, Standard Work Procedures, and Standard Operating Procedures.
- Promotes equipment standardization, recommends spare part levels, and develops or participates in the writing of maintenance and component specifications.
- Available for consultation with maintenance technicians on an on-going and open-door basis.
- Monitors new technology and keeps management/staff appraised on the new developments within the field of track maintenance and inspection.
- Leads and champions quality assurance services including first article inspections and qualifications for outside services and equipment.
- Leads on-going and systematic quality control processes for component installation and maintenance and inspection processes.
- Develops standard and procedures for major maintenance jobs. Provides technical support during major rehabilitation projects, including timelines, resource allocation and material specifications.
- Makes cost/benefit review of maintenance management programs for areas of responsibility and exchanges information with Maintenance Managers and Leadership for any necessary adjustments to requirements or resources.
- Provides technical guidance for PM and PdM (Predictive Maintenance) Programs.
- Continuously monitors performance indicators for maintenance management program effectiveness and impact to life cycle requirements.
- Optimizes maintenance strategies and recommends adjustments to maintenance management.
- Primary responsibility for analyzing equipment operating data, trend analysis and predictive maintenance programs.

The Engineering and Maintenance organizations are under the direction of the Director – Engineering and Maintenance. This is an efficient organizational structure to assure that engineering support is provided for maintenance personnel. In review of the current structure, the Superintendent – MOW Green Line Light Rail is vacant. As this is a critical position it is recommended that this position be filled with a qualified person as soon as possible. Further, it is recommended that maintenance engineers get further involved in the day to day maintenance management operations to perform the functions as listed above.

Maintenance Management MIS System

Currently the MIS system being used by the Green Line Track Department is very elementary and provides limited data for managers to quickly ascertain the condition of their track structure. What was demonstrated to the assessment team was a standard excel spreadsheet (Work Bench) with a listing of open work orders (QA/QC Reports) set by priority. This is an advancement from their previous "paper only" process, yet still it is paper intensive and relies mostly on the input from the Inspector thru Section Supervisor to the Supervisor to populate the data. Any data from the automated inspection processes still requires hand written QA/QC reports to be added to hand typed into the "Work Bench" work order listing.

Commercially available computerized rail maintenance management systems provide managers with a tool to have readily available information to maintain their infrastructure at a level that ensures steady-state performance. These systems allow for the collection of asset assessment data from many sources including notes from walking inspections and inputs from automated inspections. Additionally, these systems use assessment data along with work order data and renewal data to analyze contemporaneous conditions and to perform predictive maintenance regarding lifecycle performance of the track structure and its individual components.

According the MOW leadership, they are in the process of implementing such a MIS system named OPTRAM. This system, once fully developed, will not only assist the MBTA to make the appropriate decisions on the true condition of the system, but they will be able to trend failures, monitor inspection compliance and perform predictive maintenance. It is recommended that this system be fully developed including its work order system, daily inspection data collection capabilities and analytical capabilities.

Maintenance Management Process - Findings

Based on the physical observations of the Green Line track infrastructure, it is very apparent to the assessment team that maintenance and renewal activities are long overdue. Organizations tend to go through cycles regarding their levels of commitment and investment in the maintenance of the system. Historically, this occurs when the system reaches a tipping point when operational interruptions and other very public failures occur (i.e. derailments, crashes, injuries, etc..). It is our finding that this is the current situation facing MBTA. Fortunately, the current management team understands the need to maintain the system in a safe operational level.

The current Maintenance Management team has put some efforts into setting the foundational structure for an effective maintenance organization. It is critical that these items listed above become fully developed and the full funding is made available to implement Optram. Process development, and increased engineering and inventory control can be achieved with renewed focus in these areas.

These efforts will take continued support from senior MBTA leadership and require a commitment from all those involved in these processes. The maintenance management philosophy is sound but needs further development and resources to be "world class" as stated in the Mission and Vision statements.

Maintenance Training

Training Curriculum and Employee Requirements

Since all track inspections must be performed by Qualified Personnel as defined by the FTA, a Qualified Person must have at least:

1. Two years of satisfactory related experience inspecting, constructing, or maintaining track and special track work; or
2. A combination of experience in track maintenance and training from a qualified course in track inspection or from a college level educational program related to track inspections; or
3. Have had progressive satisfactory supervisory experience on another transit or railroad system; and be able to demonstrate to the RTS that he or she:
   a. Knows and understands the requirements of these recommended practices;
   b. Can detect deviations from these practices; and
   c. Can prescribe appropriate remedial action to correct or safely compensate for those deviations.

The Training course noted in item 2 above must contain the following materials:

i) Introduction to Track Inspection
   - Serviceability
   - Inspector qualification/Responsibility
   - Types of inspections that must be done, why, where, when
   - Safety Standards and Maintenance Standards
   - Inspection cycle times for each type

ii) Track Component Inspection
   - Rail, (wear, fatigue, action plan)
   - Cross ties (wood, concrete, direct fixation)
   - Rail fasteners and other track material
   - Turnouts, crossovers, and diamonds
   - Restraining rail
   - Ballast, subgrade
   - Track structures,
   - Crossings, (roadway and railway)
   - Wayside equipment, lubricators, wayside inspection systems, etc.

iii) Track/Train Dynamics

iv) Track Buckling and Pull-apart Inspection

v) Track Geometry Inspection
   - Methods of inspection
   - Measurements, standards and procedures
   - Gauge
   - Alignment
   - Profile, surface, crosslevel and warp

vi) Power (Catenary Power Inspections)

vii) Inspection Reports
   - Inspection records.
   - In-house job aids

This training must be given initially to all personnel who wish to become qualified and a refresher given annually to ensure the individuals remain up to date in their track knowledge.

Employee Training Records

Training records were obtained for the Track Maintenance personnel which indicated when they were hired and when they took the training.

The documents indicate that the System Repair personnel were recertified in the fall of 2016 and will be required to recertify again in the Fall of 2018, giving two years between recertification training. Although the Assessment Team was provided course outlines, they were not provided the content of the recertification training course and as such are not able to comment on the adequacy of the two-day recertification training course.

Of all the attendees shown for the Recertification, only 8 of them are shown as having taken the 10-day course in 2015. There are several reasons as to why this may have occurred; either the paperwork is incomplete and incorrect, the recertification course is being used as the initial course or the Assessment Team did not receive paperwork for a class which had previously run.

Lesson Plans and Support Documents

Two lesson plans outlines were shared with the investigation team. These are for Track Inspection (System Repairperson) and for Track laborer. Course content is as follows:

1. **Track Inspection (System Repairperson) Training**

Scope: 10-day course consists of both classroom and field training. Classroom portion included power point presentation slides and props. Field inspection training will include defect identification and report writing. Course concluded with a written exam (50 questions)

Schedule

The 10-day course will cover all aspects/areas of the MBTA Track Maintenance and Safety Standards Manual (HRT and LRT) as well as portions of the MBTA Safety Rulebook relating to R.O.W access.

Course Curriculum

1. Right of Way Safety
    - i.) PPE Requirements
        - -Boots, safety vest, safety glasses, radio, Checklist, flags, flagperson
        - -additional tools required (wrench/hammer)
    - ii.) R.O.W access procedures
        - -day/night orders, calling on/off, radio communications
    - iii.) R.O.W Hazards
        - -trains, high rail equipment, electricity, slipping, trip hazards, limited/no access areas ("level one")

2. Intro to Track Inspection
    - i.) HRT/LRT Differentiation
        - -separate manuals for each type
        - -unique track configurations for Green Line
    - ii.) Color-coded Maintenance threshold limits
        - -green, yellow and red; what are they and how to interpret in the manuals?
    - iii.) Speed Restriction Application
        - -S.O.P. for removal/installation
        - -who is responsible? / tracking

3. Roadbed and Track Structure
    - i.) Ballast
        - -properties/types
        - -drainage (proper vs poor (fouled))
        - -vegetation (issues with and control of)

    - ii.) Crossties
        - -wood/concrete/duo-block/mono-block
        - -functions
        - -crosstie defect identification
        - -tie plates (type and function)

    - iii.) Rail
        - -type (115, 85); how to identify
        - -defects (definitions of; how to identify)
        - -jointed rail (bars and bolts); pull-apart
        - -rail wear (identification, measuring)
        - -rail end mismatch (measuring)
        - -rail welds (types)
        - -CWR (definition, function, identification)

    - iv.) Restraining Rail
        - -types
        - -functions of
        - -lubrication
        - -flangeway measurements/bolt maintenance

    - v.) Track Fastener/Anchor
        - -cut spikes, lock pins, Pandrol, e-clips, J-anchors
        - -function

    - vi.) Turnouts/Switches/Crossovers
        - -types/styles (RH/LH, guarded/unguarded)
        - -components (switch rails, frogs, stock rails)
        - -point wear identification and maintenance
        - -switch certification (explanation/demo)

    - vii) Other Track Construction Types
        - -Direct Fixation
        - -Floating slab construction

4. Track Geometry
    i.) Track gauge
        -standards (wide, narrow, design)
        -how to measure
        -static or dynamic?
        -gauge transitions

    ii.) Horizontal Track Alignment
        -definition
        -types of curves (spiral, compound, simple)
        -misalignment (kinks) identification
        -how to detect deviations from standards

    iii.) Track Surface
        -definition
        -crosslevel (how to measure)
        -superelevation (how to measure)
        -warp/twist (what is it)
        -how to detect deviations from standards

5. Additional Track Appliances
    i.) 3rd Rail (contact rail)-heavy rail only
        -types (85 lb, 84 lb, 150 lb)
        -defects
        -gauge and maintenance limits
        -insulators (maintenance of)
        -anchors (maintenance of)

    ii.) Lubricators
        -location of
        -inspecting/filling
        -grease maintenance

    iii.)Bonds
        -type (c-bond, WEZE bond)
        -identification
        -maintenance of

    iv.) Derails
        -type
        -inspection/maintenance of

6. Track Inspection Schedule
    i.) Rules and Regulations (DPU, FRA, FTA)
        -where is the oversight?
        -frequency (difference between HRT and LRT)
        -Qualifications (who is qualified?)

    ii.) Inspection Report

-How to write a proper report
-make sure it's signed
-record keeping

iii.) Switch Certifications
-how to certify a switch
-frog guard check/guard face/back to back
-frequency of certifications
-tools required

7. Girder Guard Rail (Green line only)
i.) Girder guard rail type
-149 lb, 128 lb, 118 lb, NP4A identification
-maintenance standards for

ii.) Tongue and Mate Switches
-identification/operation of
-inspection of (switch certification)

iii.) Embedded Track (in Pavement)
-how to inspect (what to look for)
-types (asphalt, concrete, rubber pads)

Track Inspection (System Repairperson) Recertification (16hours)

7am – 3:30pm (8 hours)

1.	Introductions Distribute Standards Manuals	1/2 hour
2.	Safety Topic	1/2 hour
3.	Track Maintenance Standards (break) Part A – General Part B – Roadbed Part D – Structure	4 hours
4.	Lunch	1/2 hour
5.	Track Maintenance Standards (cont.) Part D – Structure Part C – Track Geometry	3 hours
		Total: 8 hours

7am – 3:30pm (8 hours)

1.	Track Maintenance Standards (break) Part C – Track Geometry (cont.)	5 hours

Part E & F – Appliances & Inspection
Part G – Girder Rail Trackwork

2.	Break	1/2 hour
3.	Track Maintenance Standards CWR	1/2 hour
4.	Re-Certification Exam	2-1/2 hours
		Total: 8 hours

Track Laborer Training

Scope: The Track Laborer training course is a one-week program that will instruct students on basic track component identification, proper use of track-related hand tools and basic track maintenance techniques. Students will also be instructed on proper rigging techniques. It will include classroom (Power Point presentation and field training). A track tool competency checklist will be completed for each student to that the student can safely operate hand tools and properly identify track components

Schedule

The 5-day course is an introduction to the MOW Department; its responsibilities and activities related to track maintenance. Portions of the MBTA Safety Rulebook relating to R.O.W access will also be included.

Course Curriculum

1. Right of Way Safety
   - i.) PPE Requirements
     - -Boots, safety vest, safety glasses, radio, Checklist, flags, flagperson, whistle
   - ii.) R.O.W access procedures
     - -day/night orders, calling on/off, radio communications
   - iii.) R.O.W Hazards
     - -trains, high rail equipment, electricity, slipping, trip hazards, limited/no access areas ("level one")
2. Intro to Track Maintenance
   - i.) Track Tools (hand tools only)
     - -spade shovel (digging ballast, hand tamping)
     - -track broom (cleaning debris from rail/ bars)
     - -track hammer (installing track spikes)
     - -sledge hammer (striking chisels/punches)
     - -chisel (removing bonds, breaking joint nuts)
     - -punch (removing joint bolts from joint bars)

-lining bar (shifting ties/rail, operate track jack)
-claw bar (remove spikes, prying rail)
-track wrench (loosen/tighten joint bar bolts)
-track jack (lifting rail/ties)
-tie tongs (lifting/moving ties)
-restraining rail wrench (115/132 assemblies)

ii.) Identify Track Components
-ballast
-crossties (wood, concrete (mono-duo block)
-Rail ("T" rail types, girder rails, 3rd rails)
-fasteners (cut spike, lock spike, pandrol e-clip)
-anchors (pandrol e-clip, J- anchors)
-track plates (cut spike, pandrol)
-joint bars ("T" rail, girder rail, compromise)
-joint bar bolts (7/8", 1")
-gauge rods (standard, single hook)

iii.) Rigging Techniques (w/overhead crane)
-sling types (nylon/polyester, rope, steel)
-proper sling placement (centering a load)
-centering/marking rail for lifts
-hand signals (proper communications)
-positioning for lift (where to stand/guide load)

Training Review – Findings

These courses appear to be appropriate as far as the FTA is concerned for course content. However, at the time of the assessment, the assessment team found that the Green line did not have a Training Department and they were only providing the required Inspection related training by an on-call trainer. (Note: Post assessment, the DPU has been notified that a Training Manager has been hired and is evaluating the efficacy of the current training program.)

There are many current ongoing issues that relate to the lack of training and refresher training. The current method of training is inadequate. We believe this insufficiency is the core of many problems. For example, the recent derailment of a revenue vehicle when a track crew allowed a train to pass over 8 unsecured tie plates, can easily be attributed to a lack of knowledge on track/train dynamics and the sequencing of maintenance work during revenue service. A good quality training and in-field mentoring program would provide personnel with the knowledge currently needed especially when the agency wants to utilize as much available track time as possible including daytime between rush hours.

The MBTA's main goal is to ensure that the system is safe. This is where the training facility comes into play. All personnel should be properly trained and retrained at regular intervals. Training needs to be improved by enhancing the existing track standards and creating better guidelines.

Each job classification from Laborer to Supervisor should have specific skills, knowledge, and behavior requirements. In most agencies, these are defined in the Position Classification Description. Once a person receives a new position there needs to be, in place, a laid-out plan for training that individual in the skills and knowledge needed to fill this new position.

It is the MBTA's duty to train and monitor Supervisors, General Forepersons, Section Forepersons, Equipment Operators, Track Repairpersons, System Repairpersons, Welders, and Laborers properly. There must be proper and scheduled follow up reviews to make sure each of these employees is consistently able to perform their duties safely and efficiently. If a problem occurs it should never be due to lack of proper training.

Significant findings for training include the following:

- They do not mention how often a refresher would be given (or if there is a refresher for the Track Laborers).
- There is no standard for a passing grade or what the prequalification of the student must be.
- There are some listings in the rosters for refresher training but no record of initial training.
- These were the only three basic courses provided to the evaluation team. Most similar Transit Agencies and railroads have specific and specialized training for key maintenance elements such as:
    1. CWR Maintenance to include: Installation, inspection, maintenance, and adjustment of CWR
    2. Track Maintenance
    3. Derailment Investigation
    4. Wheel/Rail Dynamics
    5. Use of both Hand and Power Tools
    6. Track Geometry
    7. Etc.
- There are no specific classes or curriculums for supervisors or managers. Maintenance Management classes should be provided for personnel at various levels within the maintenance organization. Such classes should include:
    1. Maintenance Leadership
    2. Strategic Maintenance Planning
    3. Use of Data for Maintenance Planning.
    4. OHSA 80 Hour Supervisor Class
    5. Etc.

Conclusions and Recommendations

The overall conclusion of the Assessment Team is that the Green Line MOW Infrastructure is safe for revenue operations but requires continuous monitoring, diligent oversight, increased investment, and a continued focus on track geometry to remain in the safest operational state possible.

The MBTA needs to continue in its efforts to rebuild and upgrade the track infrastructure and identify its Capital needs. Additionally, it must undertake a baseline review to assure that proper balance is maintained between operational requirements, and maintenance requirements. The time for inspection and maintenance needs to be built into the operating schedule.

In preparation for answering all the requirements of the RFR a full evaluation of the overall status of the MBTA Green Line MOW infrastructure including its condition, resource levels, training

program status, maintenance management philosophy, records management, and standards adherence, is included in the body of this report.

As an oversight agency as defined in 49 CFR 659, the primary concerns are the State of the Track System, the Ability of the MBTA to Maintain the Green Line to Acceptable Levels and the Adherence of the MBTA to their own and DPU Standards. As such, the following conclusions and recommendations are offered for these three primary issues:

State of Track System

The MBTA Green Line track is in need of an aggressive maintenance program due to the fact the track is in need of significant rehabilitation. The system is safe but there is a need of renewal in many locations. The MBTA must increase Capital Funding and Grant Allocations to restore and modernize the track

Ability for MBTA to Maintain a Safe and Efficient Light Rail System to Acceptable Level

The current maintenance philosophy of reactive maintenance and trying to maintain the legacy track system is ineffective and costly. The system is deteriorating at a rate that far exceeds the maintenance departments' capabilities to manage without significant investment and additional resource allocation

Modernization and standardization of physical infrastructure is critical to the long-term viability of the overall system. Capital expenditures must be increased for this effort and senior leadership must be willing to articulate the need for modernization to those in control of the budget and roadway access.

The maintenance requirements to keep the No. 8 cars operating safely are barely attainable given the level of access, personnel and budget provided. The system with its current 58 speed restrictions is a clear indication that current resources are exhausted and extended beyond their capabilities.

The current Track Maintenance and Safety Standards are barely adequate for requirements of maintaining the Green Line light rail system for the No. 8 vehicle. Geometry standards must have special focus as the vehicle is susceptible to derailment with any minor geometry deviation. The standards have not been updated to current APTA and FTA recommended best practices and consequently are inadequate to increase the performance of the track structure to a level of safety and operational viability greater that the system is currently experiencing.

Adherence to Maintenance Standards and 220 CMR Section 151.11 and 151.12

The MBTA is facing many unique challenges to maintain the infrastructure to the Maintenance Standards as described by either their own MBTA Track Maintenance and Safety Standards or to 220 CMR Section 151.11 and 151.12.

As shown above in the body of the document, MBTA staff is making a considerable effort to try to maintain the system to current standards. Their efforts are for the most part are achieving this requirement but issues are of such magnitude that Out of Standard conditions develop very rapidly and their resources are stretched to the limit by the number of issues found on the system.

END OF REPORT

Appendix A – Summary of Recommendations

State of Track Structure

- Hire additional contactors and additional staff to augment the workforce to reduce the number of conditions on the Green Line that cause speed restrictions.
- Analyze the use of "Speed Restrictions" for locations where the "Maximum Authorized Speed (MAS)" may not be set correctly for the physical characteristics of the area. Discontinue the use of "Speed Restrictions" in these areas and adjust the MAS accordingly.
- Investigate the possibility of having extended "single tracking" events to allow additional track time for repairs and rehabilitation.
- Expand current plans for short and long term "diversions" as was successfully demonstrated this year at Commonwealth Ave. Bridge for renewal efforts. Investigate similar successful programs in NYCT, WMATA and CTA.
- Require Contractor to finish profile the rail to a smoother profile.
- Replace any worn rail which has developed a "shelf" with new rail.
- Increase track inspections on tongue switches which receive heavy traffic to assure 15° angle is maintained on top gauge edge.
- Develop Criteria for go/no go on rail grinding beyond "gauge widening" (i.e. defect size, depth, type, etc.) needs to be part of the renewal of Track Maintenance Standards.

Ability to Maintain Green Line at Acceptable Levels

- Implement a "Specialized Geometry Assurance" team(s) whose only focus is geometry issues on the railroad.
- Increase training on track/train dynamics for System Repairpersons (Inspectors) to assure a high confidence in monitoring geometry conditions on the Green Line. Document any findings and action taken.
- Determine Critical Parts and Critical Stock levels for track parts.
- Increase Capital Investment for renewing track infrastructure to a state of good repair.
- Increase Capital Investment for modernized track equipment specifically capable of negotiating the Green Line.
- Implement additional inspection processes such as a Portable Track Loading Fixture (PTLF) Program for sections of track where visual inspections are obstructed.

Track Department Records and Procedures

- Develop procedures for document management and retention.
- Develop "Maintenance Control Policy".
- Formalize and document all processes utilized within the management framework.
- Identify roles and responsibilities in all processes.
- Modernize Inspection and Work Order processes to efficiently manage any renewal and maintenance program.

- Update all forms used for assessments, work order request, crew assignments, QA/QC review and work order closing.
- Complete implementation of Optram and implement analytics for defect and condition trending.
- Assure that inspection, condition assessment and speed restriction paperwork is integral to MBTA's MAP-21 TAM Performance Reporting requirements for Fixed Guideway "Percentage of track segments with performance restrictions."

Track Department Training

- Continue having the new Training Manager evaluate the current training needs.
- Update position descriptions to include skills, knowledge, and behavior requirements to meet current organizational needs.
- Hire consultant to develop training requirements to match skills and knowledge requirements for all specific jobs.
- Develop and implement Standard Work Procedures for all track work jobs. Train personnel consistently to these standard work procedures.
- Develop a clear syllabus for each training class that includes learning objectives and pass/fail criteria.
- Develop a step-by-step guide for On-The-Job training.

Is the MBTA Green Line being Maintained to Standards

- Update Track Standards to meet current APTA and FTA Recommended Practices.
- Develop a "Black Condition" rating (Out of Service) for critical geometry, wear and fixation conditions which affect the safe passage of trains and equipment.
- Divide Standards Manual into two volumes. One volume is a "Engineering/Office Reference Manual", the other is a Supervisor and Track Inspectors "Pocket Size Field Guide".
- Expand the existing QA/QC Department to include internal oversight and quality audits of Engineering and Maintenance functions.

Specific Track Standards Updating

- Rewrite section LRT213.1 Scope and remove statements on combination of conditions. Add a section to the manual to specifically address "Combination of Conditions". When a combination of conditions at a given location exists, but none individually requires action, a qualified person (as designated in LRT213.7 and 220 CMR 151.11(4)) must evaluate the condition for protection and take appropriate action. Train dynamics, track geometry and track design, location of the track, maximum speeds over the area, and any other factors that could negatively influence the severity of the conditions found must be taken into consideration when evaluating the proper action(s) to be taken, particularly in special work and curved locations. A few of the major transit properties have adopted a rule on "Combinations of Conditions" (in compliance with FTA Best Practices) and have added a section to their manual that simply states the following;
  "*In the case of the inspector finding more than one defect at the same location, the degree of severity and therefore the speed limit may be affected. Should a combination of three or more defects occur at any one location, under the discretion of the inspector or track supervisor the severity level can be dropped a minimum of one classification for any combination of defects.*

For example, if three Yellow defects affecting three different parameters, are discovered at any one location, the Severity Level should be dropped to a Red Level. Please note, the defects must occur in three different parameters, that is, three yellow wide gauge defects shall be counted as one defect, however, a yellow gauge, with a yellow tie condition and a yellow cross level condition will be cause to drop the location to a Red Level. In addition, these defects must occur within a track length which matches the axle to axle spacing on a single truck."

- Develop reference section for maintenance criteria which will assist track workers on proper maintenance activities such as torque values for joint bar bolts, torque values for fasteners, screw spike and cut spike installation patterns for tangent and curved rail.
- Develop criteria for Minimum distance between of "unsecured tie plates" or "fasteners" for both inspection findings and maintenance work. (Note: In section LRT213.109 Crossties, there is a table for "Maximum Distance Between Non-Defective Ties (CTR to CTR)" but there is no reference in the manual for maintenance if the ties are still good but the fastening has either been removed for maintenance or the spike have been deteriorated and ties are still performing. This leads to ambiguous situations that could and have resulted in derailments.
- Develop criteria for the use of temporary measures such as gauge rods and cheater bolts (i.e. duration of use and installation).
- Develop a section on what is explicitly expected for both Maintenance and Inspection if an area of the track is obscured by either temporary issues (Sand, Vegetation) or permanent issues (road crossings and platform edges).
- Expand Part F – Inspection, to include as specific section on Automated Inspections by Contractors (i.e. Geometry, Ultrasonic, GRMS, Rail Profile, etc.). Include requirements for data analysis, immediate Red Condition validation, maintenance response and marking of such defects.
- Expand the specific criteria for the inspection of the obstructed areas included embedded track (Section 213.334). With 51 crossings and several miles of embedded track. This section should have specific criteria for evaluation and restrictions, especially for surfacing and runoff.
- Include forms and examples of how they are to be filled out consistently. Additionally, if the MBTA is migrating to a computerized system where defect codes and component codes will be used for a computerized MMS such as OPTRAM. Include defect codes and component codes in a quick reference table.

<u>Inspection Activities</u>

- Implement a policy which immediately validates and reacts to any "Red" Geometry or Rail condition while performing automated inspections. Assure any action is documented fully.
- Update Switch Inspection/Turnout Forms to be industry compliant. Assure girder rail and tongue and mate forms are developed/upgraded as well.
- Assure that Track Inspectors are fully trained in track/vehicle dynamics and are fully knowledgeable of track geometry requirements for the safe operation of the No. 8 vehicles.

<u>Documentation</u>

- Implement a document management policy which includes detailed revision control, retention requirements and storage requirements.

- Review the effectiveness and thoroughness of all maintenance record forms to include:
    - Inspection Records
    - Work Order Requests
    - Shift Work Reports
    - Quality Reports
    - Switch Certification Forms
- Determine whether the level of documentation being collected provides engineering and management with a clear understanding of the condition of the railroad and any analytics required to reduce the amount of reactionary actions.

Engineering Support

- Implement a Quality Assurance Program, including a Quality Assurance review, independent of Maintenance Management, reporting to the DGM of Maintenance to assure quality in all maintenance activities:
    - Inspection Compliance
    - Standards Development
    - Standards Compliance
    - Work Standards Adherence
    - Safety Requirements
- Expand the role of Maintenance Engineer to evaluate, prioritize and manage the oversight of the Track Maintenance Program.

Inventory Control

- Determine Critical Parts
- Determine Critical Parts Inventory and Re-Order Points
- Form a cooperative team between Maintenance and Procurement to fully understand each other's needs and requirements for support.

Maintenance MIS System

- Fully fund, develop and implement the System.
- Revise all Automated Inspection Contracts to all data input into OPTRAM System.

Management Practices

- Modernize Maintenance Management Program
- Develop a "Maintenance Control Policy" Manual
- Implement defect tracking system and closed loop "cradle to grave" process.

Vehicles

- Repair KLD Wheelscan technology installed at Copley Station to assist Rail Car Engineering in determining wheel tread issues (i.e. Hollow Tread, Flat Spots, etc.)

Appendix B – Comparison of Standards

Standard	**CMR 151.11 Standard**	**Requirement**	**MBTA Green Line 2008 Standard**	**Requirement**	**Compliant**		**Comments**
					Yes	**No**	
CMR 151.11 Track Inspections							
Track Inspection Frequency - All Inspections must be made according to the schedule set out in 220 CMR 151.11(2)							
151.11(2)(a): Schedule for Track Inspections	Light Rail Passenger - Service Track	Three Times per week with at least one calendar day interval between inspections.	LRT213.233(1)(a) Track Inspection	All LRT Track must be inspected a minimum of three times per week, yard track included, with at least on calendar day interval between inspections.	X		
	Light Rail Yard and Storage Track	Weekly with at least three calendar days interval between inspections, or before use, if track is used less than once a week.	LRT213.233(1)(a) Track Inspection	All LRT Track must be inspected a minimum of three times per week, yard track included, with at least on calendar day interval between inspections.	X		This requirement exceeds industry standards.

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
151.11(2)(b): Schedule for Track Inspections	Track undergoing or awaiting repairs.	Any track undergoing or awaiting repairs that has a speed restriction place on it shall be inspected at a frequency that will ensure safe operations at all times.	LRT213.233(1)(b) Track Inspection	Any LRT track undergoing or awaiting repairs upon which a speed restriction is assigned shall be inspected at a frequency that will ensure safe operations at all times.	X		
151.11(2)(c): Schedule for Track Inspections	Switches, Turnouts and track crossings.	Each switch, turnout, and track crossing must be inspected on foot at least weekly. In the case of track that is used less than once a **week**, each switch, turnout and track crossing must be inspected before it is used.	LRT213.233(1)(c) Track Inspection	Each switch, turnout, and track crossing must be inspected on foot at least weekly. In the case of track that is used less than once a **month**, each switch, turnout and track crossing must be inspected before it is used.	X		
151.11(2)(d): Schedule for Track Inspections	Special Inspections - Fire, flood, severe storm, etc.	In the event of fire, flood, severe storm, or other occurrence which might damage track structure, a special inspection must be made of the track involved as soon as possible after the occurrence.	LRT213.233(1)(d) Track Inspection	In the event of fire, flood, severe storm, or other occurrence which might damage track structure, a special inspection must be made of the track involved as soon as possible after the occurrence.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
151.11(3)(a): Schedule for Rail Inspections	UT - Internal Rail Defect Inspection	a. In addition to 220 CMR 151.11(2)(a), at least once a year a continous search for internal rail defects must be made of all rail in all passenger service track.	LRT213.237 Inspection of Rail	In addition to the inspection schedule outlined in LRT213.233(1), the DPU requires that at least once a year a continuous seach for internal rail defects (Ultrasonic and/or induction testing) must be made of all rail in revenue track.	X		
151.11(3)(b): Schedule for Rail Inspections	Joint Bar Inspections	b. Inspection equipment, including ultrasonic rail testing equipment, must be capable of detecting defects between joint bars, in the area enclosed by joint bars.	LRT213.237 Inspection of Rail	Inspection equipment must be capable of detecting defects between the joint bars in the area of the rail enclosed by joint bars.	X		
151.11(3)(c): Schedule for Rail Inspections	Defect Marking	c. Each defective rail must be marked with highly visible marking on both sides of the web and base.	LRT213.237 Inspection of Rail	Each defective rail must be marked with highly visible marking on both sides of the web and base.	X		

Standard	**CMR 151.11 Standard**	**Requirement**	**MBTA Green Line 2008 Standard**	**Requirement**	**Compliant**		**Comments**
					Yes	**No**	
Track Personnel Qualifications- All Inspections must be made by a person designated as qualified under 220 CMR 151.11(4)							
151.11(4)(a): Personnel	Personnel Qualifications - Section 4,a, Restorations and Renewals under Traffic.	The Transportation Authority shall designate qualified persons to supervise restorations and renewals of track under traffic conditions. Each person designated must have:	LRT213.7 Designation of Personnel to Supervise Track Maintenance Activities and to Inspect Track.	LRT213.7 Designation of Personnel to Supervise Track Maintenance Activities and to Inspect Track.	X		
	(1) Experience and Education	a. One year of supervisory experience in railroad track maintenance or,			X		
		b. A combination of supervisory experience in track maintenance and training from a course in track maintenance, or			X		
		c. A college level educational program related to track maintenance.			X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
	(2) Ability to:	a. Understand Inspection Requirements	LRT213.7 Designation of Personnel to Supervise Track Maintenance Activties and to Inspect Track.	LRT213.7 Designation of Personnel to Supervise Track Maintenance Activties and to Inspect Track.	X		Better Training is needed.
		b. Detect deviations from the inspection requirements.			X		
		c. Prescribe appropriate remedial action to correct or safely compensate for deviations.			X		
		d. Procure written authorization from the Transportation Authority to prescribe remedial actions to correct or safely compensate for any deviations from the inspection requirements.			X		
151.11(4)(a): Personnel	Personnel Qualifications - Section 4 b, Qualified persons to inspect track.	The Transportation Authority shall designate qualified persons to inspect track for defects. Each person designated must have:	LRT213.233 Track Inspections (2)	**Qualifications:** The MBTA shall designate qualified persons to inspect track for defects. Each person so designated must have:	**X**		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
		a. At least one year of experience in track inspections, or		a. At least one year of experience in track inspection, or	X		
		b. A combination of experience in track inspection and in-house training from a course in track inspection.		b. A combination of experience in track inspections and training from a course in track inspection or from a college level educational program related to track inspections.	X		
		c. Prescribe appropriate remedial action to correct or safely compensate for deviations.		c. Prescribe appropriate remedial action to correct or safely compensate for deviations.	X		
		d. Procure written authorization from the Transit Authority to prescribe remedial actions to correct or safely compensate for any deviations from the inspection requirements pending review by a qualified person designated under 220 CMR 151.11 (4) (a).		d. Procure written authorization from the MBTA to prescribe remedial actions to correct or safely compensate for any deviations from the inspection requirements pending review by a qualified person designated under 220 CMR 151.08 (4) (a).	X		

Standard	**CMR 151.11 Standard**	**Requirement**	**MBTA Green Line 2008 Standard**	**Requirement**	**Compliant**		**Comments**
					Yes	**No**	
				e. Detect deviations from the inspection requirements.	X		
151.11(4)(c): Personnel Records	Personnel records for those returning track to service and inspecting tracks.	Personnel records of designees under 220 CMR151.11(4)(a) and (b) shall show:	Personnel Records.				Unknown – Out of Scope
		1. Basis for each designation.					
		2. Records must be kept available for inspection or copying by the DPU.					
151.11(5): Inspeciton Records	Track Inspection Record Keeping Requirements.	a. The Transportation Authority shall keep a record of each track and rail inspection required to be performed; and such records shall identify the designee that performed the inspection.	LRT213.241 Inspection Records	**THIS IS ALL IT STATES:**			Unknown – No Reference in the MBTA Track Standards.

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
		b. The Transportation Authority shall designate a location where each original record shall be maintained for at least one year after the track inspection covered by the inspection record. The Transportation Authority shall retain a rail inspection record for a least two years after the rail inspection and for one additional year after remedial action is taken.		A written record of each track and/or rail inspection required to be performed shall be kept on file. The MBTA is required by the DPU to designate a location where the original record of each track inspection shall be maintained for at least one year after the date of the inspection. Original records of inspections for internal rail defects must be retained for at least two years after the date of the inspection and for one additional year after remedial action is taken. Complete details of inspection requirements can be found in the DPU regulations under Section 151.08(5)	X		Inspection records are to be kept at Reservoir Yard MOW Building but some cannot be found.
		c. Track Inspection Records and Rail Inspection Reports shall be: Completed the same day, and signed by the person making the inspection.			X		
		d. Inspection Records must specify: 1) The track or rail inspected. 2) The date of the Inspection. 3) Location of any deviation. 4) Nature of any deviation from the			X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
		established track standard. 5) Remedial action taken by the person making the inspection.					
		e. Records must be kept available for inspection or copying by the DPU.			X		
CMR 151.12 Track Maintenance							
151.12(1)	Track Maintenance - Ballast	Unless otherwise structurally supported, all track must be supported by ballast material which will:	LRT213.31 - Roadbed and Part D - Track Structure, T213.103 Ballast	Unless otherwise structurally supported, all track must be supported in another fashion (i.e. concrete slab, steel stringer, etc.) it shall be supported by material (crushed ballast granite) which will meet the following requirements:	X		
		a. Transmit and distribute the load of the track and railroad rolling		a. Transmit and distribute static track loads and loads	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
		equipment to the subgrade.		of passing trains to the subgrade;			
		b. Restrain the track lateral, longitudinally, and vertically under dynamic loads imposed by railroad rolling equipment and thermal stress exerted by the rails.		b. Provide lateral, longitudinal and vertical restrain under dynamic loads imposed by passing trains and from thermal stress exerted by the rails during extremes in temperature;	X		Many Areas not in compliance to this regulation but the manual has the language.
		c. Provide adequate drainage for the track.		c. Provide proper drainage for the track structure;	X		Many Areas not in compliance to this regulation but the manual has the language
		d. Maintain proper track cross level, surface, and alignment.		d. Facilitate the maintenance of track line, surface and cross level.	X		Many Areas not in compliance to this regulation but the manual has the language
			Ballast Type	Ballast used on the Green Line shall be A.R.E.M.A. No. 4 (sieve opening 3/4" to 1 1/2") unless otherwise specified. Ballast received from supplies that is of inferior quality, the wrong grade or contains dirt or	X		Newer ballast meets this criteria. Older ballast does not.

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				other contaminates (fines) shall be rejected.			
			Ballast Shoulders and Cribs	Page 17 " Under no circumstances should the ballast shoulder measure less than 6" horizontally. The ballast level in the tie cribs (area between ties) should be maintained even with the top of the ties or no less than 1" below top of the ties."	X		Many Areas not in compliance to this regulation but the manual has the language
			Ballast Shoulders and Cribs	Page 17 " Track which is in improper ballast condition (<6" shoulder, more severe than 2:1 shoulder slope and/or cribs lower than 1" from top of tie level) should receive immediate attention and speed should be restricted until repairs can be made."	X		Many Areas not in compliance to this regulation but the manual has the language

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			Disturbed Ballast - Major TB Disturbance	Page 17 "Disturbed track through lining and especially inspection or by any other means whereby the adhesion between ties and ballast has been broken, must be inspected prior to resumption of train operations. The inspection must be conducted by personnel designated as a Qualified Person to inspect track. Speed of trains shall be restricted to 50% of the normal operating speed over the track for a minimum of 24 hours after the completion of the work."	X		This language is difficult to understand. Not 100% sure the Tamper Operator is considered a "Qualified Person"
151.12(2)	Track Maintenance - Ties	Crossties shall be made of a material to which rail can be securely fastened.	LRT213.109 Crossties	Crossties used on the Green Line shall be 7" x 9" x 8'-6", 100% hardwood and shall conform to the requirements of AREMA Specifications for Timber Crossties. All Crossties shall be equipped with approved anti-splitting devices per the AREMA	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				Specification. All tracks shall have a sufficient number of crossties which in combination provide effective support and shall:			
		a. Each 39-foot segment of track shall have a sufficient number of crossties which in combination provide effective support that will maintain gage, surface, and alignment.	G.A.S.	a) Hold Gage within the limits prescribed in LRT213.53 b) Maintain track surface within the limits prescribed in LRT213.63 and c) Maintain horizontal alignment within the limits prescribed in LRT213.55.	X		
		b. The minimum number and type of crossties specified in 220 CMR 151.12(3) effectively distributed to support the entire segment; and at least one crosstie of the type specified in 220 CMR 151.12(3) that is located at a joint location.	Non-Defective Ties per 39' section		X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
151.12(3)	Non-Defective Ties per 39' section:	Each 39 Foot segment of track shall have the minimum number and type of crossties as indicated in the following table:		Each 39' section of track shall have a minimum number of non-defective crossties as indicated on page (18 of 51).	X		
	Tangent Track is considered: Track that is straight or has radius > 1000'	Max Speed [redacted] MPH - Tangent 6, Curved 6		Maximum Distance Between Non-Defective Ties (C/C) as indicated on page (18 of 51).	X		
	Curved Track is considered: Track having a radius < 1000'	Max Speed [redacted] MPH - Tangent 8, Curved 9		Maximum number of successive defective ties (Based on 24" Ties Spacing as indicated on page (18 of 51)	X		
		Max Speed [redacted] MPH - Tangent 8, Curved 10					
	Cross tie Conditions shall not be:	a. Broken through	Cross Tie Conditions, page 17 of 51	1. Broken Through - a crosstie with a vertical break completely through the thickness of the tie.	X		
		b. Split or otherwise impaired to the extent the crossties will allow ballast to work through,		2. Split or otherwise impaired to the extent that ballast from beneath the tie has worked through or	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
		or will not hold spikes or rail fasteners.		spikes may be pulled from the tie easily by hand.			
		c. So deteriorated that the tie plate or base of rail can move laterallly two inches relative to the crossties, or		3) Deteriorated to the extent that the tie plate of rail base (in the absence of a plate) moves laterally under dynamic loading more than 1/2" relative to the tie's surface.			
		d. Cut by the tie plate (or rail base) through more than 15% (nominally 1 1/8") of the tie's thickness.		4) Cut by the tie plate (or rail base) more than 15% (nominally 1 1/8") of the tie's thickness.	X		
		e. For track constructed without crossties, such as track slab track, track connected directly to bridge structural components and track over servicing pits, the track structure must meet the requirements of 220 CMR 151.12(3) in regards to gage restraint, rail support, surface and alignment.		Page 18. For track constructed without crossties, such as concrete slab track, track with rails directed conned to bridge structural components or track over inspection/service pits, the track structure shall meet the requirements for gage in LRT213.53, Track Surface in LRT213.63, and track alignment in LRT213.55	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
151.12(4)	Gage	Gage is measured between the heads of the rails at right angles to the rails in a plan 5/8 of a inch below the top of the head.	LRT213.53 Gage	For LRT Track (Green Line), gage is measured between the heads of the rails at right angles to the rails in a plane one half of an inch (1/2") below the top of the rail head.	X		
151.12(5)	Gage Limits	Gage must be within the limits prescribed in the following table:		Min track gage in LRT track is 56 1/8" (loaded condition). Train operation over track at gage less than 56 1/8" may be manually supervised (walked through) at the discretion of the M.O.W. Line Supervisor or Superintendent on site, based on their observations of train performance and the assessment of operational safety. (Gage limits are on pages 11 and 12 of 51).	X		
		Max Speed [redacted] MPH - Min 56" Max 58"					
		Max Speed [redacted] MPH - Min 56 Max 57 1/4"					

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			Gage Maintenance - General Notes	Transitions in track gage are used by design only in special track work, entering/leaving curved track with restraining rail and at joints where new rail is connected to old rail. At such joints, the old rail has gage face wear and/or has been ground to a 15° angle from vertical for compatibility with the modified Green Line flange profile.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				Transitions in track gage shall be at the rate of 1/2" in no less than 31', except in special trackwork and when entering/leaving restrained curves, which shall be as shown in the Design Standards. **Transitions in track gage between 1/2" - 1" shall constitute YELLOW coded track conditions and transitions greater than 1" shall constitute RED coded track conditions.** YELLOW coded gage transitions exceptions shall be restricted at ■ mph and repaired within 30 days. RED coded gage transition exceptions shall be restricted at ■ mph and repaired within 72 hours.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			213.121 Rail Joints	Bolted rail joints provide structural continuity by transferring lateral and vertical wheel loads between adjacent rails with no relative movement of abutting rail ends. Properly functioning joints permit longitudinal movement within the joint bars to accommodate expansion and contraction of rails due to thermal and/or mechanical stresses.	X		
151.12(6)	Rail Joints	Each Rail Joint, insulated joint, and compromise joint must be of the proper design and dimension for the rail on which it is applied.	213.121 Rail Joints	a) Each Rail Joint, insulated joint, and compromise joint shall be of a structurally sound design and dimensions for the rail on which it is used.	X		
151.12(7)	Rail Joint Bars	If a joint bar is cracked, broken, or because of wear allows excessive vertical movement of either rail when all bolts are tight, it must be replaced.		b) If a joint bar is cracked, broken, or because of wear allows vertical movement of either rail independent of the other when all bolts are tight, it must be replaced.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
151.12(8)	Rail Joint Bars	If a joint bar is cracked or broken between the middle two bolts it must be replaced.		c) If a joint bar is cracked or broken between the middle two bolts it must be replaced. d) IF both bars of a joint are cracked or broken between the middle two bolt holes or one of the bars is found to be completely broken through, a ■ mph speed restriction must be placed on the track until the bar(s) can be replaced. e) If both bars are found to be broken completely through between the middle two bolt holes, trains may operate over the joint only under the visual supervision of a person designed under LRT213.7 until the bars are replaced.	X		
151.12(9)	Rail Joint Bar Bolts	In the case of conventional jointed rail in passenger-service track, each rail must be bolted with a least two bolts in each joint.		f) In the case of conventional revenue service track, each rail must be bolted with a least two bolts in each joint.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
151.12(10)	CWR Rail Joints	In the case of continuous welded rail (CWR) track, each rail must be bolted with at least two bolts in each joint used to connect CWR Strings or to connect CWR to conventional rail.		g) In CWR Track, each rail must be bolted with at least 2 bolts in each joint used to connect CWR strings or to connect CWR strings to conventional rail. h) When any of the conditions of f) or g) are not met, a speed restriction must be put in place until the conditions is corrected.	X		
151.12(11)	CWR Rail Joint Bar Bolts	Each joint bar must be held in position by track bolts tightened to allow the joint bar to firmly support the abutting rail ends and to allow longitudinal movement of the rail in the joint to accommodate expansion and contraction due to temperature variations.		i) Each joint bar must be held in position by track bolts sized appropriately for the rail drilling - 1" bolts in 1 1/16" holes and 7/8" bolts om 15/16" holes. Bolts must be tightened sufficiently to provide adequate supporting for abutting rail ends and to allow longitudinal movement of rails within the joint to accommodate expansion and contractions due to mechanical and thermal stresses.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			Torch Cut Bolt Holes	j) No rail or joint bar having a torch cut hole should be used in revenue service track. If, under emergency circumstances, it becomes necessary to burn a bolt hole in rail or reconfigure a joint bar by torch cutting (slotted holes), speed over the track must be restricted to ■ MPH and the rail and/or joint bar removed from track within 72 hours.	N/A		
			LRT213.122 Torch Cut Rail	Only in emergencies and removed within 24 hours for revenue service track.			
151..12(12)	Restrictions and Notification	When any condition in 220 CMR 151.12(9) and (10) is not satisfied, an operating restriction must be put in place immediately until the condition is satisfied. The Transportation Authority shall notify the Director of the Transportation of the DPU of the imposition or removal of an operating restriction			X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
		within 48 hours of said restriction.					
Other Key Inspection Items;			LRT213.1 Scope - Combination of Defects	Page 7 of 51. "A combination of track conditions, none of which individually amounts to a deviation for the requirements of this section, may require remedial action to provide for safe operations over the track."	X		Recommend that in they adopt current FRA/FTA requirements when 3 or more conditions are found at any location.
			LRT213.2	DPU Regulations reference 220 CMR 151.08, Track Inspection and 151.08, Track Maintenance.	X		

Standard	**CMR 151.11 Standard**	**Requirement**	**MBTA Green Line 2008 Standard**	**Requirement**	**Compliant**		**Comments**
					Yes	**No**	
			LRT213.3 Application of Standards	Green - Track Conditions are not exceptions to MBTA Track Maintenance Standards and do not necessarily require immediate remedial actions.			Three standards do not specifically require OUT OF STANDARD conditions. Recommend that they adopt current detailed FTA standards format and adopt a fourth standard of "Black" which is OUT OF STANDARD.
				Yellow - Track Conditions which have reached or are closely approaching maintenance limits for train operations at normal posted speed.			
				Red - Track Conditions which **MAY** generate speed restrictions and at the most sever level are grounds for removing track from service until repairs can be made. Supervisory notification (immediate) is required and remedial action is within 72 hours.			

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			Normal Operating Conditions - Standards	The track maintenance guidelines are intended to apply to normal operating conditions. During maintenance activities or under temporary conditions, interim modifications of the Standards may be required and would be subject to existing site conditions.	X		.
			LRT213.4 Track Maintenance Strategies	See page 8 of 51.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			LRT213.6 Restricted Speed Rules	Any crack condition which may interfere with the safe operation or passage of Trains is considered an "obstruction". Protection shall be provided for any track which is obstructed or not considered safe for the passage of trains at the normal, posted operating speed. Protection shall be provided as outlined in SMI Special Order #98-2. Proper notification must be given using Restricted Operation Notification form found in the M.O.W. Division Book of Policies and Standard Operating Procedures. It is critical that the M. o. W. person responsible for the placement of a restricted speed order remain at the scene until the appropriate speed signs are in place and/or a Subway Operations official has	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				arrived on the scene to provide relief.			

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			LRT213.13 Measuring Track Not Under Load.	When unloaded track (static condition) is measured to evaluate compliance with the requirements of these Standards, any apparent rail movement (both vertically and horizontally) must be added to the measurements of Ute unloaded track. The resulting product (dynamic condition) will be used to determine compliance with the Standards.	X		
			LRT213.33 Drainage - General	Proper drainage from the track structure is critical to the performance of the track structure, Improperly drained track becomes unstable and maintenance intensive. Maintenance programs should be in place to keep all drainage facilities beneath and adjacent to the track free from obstructions and able to accommodate the	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				expected water flow fur the area served by the drainage facilities.			
			LRT213.33 Drainage - Tunnels/Subway	Within tunnels and/or subway structures, defects which result in water falling onto track components should be repaired as soon as possible. Water must be diverted to a drainage system or the leak sealed.	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			LRT213.37 Vegetation	Vegetation on MBTA property which is within or immediately adjacent to the track area must be controlled. Vegetation is a deterrent to drainage and causes a wide range of problems within the right-of- way. Some consequences of failure to control vegetation are:	X		
				a. Fouled roadbed and ballast sections from roots and vines.			
				b. Fire hazard, especially in dry weather or in the autumn.			
				c. Obstructed visibility with respect to wayside signals, speed signs, etc.			
				d. Safety hazard due to line-of-sight interference for operating personnel.			
				e. Interference to employees performing			

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				track, power and signal duties.			
				f. Improper functioning of signal and communication equipment.			
			LRT213.54 - Flangeway Widths	Flangeway widths in double restrained track are 1-1/2" both inner and outer. Refer to LRT213.53 for flangeway criteria in special trackwork. Flangeway width opposite the frog on the straight side of tee rail turnouts is 1·3/8", on the curved side 1·5/8". Nominal flangeway depth through flange bearing special trackwork is 11/16".	X		

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				Maintenance Threshold Limits for standard flangeway width are: Green [redacted]", Yellow - [redacted]" and Red- [redacted]"; for double restrained track: Green - [redacted]" Yellow [redacted]" and Red - 2"; for opposite frogs on the straight side of tee rail turnouts: Green - [redacted]" Yellow - [redacted]" and Red - [redacted]"			
				Maintenance Threshold Limits for design flangeway widths within special trackwork are given in LRT213.53. Response Actions upon reaching flangeway width Maintenance Threshold Limits are: Yellow - schedule work to re-establish proper flange way width and Red - restrict speed to [redacted] mph, perform required work within 72 hours.			

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			LRT213.129 Rail Shims	If track geometry is out of compliance with the requirements set forth under Part C herein and the working of ballast is not possible due to weather or other natural conditions, rail shims may be used to temporarily correct the deficiencies, The shims must be removed, track resurfaced and the ties tamped to a solid bearing as soon as weather permits.	X		
				Shimmed track must be inspected on a greater frequency than that required for regular track. Special attention must be given to the gage holding and surface maintaining capabilities of the shims.			

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			LRT213.135 Switches	a) Stock rails must be properly and securely seated within switch plates. Care must be exercised not to overdrive adjustable rail braces which will unseat the rail base, affect gage and cant the rail.	X		
				b) Switch points must fit against stock rails properly with the switch thrown in either direction. Train wheels most be able to pass through switches without contacting the tip of switch points. Lateral and/or vertical movement of a stock rail within switch plates or of a switch plate on a tie must not adversely affect the fit of a point to a stock rail. Nor shall such movement adversely affect the locking capability of the switch machine. Prompt corrective action is required in such eventualities:			

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				c) The heel of each switch point must be secure, loose bolts tightened and missing or broken bolts promptly replaced.			
			Switch Point Replacement	Immediately repair/replace a switch point and/or stock rail when:	X		
				a. The switch point is chipped or worn 5/8" down from top of stock rail for a distance of 6" or more			
				b. The switch point has an unprotected flat horizontal surface of 1/4" or more due to wear or fracturing			
				c. There is a 1/8" or greater gap at the point of switch when the switch is fully thrown (closed)			
				d. There is a gap between the switch point and stock rail greater than 3/8" at the #2, #3 or #4 rods			

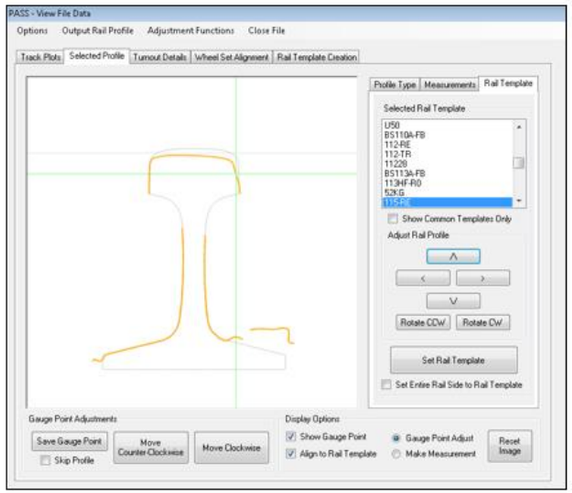
Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				e. There is 1/2" or more gage face wear on the stock rail within 5' of the point of switch			
			LRT213.137 Frogs	a) All frogs in LRT track are flange-bearing. The flangeway depth of frogs, measured from a plane across the wheel-bearing area (straightedge on point and both wings), is designed to be 11/16". Refer to LRT213.337 for maintenance limits for depth of grooves in the floor of flange-bearing frogs.			
				b) Any frog point chipped, broken or worn 5/8" deep from the plane measured in LRT213.137 a) and within 6"of the tip of the frog point calls for a speed restriction of [redacted] mph max. Over that frog and immediate replacement.			

Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
				c) If the tread portion (wings) of a frog casting is worn down more than 3/8" below the original contour, operating speed over that frog is limited to [redacted] mph.			
				d) Grinding of "flowed metal" on frog points and wings at impact areas should be done before cracking occurs. This practice will prolong the life of frogs and help prevent breakouts. Battered frog points should be built up by welding before wings begin to show signs of batter.			
				e) Loose frog bolts should be tightened and missing/broken bolts replaced as a matter of routine maintenance. Frog fasteners should be maintained and plates should be checked during Switch Certification for signs of movement.			

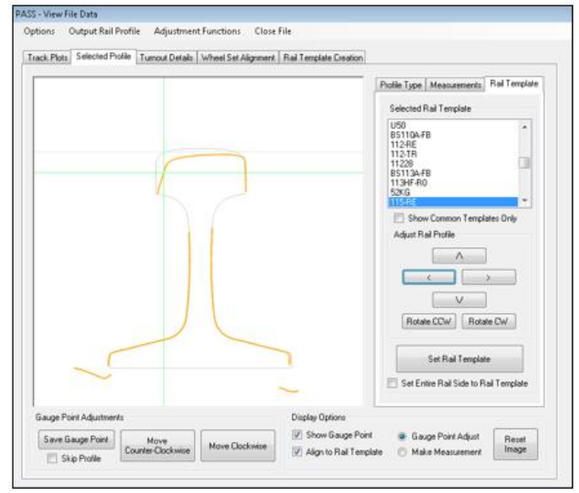
Standard	CMR 151.11 Standard	Requirement	MBTA Green Line 2008 Standard	Requirement	Compliant		Comments
					Yes	No	
			LRT213.143 Frog Guard Check Gage.		X		
				Green [redacted]" - [redacted]". No Action Required.			
				Red <[redacted]" and> [redacted]" . Restrict @ [redacted] mph, repair immediately.			

Example Rail Profile Pair

Track 2: 0+1943



Vert: 0.22”
Side: 0.133”

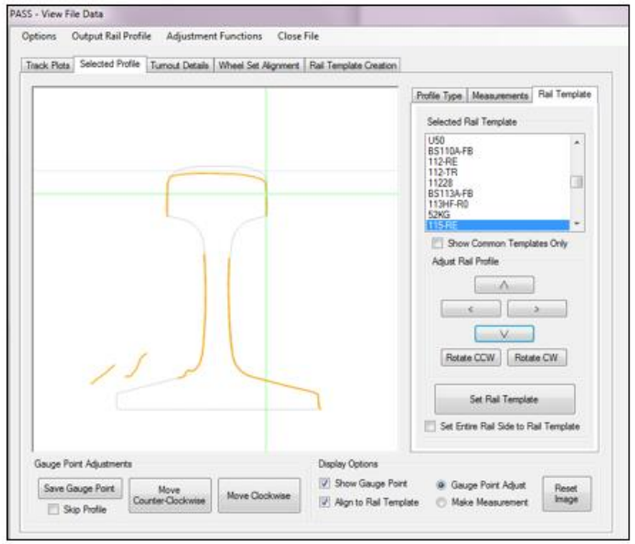


Vert: 0.200”
Side: 0.244”

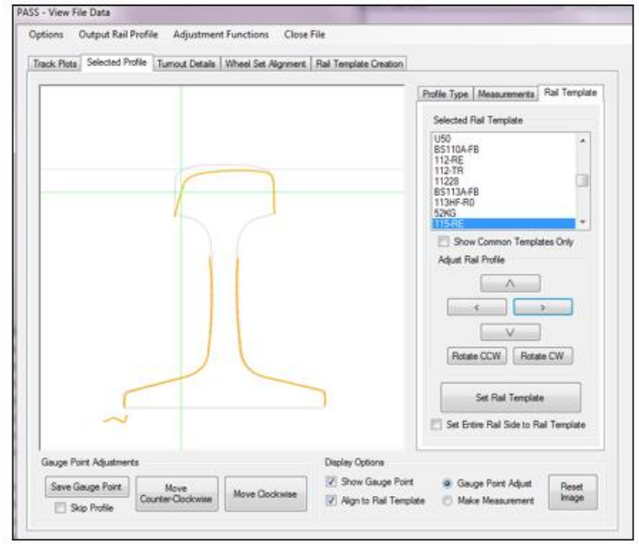
6

Example Rail Profile Pair

Track 1: 2+7919



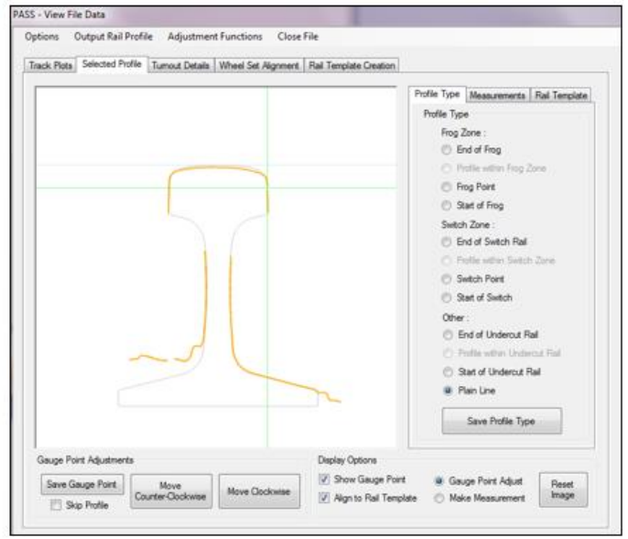
Vert: 0.178”
Side: 0.000”



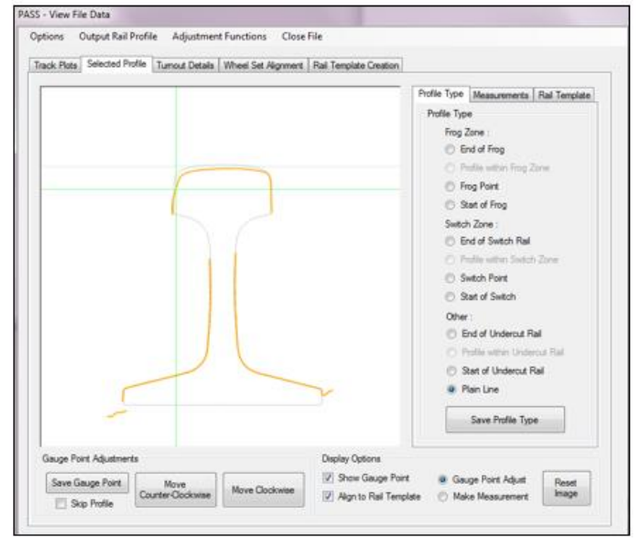
Vert: 0.133”
Side: 0.178”

Example Rail Profile Pair

Track 1: 2+8535



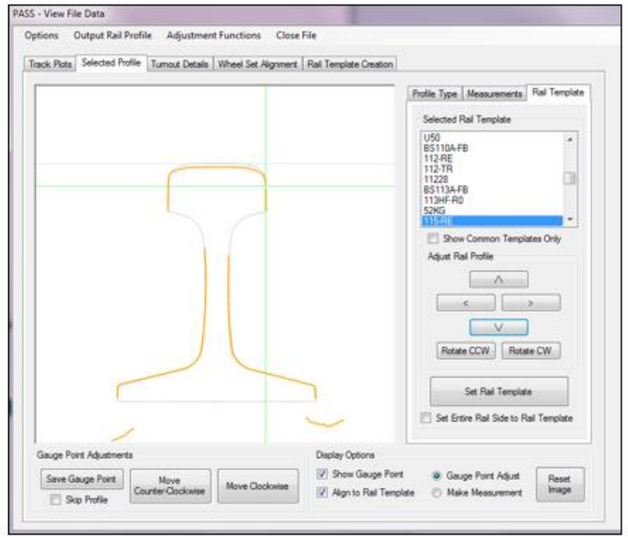
Vert: 0.045”
Side: 0.000”



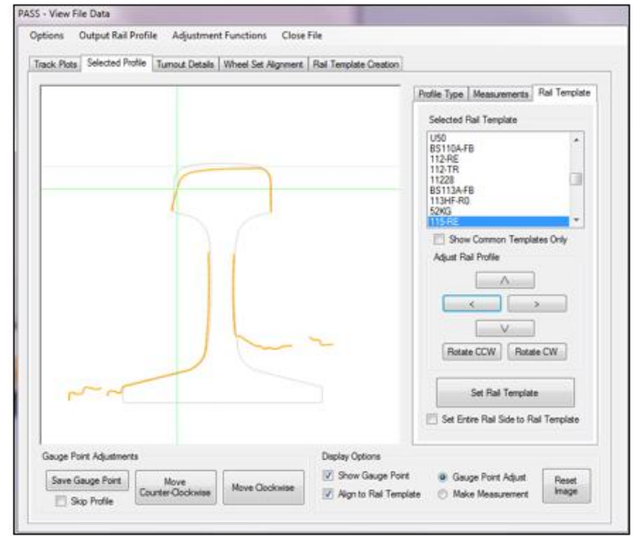
Vert: 0.067”
Side: 0.045”

Example Rail Profile Pair

Track 1: 3+1271



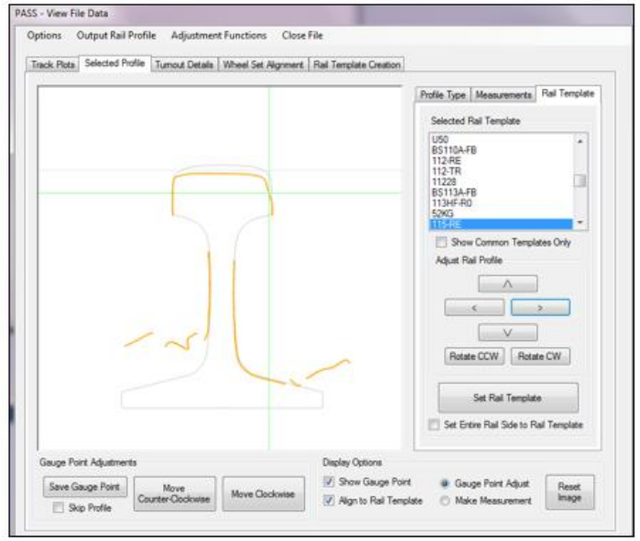
Vert: 0.045”
Side: 0.067”



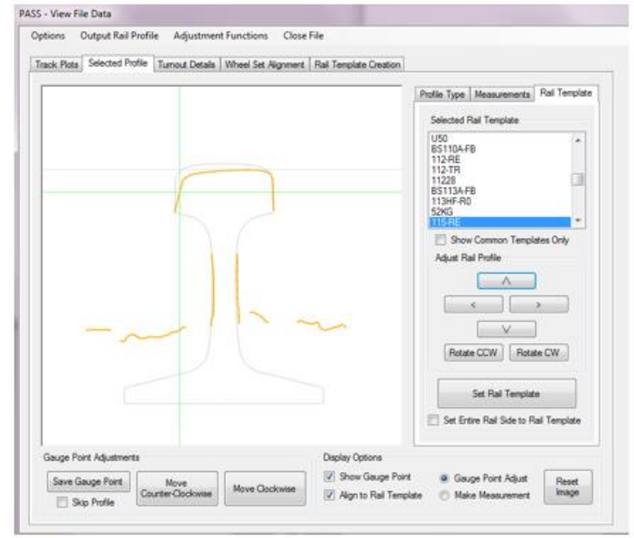
Vert: 0.133”
Side: 0.089”

Example Rail Profile Pair

Track 1: 3+4747



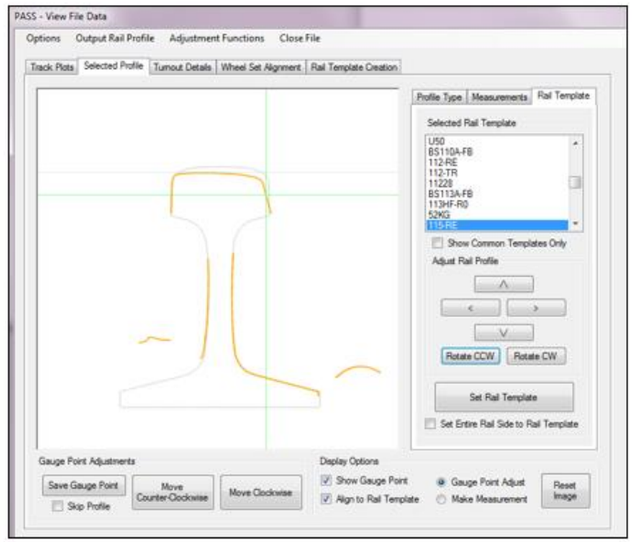
Vert: 0.200”
Side: 0.045”



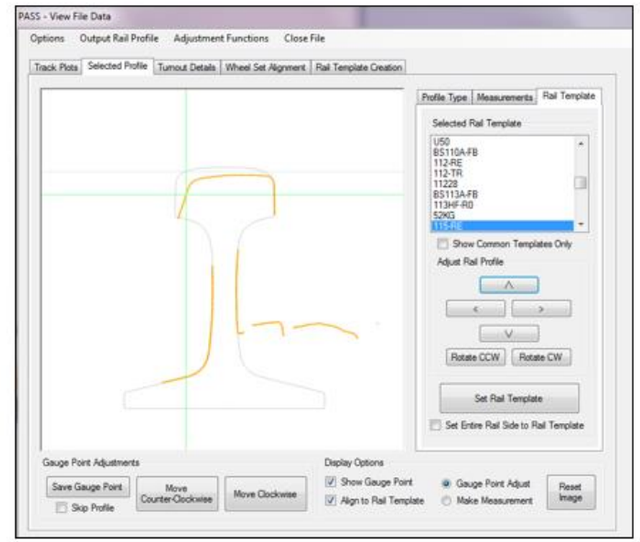
Vert: 0.156”
Side: 0.111”

Example Rail Profile Pair

Track 2: 0+855



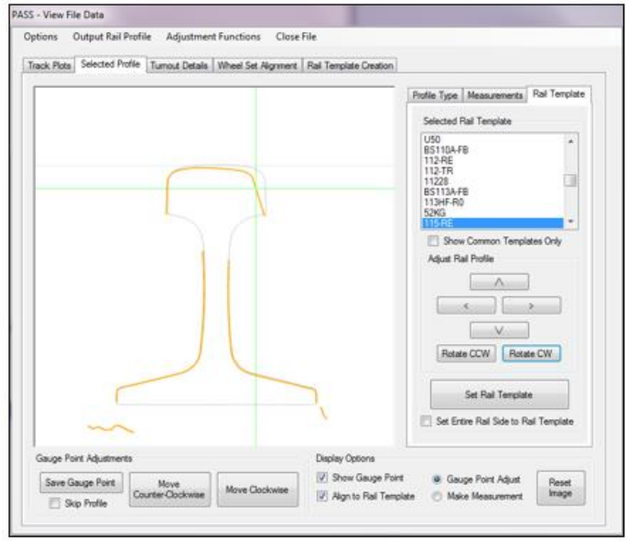
Vert: 0.156”
Side: 0.111”



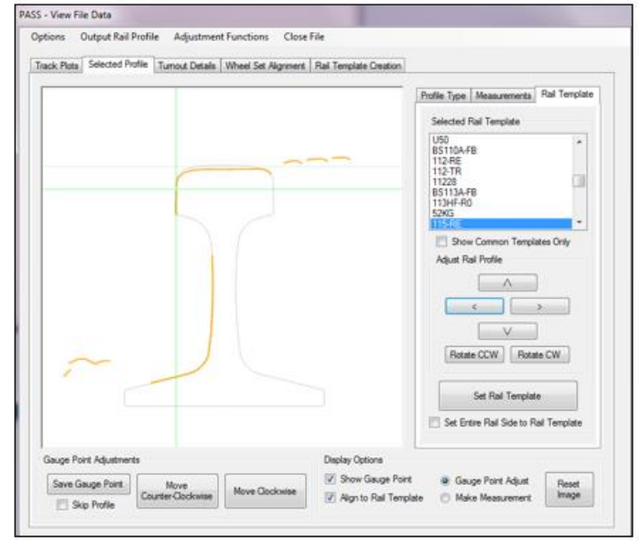
Vert: 0.200”
Side: 0.245”

Example Rail Profile Pair

Track 2: 0+1379



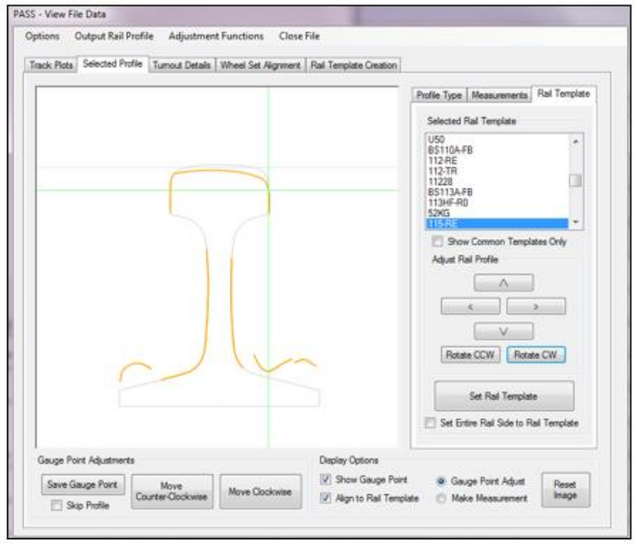
Vert: 0.045”
Side: 0.245”



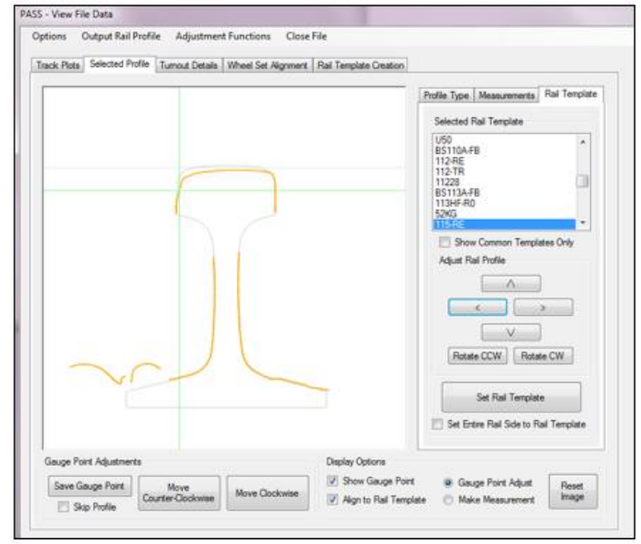
Vert: 0.111”
Side: 0.000”

Example Rail Profile Pair

Track 2: 0+2707



Vert: 0.133”
Side: 0.000”



Vert: 0.111”
Side: 0.045”