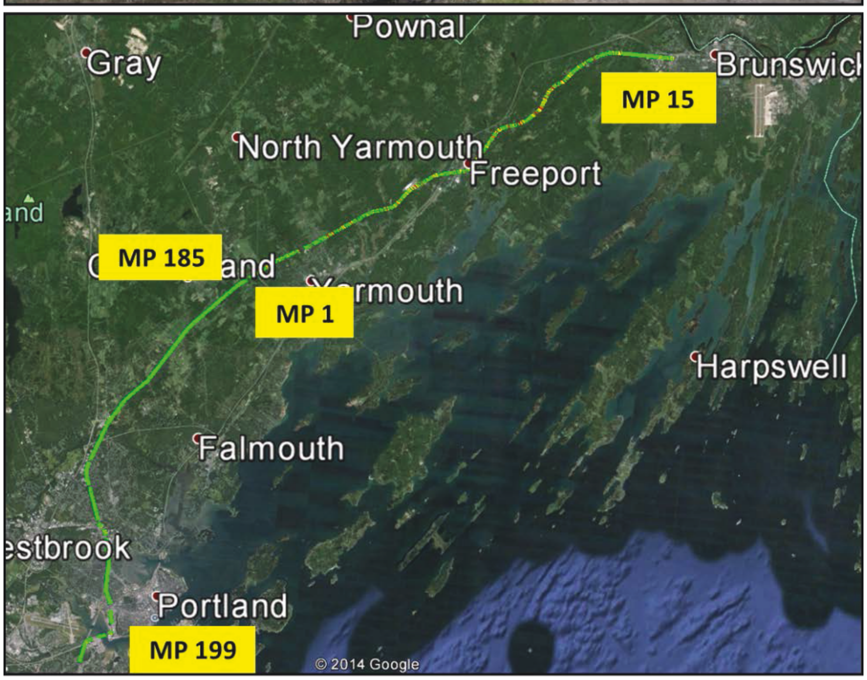
U.S. Department of Transportation

Federal Railroad Administration

DOTX 218 Survey Conducted on Pan Am Railways

Office of Research, Development
and Technology
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words)

This report summarizes the results from a May 12, 2014, survey conducted with the Federal Railroad Administration's (FRA) gage resistant measurement system vehicle (GRMS), DOTX 218, on the Pan Am Railways (PAR) track between Portland, ME, and Brunswick, ME. The survey was designed to capture the post-construction condition of the newly upgraded track, including its gage restraint capabilities and track geometry characteristics, to facilitate the comprehensive evaluation of the implemented enhancements to the PAR track under the Northern New England Passenger Rail Authority's (NNEPRA) Downeaster-Portland North project.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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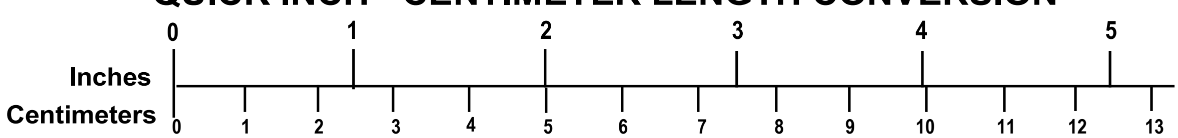
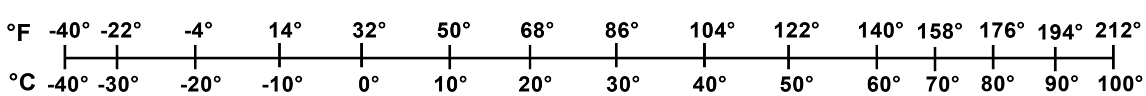
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



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Executive Summary

For a comprehensive characterization of track structural performance of newly constructed or maintained track, the rail industry needs to assess the track with a set of performance criteria to ensure that the track quality meets the requirements for the intended operation. The Federal Railroad Administration's (FRA) Office of Research, Development and Technology is currently evaluating the role of existing measurement technologies in the assessment of newly constructed track. In the case of refurbished track, the condition of the track prior to and following rehabilitation efforts is a key component to the assessment of the track condition after improvements.

This report summarizes the data analysis results collected by ENSCO, Inc. from a May 12, 2014, survey conducted by FRA with its gage resistant measurement system vehicle, DOTX 218, on the Pan Am Railways (PAR) track between Portland, ME, and Brunswick, ME. The survey was designed to capture the post-construction condition of the newly upgraded track, including its gage restraint capabilities and track geometry characteristics, to facilitate the comprehensive evaluation of the implemented enhancements to PAR track under the Northern New England Passenger Rail Authority's (NNEPRA) Downeaster-Portland North project.

Following the analysis of the data collected, significant findings were proven to be valuable to project stakeholders. The report intends to show the scope of the improvements that were made to the track, and the results can serve as a baseline for future testing.

The following are the survey results in this report:

- A summary of the measured exceptions to track geometry and gage restraint thresholds established in FRA's Track Safety Standards (TSS).
- Sample track bed and right-of-way video images showing significant improvement of track conditions.
- A comparison of the track geometry and gage restraint system results, with the results from previous surveys to assess the improvements.
- A curve analysis conducted for both 3-inch and 4-inch allowable unbalanced elevation.

A full list of exceptions is provided in Appendix A. Appendix B shows strip charts for the safety exceptions. Appendix C has a full list of curves and required elevations for 3-inch and 4-inch unbalance. Additional data can be provided by the Applied Technology & Engineering (ATE) Division of ENSCO, Inc. upon request.

1. Introduction

The Federal Railroad Administration's (FRA) Office of Research, Development and Technology (RD&T), assisted by ENSCO, Inc., performed a survey on the Pan Am Railways (PAR) track between Portland, ME, and Brunswick, ME, using FRA's DOTX 218, a gage restraint measurement system (GRMS) vehicle. The survey was conducted to evaluate the gage restraint capabilities and track geometry characteristics after the completion of right-of-way enhancements to the PAR track under the Northern New England Passenger Rail Authority's (NNEPRA) Downeaster-Portland North project to achieve higher speed passenger service.

1.1 Background

The construction project was funded by a grant from FRA to NNEPRA as specified by the American Recovery and Reinvestment Act of 2009 (ARRA), Pub. Law No. 111-5. In 2010, FRA's DOTX 218 conducted the first survey on the territory before all improvements associated with the NNEPRA grant began [3]. This survey was conducted to assess track conditions prior to any rehabilitation efforts and to establish a baseline for any future testing and comparisons. The second test (i.e., follow-up survey) was conducted in 2014 following the completion of the construction project.

1.2 Objective

The objective of the 2014 test was to establish key evaluation methods for the assessment of track upgrades, and to use this analysis to quantify improvements in track conditions that were outlined in the 2010 survey.

1.3 Overall Approach

The assessment of the track upgrades was established by comparing the amount of track geometry and GRMS exceptions generated between the two surveys. Improvement in curve geometry was established by comparison of a required change in elevation to achieve required curving speeds. Since track geometry exception thresholds are track class dependent, unlike the GRMS thresholds, an objective comparison of track geometry required reprocessing of the two data sets to generate potential track geometry exceptions at the same class of track.

1.4 Scope

The scope of these efforts is limited to analysis of track geometry and GRMS data augmented by manual review of images of track, all collected by the DOTX 218 during the 2010 and 2014 surveys. Analysis of data from other measurement systems on the DOTX 218, such as rail profile or data collected by other inspection vehicles was not performed.

1.5 Organization of the Report

This report is organized in the following sections:

- Section 1 provides a conceptual background for this effort
- Section 2 introduces GRMS and related concepts

- Section 3 provides a summary of the 2014 and 2010 surveys
- Section 4 provides data from the 2014 survey
- Section 5 provides data analysis and a comparison of the 2014 and 2010 surveys
- Section 6 summarizes all the survey activities, and states key observations and conclusions

Additional test results and raw data are provided in Appendix A through Appendix C.

2. GRMS and Related Concepts

The GRMS is an automated mechanical inspection system that identifies locations with poor gage widening characteristics. It gages these characteristics by exercising the gage strength of the track, in turn applying known lateral and vertical loads to each rail. The technology was developed in the 1980's and adopted by the industry in the 1990's. The technology can currently be deployed on a rail bound or high-rail vehicle.

2.1 GRMS Installation on the DOTX 218

The current GRMS was developed and installed on the DOTX 218 in 2004. In general, a GRMS uses a split-axle to apply a lateral and vertical force to both rails. On the DOTX 218, the split-axle does not replace one of the axles in the vehicle's trucks, but is a separate deployable axle that is lowered to the track when making measurements and raised during vehicle transits or when a potential problem with the lowered axle is detected. In addition to the split-axle, the GRMS includes two gage measurement beams suspended from the vehicle, one close to the split axle to measure loaded gage and the other 19 feet ahead of the split axle to measure unloaded gage.

The GRMS split-axle applies a lateral load of 14,000 pounds (14 kips) to each track, a load that was determined through experience and testing to adequately overcome the inertia and friction inherent in the rail/tie plate/fastener/tie mechanical system and to fully and rapidly load the track structure. A vertical load of 20,000 pounds (20 kips) was selected to yield an overall lateral-to-vertical ratio (L/V) of 0.7. As a safety precaution, the GRMS will automatically retract the axle if loaded gage exceeds 58.25 inches.

During gage restraint testing, the GRMS calculates two Track Strength Indices in real time and reports the locations along the track where either calculated index exceeds the user-specified maintenance or safety thresholds. The Track Strength Indices are explained in Section 2.2.

2.2 Track Strength Indices

The Projected Loaded Gage (PLG24) index and the Gage Widening Projection (GWP) index were developed by the John A. Volpe National Transportation Systems Center based on research on load environments and minimum strength criteria established for rail restraint. PLG24 is used as a safety and maintenance index that was developed to estimate a margin of safety before gage widening derailment. PLG24 estimates peak gage widening under severe train loads assuming minimally adequate track strength. The GWP index measures only the change in gage caused by an applied load, and normalizes the amount of deflection to a constant loading condition. The normalization process is used to eliminate changes in gage caused by variations in the applied loads. The GWP index indicates lateral rail restraint availability while the PLG24 index identifies the risk for derailment.

2.2.1 Projected Loaded Gage 24

The PLG24 index uses measurements of loaded gage, unloaded gage, and wheel forces to estimate gage when subjected to severe loads to identify locations that would allow wheel drop if under such load conditions. The index is:

$$PLG24 = GAGE_{UNLOADED} + (A_{FACTOR} \cdot \Delta GAGE)$$

Where:

PLG24 = estimated gage, in inches, under a designated severe lateral load

$GAGE_{UNLOADED}$ = gage of the track, in inches, with no loads applied

A_{FACTOR} = factor used to extrapolate from test loads to severe loading conditions

$\Delta GAGE = GAGE_{LOADED} - GAGE_{UNLOADED}$ = delta gage = difference between the unloaded gage and the gage where the test load is applied.

The extrapolation factor, A_{FACTOR}, was derived based on an investigation of loads experienced by high and low rails in severe curve conditions [2]. A_{FACTOR} scales the deflection measured under test loads to a severe loading configuration of 24 kips lateral force and 33 kips vertical force and is calculated using the following equation:

$$A_{FACTOR} = \frac{13.513}{(L - 0.258 \cdot V) - 0.009 \cdot (L - 0.258 \cdot V)^2}$$

Where:

L = actual GRMS applied lateral force, in kips

V = actual GRMS applied vertical force, in kips

According to the TSS, a track location with an extrapolated gage, or PLG24, of 59.0 inches is a "first level exception" - a high risk for a gage widening derailment, requiring immediate corrective action. The TSS further specifies that a location having a PLG24 of 58.0 inches is a "second level exception"—a maintenance area that would likely grow to an exception of 59.0 inches without corrective action. In the GRMS, the PLG24 safety and maintenance thresholds are settable parameters.

2.2.2 Gage Widening Projection

The GWP was developed based on the mechanical concept of track compliance, which is a measure of the spring rate the track exhibits as it deflects outward under an applied lateral load. At any given location, the measured track compliance equals the difference between the loaded and unloaded gage divided by the instantaneous lateral load applied to cause the deflection. Its units are inches of deflection per pound of applied force.

If track is treated as a spring with a constant stiffness, the deflection measured is directly proportional to the load severity applied. An increase in deflection only indicates a higher load was applied, not a change in stiffness. The GWP normalizes the track deflection measured by a GRMS to the deflection expected if 8.26 kips had been the actual test load severity. GWP is calculated as follows:

$$GWP = \frac{\Delta GAGE}{L - 0.258 \cdot V} \cdot 8.26$$

Where:

GWP = estimated gage widening under 8.26 kips load severity

$\Delta GAGE = GAGE_{LOADED} - GAGE_{UNLOADED} = \Delta GAGE$ = difference between the unloaded gage and applied

L = actual GRMS applied lateral force, in kips

V = actual GRMS applied vertical force, in kips

8.26 = normalizing load severity, in kips

The term "projection" is used to indicate that a normalization/extrapolation operation has been performed and the actual deflection, which occurred in the field, may have been greater than or less than the reported GWP, depending on the actual applied test load at the reported location.

The GWP was developed from a previously developed parameter, the Gage Widening Ratio (GWR) [5]. According to the TSS, a track location with a GWR of 1.0 inches or greater is a "first level exception"—a high risk for a gage widening derailment, requiring immediate corrective action. Prior demonstrations showed that a GWR or GWP value of 1.0 inch typically indicates three or more consecutive ties or missing tie locations each allowing over 0.5 inches of rail lateral movement. This is most often caused by spike killed ties and degraded tie conditions, but may also be caused by un-spiked or missing ties. The TSS further specifies that a location having a GWR of 0.75 inches is a "second level exception"—a maintenance area that would likely grow to a GWR of 1.0 inches without corrective action. In the DOTX 218 the GWR/GWP safety and maintenance thresholds are settable parameters. Furthermore, the software can be configured to calculate GWP or GWR. For the testing described in this report, GWP was used in conjunction with thresholds developed for GWR.

3. Surveys

Two surveys over the same PAR territory were conducted with the DOTX 218. In August 2010, the DOTX 218 performed its first survey prior to track improvements to support higher passenger speeds. The survey assessed the track condition prior to the upgrades and provided additional non-binding guidance to the track construction efforts and optimal allocations of available resources. The DOTX 218 surveyed the territory again in May 2014 to quantify achieved track improvements and evaluate overall post-upgrade track conditions.

3.1 Overview of the 2014 Survey

The DOTX 218 conducted a survey on May 12, 2014, starting westbound from Milepost (MP) 15. Segments of the track covered included: MP 15 to MP 1 and MP 185 to MP 199 (PAR), with a total survey length of 28.9 miles. The route used in the survey is shown in Figure 1.

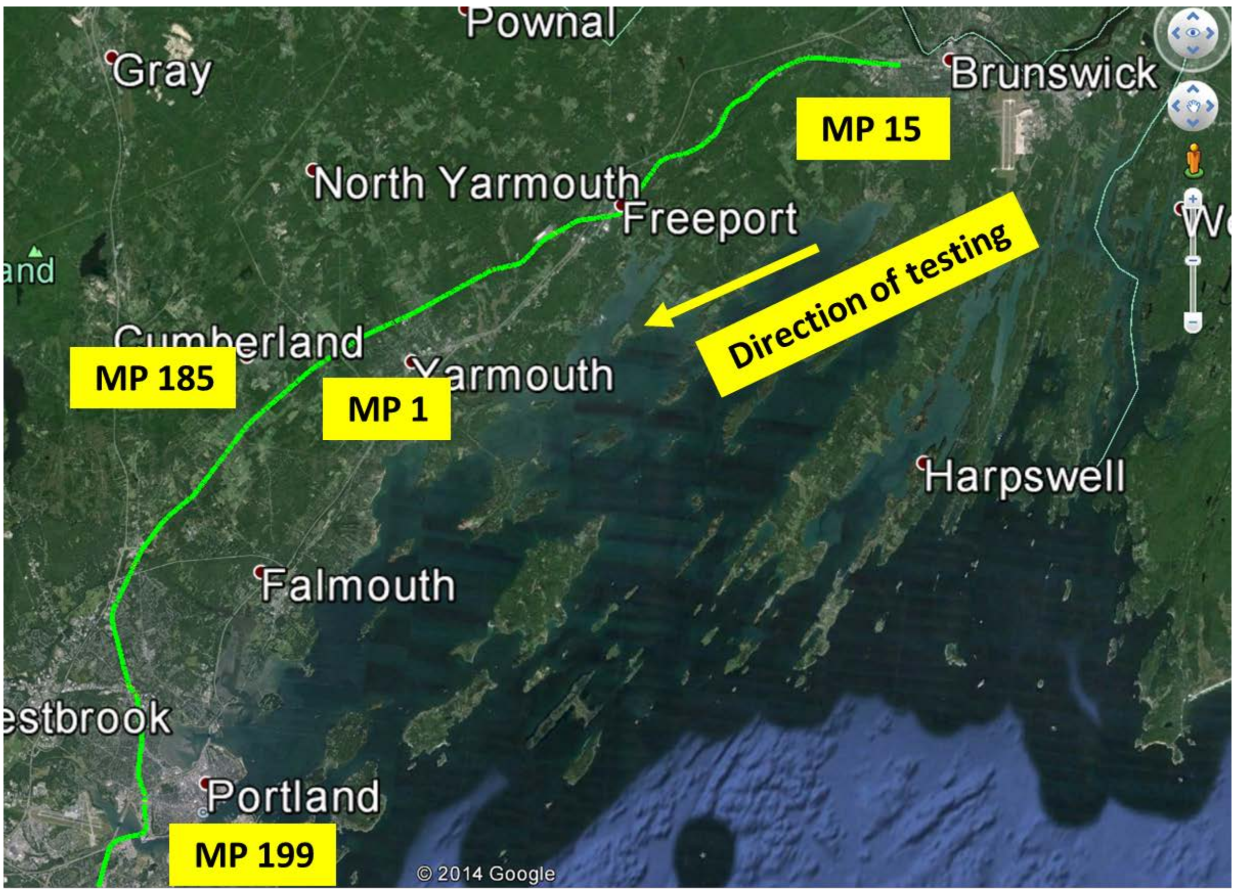

Figure 1. Route of DOTX 2018 Survey Conducted in 2014

The surveyed track was predominantly class 3 with others at class 2 and 4. The entire track consisted of wooden ties and spike fasteners.

Table 1. 2014 Survey Class by MP

Range	Class	Miles
MP 15 – MP 1	Class 3	14.7
MP 185 – MP 189	Class 4	4.4
MP 189 – MP 193	Class 3	5.0
MP 193 – MP 198	Class 2	4.4
MP 198 – MP 199	Class 3	0.4

Table 2. 2014 Survey Class as % Surveyed

Class	Miles	% of Track Surveyed
Class 2	4.4	15.2%
Class 3	20.1	69.6%
Class 4	4.4	15.2%

The DOTX 218 was equipped with the following measurement systems:

- Track Geometry Measurement System (TGMS)
- GRMS
- Ride Quality Measurement System
- Right-of-way (ROW) and track bed video image system

Since this was not a compliance inspection, the exceptions found during the survey were only meant for comparison to the survey taken before the improvements.

Note on track location designation: Wherever track location is indicated, the feet after milepost are marked according to the travelling direction of the DOTX 218. When surveying PAR track in 2014, the DOTX 218 traveled down milepost from MP 15 to MP 1 then up milepost from MP 185 to MP 199. Therefore, the feet after milepost from MP 15 to MP 1 are incremental towards the lower milepost. The feet after milepost from MP 185 to MP 199 are incremental towards the higher milepost.

3.2 Overview of the 2010 Survey

A very similar survey was conducted by the DOTX 218 on August 13, 2010, starting eastbound from MP 198. Segments of the track covered include: MP 198 to MP 185 and MP 2 to MP 15 (PAR), and MP 15 to MP 16 (Maine Owned), with a total survey length of 151,080 feet (approximately 28.5 miles). The route used in the survey is shown in Figure 2.

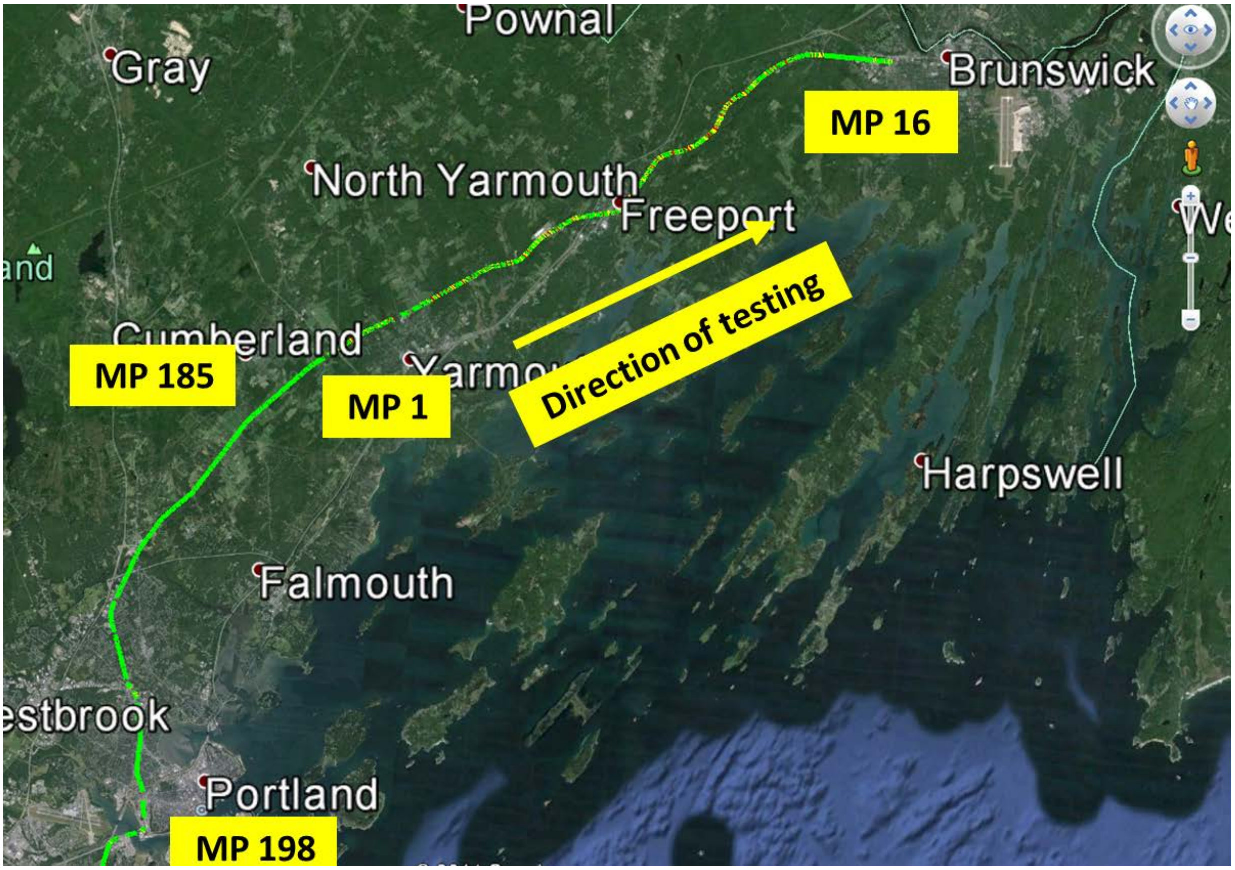

Figure 2. Route of DOTX 2018 Survey Conducted in 2010

The surveyed track was predominantly class 1 track (90%) while a small portion (10%) was class 2 track. The territory was composed of jointed rail and wooden ties with spike fasteners. Ties showed signs of advanced deterioration in many areas.

The DOTX 218 was equipped with the same equipment that was used in the 2014 survey.

This survey was completed before all improvements associated with the NNEPRA grant to improve the track for higher speed passenger service. The results of this test are included in a previous report and are used in comparison with the 2014 results to determine how the track was improved [3].

Note on track location designation: Wherever track location is indicated, the feet after milepost are marked according to the travelling direction of the DOTX 218. When surveying PAR track in 2010, the DOTX 218 traveled down milepost from MP 199 to MP 185 then up milepost from MP 1 to MP 15. Therefore, the feet after milepost from MP 199 to MP 185 are incremental towards the lower milepost. The feet after milepost from MP 1 to MP 15 are incremental towards the higher milepost.

3.3 Pan Am Railways Construction Agreement

The construction project was funded by a grant from FRA to NNEPRA as specified by ARRA of 2009, Pub. L. No. 111-5. According to the construction agreement for rail line improvements between Portland, ME, and Brunswick, ME, the following track upgrades were performed between MP 196 and MP 15:

- 28,215 new ties were installed
- 26.4 track-miles of new 115 pounds of Continuous Welded Rail were installed to replace all jointed rail
- 30.1 track-miles of surfacing and new ballast to maintain proper track profile
- 34 grade crossing rehabilitations
- 12 turnouts were replaced
- 1 diamond was replaced

Information pertaining to the specific distribution of tie replacements was not provided to the authors of this report.

4. Data Products

This section discusses GRMS and TGMS exception data as well as video images of the exceptions.

4.1 GRMS Exceptions

GRMS measurements provide information on gage restraint capacity of the track in question. The measurement parameters are discussed in Section 2.2 of this report. The thresholds for the evaluation parameters are given in Table 3.

Table 3. Thresholds for GRMS Parameters

GRMS Parameter	Maintenance Threshold (inches)	Safety Threshold (inches)
Unloaded Gage	NA	58.00
Loaded Gage	58.00	58.00
Gage Widening (GWP)	0.75	1.00
Projected Loaded Gage (PLG24)	58.00	59.00

The maintenance thresholds are meant for railroads to use in planning and carrying out maintenance activities. The safety thresholds are used to identify locations where immediate remedial actions should be taken for safe operation of trains at the posted track class (and speed).

Table 4 shows the summary of the exceptions found by the GRMS. The survey identified only one GRMS safety exception. It also identified an additional 36 locations of interest for possible maintenance. The full list of the GRMS and TGMS exceptions is given in Appendix A.

Table 4. 2014 GRMS Summary

Exception Type	Threshold	# of Locations	# of Feet	% Total Survey
PLG24 Safety	59.00	0	0	0.00%
GWP Safety	1.00	1	1	0.00%
Maintenance (GWP/PLG24)	0.75/58.00	36	182	0.12%

The single GRMS Safety exception was found at MP 4 as shown in Table 5. Note that the DOTX 218 traveled down milepost from MP 15 to MP 1 in 2014, therefore, the feet after milepost indicate how far a specific location is past a referenced milepost towards the lower milepost.

Table 5. Details of 2014 GRMS Exceptions

MP	FT	Type	Value (inches)	Length (feet)
5	3927	GWP Safety	1.04	1

4.2 TGMS Exceptions

TGMS measures track geometry parameters as detailed in the FRA's Track Safety Standards Compliance Manual [4]. The TGMS exceptions are summarized in Table 6. There were two TGMS exceptions totaling 18 feet. The details of the two TGMS exceptions are given in Table 7.

Table 6. 2014 TGMS Summary

Exception Type	Threshold (Class 2 / 3 / 4)	# of Locations	# of Feet	% Total Survey
Wide Gage	57.75 / 57.75 / 57.5	1	6	0.00%
Crosslevel	2.00 / 1.75 / 1.25	1	12	0.01%
Profile	2.75 / 2.25 / 2.00	0	0	0.00%
Alignment	3.00 / 1.75 / 1.50	0	0	0.00%
Warp	2.25 / 2.00 / 1.75	0	0	0.00%

Table 7. Details of 2014 TGMS Exceptions

MP	FT	Track Class	Type	Value (inches)	Length (feet)
188	4623	4	Crosslevel	1.50	6
199	327	3	Gage Wide	58.04	12

The Crosslevel exception occurred on the 4.4-mile section of class 4 track between MP 185 and MP 189. The Wide Gage exception occurred on class 3 track within yard limits in Portland, ME, and outside of bounds of the rehabilitation project. Neither location was an exception during the pre-rehabilitation survey in 2010.

4.3 Video Images

During the survey, a video imaging system was used to collect ROW track images and track bed images. Two cameras were mounted in front of the DOTX 218; one was focused to collect track bed images and the other was configured to capture ROW images. The cameras were all triggered at 10-foot intervals synchronized with the geometry system's output. Both track bed and ROW images can be viewed as continuous videos or single images.

The track bed images can give additional information about individual exceptions. The ROW image can assist track inspectors in locating track features or trouble spots when GPS data is not available or the inspectors do not have access to GPS data. A sample track bed snapshot from the 2010 survey is shown in Figure 3. This location produced a GWP Safety Exception in 2010. The image in Figure 4 was taken at the same location in 2014 and the ties show significant improvement. The MP + ft designations are different because the test train tested in the opposite direction.

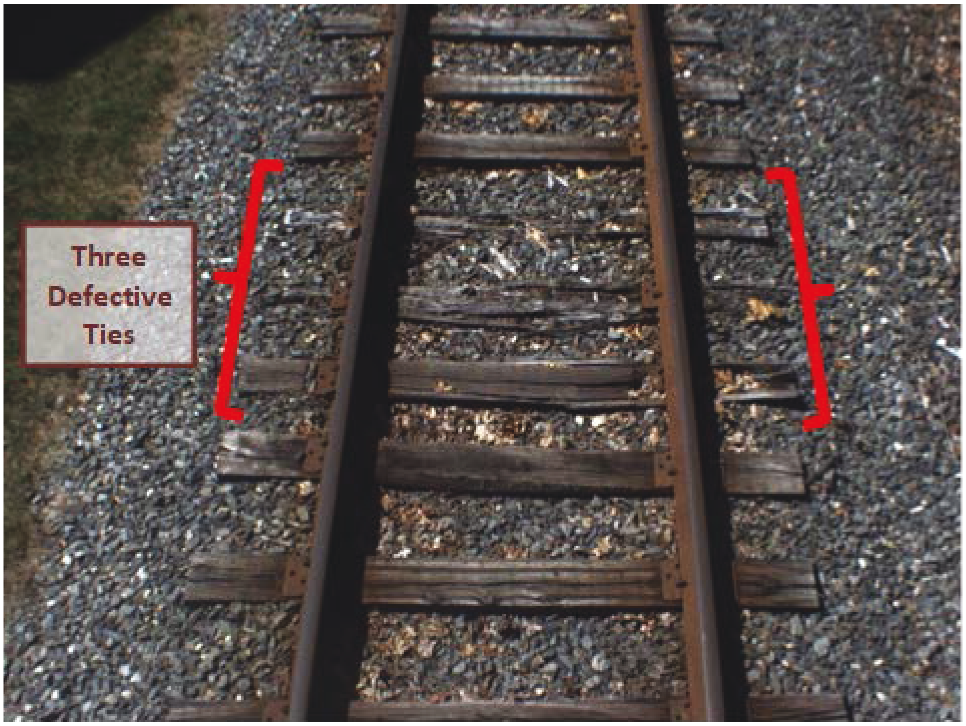

Figure 3. Track Bed Image of 2010 GRMS Exception at MP 7 FT 3734

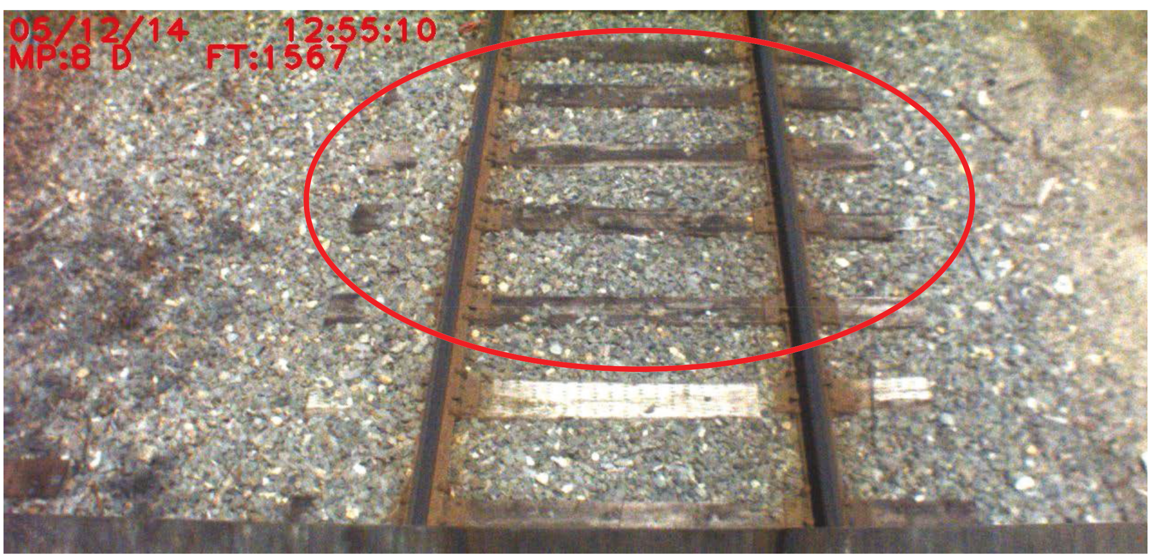

Figure 4. Track Bed Image of 2014 GRMS Exception at MP 8 FT 1535

Two 400-foot strip charts with GRMS and TGMS parameters around this location are shown in Figure 5 and Figure 6, which shows that the GWP exception from 2010 is not present in 2014. The location of the exception in the strip charts is marked by a gray line. It is also apparent from the improvement in the foot by foot signal of the GRMS parameters in Figure 5 that the decayed ties from 2010 have been replaced.

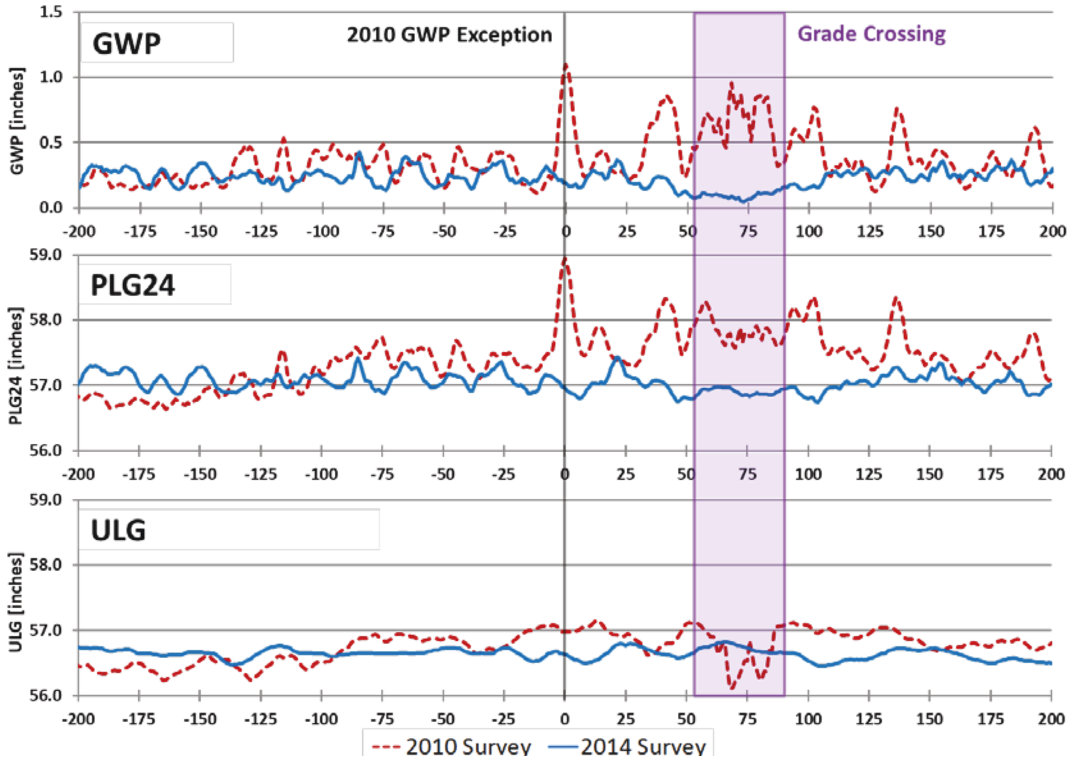

Figure 5. GRMS Strip Chart at 2010 GWP Safety Exception

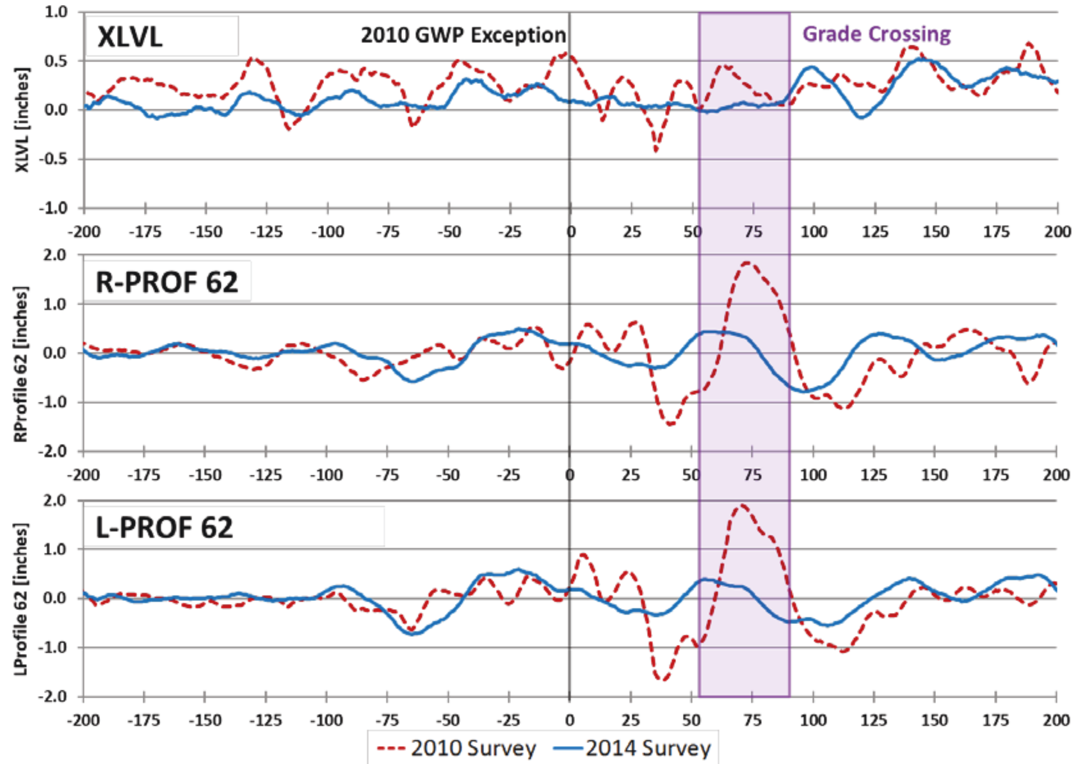

Figure 6. TGMS Strip Chart at 2010 GWP Safety Exception

5. Analysis Results

This section discusses analysis and results from GRMS and TGMS data.

5.1 GRMS Improvement Between 2010 and 2014

After the GRMS survey in 2010 a Tie Replacement Analysis was performed and presented to NNEPRA. The results of the 2014 survey were analyzed to determine how the track has improved as a result of the construction that occurred after the 2010 survey. Table 8 summarizes the GRMS exceptions from 2010 and 2014. As can be seen there is a 99.7 percent improvement in the number of feet that exceed safety exception thresholds. There is a 95 percent improvement in the number of feet that exceed maintenance thresholds.

Table 8. 2014 GRMS Improvement Between 2010 and 2014

		2014 Survey		2010 Survey		
Exception Type	**Threshold**	**# of Loc.**	**Length (ft.)**	**# of Loc.**	**Length (ft.)**	**% Improvement (by Feet)**
PLG24 Safety	59.00	0	0	20	306	100.0%
GWP Safety	1.00	1	1	44	325	99.7%
Maintenance (GWP/PLG24)	0.75/58.00	36	182	620	3817	95.2%

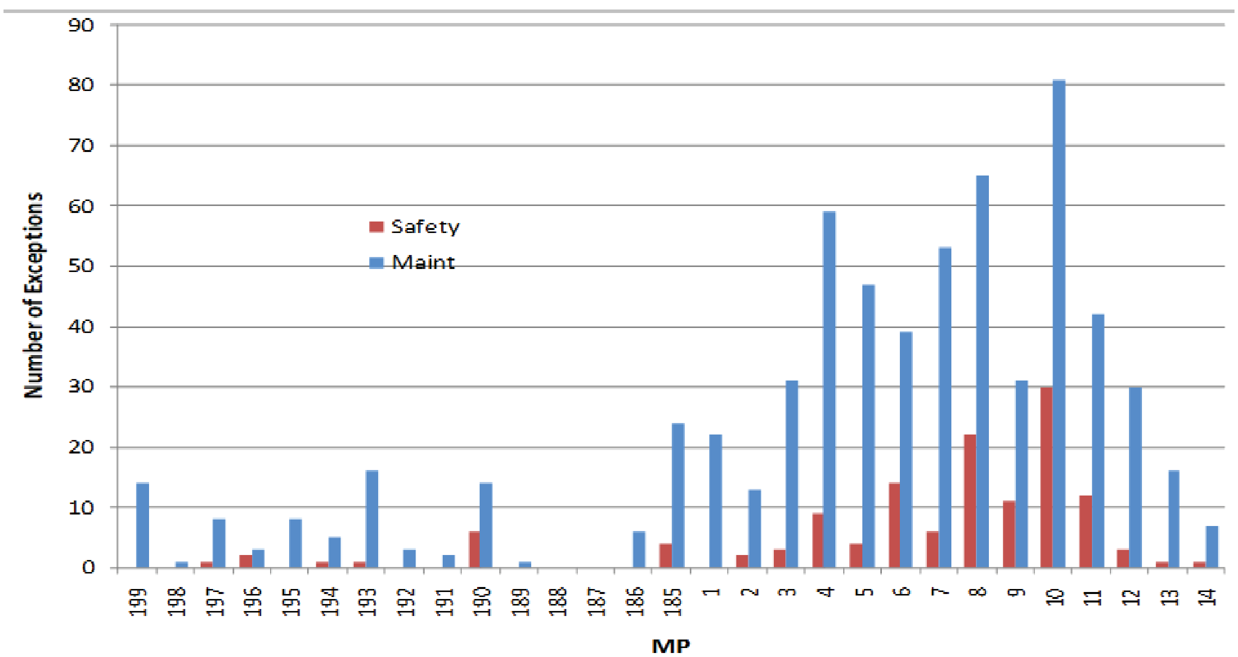

Figure 7. 2010 Mile-Based GRMS Exception Distribution

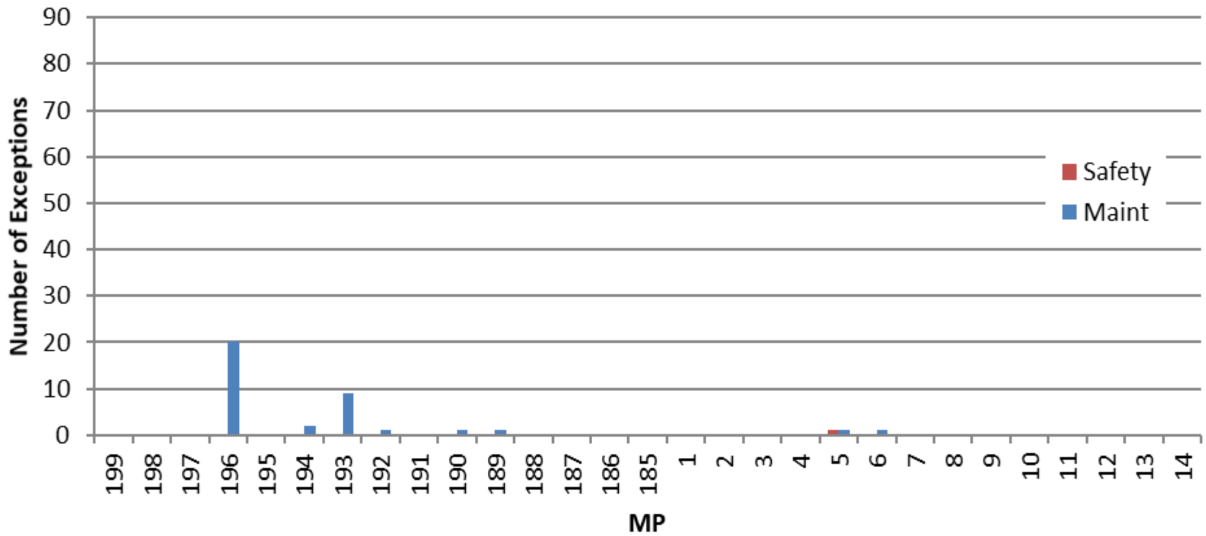

Figure 8. 2014 Mile-Based GRMS Exception Distribution

Figure 7 shows the exception distribution in 2010, while Figure 8 shows the distribution in 2014. As can be observed, there is a significant decrease in exception counts, especially between MP 1 to MP 15 where the most track work, including tie replacement, appears to have occurred and had the most impact. There is a decrease in exceptions from 2010 to 2014 in every mile. There is a decrease in maintenance locations from 2010 to 2014 in every mile except MP 196. It is possible that many original ties were not replaced at this milepost and the increased number of maintenance exceptions is a result of natural degradation process.

Table 9. Average GWP in 3,000 Foot Segments

Section	MP	Class 2014	Class 2010	Average GWP 2014	Average GPW 2010	% Improvement Normalized to Threshold
1	196	2	1	0.31	0.30	-2%
2	195	2	1	0.28	0.23	-5%
3	194	2	2	0.28	0.20	-8%
4	193	3	1	0.28	0.26	-2%
5	190	3	1	0.30	0.28	-2%
6	188	4	1	0.32	0.28	-4%
7	186	4	1	0.28	0.29	1%
8	185	4	2	0.30	0.27	-3%
9	3	3	1	0.27	0.33	6%
10	5	3	1	0.28	0.41	13%
11	7	3	1	0.23	0.33	10%
12	12	3	1	0.26	0.37	11%

Table 9 presents several 3,000-foot segments extracted from the entire track and compares the average GWP from 2010 and 2014 at these segments. The table shows significant improvement in the track between MP 1 and MP 15. The track between MP 196 and MP 188 exhibits degradation as the average GWP values increased in 2014. The values, however, are still well within acceptable limits.

GWP is an inverse measure of lateral track strength where a larger number indicates weaker track. The track lateral strength will weaken upon normal use due to track degradation involving rail traffic and environmental impacts, which increases GWP over time. It is expected that track maintenance will generally strengthen and reduce the GWP value. The distribution of replacement ties during the improvements made between 2010 and 2014, was unknown to the authors of this report. However, it was expected that a larger proportion of ties were used to improve MP 1 to MP 15 since this section had a significantly weaker initial state in 2010 and showed most improvement in 2014. On the other hand, MP 188 to MP 196 appears to receive less replacement ties and the average lateral track strength decreased due to the degradation process. The graph in Figure 9 shows the average GWP for the different sections. In 2014 the track has a more uniform strength.

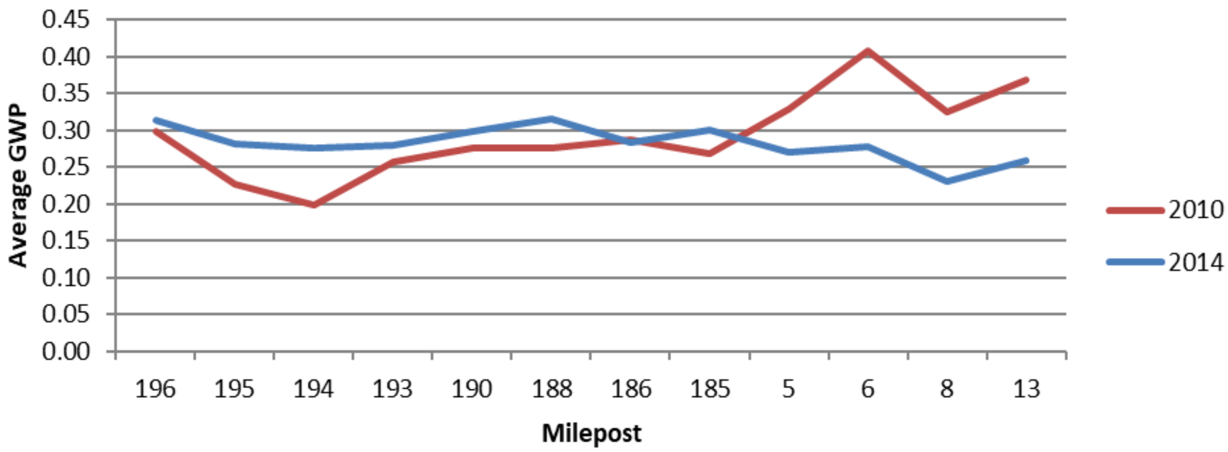

Figure 9. Average GWP in 3,000-Foot Segments

The average GWP for different sections of PAR track following the rehabilitation efforts are consistent with GWP values found across the United States. FRA has analyzed GRMS data from across the United States to determine typical values for GWP and PLG24 depending on track class [1]. The data collected by the DOTX 218 was utilized by FRA's Autonomous Track Inspection Program (ATIP) in 2007, 2008, 2009, and 2013. Results for GWP are shown in Table 10.

Table 10. Typical GWP Values Based on Track Class

GWP	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5
Average Value:	**0.30**	**0.19**	**0.24**	**0.22**	**0.20**
Standard Deviation	0.15	0.14	0.13	0.10	0.09
Maximum Value	1.94	2.33	2.75	1.96	1.32
Minimum Value	0.01	0.01	0.01	0.01	0.01
Sample Size (miles)	**92**	**749**	**1930**	**2944**	**1965**

The results for track class 1 are affected by the limited sample size at this class of track. The average value for track class 2 does not fit the trend of the other classes due to the high percentage of class 2 track in the sample with concrete ties. It is likely that track class 2 was used as a method of applying speed limits to highly curved track through mountainous terrain in the available sample set.

5.2 2014 GRMS Safety Exception

The DOTX 218 detected a single GRMS safety exception during the 2014 survey, see Table 5 for details. This location, shown in Figure 10, was particularly difficult to distinguish visually during a follow-up high-rail inspection. However, it had a peak GWP value of 1.04 inches. This location was an outlier and required repair. The contributing factors to the defect were four consecutive defective ties that offered no lateral restraint and little vertical support. There was a significant vertical gap between each of these four ties and the rail. The next highest GWP value anywhere on the track was 0.88 inches.

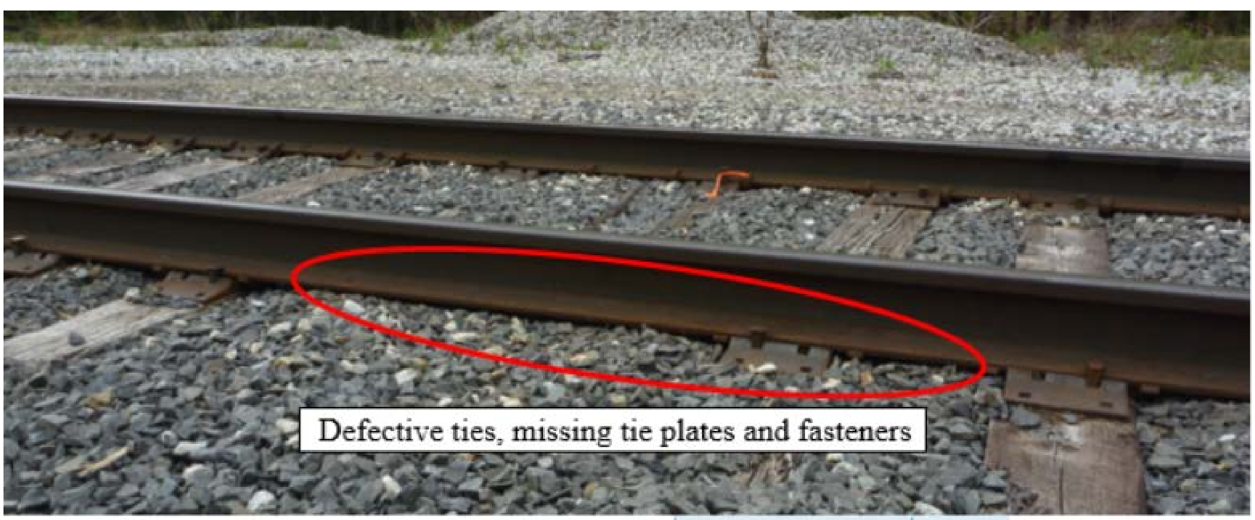

Figure 10. Field Conditions at the 2014 GWP Safety Exception

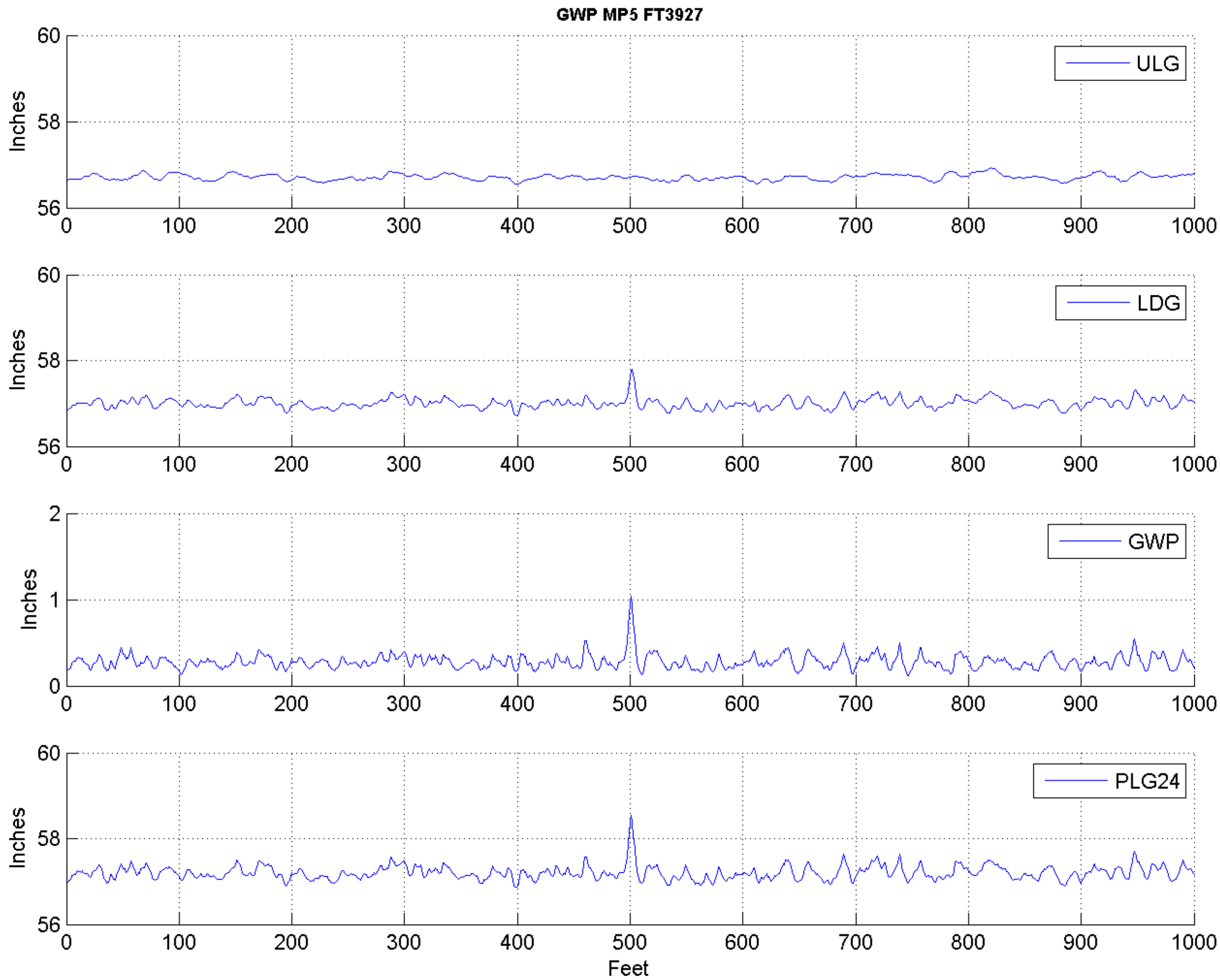

Figure 11. Strip Chart of GRMS Parameters at the 2014 GWP Safety Exception

5.3 TGMS Improvements Between 2010 and 2014

To compare track geometry from 2010 to 2014, all the data from both surveys was reprocessed at track class 4. Table 11 presents a summary of the locations from the 2010 survey that would have exceeded class 4 geometry thresholds and could be potential class 4 exceptions. These do not represent actual exceptions. The data would have to be further reviewed and edited to remove location with invalid data signatures, such as spikes. Table 12 presents the same summary for the 2014 survey.

Table 11. Summary of 2010 TGMS Data Reprocessed at Track Class 4

Parameter	Threshold (Class 4)	# of Locations	# of Feet	% Total Survey
Wide Gage	57.50	207	1894	1.25%
Crosslevel	1.25	105	928	0.61%
Profile	2.00	7	47	0.03%
Alignment	1.50	1*	11	0.01%
Warp	1.75	96	4932	3.26%

*Note that in 2010 there was only one potential class 4 alignment exception when the data was reprocessed. This is due to the 29 mph low speed cutoff of the alignment 62 channel. The 62-foot chord alignment is invalid if the test vehicle is travelling less than 29 mph due to the performance of the inertial sensors used. Since most of the track (90 percent) was class 1 the test train rarely went fast enough to calculate valid alignment. Therefore, this exception type is ignored when comparing 2014 data to 2010 data.

Table 12. Summary of 2014 TGMS Data Reprocessed at Track Class 4

Parameter	Threshold (Class 4)	# of Locations	# of Feet	% Total Survey	% Improvement (by feet)
Wide Gage	57.50	8	75	0.05%	96%
Crosslevel	1.25	5	36	0.02%	96%
Profile	2.00	0	0	0.00%	100%
Alignment	1.50	9	112	0.07%	N/A
Warp	1.75	5	253	0.17%	95%

Based on the reduction of the number of feet where the track would potentially exceed class 4 exception thresholds, there is a 95–100 percent improvement post-construction. Ignoring alignment, the number of potential class 4 TGMS exceptions drops from 415 (7801 feet) to 18 (364 feet), a 95.7 percent reduction in the number of exceptions (95.3 percent by distance). This is a significant improvement of track conditions. Note that these are not actual exceptions based on the posted track class.

5.4 Curve Analysis

The purpose of curve analysis is to determine if the current curve geometry is adequate for the current track class.

5.4.1 Approach

The curve analysis was performed based on the V_{max} formula to calculate the maximum allowable operating speed:

$$V_{max} = \sqrt{\frac{E_a + E_u}{0.0007D}}$$

Where:

V_{max} = Maximum allowable operating speed (miles per hour).

E_a= Actual elevation of the outside rail (inches)

E_u=Amount of unbalanced elevation of the outside rail (inches)

D = Degree of curvature (degrees)

In this analysis, the above equation was used to determine the required actual elevations of the outside rail for track classes 1 through 5, using the corresponding class speeds as the V_{max}. The degree of curvature, D, was the average curvature as measured during the survey. Both 3 and 4 inch unbalanced elevations were evaluated for both speeds to replicate original requirements for curve analysis conducted in 2010.

5.4.2 Results

The analysis was performed for two different allowable unbalance elevations (3 inch and 4 inch) and two different speeds for each curve (freight and passenger at current track class). Table 13 shows the freight and passenger speed limits for track classes 1 through 5.

Table 13. Maximum Speeds for Track Class 1 to 5

Track Class	Freight Speed, mph	Passenger Speed, mph
1	10	15
2	25	30
3	40	60
4	60	80
5	80	90

The required elevations for a 3-inch allowable unbalanced elevation are given in Appendix C. Table 14 presents the required elevation change to meet the current track class speed limit and gives the maximum speed limit for the current elevation when 3-inch unbalanced elevation is considered. Negative curvature indicates a curve to the left (left is determined by the direction of travel). Negative elevation indicates that the right rail (in the direction of travel) is higher than the left rail.

The cells colored in green indicate adequate elevation for the average degree of curvature and allowable unbalance of 3 inches. Cells in orange indicate the necessary change in elevation to operate at the class determined speed limit for an allowable unbalance of 3 inches. Cells in red indicate that the required elevation exceeds maximum allowable elevation and is unachievable. Cells in yellow indicate that for the current track class and elevation, the maximum speed limit is below the freight speed limit. Cells in purple indicate that for the current track class and elevation, the maximum speed limit is above the freight speed limit, but below the passenger speed limit.

Table 14. Required Elevation Change for 3 Inch Unbalanced Elevation

Curve No.	Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)		Maximum Speed at Current Elevation
	Class	Degrees	Inches	Ft	mph	mph	Fr	Passenger	mph
1	3	-3.06	-0.11	215	40	60	-	-4.60	38.1
2	3	2.79	-0.51	234	40	60	-	3.52	42.4
3	3	-1.04	-3.12	3164	40	60	-	--	91.7
4	3	-1.54	-3.88	957	40	60	-	--	79.9
5	3	-1.44	-3.48	1052	40	60	-	--	80.2
6	3	2.90	4.22	1070	40	60	-	0.09	59.6
7	3	-1.89	-3.66	939	40	60	-	--	70.9
8	3	-1.21	-3.92	526	40	60	-	--	90.4
9	3	-2.97	-3.71	1098	40	60	-	-0.77	56.8
10	3	1.30	2.38	785	40	60	-	--	76.9
11	3	2.84	3.78	1041	40	60	-	0.37	58.4
12	3	1.46	2.68	1265	40	60	-	--	74.5
13	3	2.45	3.97	940	40	60	-	--	63.8
14	3	-0.87	-4.21	1392	40	60	-	--	108.8
15	3	-2.84	-4.04	1447	40	60	-	-0.12	59.5
16	3	2.90	0.59	1505	40	60	-	3.72	42.0
17	3	1.85	1.24	607	40	60	-	0.42	57.2
18	3	-2.90	-3.46	1104	40	60	-	-0.85	56.4
19	3	-0.97	-2.00	2039	40	60	-	--	85.8
20	3	2.95	3.58	1538	40	60	-	0.85	56.5
21	3	1.36	2.75	569	40	60	-	--	77.7
22	3	-1.65	-2.77	1249	40	60	-	--	70.7
23	3	0.54	1.57	935	40	60	-	--	110.0
24	3	-1.02	-1.71	880	40	60	-	--	81.3
25	3	-0.64	-1.09	1391	40	60	-	--	95.6
26	4	-0.95	-1.34	1408	60	80	-	--	80.8
27	4	1.29	3.57	1195	60	80	-	--	85.3
28	3	-1.95	-3.63	916	40	60	-	--	69.7
29	3	-0.96	-1.39	1289	40	60	-	--	80.9
30	3	-1.81	-3.63	2633	40	60	-	--	72.3
31	3	-3.78	-1.18	1004	40	60	-	-5.34	39.8
32	2	4.57	1.28	1149	25	30	-	--	36.6
33	2	3.33	1.10	727	25	30	-	--	41.9
34	2	-1.46	-0.39	424	25	30	-	--	57.6
35	2	-3.09	-0.64	1054	25	30	-	--	41.0
36	2	-0.54	-0.63	383	25	30	-	--	98.0
37	2	8.02	3.04	469	25	30	-	--	32.8
38	2	-1.92	-1.01	383	25	30	-	--	54.6
39	2	-0.93	-1.00	562	25	30	-	--	78.4
40	2	6.53	2.28	1587	25	30	-	--	34.0
41	2	-2.08	0.16	359	25	30	-	--	46.6
42	2	-2.14	0.01	666	25	30	-	--	44.8

Curve No.	Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)		Maximum Speed at Current Elevation
	Class	Degrees	Inches	Ft	mph	mph	Fr	Passenger	mph
43	2	-2.94	-0.97	1693	25	30	-	--	43.9
44	3	-2.58	0.05	245	40	60	-	-3.45	41.1
45	3	2.78	-0.28	238	40	60	-	3.72	41.1
46	3	1.29	0.08	237	40	60	-	0.18	58.4
47	3	-4.42	-1.10	232	40	60	-	NA	36.4

Notes:

- DOTX 218 traveled down milepost from MP 15 to MP 1 and then up milepost from MP 185 to MP 199. The feet are always marked after the milepost according to the direction of travel.
- NA = Not Achievable
- FTSS § 213.57 57(a) stipulates that "The maximum crosslevel on the outside rail of a curve may not be more than 8 inches on track classes 1 and 2 and 7 inches on classes 3 through 5."

The required elevations for a 4-inch allowable unbalanced elevation are given in Appendix C. Table 15 presents the required elevation change to meet the current track class speed limit and gives the maximum speed limit for the current elevation when 4-inch unbalanced elevation is considered. The cell colorization scheme is the same as in Table 14.

Table 15. Required Elevation Change for 4 Inch Unbalanced Elevation

Curve No.	Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)		Maximum Speed at Current Elevation
	Class	Degrees	Inches	Ft	mph	mph	Fre	Passenger	mph
1	3	-3.06	-0.11	215	40	60	--	-3.60	43.8
2	3	2.79	-0.51	234	40	60	--	2.52	48.0
3	3	-1.04	-3.12	3164	40	60	--	--	98.9
4	3	-1.54	-3.88	957	40	60	--	--	85.5
5	3	-1.44	-3.48	1052	40	60	--	--	86.1
6	3	2.90	4.22	1070	40	60	--	--	63.6
7	3	-1.89	-3.66	939	40	60	--	--	76.1
8	3	-1.21	-3.92	526	40	60	--	--	96.7
9	3	-2.97	-3.71	1098	40	60	--	--	60.9
10	3	1.30	2.38	785	40	60	--	--	83.8
11	3	2.84	3.78	1041	40	60	--	--	62.6
12	3	1.46	2.68	1265	40	60	--	--	80.8
13	3	2.45	3.97	940	40	60	--	--	68.2
14	3	-0.87	-4.21	1392	40	60	--	--	116.1
15	3	-2.84	-4.04	1447	40	60	--	--	63.6
16	3	2.90	0.59	1505	40	60	--	2.72	47.5
17	3	1.85	1.24	607	40	60	--	--	63.6
18	3	-2.90	-3.46	1104	40	60	--	--	60.6

Curve No.	Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)		Maximum Speed at Current Elevation
	Class	Degrees	Inches	Ft	mph	mph	Fre	Passenger	mph
19	3	-0.97	-2.00	2039	40	60	--	--	94.0
20	3	2.95	3.58	1538	40	60	--	--	60.6
21	3	1.36	2.75	569	40	60	--	--	84.2
22	3	-1.65	-2.77	1249	40	60	--	--	76.6
23	3	0.54	1.57	935	40	60	--	--	121.4
24	3	-1.02	-1.71	880	40	60	--	--	89.5
25	3	-0.64	-1.09	1391	40	60	--	--	106.6
26	4	-0.95	-1.34	1408	60	80	--	--	89.6
27	4	1.29	3.57	1195	60	80	--	--	91.5
28	3	-1.95	-3.63	916	40	60	--	--	74.8
29	3	-0.96	-1.39	1289	40	60	--	--	89.6
30	3	-1.81	-3.63	2633	40	60	--	--	77.6
31	3	-3.78	-1.18	1004	40	60	--	-4.34	44.3
32	2	4.57	1.28	1149	25	30	--	--	40.6
33	2	3.33	1.10	727	25	30	--	--	46.8
34	2	-1.46	-0.39	424	25	30	--	--	65.5
35	2	-3.09	-0.64	1054	25	30	--	--	46.3
36	2	-0.54	-0.63	383	25	30	--	--	110.6
37	2	8.02	3.04	469	25	30	--	--	35.4
38	2	-1.92	-1.01	383	25	30	--	--	61.1
39	2	-0.93	-1.00	562	25	30	--	--	87.6
40	2	6.53	2.28	1587	25	30	--	--	37.1
41	2	-2.08	0.16	359	25	30	--	--	53.5
42	2	-2.14	0.01	666	25	30	--	--	51.7
43	2	-2.94	-0.97	1693	25	30	--	--	49.1
44	3	-2.58	0.05	245	40	60	--	-2.45	47.3
45	3	2.78	-0.28	238	40	60	--	2.72	46.9
46	3	1.29	0.08	237	40	60	--	--	67.2
47	3	-4.42	-1.10	232	40	60	--	-6.04	40.6

Notes:

- DOTX 218 traveled down milepost from MP 15 to MP 1 and then up milepost from MP 185 to MP 199. The feet are always marked after the milepost according to the direction of travel.
- NA = Not Achievable
- FTSS § 213.57 57(a) stipulates that “The maximum crosslevel on the outside rail of a curve may not be more than 8 inches on track classes 1 and 2 and 7 inches on classes 3 through 5.”

With a 3 inch allowable unbalance:

- For freight speeds, 3 curves were identified for elevation adjustment.
- For passenger speeds, 15 curves were identified for elevation adjustment.

With a 4 inch allowance in the unbalance:

- No curves were identified for elevation adjustment at freight speeds.
- At passenger speeds, 7 curves were identified for elevation adjustment.

Note that the analysis was performed using the average curvature and elevation for the entire curve without considering the effect of location curvature and elevation deviations, as well as the ability to operate at actual cant deficiency 1 inch higher than qualified cant deficiency if actual elevation and degree of curvature change as a result of track degradation as specified in the current Track and Rail and Infrastructure Integrity Compliance Manual: Volume II – Chapter 1:

"*If the actual elevation, E_a, and degree of curvature, D, change as a result of track degradation, then the actual cant deficiency for the maximum allowable posted timetable operating speed, Vmax, may be greater than the qualified cant deficiency, Eu. This actual cant deficiency for each curve may not exceed the qualified cant deficiency, Eu, plus 1 inch.*"[1]

The analysis was intended to quantify the general curve geometry following the rehabilitation project and as a measure of a possible additional realignment of the curves to improve the curving speeds further using the same analysis methodology as in 2010. Therefore, curves identified in this analysis for adjustment are not necessarily out of compliance with the current track standards. Only one Limiting Speed 3 exception was produced during the 2014 survey by the DOTX 218.

[1] Federal Railroad Administration. (2017, January 01). Track and Rail and Infrastructure Integrity Compliance Manual: Volume II - Chapter 1. *Track Safety Standards* (pp. 2.1.37). Office of Railroad Safety: Washington, DC. Available at: https://www.fra.dot.gov/eLib/details/L18604.

6. Conclusion

FRA's DOTX 218 conducted two surveys on PAR in Maine. The first took place on August 13, 2010, prior to a rehabilitation project to increase passenger speeds, while the second occurred on May 12, 2014, after the completion of the rehabilitation project. The analysis of the post-construction survey and comparison to the previous survey are used to quantify the improvements that were made to the track and to set a baseline of track condition for future tests going forward.

The analysis showed the following significant track improvement from 2010 to 2014:

- The number of GWP exceptions dropped from 44 to 1, a 98 percent reduction.
- The number of feet above the GWP threshold dropped from 325 to 1, a 99.7 percent reduction.
- The number of PLG24 exceptions dropped from 20 to 0, a 100 percent reduction.
- The number of feet above the PLG24 threshold dropped from 306 to 0, a 100 percent reduction.
- Disregarding alignment, the number of potential class 4 TGMS exceptions dropped from 415 (7801 feet) to 18 (364 feet), a 95.7 percent reduction in the number of potential class 4 exceptions (95.3 percent by distance). The potential class 4 thresholds were only used as means for comparable comparison and do not imply that the track was or will be classified as class 4.
- The track exhibits more uniform lateral strength throughout the entire territory following the rehabilitation efforts.
- GRMS also showed that track continues to degrade.
- Curve analysis showed the significantly improved curve geometry in 2014 and identified several curves where additional adjustments to elevation would be beneficial.

The two surveys demonstrated the usefulness of the DOTX 218 for comprehensive track condition assessment. The effort also illustrated the value of using a variety of assessment technologies for track rehabilitation planning and determination of improvement effectiveness.

7. References

1. Bruzek, R., and Clemenzi, J. (2014). *Track Strength and Gage Widening Studies Class Based GRMS Analysis Report (Internal ENSCO Report SERV-REPT-0000356 REV A).* Springfield, VA: ENSCO, Inc.
2. Dwonczyk, D., Jeong, D., and Kish, A. (1984). *Experimental Investigation of Gauge Widening and Rail Restraint Characteristics*, Technical Report, FRA/ORD-84/12. Available at: https://www.fra.dot.gov/eLib/details/L16988#p1_z5_gD_kExperimental%20Investigation%20of%20Gauge%20Widening.
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5. Sundram, N., and Sussman, T. (2006). Development of Development of Gage Widening Projection Parameter for the Deployable Gage Restraint Measurement System (ORD-06/13). Federal Railroad Administration, Office of Research and Development. Washington, DC: US Department of Transportation. Available at: https://www.fra.dot.gov/eLib/details/L02543#p1_z5_gD_y2006_kgage%20widening.

Appendix A.
List of Exceptions

This appendix lists all exceptions produced by the DOTX 218 GRMS and TGMS systems. The two TGMS exceptions, one Limiting Speed 3, and one GRMS safety exception are in bold.

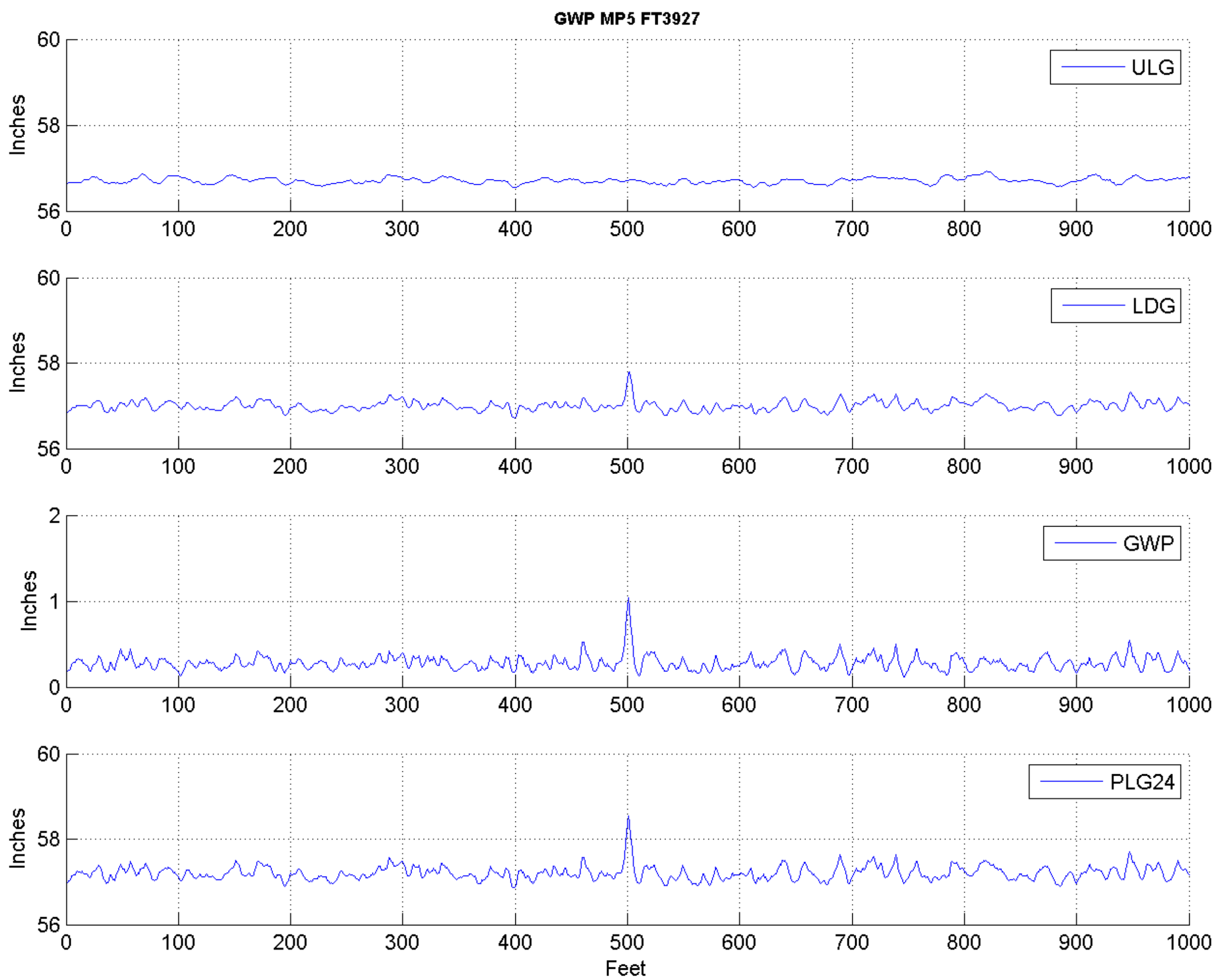
MP	FT	Parameter	Value	Length (feet)	Tangent Spiral Curve	Com-pliant Class	Posted Class	Track No.	Latitude	Longitude
6	408	GWP Maint	0.83	4	T	3	3	5	43.84588	-70.1307
5	**3927**	**GWP Safety**	**1.04**	**1**	**C**	**3**	**3**	**5**	**43.83215**	**-70.1563**
5	3927	GWP Maint	1.04	4	C	3	3	5	43.83215	-70.1563
5	3927	PLG24 Maint	58.55	5	C	3	3	5	43.83215	-70.1563
186	**5050**	**Lmt Speed 3**	**64**	**1413**	**C**	**0**	**4**	**5**	**43.77655**	**-70.2532**
188	**4623**	**Crosslevel**	**1.50**	**6**	**T**	**3**	**4**	**5**	**43.75277**	**-70.2735**
189	165	PLG24 Maint	58.16	6	C	4	4	5	43.75083	-70.2754
190	4985	GWP Maint	0.78	1	T	3	3	5	43.72717	-70.2971
192	1710	PLG24 Maint	58.13	3	C	3	3	5	43.70933	-70.3039
193	4655	PLG24 Maint	58.09	3	C	3	3	5	43.68863	-70.2928
193	4676	PLG24 Maint	58.15	6	C	3	3	5	43.68859	-70.2927
193	4717	PLG24 Maint	58.03	1	C	3	3	5	43.6885	-70.2926
193	4902	PLG24 Maint	58.06	2	S	3	3	5	43.68813	-70.2922
193	5754	PLG24 Maint	58.07	1	C	3	3	5	43.68653	-70.2899
193	5772	PLG24 Maint	58.18	3	C	3	3	5	43.68649	-70.2898
193	5775	PLG24 Maint	58.13	1	C	3	3	5	43.68648	-70.2898
193	5790	PLG24 Maint	58.60	10	C	3	3	5	43.68645	-70.2898
193	5866	PLG24 Maint	58.43	9	C	2	2	5	43.68627	-70.2896
194	110	PLG24 Maint	58.06	1	C	2	2	5	43.68589	-70.2894
194	154	PLG24 Maint	58.18	4	C	2	2	5	43.68578	-70.2893
196	1425	PLG24 Maint	58.51	36	S	2	2	5	43.65565	-70.2813
196	1442	GWP Maint	0.88	3	S	2	2	5	43.65561	-70.2812
196	1496	PLG24 Maint	58.18	20	S	2	2	5	43.65547	-70.2812
196	1504	PLG24 Maint	58.01	2	S	2	2	5	43.65545	-70.2812
196	1508	PLG24 Maint	58.05	3	S	2	2	5	43.65544	-70.2812
196	5176	PLG24 Maint	58.01	1	S	2	2	1	43.64556	-70.2793
196	5454	PLG24 Maint	58.01	1	C	2	2	1	43.64481	-70.2793
196	5492	PLG24 Maint	58.03	2	C	2	2	1	43.64471	-70.2794

MP	FT	Parameter	Value	Length (feet)	Tangent Spiral Curve	Com-pliant Class	Posted Class	Track No.	Latitude	Longitude
196	5667	PLG24 Maint	58.11	2	C	2	2	1	43.64427	-70.2796
196	5966	PLG24 Maint	58.17	5	C	2	2	1	43.64361	-70.2803
196	6113	PLG24 Maint	58.05	2	S	2	2	1	43.64337	-70.2808
196	6121	PLG24 Maint	58.12	4	S	2	2	1	43.64336	-70.2808
196	6135	PLG24 Maint	58.12	3	S	2	2	1	43.64334	-70.2808
196	6156	PLG24 Maint	58.03	3	S	2	2	1	43.64331	-70.2809
196	6212	PLG24 Maint	58.41	9	S	2	2	1	43.64324	-70.2811
196	6230	PLG24 Maint	58.47	11	S	2	2	1	43.64322	-70.2811
196	6278	PLG24 Maint	58.02	1	S	2	2	1	43.64316	-70.2813
196	7762	PLG24 Maint	58.21	4	S	2	2	1	43.64189	-70.2866
196	7776	PLG24 Maint	58.16	6	S	2	2	1	43.64188	-70.2866
196	7787	PLG24 Maint	58.20	6	S	2	2	1	43.64187	-70.2867
196	7800	PLG24 Maint	58.06	2	S	2	2	1	43.64186	-70.2867
199	**327**	**Gage Wide**	**58.04**	**12**	**S**	**0**	**3**	**2**	**43.62534**	**-70.2967**

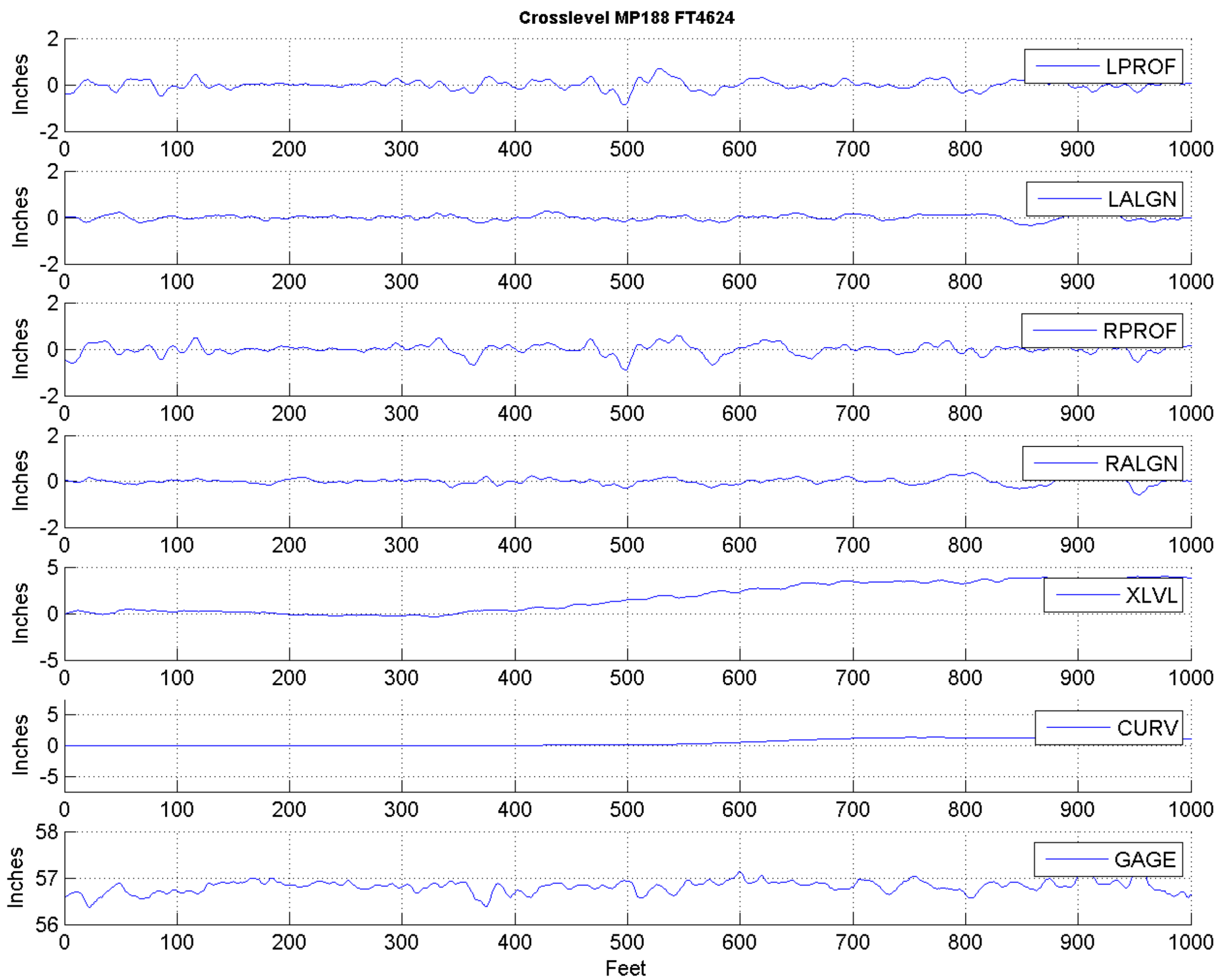
Appendix B.
Exception Strip Charts

Strip charts of the one GRMS safety exception and the two TGMS exceptions are provided.

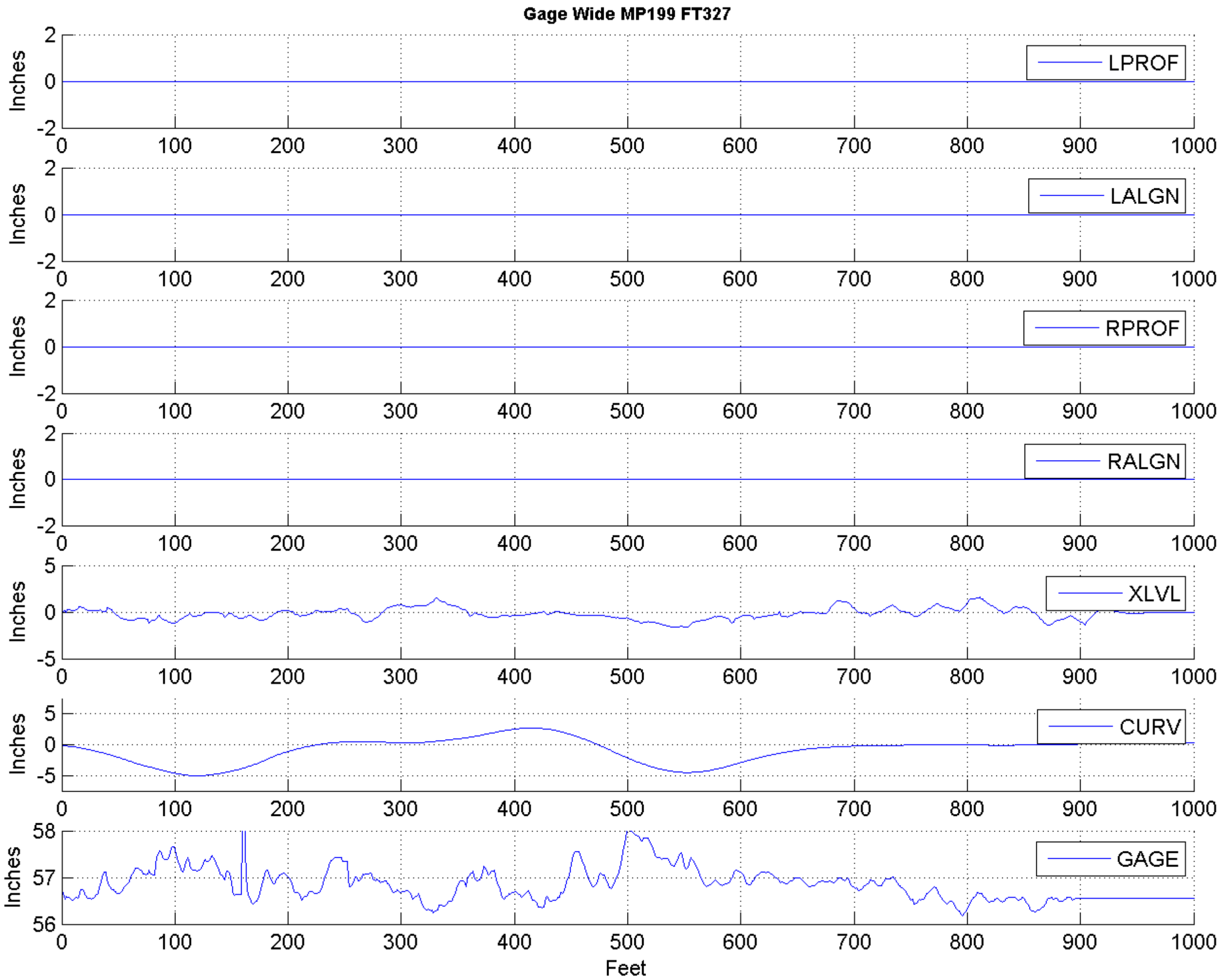
MP	FT	Parameter	Value	Length (feet)	Tangent Spiral Curve	Com-pliant Class	Posted Class	Track No.	Latitude	Longitude
5	3927	GWP Safety	1.04	1	C	3	3	5	43.83215	-70.1563



MP	FT	Parameter	Value	Length (feet)	Tangent Spiral Curve	Com-pliant Class	Posted Class	Track No.	Latitude	Longitude
188	4623	Crosslevel	1.50	6	T	3	4	5	43.75277	-70.2735



MP	FT	Parameter	Value	Length (feet)	Tangent Spiral Curve	Com-pliant Class	Posted Class	Track No.	Latitude	Longitude
199	327	Gage Wide	58.04	12	S	0	3	2	43.62534	-70.2967



Appendix C.
List of Curves

This appendix lists each of the curves from the 2014 survey and presents the absolute required elevation for each curve to meet an allowable unbalance of 3 inches or 4 inches. Negative curvature indicates a curve to the left (left is determined by the direction of travel). Negative elevation indicates that the right rail (in the direction of travel) is higher than the left rail. The cells colored in green indicate adequate elevation for the allowable unbalance. Cells in orange indicate the minimum absolute elevation that needs to be reached to operate at the class determined speed limit for the allowable unbalance. Cells in red indicate that the required elevation exceeds maximum allowable elevation and is unachievable.

The following table considers 3 inches unbalance:

Curve No.	Start of Curve		End of Curve		Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)	
	MP	FT	MP	FT	Class	Degrees	Inches	Ft	mph	mph	Freight	Passenger
1	0	235	0	449	3	-3.06	-0.11	215	40	60	-0.43	-4.71
2	0	449	0	682	3	2.79	-0.51	234	40	60	0.12	4.03
3	13	3920	13	1812	3	-1.04	-3.12	3164	40	60	0.00	0.00
4	13	3397	13	4353	3	-1.54	-3.88	957	40	60	0.00	-0.88
5	12	541	12	1592	3	-1.44	-3.48	1052	40	60	0.00	-0.63
6	12	2827	12	3896	3	2.90	4.22	1070	40	60	0.25	4.31
7	12	4331	12	5269	3	-1.89	-3.66	939	40	60	0.00	-1.76
8	12	5269	11	419	3	-1.21	-3.92	526	40	60	0.00	-0.05
9	11	419	11	1516	3	-2.97	-3.71	1098	40	60	-0.33	-4.48
10	11	1974	11	2758	3	1.30	2.38	785	40	60	0.00	0.28
11	11	3421	11	4461	3	2.84	3.78	1041	40	60	0.18	4.16
12	10	408	10	1672	3	1.46	2.68	1265	40	60	0.00	0.68
13	10	2341	10	3280	3	2.45	3.97	940	40	60	0.00	3.17
14	10	3902	10	5293	3	-0.87	-4.21	1392	40	60	0.00	0.00
15	10	5293	9	1418	3	-2.84	-4.04	1447	40	60	-0.18	-4.16
16	8	1951	8	3455	3	2.90	0.59	1505	40	60	0.25	4.31
17	8	3455	8	4061	3	1.85	1.24	607	40	60	0.00	1.66
18	7	2267	7	3370	3	-2.90	-3.46	1104	40	60	-0.25	-4.31
19	6	1158	6	3196	3	-0.97	-2.00	2039	40	60	0.00	0.00
20	6	4570	5	890	3	2.95	3.58	1538	40	60	0.30	4.43
21	5	890	5	1458	3	1.36	2.75	569	40	60	0.00	0.43
22	5	3333	5	4581	3	-1.65	-2.77	1249	40	60	0.00	-1.16
23	3	2925	3	3859	3	0.54	1.57	935	40	60	0.00	0.00
24	2	3953	2	4832	3	-1.02	-1.71	880	40	60	0.00	0.00
25	1	5819	185	1383	3	-0.64	-1.09	1391	40	60	0.00	0.00
26	186	4838	187	850	4	-0.95	-1.34	1408	60	80	0.00	-1.26
27	188	4625	189	462	4	1.29	3.57	1195	60	80	0.25	2.78
28	189	3972	189	4887	3	-1.95	-3.63	916	40	60	0.00	-1.91
29	190	2520	190	3808	3	-0.96	-1.39	1289	40	60	0.00	0.00
30	190	9938	192	2438	3	-1.81	-3.63	2633	40	60	0.00	-1.56
31	193	4111	193	5114	3	-3.78	-1.18	1004	40	60	-1.23	-6.53
32	193	5228	194	467	2	4.57	1.28	1149	25	30	0.00	0.00

Curve No.	Start of Curve		End of Curve		Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)	
	MP	FT	MP	FT	Class	Degrees	Inches	Ft	mph	mph	Freight	Passenger
33	194	4717	195	481	2	3.33	1.10	727	25	30	0.00	0.00
34	195	1351	195	1774	2	-1.46	-0.39	424	25	30	0.00	0.00
35	195	3527	195	4580	2	-3.09	-0.64	1054	25	30	0.00	0.00
36	196	557	196	939	2	-0.54	-0.63	383	25	30	0.00	0.00
37	196	1302	196	1770	2	8.02	3.04	469	25	30	0.51	2.05
38	196	2219	196	2601	2	-1.92	-1.01	383	25	30	0.00	0.00
39	196	3247	196	3808	2	-0.93	-1.00	562	25	30	0.00	0.00
40	196	4857	196	6443	2	6.53	2.28	1587	25	30	0.00	1.11
41	196	7601	196	7959	2	-2.08	0.16	359	25	30	0.00	0.00
42	196	8477	196	9142	2	-2.14	0.01	666	25	30	0.00	0.00
43	196	9142	196	1083	2	-2.94	-0.97	1693	25	30	0.00	0.00
44	198	1559	198	1803	3	-2.58	0.05	245	40	60	0.00	-3.50
45	198	1803	198	2040	3	2.78	-0.28	238	40	60	0.11	4.01
46	198	2437	199	304	3	1.29	0.08	237	40	60	0.00	0.25
47	199	304	199	535	3	-4.42	-1.10	232	40	60	-1.95	-8.14

Notes:

- DOTX 218 traveled down milepost from MP 15 to MP 1 and then up milepost from MP 185 to MP 199. The feet are always marked after the milepost according to the direction of travel.
- FTSS § 213.57 57(a) stipulates that "The maximum crosslevel on the outside rail of a curve may not be more than 8 inches on track Classes 1 and 2 and 7 inches on Classes 3 through 5."

The following table considers 4 inches unbalance:

Curve No.	Start of Curve		End of Curve		Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)	
	MP	FT	MP	FT	Class	Degrees	Inches	Ft	mph	mph	Freight	Passenger
1	0	235	0	449	3	-3.06	-0.11	215	40	60	0.00	-3.71
2	0	449	0	682	3	2.79	-0.51	234	40	60	0.00	3.03
3	13	3920	13	1812	3	-1.04	-3.12	3164	40	60	0.00	0.00
4	13	3397	13	4353	3	-1.54	-3.88	957	40	60	0.00	0.00
5	12	541	12	1592	3	-1.44	-3.48	1052	40	60	0.00	0.00
6	12	2827	12	3896	3	2.90	4.22	1070	40	60	0.00	3.31
7	12	4331	12	5269	3	-1.89	-3.66	939	40	60	0.00	-0.76
8	12	5269	11	419	3	-1.21	-3.92	526	40	60	0.00	0.00
9	11	419	11	1516	3	-2.97	-3.71	1098	40	60	0.00	-3.48
10	11	1974	11	2758	3	1.30	2.38	785	40	60	0.00	0.00
11	11	3421	11	4461	3	2.84	3.78	1041	40	60	0.00	3.16
12	10	408	10	1672	3	1.46	2.68	1265	40	60	0.00	0.00
13	10	2341	10	3280	3	2.45	3.97	940	40	60	0.00	2.17
14	10	3902	10	5293	3	-0.87	-4.21	1392	40	60	0.00	0.00

Curve No.	Start of Curve		End of Curve		Track	Average Curvature	Average Elevation	Length	Freight Speed	Passenger Speed	Required Elevation Change to (inches)	
	MP	FT	MP	FT	Class	Degrees	Inches	Ft	mph	mph	Freight	Passenger
15	10	5293	9	1418	3	-2.84	-4.04	1447	40	60	0.00	-3.16
16	8	1951	8	3455	3	2.90	0.59	1505	40	60	0.00	3.31
17	8	3455	8	4061	3	1.85	1.24	607	40	60	0.00	0.66
18	7	2267	7	3370	3	-2.90	-3.46	1104	40	60	0.00	-3.31
19	6	1158	6	3196	3	-0.97	-2.00	2039	40	60	0.00	0.00
20	6	4570	5	890	3	2.95	3.58	1538	40	60	0.00	3.43
21	5	890	5	1458	3	1.36	2.75	569	40	60	0.00	0.00
22	5	3333	5	4581	3	-1.65	-2.77	1249	40	60	0.00	-0.16
23	3	2925	3	3859	3	0.54	1.57	935	40	60	0.00	0.00
24	2	3953	2	4832	3	-1.02	-1.71	880	40	60	0.00	0.00
25	1	5819	185	1383	3	-0.64	-1.09	1391	40	60	0.00	0.00
26	186	4838	187	850	4	-0.95	-1.34	1408	60	80	0.00	-0.26
27	188	4625	189	462	4	1.29	3.57	1195	60	80	0.00	1.78
28	189	3972	189	4887	3	-1.95	-3.63	916	40	60	0.00	-0.91
29	190	2520	190	3808	3	-0.96	-1.39	1289	40	60	0.00	0.00
30	190	9938	192	2438	3	-1.81	-3.63	2633	40	60	0.00	-0.56
31	193	4111	193	5114	3	-3.78	-1.18	1004	40	60	-0.23	-5.53
32	193	5228	194	467	2	4.57	1.28	1149	25	30	0.00	0.00
33	194	4717	195	481	2	3.33	1.10	727	25	30	0.00	0.00
34	195	1351	195	1774	2	-1.46	-0.39	424	25	30	0.00	0.00
35	195	3527	195	4580	2	-3.09	-0.64	1054	25	30	0.00	0.00
36	196	557	196	939	2	-0.54	-0.63	383	25	30	0.00	0.00
37	196	1302	196	1770	2	8.02	3.04	469	25	30	0.00	1.05
38	196	2219	196	2601	2	-1.92	-1.01	383	25	30	0.00	0.00
39	196	3247	196	3808	2	-0.93	-1.00	562	25	30	0.00	0.00
40	196	4857	196	6443	2	6.53	2.28	1587	25	30	0.00	0.11
41	196	7601	196	7959	2	-2.08	0.16	359	25	30	0.00	0.00
42	196	8477	196	9142	2	-2.14	0.01	666	25	30	0.00	0.00
43	196	9142	196	1083	2	-2.94	-0.97	1693	25	30	0.00	0.00
44	198	1559	198	1803	3	-2.58	0.05	245	40	60	0.00	-2.50
45	198	1803	198	2040	3	2.78	-0.28	238	40	60	0.00	3.01
46	198	2437	199	304	3	1.29	0.08	237	40	60	0.00	0.00
47	199	304	199	535	3	-4.42	-1.10	232	40	60	-0.95	-7.14

Notes:

- DOTX 218 traveled down milepost from MP 15 to MP 1 and then up milepost from MP 185 to MP 199. The feet are always marked after the milepost according to the direction of travel.
- FTSS § 213.57 57(a) stipulates that "The maximum crosslevel on the outside rail of a curve may not be more than 8 inches on track Classes 1 and 2 and 7 inches on Classes 3 through 5."

Abbreviations and Acronyms

ARRA	American Recovery and Reinvestment Act of 2009
ATIP	Automated Track Inspection Program
FRA	Federal Railroad Administration
GRMS	Gage Restraint Measurement System
GWP	Gage Widening Projection
GWR	Gage Widening Ratio
GPS	Global Positioning System
MP	Milepost
NNEPRA	Northern New England Passenger Rail Authority
RD&T	Office of Research, Development and Technology
PAR	Pan Am Railways
PLG24	Projected Loaded Gage
ROW	Right-Of-Way
TGMS	Track Geometry Measurement System
TSS	Track Safety Standards