FTA Report No. 0215

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

Research Report and Findings: Review of Standards for Track Inspection and Maintenance

Final Report

PREPARED BY

Stephen Wilk, David Davis, Stephen Dick, Yuqing Zeng, MaryClara Jones
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads

MAY 2022

U.S. Department of Transportation
Federal Transit Administration

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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14. ABSTRACT
This research was performed to determine the state of inspection and maintenance practices for rail transit agencies in the U.S. Project objectives included (1) performing an extensive literature review to summarize and compare current specifications and standards for rail transit track inspection and maintenance in the U. S. and other countries, including what is being used by agencies in the U.S., (2) performing a gap analysis to determine deficiencies in current standards, and (3) establishing recommendations to FTA for developing voluntary standards, protocols, guidelines, or recommended practices associated with rail transit track inspection and maintenance. A series of findings are presented.

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Rail transit track inspection, rail transit maintenance, derailment threat reduction, visual and automated track inspections

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Abstract

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This report was prepared for the Center for Urban Transportation Research (CUTR) by Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), Pueblo, CO. This report is based on investigations and tests conducted by TTCI with the direct participation of CUTR to criteria approved by them. The contents of this report imply no endorsements whatsoever by TTCI of products, services, or procedures, nor are they intended to suggest the applicability of the test results under circumstances other than those described in this report. The results and findings contained in this report are the sole property of CUTR. They may not be released by anyone to any party other than CUTR without the written permission of CUTR. TTCI is not a source of information with respect to these tests, nor is it a source of copies of this report. TTCI makes no representations or warranties, either express or implied, with respect to this report or its contents. TTCI assumes no liability to anyone for special, collateral, exemplary, indirect, incidental, consequential, or any other kind of damages resulting from the use or application of this report or its contents.

Executive Summary

Transportation Technology Center, Inc. (TTCI), with support from the Center for Urban Transportation Research (CUTR) at the University of South Florida, was tasked by the Federal Transit Administration (FTA) to research and develop specifications and guidelines for rail transit track inspection and maintenance.

Project objectives include (1) performing an extensive literature review to summarize and compare current specifications and standards for rail transit track inspection and maintenance in the U.S. and other countries, including what is being used by agencies in the U.S., (2) performing a gap analysis to determine deficiencies in current standards, and (3) establishing recommendations to FTA for developing voluntary standards, protocols, guidelines, or recommended practices associated with rail transit track inspection and maintenance.

The literature review consisted of identifying industry needs based on accident reports, a review of inspection literature, and results from a data collection effort. Accident reports involving passenger trains from the Federal Railroad Administration (FRA), National Transportation Safety Board (NTSB), and National Transit Database (NTD) accident databases were reviewed and show that an estimated 35–40% of mostly passenger service train derailments are from track causes (NTD began capturing yard derailments starting in 2015). A high proportion of track-caused derailments occur from track geometry, special trackwork (turnouts, crossing diamonds and rail joints on moveable span bridges), and rail defects. Also, about 75% of all track-caused accidents occur in yards (other than on mainline) tracks. The FRA database is more comprehensive in assigning a cause to each accident, whereas NTD reports often do not list a cause. The relevant NTSB reports typically identified that causes of a derailment included lack of inspection to standards and not because the standards are inadequate or lacking.

A literature review of data collection results showed that the majority of agencies use FRA, American Public Transportation Association (APTA), or agency standards that are typically based on FRA or APTA standards. FRA and APTA standards were compared against North American, Chinese, and some European standards; North American standards were all similar, and Chinese and European standards have stricter track geometry restrictions, typically because of their higher train speeds.

An industry data collection effort was completed to investigate the use of specifications and standards related to track maintenance and inspection. The data collection effort used State Safety Oversight Agency (SSOA) contacts to collect data from the rail transit agencies in representative states. Data collection results showed that U.S. transit agencies have a wide range of infrastructure systems, inspection and maintenance practices, and needs. Systems range from less than a mile to over 200 miles and have heavy rail, light rail, and streetcar modes. Consistent with the literature review findings, the majority of agencies use either FRA, APTA, or their own agency standards. Other key findings were as follows:

- The majority of agencies that responded use gauges for hand measurements and conduct annual geometry and rail flaw tests.
- All agencies responded that they use predictive maintenance planning practices as a policy. However, smaller agencies (in terms of track miles operated) accomplish this more often, with larger agencies having to resort to reactive maintenance more frequently. A correlation between agency size and the average age of the infrastructure comes into play as well. However, larger agencies likely have a larger number of unplanned maintenance activities, if not a higher rate.
- Overall, 50% of agencies that responded have less than 4-hour time windows for maintenance each day.
- Larger agencies would benefit from more automated inspection and maintenance practices.

The comprehensive literature review and survey results were used to analyze the needs and gaps in rail transit inspection and maintenance practices and to establish findings related to the development of voluntary rail inspection and maintenance standards, protocols, guidelines, or recommended practices associated. The gap analysis revealed several potential opportunities for improvements in track inspection and maintenance standards, methods, and technologies. These opportunities may produce improvements in the safety and efficiency of transit operations.

Based on the results of the research, feedback, and suggestions from CUTR's Transit Safety Standards Working Group, the following findings are provided for consideration; as many of the findings are interrelated, it is possible that addressing some combination of findings will eliminate the need for some of the others:

- **Finding 1:** Lower track speed safety standards (Class 1 track class) result in a higher number of yard accidents, as shown by NTD data. Further investigation is needed to determine specific causes and prevention methods. Policy reviews and possible improvements may reduce non-revenue service operation and vehicle incidents. Based on accident data, it is apparent that a significant number of accidents occur with non-revenue service operations.
- **Finding 2:** Switch point inspection improvements can be made. Purpose-built gauges to assess wheel/rail contact developed specific to an agency's

track geometry will assist in inspections. An FTA or industry project to develop gauges for the range of rail and wheel profile combinations is an option.

- **Finding 3:** Training for turnout operations can reduce incidents, and APTA could consider revising its recommended practice on turnout inspections.
- **Finding 4:** The NTD data reporting system does not include derailment cause finding reporting; inclusion of that data definer will assist in future data analysis efforts.
- **Finding 5:** Vehicle/track interaction plays a large role in derailment incidents. Track maintenance standards can be tailored to agency types and characteristics of vehicles. One standard defining requirements for track maintenance may not fit all agencies due to differences in vehicle types, track gage, wheel profile, wheel back-to-back spacing, and more. Sister agencies that have the same vehicle, track, and operational characteristics may be able to confer and improve their inspection procedures and policies.
- **Finding 6:** Industry track geometry safety standards and recommended practices exist, including FRA Track Safety Standards (49 CFR Part 213); APTA Inspection and Maintenance Standard (RT-FS-S-002-02, Rev 1), which is similar in scope to 49 CFR Part 213 and directly accounts for a variety of track gages found in rail transit; and APTA RT-FS-S-002-2 Rev 1, Rail Transit Track Inspection and Maintenance, which lists inspections under load. Loaded conditions flex track geometries and increasing the frequency of inspections can reduce incidents.
- **Finding 7:** New automated inspection technology developments may be worthy of demonstration/validation.
- **Finding 8:** A thorough review by the industry can improve turnout design with respect to the vehicles and operating speeds used in transit today.

Section 1 Introduction

Inspection and maintenance of track are integral parts for ensuring the continuation of safe passenger rail service in the U.S. A railroad track structure is a complex system in which all components must be functioning properly for it to perform as intended. On a regular basis, all these components must be inspected to find any defects; if any defects are found or if a component is likely to develop a defect in the near future, maintenance must be performed. The inspection and maintenance process must be continual and can be challenging for transit agencies because of limited time windows for personnel to safely perform the work.

The Federal Transit Administration (FTA) is sponsoring research to determine the state of inspection and maintenance practices for rail transit agencies in the U.S. The research includes (1) determining the causes of previous track-induced derailments, (2) reviewing existing inspection and maintenance standards used by agencies in the U.S., and (3) surveying transit agencies to determine current inspection and maintenance practices. Gaps in standards or practices will be identified, along with recommendations for how FTA can improve rail transit inspection and maintenance in the U.S. through standards or guidelines.

Section 2

Industry Need

U.S. transit agency accident data and incident reports were reviewed to investigate possible trends from track inspection or maintenance-related derailments. This review provided insight into problematic aspects of track inspection and maintenance, and helped determine how improvements in standards and practices could address these problems. Federal Railroad Administration (FRA) and National Transit Database (NTD) accident databases were reviewed. FRA compiles accident reports for track governed by FRA track safety standards; this includes the freight railroad network, Amtrak operations, and many other heavy rail passenger operations. The FRA database includes details about the track and mechanical components involved in accidents. The database also assigns a predominant cause to each accident, using a cause code. NTD data consist of transit agency-reported incidents, including derailments, compiled by FTA. NTD records describe accidents with fewer details related to the components and factors involved; often, causes are not assigned to accidents.

Incident reports are published by the National Transportation Safety Board (NTSB), an independent U.S. agency. The NTSB typically investigates accidents and incidents that involve public safety on U.S. transportation infrastructure. The next section includes summaries of all investigated passenger derailments from track inspection or maintenance related issues in the past 20 years. Note that the NTSB does not investigate all incidents or derailments, only major accidents, and typically those related to public safety.

Accident Reports

Accident data from the FRA and NTD databases were analyzed to determine the predominant track-caused accident failure modes. The objective of the analysis was to summarize causal information and identify areas related to track inspection and maintenance standards and practices that may benefit from improvements.

In the FRA database, the 10-year period of 2007–2016 was analyzed for trends. The first data analysis identified all derailments related to passenger trains, thus reducing the FRA data set to the operations of interest in this study—heavy rail passenger operations. Figure 2-1 shows the number of passenger related derailments during this period (226). The FRA database includes all track governed by FRA track safety standards. Approximately 40% of 90 passenger train-related derailments were track-caused (Figure 2-2).

A further breakdown of track-caused FRA accidents is shown in Figure 2-3, with the 90 track-caused accidents divided into major sub-groups of causes. The figure shows that track geometry defects are the leading subgroup, with about 37% of the total, followed by special trackwork, with 3%, and rail, joint bar, and anchoring at 23%. Roadbed failures comprise about 5% of the total. This distribution suggests that track-caused derailments of passenger trains on track governed by FRA safety standards have several causes without a dominant failure mode. However, additional scrutiny should be given to inspection and maintenance standards related to track geometry, turnouts, and rail to make improvements in performance.

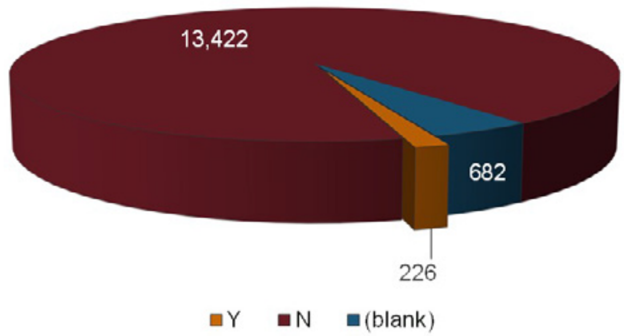

Figure 2-1 *FRA accidents associated with passenger trains*

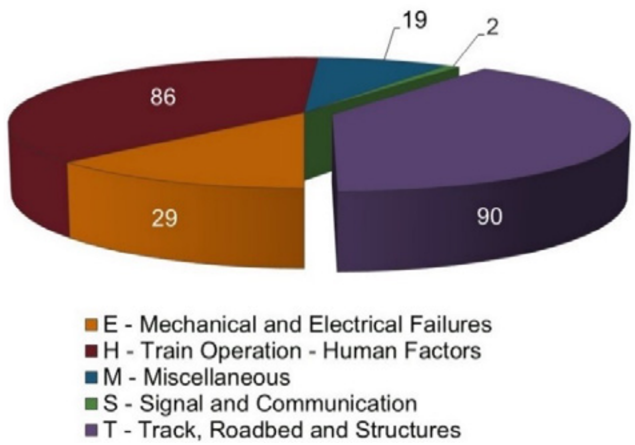

Figure 2-2 *Passenger train accidents classified by main cause (FRA database)*

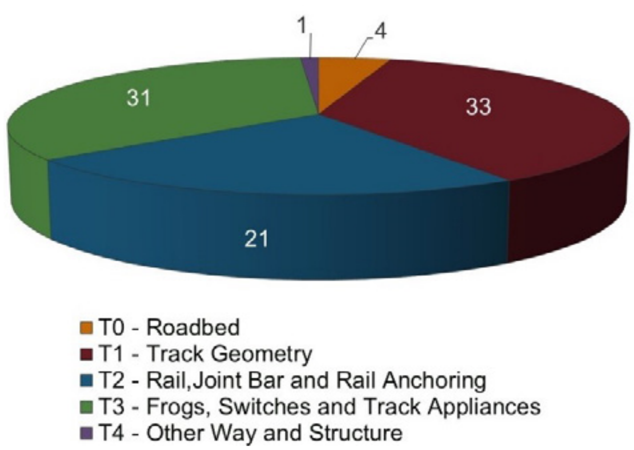

Figure 2-3 *Track-caused passenger train accidents by sub-group (FRA database)*

NTD data also were examined for track-caused derailments for 2008–2016. The NTD database covers accidents on track not governed by FRA safety standards and has more types of incidents than the FRA database due to the varied transit system operations. This same time period was examined, as shown in Figure 2-4. In this larger database, TTCI found 505 derailments. Non-roadway crossing collisions comprised about 75% of the entries in the database.

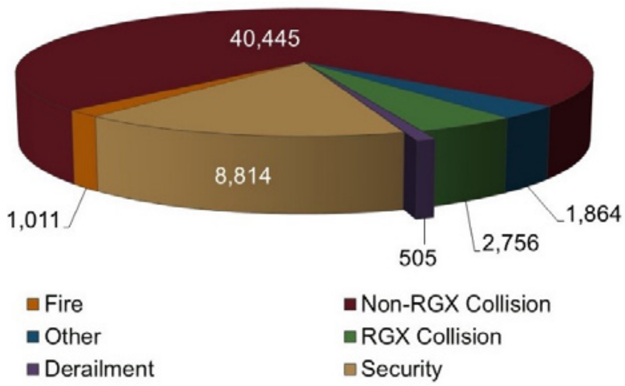

Figure 2-4 *NTD derailment accident data, 2008–2016*

Figure 2-5 shows the number of derailments occurring each year. Of note is that reporting requirements changed in 2015; among the changes, derailments in yard tracks were included. Although the number of derailments before 2015 is not directly comparable to the number reported from that time forward, it can be surmised that more than half of derailments occur on non-mainline tracks. The increases in non-mainline track derailments likely diminishes derailment damage and public safety risks due to lower speeds and the higher likelihood of empty trains in yards. This finding also suggests that inspection and maintenance of non-mainline tracks should be given increased attention.

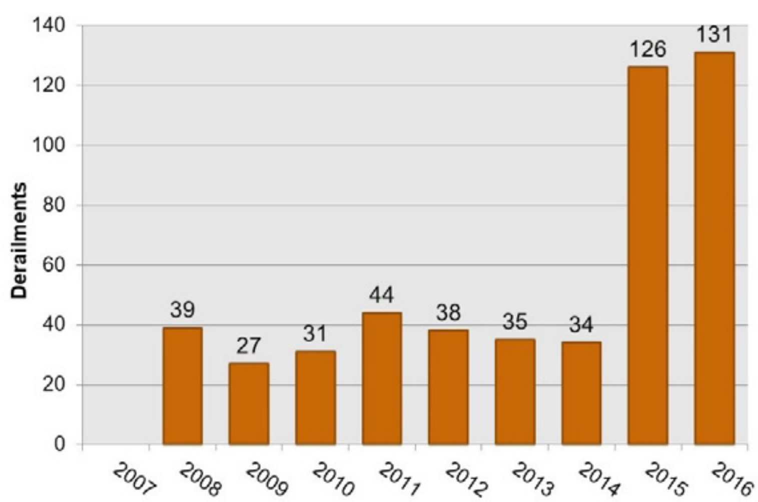

Figure 2-5 *Annual derailments, 2007–2016 (NTD)*

Note: Includes yard derailments for 2015 and 2016

An attempt was made to classify NTD derailments by cause. Unlike the FRA database, the NTD database does not list a cause for most derailments; there is a description of the event, but the cause is often ambiguous. Even when there are broken components, a derailment cause may not be assigned. Figure 2-6 shows that 30 of the 505 derailments in the database were identified as having a track cause; these 30 entries assigned the track as the cause of the derailment.

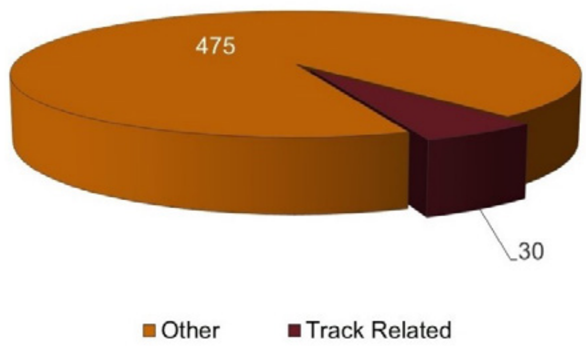

Figure 2-6 *Derailments attributed to track causes (NTD)*

After review by the CUTR Transit Safety Standards Working Group, a further examination of the 505 derailments was conducted. The Working Group was concerned that reporting 30 track-caused derailments of 505 (6%) gives the impression that track-caused derailments are low on the research priority list. With many of the 505 derailments not having assigned causes, this percentage is misleading. Thus, a random sample of 100 derailments from the 485 derailments not identified as track-caused was examined in detail. Of this sample, one was determined to be track-caused; debris blocking a switch was the cause of the accident. An additional 37 of the 100 derailments occurred on turnouts but were not assigned a cause. A few additional derailments occurred in turnouts and were assigned human factors causes. Also listed were derailments without assigned causes, where vehicles derailed in curves and yard tracks.

If half or more of these derailments were track-caused, then track-caused derailments are likely to be 25–35% of the total. This also agrees reasonably well with the FRA database, in which approximately 40% of passenger derailments were track-caused. The lack of details related to determining the cause of derailments in the database limits its usefulness for studies such as this one. However, the small sample of 30 derailments reported as track-caused can provide some insight into the failure modes occurring under transit operations.

The 30 identified track-caused derailments from the NTD were further classified into cause sub-groups to help compare causes from two different datasets. Figure 2-7 shows the results of that exercise. Note that 67% of the total were turnout-related events; rail defects accounted for 20% of the total, and track geometry accounted for another 10%. This differs from the FRA database, in that turnouts are a much larger share of the FTA total, with track geometry causes being much less. This may be due to the small sample size of identified track causes, the relative difficulty in assigning certain track geometry causes, or the relatively higher number of turnouts in transit track. Regardless, the data available suggest that turnouts should be a focus area for improving track inspection and maintenance standards.

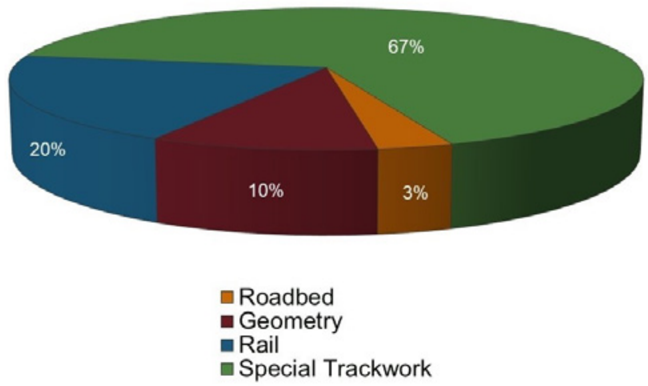

Figure 2-7 *Track-caused derailments by sub-group (NTD)*

In summary, the following findings are from review of accident databases:

- Track-caused derailments are about 35–40% of the total number of derailments.
- Turnouts are the track component or feature associated with the largest number of track-caused accidents on transit operations. Track geometry defects are the leading cause of passenger train derailments on track governed by FRA safety standards; rail defects and turnouts are the second-leading track cause in the NTD and FRA databases.
- Many track-caused derailments found in the NTD database occurred in yards.
- The NTD database is less useful for a derailment cause analysis than the FRA database due to lack of details about track and vehicles involved; there often is no cause of derailment assigned in the reports.

National Transportation Safety Board (NTSB) Reports

NTSB investigated the following six transit derailments regarding track structure in the past 20 years. Each description includes a summary of the incident and NTSB recommendations. Only track inspection-related derailments were reported.

Derailment of WMATA Metrorail Train[1]

On July 29, 2016, at about 6:14 am EST, a westbound Washington Metropolitan Area Transit Authority (WMATA) Metrorail train derailed while passing a crossover in the East Falls Church interlocking. Three of the 63 passengers on the six-car train reported injuries.

Investigations revealed the following:

- Static track gage was 58¼ in. with additional movement of 0.75 in. from dynamic loading, resulting in a projected total track gage of 59 in. at the moment of derailment. The WMATA nominal track gage is 56¼ in., and the upper limit is 57¼ in.
- More than 400 in. of track with no effective rail fasteners were observed due to deteriorated crossties; the WMATA limit is 120 in.
- Track inspections occurred monthly instead of the WMATA-prescribed bi-weekly basis.

The probable cause determined by NTSB was:

> … a wide track gage condition resulting from the sustained use of deteriorating wooden crossties due to Washington Metropolitan Area Transit Authority's ineffective inspection and maintenance practices and inadequate safety oversight.

The NTSB also concluded that neither regulatory powers authorized due to Moving Ahead for Progress in the 21st Century (MAP-21) legislation nor the creation of the Washington Metrorail Safety Commission would resolve the identified deficiencies in safety oversight of WMATA.

Amtrak Derailment near Cimarron, KS[2]

On March 14, 2016, at about 12:02 pm CDT, an eastbound Amtrak (National Railroad Passenger Corporation) train derailed while crossing a misaligned track. Of the 2 locomotives and 10 cars, the last 4 cars derailed, and 28 of the 144 passengers and employees were injured. The estimated damage was more than $1.4 million. The misaligned track was from an unattended two-axle agricultural truck that rolled down a hill, crossed a highway, and collided with BNSF track. An employee of the feed plant that was responsible for the truck was not aware that the track was damaged and did not report the collision with BNSF. However, the collision caused track damage and misalignment.

[1] NTSB (2017), Derailment of WMATA Metrorail Train in Interlocking Falls Church, Virginia, RAB-16/06, updated 3 April 2017, Washington DC.

[2] NTSB (2017), Amtrak Train Derailment on BNSF Railway Tracks, Cimarron, KS, RAB-17/11, Washington DC.

The probable cause determined by NTSB was:

> … the agriculture truck driver's failure to properly secure his unattended truck, which rolled downhill and struck the BNSF railroad tracks causing them to misalign. Contributing to the accident was the failure of the truck's driver and his supervisor to report the incident to the local authorities.

Metro-North Railroad Derailment[3]

On July 18, 2013, at 8:29 pm EST, a northbound CSX train derailed along the Metro-North Railroad Hudson Line. Of the 2 locomotives and 24 modified flat cars, cars 11 through 20 derailed. There were no injuries or fatalities, and the estimated damage was $827,000.

Investigations revealed the following:

- Improper fasteners allowed for lateral movement during train passage.
- Fouled ballast was noted in the derailment area; the fouling was likely from concrete tie degradation.
- Wear on the field side of the rail seat and center cracking were observed on a number of ties.
- The concrete ties were installed in 2000 (13 years prior to the incident) and last surfaced in 2004 (9 years prior to the incident). The maintenance program states that concrete ties should be replaced every 6–7 years and surfaced every three years.

The probable cause determined by NTSB was:

> … excessive track gage due to a combination of fouled ballast, deteriorated concrete ties, and profile deviations resulting from Metro-North's decision to defer scheduled track maintenance.

Derailment of WMATA Train[4]

On January 7, 2007, at about 3:45 pm EST, a northbound WMATA train derailed one car while traversing a crossover. Of a six-car train, the fifth car derailed, and 20 of the 80 passengers on board were injured.

The probable cause determined by NTSB was the following:

> … a wheel climb on car 5152 that was initiated by a rough wheel surface created when the wheel was trued with a milling machine, the lack of quality control measures to ensure that wheel surfaces were

[3] NTSB (2014), Metro-North Railroad Derailment. RAB-14/11, Washington, DC.

[4] NTSB (2007), Derailment of Washington Metropolitan Area Transit Authority Train near the Mt. Vernon Square Station, RAR-07/03, Washington, DC.

> smoothed after truing, the lack of a guard rail on the No. 8 turnout, and Washington Metropolitan Area Transit Authority's failure to have an effective process to implement safety improvements identified following similar accidents and related research projects.

Derailment of CTA Train[5]

On July 11, 2006, at about 5:06 pm CDT, the last car of a northbound CTA blue line train derailed in a subway in downtown Chicago. About 1,000 passengers were onboard the 8-car rapid transit train. There were 152 reported injuries and no fatalities. The total damage exceeded $1 million.

Investigations determined the following:

- Corroded tie plate and fasteners and water damaged half-ties.
- At the point of the derailment, the gage was 60¼ in. CTA optimum gage measurement is 56½ in., and any track with gage above 58 in. should be put out of service.
- Only a portion of the track section could be inspected in a single day, instead of the prescribed entire section.
- CTA's track inspection training did not properly prepare track inspectors for required duties.

The probable cause determined by NTSB was:

> … the Chicago Transit Authority's ineffective management and oversight of its track inspection and maintenance program and its system program, which resulted in unsafe track conditions. Contributing to the accident were the Regional Transportation Authority's failure to require that action be taken by the Chicago Transit Authority to correct unsafe track conditions and the Federal Transit Administration's ineffective oversight of the Regional Transportation Authority. Contributing to the seriousness of the accident was smoke in the tunnel and the delay in removing that smoke.

Derailment of MBTA Train[6]

On May 4, 1998, at 3:23 pm EST, a Massachusetts Bay Transportation Authority (MBTA) passenger train derailed its first two lead cars along MBTA system's Blue Line. Three of the 10 passengers and the train operator reported injuries.

[5] NTSB (2007), Derailment of Chicago Transit Authority Train Number 220 Between Clark/Lake and Grand/Milwaukee Stations, RAR-07/02, Washington, DC.
[6] NTSB (1998), Derailment of MBTA Train, RAB-98/24, Washington, DC.

Investigations revealed the following:

- The restraining rail was not put back in place after replacing the track structure the prior night.

The probable cause determined by NTSB was:

> … the failure of the Massachusetts Bay Transportation Authority to have adequate procedures in place to ensure safe operations when restraining rails are not in place

Section 3 Review of Inspection Literature

This section presents a literature review of existing U.S. and international standards and guidelines regarding railroad transit track inspection. The objective was to determine what standards currently exist, how different standards compare, and what knowledge gaps exist.

Multiple sources were compiled to understand existing standards and recommended practices from inside and outside the U.S. The literature review is divided into the following sections based on topic:

- Track Structure
- Roadbed
- Track Geometry
- Inspection

The Track Structure section covers the general track structure components including rail, crossties, ballast, and special trackwork. The Roadbed section covers drainage and vegetation. The Track Geometry section covers track geometry limits. Inspection covers the specified methods and frequencies of inspection of various track components. The documents used in the literature review are shown in Table 3-1. The majority are from North American regulatory agencies, but standards from Europe and Asia also are included. Many freight and passenger railroads have their own agency standards. Many standards are proprietary and could not be included in this analysis.

There were two types of limits in the reviewed documents, and it is important to recognize the differences between them. Safety standards, also referred to as safety limits or intervention limits, are limits that, if surpassed, are considered safety and derailment risks by the controlling regulatory agency. Maintenance standards, also referred to as maintenance limits or alert limits, are typically stricter than safety limits. Transit agencies often use maintenance limits internally to ensure that no safety limits are ever exceeded, and regulatory or non-regulatory government agencies often use these as guidelines or recommendations for the transit agencies to follow. Also, some transit agencies have multiple maintenance limits referring to the urgency of repair (red, yellow, green, for example) that allow the transit agencies to prioritize maintenance.

Table 3-1 *Inspection Documents Used in Literature Review*

Affiliation	Reference Number	Title	Year
Federal Railroad Administration (FRA)	49 CFR 213	Track Safety Standards (TSS)	2014
American Public Transportation Association (APTA)	RT-FS-S-002-02, Rev 1	Rail Transit Track Inspection and Maintenance	2017
Federal Transit Administration (FTA)	None	Pocket Guide: Compilation of Rail Transit Industry Best Practices for Track Inspection and Maintenance (2010)	2010
Transport Canada (TC)	TC E-54	Rules Respecting Track Safety	2012
European Norm (European Committee for Standardization) (EN)	EN 13848-5	Safety Standards	2017
China Railway (CR)	None	Rules of Track Maintenance	2006

FRA Track Safety Standards, published under Title 49, Code of Federal Regulations (CFR) Part 213 (CFR 49 – Part 213) are the track safety standards applied to all freight railroad track and some passenger (commuter) track in the U.S.

The APTA Rail Transit Track Inspection and Maintenance Standard is referred as APTA RT-FS-S-002-02, Rev 1 and covers minimum requirements for inspecting and maintaining rail transit tracks. The Standard was first developed in 2002 and was updated in 2017.

FTA Pocket Guide: Compilation of Rail Transit Industry Best Practices for Track Inspection and Maintenance suggests inspection and maintenance limits that can be used by rail transit agencies in the U.S., which differs from the FRA and APTA standards because it does not state safety limits that must be adhered to, but rather recommends maintenance limits in which the suggested fix is dependent on the severity of the defect.

TC Rules Respecting Track Safety are track safety standards for Canada, published in 2012, and cover freight and passenger lines in Canada. TC standards are similar to FRA standards.

EN 13848-5 are European standards that focus solely on track geometry standards.

CR standards are developed by the Ministry of Railway (MOR, predecessor of China Railway) and apply to all railroads in China. Topics covered by CR standards are similar to FRA safety standards.

The scope of this literature review involved identifying general topics that each standard or recommendation covers, with general comments comparing the standards. As wording is slightly different, and each standard or recommendation has slightly different topics and lists, noting specific differences between each standard was beyond the scope of this project and would require in-depth follow-up. The goal of the literature review was to present a general overview of what is in each standard and where general gaps reside.

Track Structure

Track structure incorporates various components that structurally support the running surface during train passage. Track structure generally includes rail, fastening systems, crossties, and ballast but can also include components that combine various sections of rail, such as joint bars, welds, or components that allow for tracks to separate and cross each other. Rails, fastening systems, and crossties can be referred to as the superstructure, and the ballast and underlying subbase often are referred to as the substructure. A photograph of a typical structure is shown in Figure 3-1.

Figure 3-1 *Typical track section with timber crossties and elastic fasteners*

Rail

The rail is the track structure component that serves as a guideway for the passing train wheel. The rail is composed of steel and is manufactured in long sections that are combined using joint bars or welds. Due to rail providing direct support for the wheels, ensuring proper rail integrity is important for the safe passage of trains. Rails can fail from multiple mechanisms, including fractures, wear, and localized defects. A photograph of a rail section is shown in Figure 3-2.

Figure 3-2 *Cut section of rail*

General requirements for rails are:

- Defective Rail – list of all conditions that can produce what is defined as a defective rail
- Rail Wear – maximum amount of rail wear allowed
- Rail End Mismatch – allowable mismatch between rails at joints
- Torch Cut Rail – restrictions on torch cut rails

The standards and practices that cover the above topics are shown in Table 3-2. The majority of the standard is a list of rail defects; the APTA and FTA standards go into more detail about defect severity and recommended remediation.

Table 3-2 *Covered Topics for Rail*

Topics	FRA	APTA	FTA	TC	CR
Defective Rails	213.113	10.1	2.1	D-III	3.4, 6.4, 7.2
Rail Wear	N/A	10.2	2.2	D-X	3.4, 7.2
Rail End Mismatch	213.115	10.3.3	2.5	D-IV	3.4, 6.4, 7.2
Torch Cut Rails	213.122	10.1.6	2.12		3.4, 4.3

Fastening System

The fastening system connects the rail to the underlying structure, typically crossties or slab track. The type of fastening system depends on the underlying structure and can range from cut spikes in timber crossties (Figure 3-3a) to elastic fasteners when attaching to concrete (Figure 3-3b). The elastic fasteners also include pads for damping and reduction in stiffness. Fastening systems can fail from a wide range of mechanisms and are generally considered defective if the fasteners fail in any manner.

(a) (b)

Figure 3-3 *(a) Cut spikes in timber crossties; (b) elastic fasteners on concrete crossties*

General requirements for fastening systems are:

- Track Geometry – have effective rail fastening systems to maintain track geometry
- Longitudinal Restraint – track system should provide longitudinal restraint except for circumstances where rail needs to be able to move
- Defective Fasteners – list of conditions that constitutive defective rail fasteners or direct fixation rail fastening systems
- Joints – have non-defective fasteners near joints
- Tie Plates – should be present in track with timber crossties
- Maximum Number Defective – have a maximum number of defective fasteners for a prescribed length of track
- Maximum Number Consecutive – have a maximum number of consecutive defective fasteners

The standards and practices that cover the above topics are shown in Table 3-3. FRA standards emphasize track geometry and APTA standards emphasize defective fasteners. These factors are related, but APTA appears to emphasize the cause—defective fasteners—whereas FRA emphasizes the effect—track geometry. The *FTA Pocket Guide* generally lists what constitutes a defective fastener and the maximum number of defective fasteners allowed in 100 ft of rail.

Table 3-3 *Covered Topics for Fastening Systems*

Topics	FRA	APTA	FTA	TC	CR
Track Geometry	213.127	9.2.1		D-VIII	3.5, 6.4, 7.2
Longitudinal Restraint	213.127			D-VI	3.5, 6.4, 7.2
Defective Fasteners		9.2.4	3.7		3.5, 6.4, 7.2
Joints	213.127	9.2.5			3.5, 6.4, 7.2

Topics	FRA	APTA	FTA	TC	CR
Tie Plates	213.123	9.2.6	3.6	D-VI	3.5, 6.4, 7.2
Minimum # Defective		9.2.1	3.7		
Minimum # Consecutive		9.2.1			

Crossties

Crossties serve as a bearing layer that distributes the wheel load from the rail into the ballast substructure. They generally are composed of timber or concrete and can come in various shapes, are oriented perpendicular to the rail, and are spaced in 19.5–24-in. center-to-center increments. Some track does not use crossties and directly fastens the rail to a concrete slab or some other structure (direct fixation track). The crosstie material affects common failure mechanisms and can fail from fracturing, wear, and local defects.

General tie requirements include the following:

- Material – consist of a material that can be securely fastened and restricts horizontal and vertical movement
- Track Geometry – have enough effective ties to maintain track geometry
- Defective Timber Ties – conditions that constitute defective timber ties
- Defective Concrete Ties – conditions that constitute defective concrete ties
- Maximum Number Defective – maximum number of defective ties for prescribed length of track
- Minimum Number Consecutive – have a maximum number of consecutive defective ties
- Joints – have non-defective ties near joints

The standards and practices that cover the above topics are shown in Table 3-4. The FTA handbook does not cover the material and track geometry, but all standards are similar otherwise. The number of defective ties may be related to material and track geometry. The list of conditions that constitute a timber or concrete tie defect have slight differences but are generally similar.

Table 3-4 *Covered Topics for Crossties*

Topics	FRA	APTA	FTA	TC	CR
Material	213.109	9.2.1		D-II	3.3, 6.4, 7.2
Track Geometry	213.109	9.2.1		D-II	3.3, 6.4, 7.2
Defective Timber	213.109	9.2.2	3.2	D-II	3.3, 6.4, 7.2
Defective Concrete	213.109	9.2.3	3.3		3.3, 6.4, 7.2
Minimum # Defective	213.109	9.2.1	3.1	D-II	
Minimum # Consecutive	213.109	9.2.1	3.1	D-II	
Joints	213.109	9.2.5	3.5	D-II	3.3, 6.4, 7.2

Ballast

Ballast is a material that provides support for the overlying superstructure and generally consists of granular rock material that allows for support and drainage. The gradation and quality of the granular rock material depends on the traffic loading.

Specifications for ballast generally include the following:

- Load distribution – transmit and distribute load of track and railroad rolling equipment into subgrade
- Track Restraint – restrain track laterally, longitudinally, and vertically under dynamic loads imposed by railroad rolling equipment and thermal stress exerted by rails
- Drainage – provide adequate drainage for track
- Track Geometry – maintain proper track cross level, surface, and alignment
- Vegetation – inhibit growth of vegetation
- Crib Ballast Height – height of crib ballast with relation to ties
- Rail-Ballast Clearance – gap height between rail and ballast to allow for rail vertical deflection during train passage
- Drainage Obstructions – preventing formation of obstructions in track drainage areas

The wording may vary slightly, but most standards cover load distribution, track restraint, drainage, geometry, and crib ballast. Other topics such as vegetation and drainage obstructions are also covered in the Roadbed section.

The standards and practices that cover the above topics are shown in Table 3-5. FTA and APTA tend to have more standards/recommendations than FRA; these additional standards typically affect and relate to FRA standards (load distribution, track restraint, drainage, and track geometry) and so are not completely independent specifications.

Table 3-5 *Covered Topics for Ballast*

Topics	FRA	APTA	FTA	TC	CR
Load Distribution	213.103	9.1	4.1	D-I	3.2, 6.4, 7.2
Track Restraint	213.103	9.1	4.1	D-I	3.2, 6.4, 7.2
Drainage	213.103	9.1	4.1	D-I	3.2, 6.4, 7.2
Geometry	213.103	9.1	4.1	D-I	3.2, 6.4, 7.2
Vegetation			4.1		6.4, 7.2
Crib Ballast Height		9.1	4.1		3.2, 6.4, 7.2
Rail-Ballast Clearance		9.1	4.1		3.2, 6.4, 7.2
Drainage Obstructions		9.1	4.1		3.2, 6.4, 7.2

Rail Joints

Rail Joints are locations that connect two rail sections with a joint bar. A second option for connecting rail—continuously welded rail (CWR)—is described a subsequent section.

General specifications for rail joints include the following:

- Structurally Sound – every joint should have a structurally sound design that is specific to the application
- Cracked – specifications on how to remediate cracked joint bars
- Bolts – specifications on number of bolts and maintenance procedures in case of missing bolts
- Stagger – specifications on distance between staggered joints.
- Defective Rail – specifications on how to apply joint bars on defective rails

The standards and practices that cover the above topics are listed in Table 3-6. The standards are similar, with APTA and FTA going into more detail about stagger distances.

Table 3-6 *Covered Topics for Rail Joints*

Topics	FRA	APTA	FTA	TC	CR
Structurally Sound	213.121	10.3.1	2.6	D-V	3.5, 6.4, 7.2
Cracked	213.121	10.3.1	2.6	D-V	3.5, 6.4, 7.2
Bolts	213.121	10.3.1	2.6	D-V	3.5, 6.4, 7.2
Stagger		10.3.2	2.8		3.5, 6.4, 7.2
Defective Rail			2.9		4.6

Continuously Welded Rail (CWR)

CWR is rail that is welded into very long lengths with no mechanical joints; typically, rail longer than 400 ft is defined as CWR. The welds can be made with either thermite or electric flash processes. A photograph of a welded joint is shown in Figure 3-4. Although CWR reduces the impacts at joints because of the lack of a running surface gap, it is more susceptible to longitudinal stress from temperature expansion and contraction in hot and cold environmental conditions. If the rail temperature exceeds the rail installation temperature, compressive longitudinal stress could cause a track buckling failure. If the rail temperature becomes too low, excessive tensile longitudinal stress can produce breaks in the rail.

Figure 3-4 *Welded rail*

FRA and APTA specify that each rail system that has track constructed with CWR must have written procedures that address the installation, adjustment, maintenance, and inspection of CWR.

Included in the specifications are the following:

- Installation Procedures – includes calculating desired rail neutral temperatures (RNT) and de-stressing methods
- Anchoring – requirements to provide sufficient longitudinal restraint
- Joint Installation and Maintenance – general specifications on how rail joint bolts should be used during CWR installation
- Rail Neutral Temperature – procedures on maintaining an RNT when cutting, repairing, and welding track
- Curves – procedures for monitoring CWR in curved track
- Train Speed – procedures for monitoring train speed on CWR during maintenance, track rehabilitation, track construction, or other track work that may disturb the track
- Buckling – procedures related to inspections on track buckling-prone conditions
- Inspection – procedures related to scheduling inspections to detect cracks and other premediated failures
- Training – comprehensive training program for applying CWR procedures
- Recordkeeping – comprehensive record-keeping to provide a history of CWR track

The standards and practices that cover the above topics are shown in Table 3-7. The three standards in the U.S. are essentially word-for-word replicates, but Canadian standards (TC) requests written procedures, not standards.

Table 3-7 *Covered Topics for Continuously Welded Rail*

Topics	FRA	APTA	FTA	TC	CR
Install Procedures	213.119	10.4	2.16		3.10, 4.3
Anchoring	213.119	10.4	2.16		3.10
Joint Install and Maintenance	213.119	10.4	2.16		3.10, 4.3, 4.6
Rail Neutral Temp	213.119	10.4	2.16		3.10, 4.3, 4.6
Curves	213.119	10.4	2.16		3.10, 4.3, 4.6
Train Speed	213.119	10.4	2.16		3.10
Buckling	213.119	10.4	2.16		3.10
Inspection	213.119	10.4	2.16		3.10, 8.1, 8.2, 8.3, 8.4
Training	213.119	10.4	2.16		
Record Keeping	213.119	10.4	2.16		3.10

Special Trackwork (STW)

Special trackwork provides for trains to cross other tracks at the same elevation (i.e., at-grade (crossing diamonds) and for trains to move from one track to another (turnouts). Turnouts are track locations in which a single track diverges into two and involves both switches and frogs. A switch has moveable rails that allow selection of the desired route through the turnout, and a frog allows flanged wheeled vehicles to cross another rail. Crossing diamonds are track locations in which two tracks cross each other without the provision for trains to change tracks. Special trackwork often plays a prominent role in accidents due to human factors, switch equipment interfaces, signal systems, and track causes.

Photos of both ends of a turnout are shown in Figure 3-5, and a close-up of a switch is shown in Figure 3-6, with the switch directed to allow trains to run on the mainline track (straight ahead). Figure 3-7 shows a frog with guard rails on either side of the track, and Figure 3-8 shows a switch stand.


(a)


(b)

Figure 3-5 *a) Turnout in facing point, b) trailing point directions*

Figure 3-6 *Switch*

Figure 3-7 *Frog*

Figure 3-8 *Switch stand*

The standards and practices that cover special trackwork components are shown in Table 3-8. The standards are similar, with APTA having a few more restrictions on wear. FTA has multiple tables with recommended limits on various wear mechanisms and includes switch stands and diamond crossings.

Table 3-8 *Covered Topics for Special Trackwork*

Topics	FRA	APTA	FTA	TC	CR
Turnouts	213.133	12.2	5.1	D-XI	3.9, 6.4, 7.2
Switches	213.135	12.2	5.1	D-XII	3.9, 6.4, 7.2
Frogs	213.137	12.3	5.2	D-XIII	3.9, 6.4, 7.2
Spring Rail Frogs	213.139	12.3.3	5.3	D-XIV	3.9, 6.4, 7.2
Self-Guarded Frogs	213.414	12.3.4	5.4	D-XV	3.9, 6.4, 7.2
Guard Rails	213.413	12.4	5.5	D-XVI	3.9, 6.4, 7.2
Switch Stands			5.6		3.9, 6.4, 7.2
Diamond Crossings			5.7, 5.8		

Roadbed

The track roadbed is the lower portion of the track that supports the track structure. The track roadbed may consist of the natural subgrade, fill material, ballast, sub-ballast (similar to a roadway bed), or some other constructed material such as concrete or steel. Figure 3-9 shows the typical cross section layers of a ballasted track.

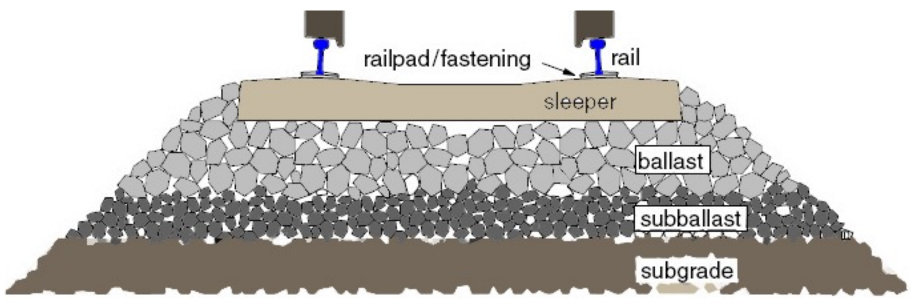

Figure 3-9 *Typical cross section of ballasted track*

Roadbed specifications often repeat ballast specifications. Specifications for roadbed generally are the following:

- Drainage – ensure that each drain, cross-drain, or other water carrying facility near the track is clear of any obstructions
- Vegetation – inhibit growth of vegetation
- Equipment Storage – procedures on how to properly store equipment near the track

The standards and practices that cover roadbed topics are shown in Table 3-9. The standards are similar, with an additional provision by APTA for equipment storage.

Table 3-9 *Covered Topics for Track Roadbed*

Topics	FRA	APTA	FTA		CR
Drainage	213.33	6.1	4.2	B-I	3.2, 6.4, 7.2
Vegetation	213.37	6.2	4.3	B-II	3.2, 6.4, 7.2
Equipment Storage		6.3			

Track Geometry

To ease transport of rolling stock, it is preferred to have rails with consistent vertical and lateral surfaces to reduce forces within the train. On curves, some superelevation, which involves raising the outside rail to a higher elevation than the inside rail, is required to keep the left and right rail forces balanced. Superelevation also allows vehicles to travel at higher speeds without overturning. However, settlement within the substructure or defects within the crosstie or fastening systems can cause deviations within the track surface. Track geometry limits are specified maximum deviations from the theoretical designs.

Limits involved with general track geometry issues include the following:

- Track Gage – described as the distance between the rails. Standard U.S. freight gage is 4 ft 8.5 in., but some mass transit agencies have different gage values. Both tight and wide gages can increase the risk of derailments; wide gage can reduce the margin of safety for a wide gage derailment under lateral loads, and tight gage can reduce the ability of wheelsets to steer in curves, causing dynamic instability, thus increasing the potential for wheel climb and rail rollover events.
- Track Alignment – lateral deviation of parallel rails from the intended course; typically measured within 62-ft intervals (see Figure 3-10).
- Track Surface – often refers to cross level, vertical surface, and warp. Cross level is the elevation difference between the inside and outside rail at any point (see Figure 3-11). Vertical surface, also known as running surface profile, is the deviation in vertical surface along the track (see Figure 3-12). Vertical surface is typically measured within 62-ft intervals. Warp is the deviation in cross level along the track.
- Superelevation – on curves, the outside rail must be superelevated to maintain balanced forces and properly distribute the wheel/rail forces between the high and low rail. The calculation for superelevation is dependent on train velocity and degree of curvature.

The standards and practices that cover the above topics are shown in Table 3-10. All standards have similar but list slightly different limits. FRA, APTA, TC, EN, and CR standards emphasize train speed, and FTA is maintenance level dependent.

CR and EN also emphasize maintenance level. In this regard, the maintenance level approach is intended to be more proactive, allowing maintenance work to be planned and executed before speed restrictions are required.

Table 3-10 *Covered Topics for Track Geometry*

Topics	FRA	APTA	FTA	TC	EN	CR
Track Gage	213.53	8.1	7.1	C-2	X	3.7, 6.2, 6.3, 6.4, 7.2
Track Alignment	213.55	8.2	7.3	C-3	X	3.7, 6.2, 6,3 6.4, 7.2
Track Surface	213.63	8.3	7.10	C-6	X	3.7, 6.2, 6.3, 6.4, 7.2
Superelevation	213.57	8.4	7.4 - 7.8	C-4, C-5	X	3.7, 6.2, 6.3, 6.4, 7.2

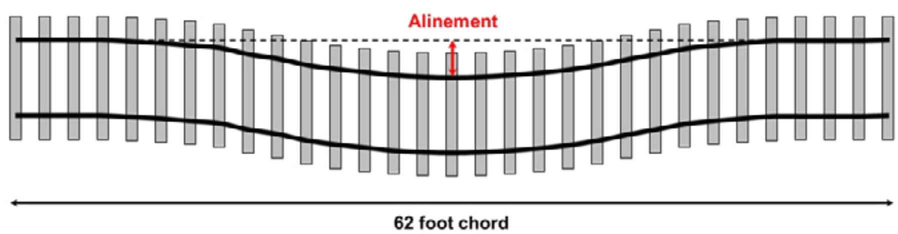

Figure 3-10 *Diagram of exaggerated alignment issue*

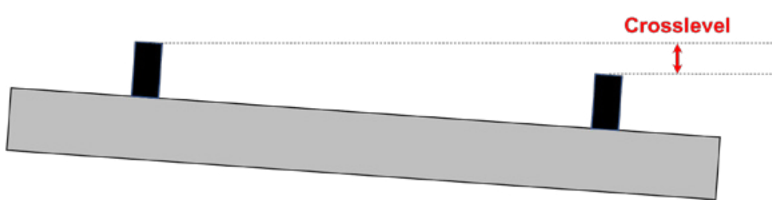

Figure 3-11 *Diagram of exaggerated cross level issue*

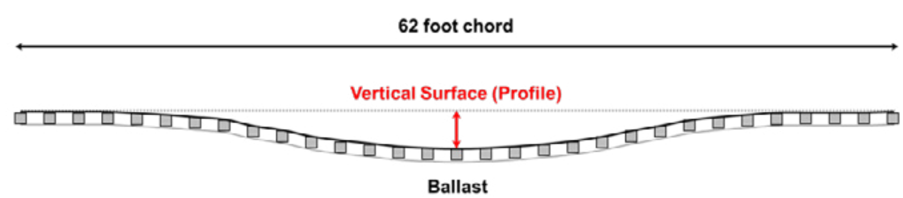

Figure 3-12 *Diagram of exaggerated vertical surface (profile) issue*

Comparisons between the various standards and recommendations, with regard to gage, alignment, surface, and cross level, are shown in Figures 3-13 through 3-16. Although measurements are not always identical because of SI (International System of Units) and U.S. Customary unit conversions, the displayed values are close enough for a relevant comparison. For agencies with multiple maintenance limits instead of a single maintenance limit, the largest value was taken because that correlates to a safety limit in which the track deviation must be remediated. EN standards do not have an independent cross level specification, as it is integrated with super-elevation.

As with all track geometry requirements, allowable deviations decrease with higher allowable train speeds because geometry deviations produce greater vertical and lateral accelerations and risk of derailment increases. Other observations are that North American safety standards (FRA, APTA, TC) are similar or identical; CR often has the strictest geometry standards. FTA does not account for speed and uses emergent maintenance grading levels (Green, Yellow, Red, and Black; only Black limit shown) and contains unexplained values that deviate from other North American safety standards. Europe is often stricter than North America but less restrictive than China. Europe and China tend to run trains at much higher velocities than those in North America.

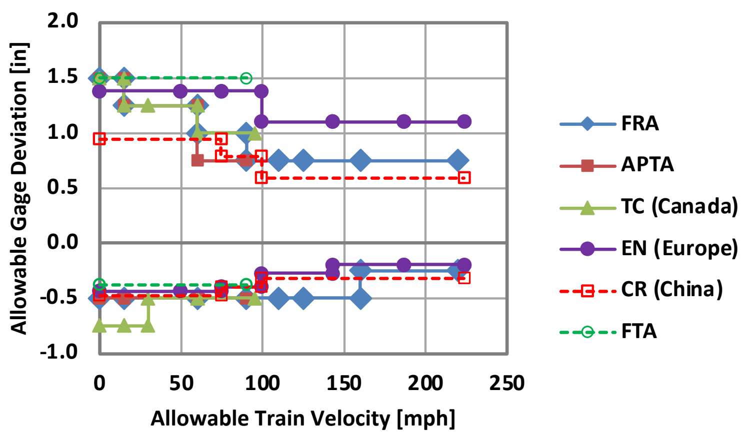

Figure 3-13 *Comparison of allowable track gage deviations with train velocity*

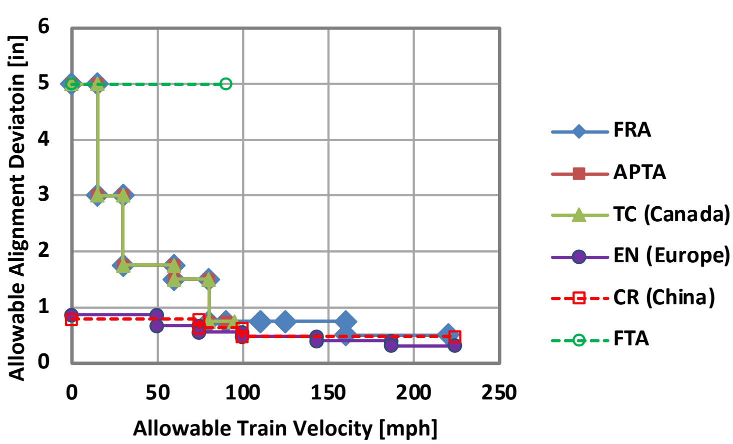

Figure 3-14 *Comparison of allowable track alignment deviations with train velocity*

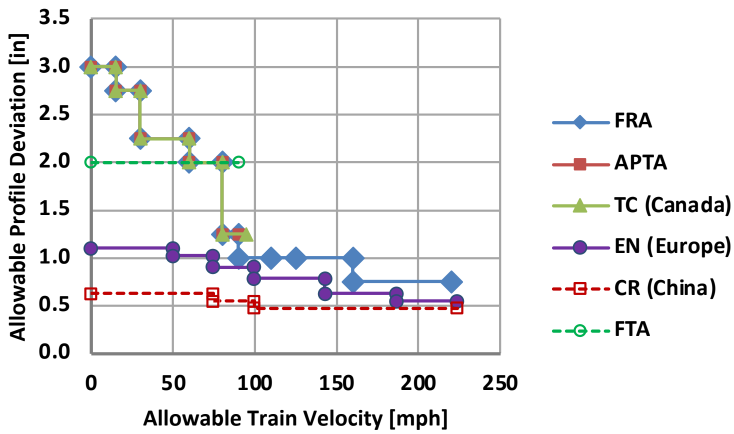

Figure 3-15 *Comparison of allowable track surface profile deviations with train velocity*

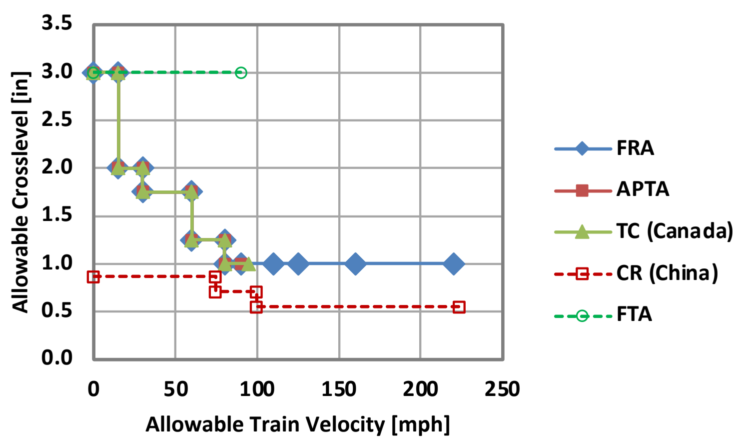

Figure 3-16 *Comparison of allowable cross level with train velocity*

Inspection

Inspection frequency is important because identifying track problems early mitigates safety issues that can cause derailments. Inspection frequency depends on the track component(s) being inspected, inspection methods, and train velocities, and tonnages. Primary track inspection types are the following:

- Track Inspection – generally refers to walking or riding inspections at speed limits in which all track components can be viewed and inspected; generally occurs once or twice per week
- Special Trackwork – switches, track crossings, and lift rail (rail joints on moveable span bridges) components must be inspected on a regular basis
- Concrete Ties – in addition to regular track inspections, FRA specifies automated inspections to find rail seat degradations with concrete

crossties that supplement visual track inspections. Crossties made of non-concrete materials are not required to have automated inspections; tie integrity checks fall under Track Inspection

- Rail – inspection involves using rail flaw detection devices to search for internal rail defects not visible from the surface
- Geometry – inspection generally involves using a track geometry car to determine track geometry specified in previous section

The standards and practices that cover the above topics are shown in Table 3-11, and inspection frequencies for each topic are shown in Table 3-12. The standards and recommended practices are similar but there are some differences. FRA and TC generally specify more frequent visual track inspections. FRA requires automated inspections of concrete crossties but not track geometry vehicle inspections. TC and CR specify more frequent track geometry measurements than FTA and APTA in the U.S.

Table 3-11 *Covered Topics for Inspection Frequencies*

Topics	FRA	APTA	FTA	TC	CR
Track Inspection	213.233	3.1	1.7	F-2	8.1, 8.2, 8.4
Special Trackwork	213.235	3.5	1.11	F-3	8.1, 8.2, 8.4
Concrete Tie	213.234				8.1, 8.2, 8.4
Rail	213.237	3.2	1.8	F-5	8.1, 8.2, 8.3, 8.4
Geometry		3.4	1.10	F-4	8.1, 8.2, 8.4

Table 3-12 *Specified Inspection Frequencies*

Topics	FRA	APTA	FTA	TC	CR
Track Inspection*	Bi-weekly**	Weekly	Weekly	Bi-weekly	Bi-weekly
Special Trackwork	Monthly	Monthly	Monthly	Monthly	Twice per month
Concrete Tie	Yearly				Monthly
Rail	Yearly	Yearly	Yearly	1–4 per year	1 inspection car + 6 manual
Geometry		Yearly	Yearly	1–3 per year	Monthly

**FRA bi-weekly track inspections are for Class 4 and 5; Class 1 to 3 require only weekly inspection.*

***Weekly inspection frequencies require at least three days between inspections; bi-weekly inspection frequencies require at least one day between inspections.*

Section 4

Review of Track Inspection Tools

This section presents a review of various tools and technologies that are being or could be used to inspect track structure in transit railway track. Manual track inspection tools are devices used during walking inspection of the track; automated inspection tools are technologies typically installed on a train car that collect and process information in near real-time.

Manual Track Inspection Tools

Multiple manual track inspection tools are available to measure track geometry, rail wear, grinding and weld templates, and other track parameters during walking inspections or to verify automated inspection measurements. Based on responses from the data collection, typical manual inspection tools used by transit agencies are laser level, rail gauge, frog gauge, step gauge, rail wear gauge, angle wear gauge, taper gauge, straight edge, spring frog tester, and contour gauges.

Although automated methods can often measure track geometry and other aspects of the track more effectively and accurately than hand tools, hand tools are useful for verification and often serve as templates when grinding or welding rail.

A brief description of selected manual track inspection tools is as follows:

- Track Gauge – measures the track gage (see Track Geometry section) and gives indication if track is too wide or narrow; sometimes similar devices can be used for measuring cross level along with track gage (level board)
- Stringline – measures vertical surface of the track using a 31-ft, 62-ft, or 124-ft string.
- Rail Wear Gauge – measures vertical, horizontal, and sometimes angle wear of a rail; can be done with screws at top and sides; more advanced units can measure entire rail profile with a wheel or lasers
- Step and Taper Gauge – used to measure height of gaps within track system, typically between rail and fastening system or underneath fastening system
- Frog and Contour Gauge – templates that help verify that frogs and other special trackwork are welded and grinded correctly

Automated Track Inspection Technologies

Advances have been made through the years in automated track inspection. The benefit of automated inspection systems is that they can collect data quickly, cover the entire track network, and avoid requiring track personnel to foul (i.e., occupy) the track to collect measurements. Some of these technologies are not currently implemented other than for testing, but continued advances may make them feasible in the future. This section explores automated technologies currently in use and that could be beneficial in the future.

Automated technologies are becoming increasingly common among U.S. freight networks and larger rail transit agencies. The goal is to integrate multiple technologies on a single platform to characterize the full track condition for the entire network and increase the efficiency of recording, analyzing, and mitigating flaws before issues arise. This added information supports Maintenance Department maintenance prioritization and resolution. Existing inspection technologies are presented in the order of most common use. Transit and passenger rail modal agencies are currently conducting research to better use historical automated inspection data to make predictive maintenance decisions to schedule long-term and respond to emergent work.

Rail Flaw Detection Car

Rail flaw detection cars use ultrasonic methods to detect cracks, fractures, and other defects within the rail. Current inspection systems use two technologies: 1) a contacting ultrasonic inspection that uses a pulse-echo technique to send energy into the rail at specific angles to the surface; the rail is pulsed, then the same probe "listens" for an echo or reflection from the flaw; the angle of the pulse is critical to finding the flaws; 2) magnetic induction that finds flaws at a wider range of orientations and looks for distortions in the energy flux field due to discontinuities such as rail cracks.

The current technologies are capable of finding flaws in the head of the rail, in the web, and in the base directly under the web, provided the flaws are oriented such that a reflection of the inspection wave will return to the probe.

New guided wave and ultrasonic rail inspection technology is in proof-of-concept testing or just entering regular service and offers additional capabilities. These systems can inspect the base of the rail through air-coupled, ultrasonic transducers and detect flaws at any orientation using phased arrays or conventional probes using a pitch-catch or through transmission methodology.

FRA, APTA, and TC require or recommend internal rail flaw inspection to occur on different frequencies based on Class of track, annual million gross tons (MGT), and whether passenger trains run on the track. FRA 213.237 (a) states that for Class 4 and 5 track or Class 3 track with passenger service, internal rail flaw inspection should be made at least once every 40 MGT or annually, whichever interval is shorter. For non-passenger service Class 3 track, rail flaw inspection is required every 30 MGT or at least once per year, whichever is shorter. APTA (Section 3.2) requires ultrasonic flaw inspection at least once per year. TC (Subpart F Section 5) requires rail flaw ranging from 2–4 times per year, depending on track class and annual MGT.

Past studies evaluated how to assess historic ultrasonic data to make predictive maintenance decisions. Proactive maintenance using risk-based theory should consider 1) defect initiation, 2) defect growth, and 3) detection reliability. Other factors such as amount of MGTs passing over the rails since installation, sectional properties of worn rail, rail configuration, and vehicle dynamics all contribute to flaw initiation and growth. Risk-based preemptive maintenance should consider all these factors, and agencies should tailor appropriate mitigation strategies balanced against the efficient use of available resources and funding.

Track Geometry Car

Track geometry measuring systems measure and evaluate various track geometry aspects such as gage, cross level, alignment, and surface. These are used to identify existing defects and locations that may eventually become defects. Information on locations that may eventually become defects can help transit agencies plan maintenance activities and stay ahead of future track geometry defects.

Track geometry measurements are required by TC and recommended by APTA at least once or more per year. FRA requires track geometry measurements, but they do not necessarily have to be done with a vehicle-mounted track geometry measurement system. However, track geometry cars are often heavily used by U.S. freight railroads.

Lasers

Lasers can be used to measure rail and wheel running surface profiles by scanning a laser across the component of interest. The distance is measured by the laser, or machine vision is used to analyze the image created by the laser. The image is then compared against the standard and condemning profiles to determine maintenance interventions. Track geometry measurements, such as gage, may also be measured by laser or LIDAR (Light Detection and Ranging).

Missing components are detected by measuring and analyzing expected distances from the detection point on the vehicle to the track component. Rail clips, tie plates, or crossties may be inspected this way. For example, missing rail clips may be found by measuring the vertical distance from the vehicle to the rail base. If this distance changes as the vehicle goes over a crosstie, then the clip is presumed to be missing and is recorded for further inspection.

LIDAR

LIDAR is used to make precise measurements of distance or speed. As such, it is often used to measure track clearances and vehicle speeds. For example, a LIDAR-based stuck brake/wheel skid detector is used by freight railroads; it also is used to measure surface defects in crossties and deficiencies in the ballast section.

Vehicle-Track Interaction (VTI)

VTI systems measure dynamic forces and accelerations in revenue service vehicles to provide indications of both ride quality and vehicle safety and identify areas of track that may be exciting vehicle dynamic responses. The systems often use a three-axis accelerometer package securely mounted to a large mass that is anchored to the vehicle floor, typically over a bolster. The systems are used to ensure an absolute minimum level of performance and to determine changes in performance over time. In this way, the information can be used to program track and vehicle maintenance.

Gage Restraint Measurement System (GRMS)

Track, especially curved track, may move outward due to wheel flange-imparted lateral forces, which can be an indicator of defective ties and fasteners. GRMS measure the resistance to gage widening during dynamic loading. Typical gage measurements occur under static conditions when no train is passing; however, the track may still move outwards due to the lateral forces of train passage and exceed gage limits, which can be an indicator of defective ties and fasteners. By measuring head and base deflections, the inspection also can help determine which track component requires maintenance. If the rail is rolling under load, the rail fasteners require maintenance, whereas lateral translation of the rail under load suggests the tie plate fasteners and the tie itself may require maintenance.

Ultrasound

Ultrasonic inspection is typically used to search for flaws in metallic components, such as rail or bridge girders. The flaws can be located and sized to a high degree of precision. Ultrasonic inspection also can be used to inspect crossties. Methods include the traditional pulse-echo technique as well as through transmission (i.e., pitch-catch). Phased array technology also is being implemented. Phased array technology allows the ability to find flaws at more orientations in the rail and enables more precise location and sizing of flaws.

Ground Penetrating Radar (GPR)

GPR is a system that uses radar to characterize track substructure conditions at various depths. Changes in substructure properties may vary due to fouling levels, moisture levels, or substructure layers. Common outputs from GPR are the depth of the free-draining layer and ballast fouling index. The depth of the free-draining layer gives an indication of drainage within the track substructure and how much free-draining granular material remains. The ballast fouling index gives an indication of the percentage of fines within the ballast structure. Increased fines can impede drainage and weaken the track structure. GPR is used to diagnose the cause of reoccurring track geometry problems and plan ballast maintenance activities.

Machine Vision

Machine vision technologies are used to identify defects on vehicles and all track structure components. Cameras attached to rail vehicles take video of the track structure from multiple angles. Machine vision systems analyze the video and can identify defects with fasteners, anchors, joint bars, concrete ties, rail head condition, ballast height, and multiple other defects using detection algorithms for various condemning criteria.

Unmanned Aerial Vehicles (UAVs)

UAVs (drones) have the potential to increase the efficiency of track inspection by inspecting track from the air without the need for a track inspector on the ground. UAVs allow for inspection of track that is difficult because of train occupancy, unfavorable environments, unsafe weather conditions, or difficult-to-access locations. Freight railroads have begun using UAVs in recent years to aid track and bridge inspection.

Thermography

Thermography is used by railroads and transit agencies to find failing bearings on vehicles. Infrared cameras can also be used to detect electrical faults in insulated rail joints, hot third-rail insulators, and stuck brakes on vehicles.

X-Ray

X-ray technology is in development to detect cracks, voids, and other defects in timber crossties. X-ray technology will be used by timber crosstie manufacturing companies or railroad companies for quality condition testing. Hi-rail or inspection vehicle mounting is possible and allows efficient, automated inspection for internal timber tie defects. The goal is to use the technology in conjunction with laser and other visual scanner methods to assess the internal and external timber crosstie condition.[7]

Timber crossties fail from fatigue and progressive environmental deterioration, such as wood decay and splitting. X-ray technology works by determining density changes within the timber crosstie, and identifies progressive voids, treatment penetration depths, and foreign objects. Density changes are recorded and converted to 2D and 3D images that are correlated with the respective defects. An automated inspection system produces condition ratings and facilitates proactive, planned maintenance activities. The technology is being used during revenue service by some passenger and freight railroads. All major freight railroads have tried x-ray technology, and many use it on a regular basis.

[7] Liesenfelt, M. J. Baciak, T. Euston, G. Grissom (2017), "X-Ray Technology Development for New Wood Crosstie Inspection," *Proceedings of the American Railroad Engineering and Maintenance-of-Way Association Conference*, Indianapolis, IN, Sept 17–20, 2017.

Augmented Reality (AR)

The goal of AR is to use high-definition video or photographs of the entire track, taken either from a railcar or UAV. The footage would be submitted to a database where it would be compiled into a map-based program and analyzed by inspectors for defects. AR could be used to perform track inspections without requiring track inspectors to physically walk the track. AR technology is similar to Google Maps™ street view technology applied to the rail transit environment and would allow track inspectors to virtually inspect the track at off-track locations, thus reducing time and interference of the right-of-way.

Integrating this technology with machine vision could help defect detection so track inspectors could make decisions on defect validation, severity, and remediation. AR technology is still in its infancy but may mature to be very useful to transit agencies and offers a safer alternative to exposing track walkers to interaction with revenue service trains. AR requires additional research and development and regulatory changes. Currently, regulations require that electronic devices that would distract from situation awareness (e.g., cell phones) cannot be used while on track.

Section 5

Review of Maintenance Methods

This section presents a literature review of existing U.S. and international standards and guidelines regarding railroad transit track maintenance. The objective is to determine what standards currently exist, how the different standards compare, and what knowledge gaps exist.

Scheduled vs. Spot Maintenance Philosophies

Railroads typically use two types of maintenance philosophies, scheduled maintenance and spot maintenance. Scheduled maintenance involves complete replacements of components along sections of track at predetermined periodicities. For example, a section of track may require tie replacement every 3 years, rail replacement every 5 years, and ballast undercutting every 10 years. Scheduled maintenance is a planned, proactive, system-based maintenance philosophy and uses historical data to anticipate component life and replace items prior to becoming defective. Effective scheduled maintenance requires estimation of the service life of a component that will depend upon component type, tonnage, train velocity, and environmental factors. Spot maintenance involves maintaining or replacing components after they become defective. Spot maintenance is also referred to as unplanned or unscheduled maintenance and is undesirable because maintenance plans become overloaded, unpredictable, and inefficient.

Transit agencies have the burden of planning scheduled and spot maintenance activities during short non-revenue hours, and the limited time windows are especially challenging for mature systems that contain aging infrastructure. Some agencies eventually shut down entire sections of track during long holiday weekends or for longer periods to complete necessary repairs due to large maintenance backlogs and aging infrastructure approaching end of useful life.

Rail

Rail grinding involves using a grinder to remove some of the surface from the rail. Rail grinding can be done to remove rail defects such as spalling or rail contact fatigue, to smooth rail from rail flow and corrugations, or to restore a smooth continuous running surface. Rail grinding often is performed in reaction to a problem. Build-up repair welding involves using a welder to “build-up” rail and frog castings, and can be performed in response to a crack or chip-out or to restore a smooth continuous running surface. Rail grinding can be performed over long runs using a rail grinding vehicle.

In the case of a rail fracture, joint bars can be installed to temporarily fix the break until the CWR is sliced into that section. According to the FTA Pocket Guide, joint bars should be used in certain cases with transverse fissures, compound fissures, detail fractures, engine burn failures, defective welds, ordinary breaks, and damaged welds.

Fastening Systems

The replacement of fastening systems typically occurs alongside crosstie replacement.

Crossties

The replacement of crossties occurs through either scheduled or spot maintenance. The replacement of crossties generally involves (1) removing the fastening system, (2) pulling out the existing tie, (3) inserting the new tie, and (4) applying the fastening system. Afterwards, tamping or some other surfacing method may be used.

Resurfacing

Track resurfacing involves leveling the track to repair or prevent any track geometry defects. Track resurfacing can be accomplished through either scheduled or spot maintenance. Ballast resurfacing involves up to three systems, including tamping, ballast regulating, and ballast stabilizing. Tamping the track involves using a tamper machine to lift the track to the desired elevation, then pushing and squeezing multiple vibrating prongs into the ballast, which compacts the ballast underneath the crossties. A ballast regulator follows, which uses its large rotating broom to push and distribute ballast evenly across the track bed. The track stabilizer then uses a combination of weight and vibration to compact the ballast and stabilize the material. This combination of machinery is often used for scheduled maintenance.

For spot maintenance, similar techniques can be used or may involve just using a tamper or a hand tamper. Hand-tamping involves using a pneumatic device to push ballast material under and around each replacement crosstie. Hand-tamping process is more time-consuming, and the effectiveness is highly dependent on the operator, but it can be less expensive for smaller resurfacing jobs.

Ballast Cleaning

Ballast often becomes contaminated with fine particles that eventually impede drainage, reduce track stiffness, and increase track stiffness. Ballast contamination occurs from multiple sources including ballast degradation; surface infiltration from falling off cars, wind-blown, or crosstie degradation; or subsurface infiltration from the sub-ballast or subgrade. The amount and type of fine material can significantly affect the performance of the track.

Two methods often are used to replace the entire ballast section or remove the fines. The first method is called shoulder cleaning and involves replacing the ballast in the shoulders but not underneath the crossties. The purpose of this is primarily to improve the drainage path from the middle of the track. Undercutting is a second method and involves replacing the ballast in the entire track section, including the shoulders and underneath the crossties. Undercutting provides new ballast underneath the entire track and improves performance until the ballast deteriorates and needs to be replaced again.

Section 6

Data Collection

To better understand the inspection and maintenance practices and standards used for transit agencies, TTCI surveyed agencies in the U.S. This data collection was completed via SSOAs in each state; in total, 30 agencies responded to the data collection survey.

The purpose of the data collection was to get an overview of (1) the transit infrastructure and operations, (2) track inspection methods and technologies, (3) track maintenance methods and philosophies, and (4) industry needs. The data collection form sent to the transit agencies is provided in Appendix A.

Track Infrastructure and Operation Overview

This section covers the results from the track infrastructure and operation overview, including track miles, inception (year opened), top speed, rail section, crosstie material, wheel tread taper, and wheel tread width. These data are helpful to explain differences in the inspection techniques and maintenance philosophies displayed in subsequent sections, as the needs of large, heavy car transit systems will be different than small streetcar systems.

Figure 6-1 shows the track miles of transit agencies that responded to the data collection survey separated by heavy rail, light rail, and streetcar. Streetcar systems tend to be smaller, with the majority having fewer than 10 miles of track; heavy and light rail systems tend to be in the 51- to 100-mile range, with a few having more than 200 track miles.

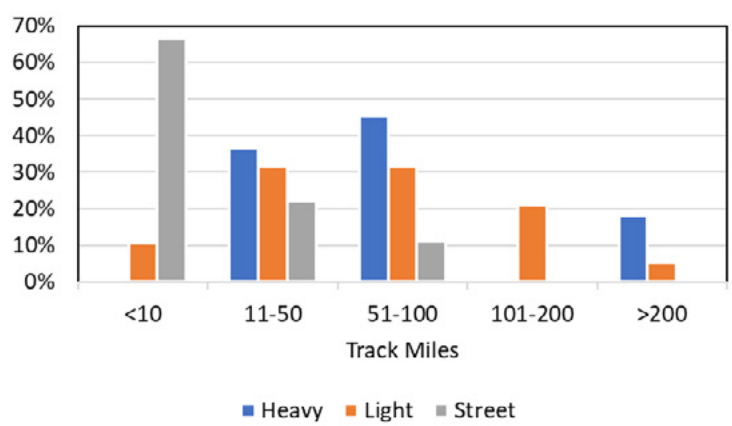

Figure 6-1 *Distribution of track miles by transportation mode*

Figure 6-2 shows the distribution of agencies by the year of inception or when service began. Figure 6-2 graph is not separated by transportation mode because multiple agencies have multiple transportation modes. Other survey questions were mode-specific (see Appendix A). The plot shows that many transit agencies began service in the early 1900s, with a second wave occurring over the past six decades.

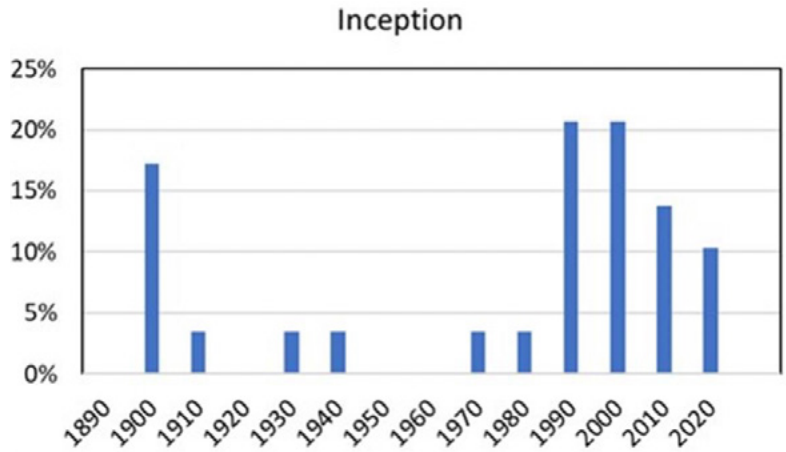

Figure 6-2 *Distribution of transit agencies by year of inception, 1890–2020*

Figure 6-3 shows the distribution of top speed by transportation mode, indicating that all streetcar agencies operate at speeds below 35 mph, the majority of light rail operate between 45 and 55 mph, and the heavy rail systems tend to be faster than 45 mph, with about half above 60 mph.

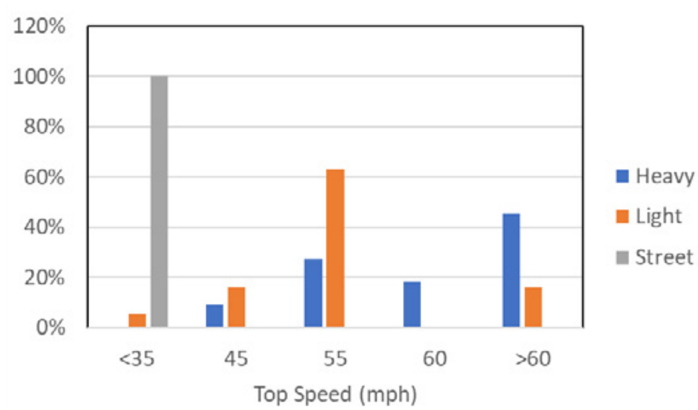

Figure 6-3 *Distribution of top speed by transportation mode*

Figure 6-4 shows the distribution of crosstie material by agencies. Eight agencies use more than one type of tie, typically wood and concrete, whereas most agencies use either wood or concrete. The agencies using steel or rubber ties are all streetcars. (Note: Agencies may use combinations of ties, so the total distribution is more than 100%.)

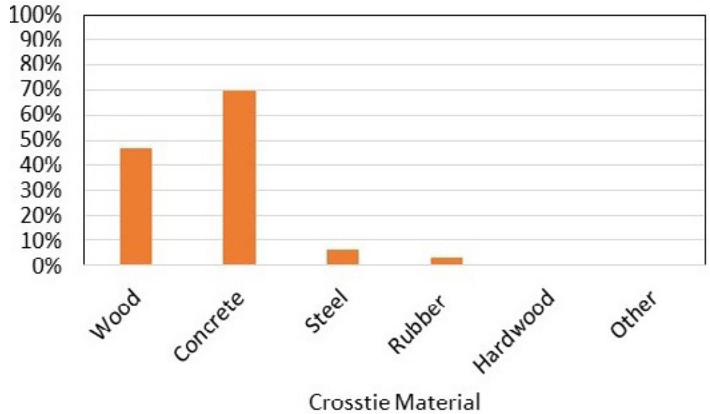

Figure 6-4 *Distribution of crosstie material*

Figure 6-5 shows the distribution of rail sections, with larger rail section indicating heavier, and therefore stronger, rail. The majority of rail is 115 pounds per yard for all transportation modes; 90- and 100-pound rail is also used for height restricted operations. Other sections are obsolete and not available except in the used rail market.

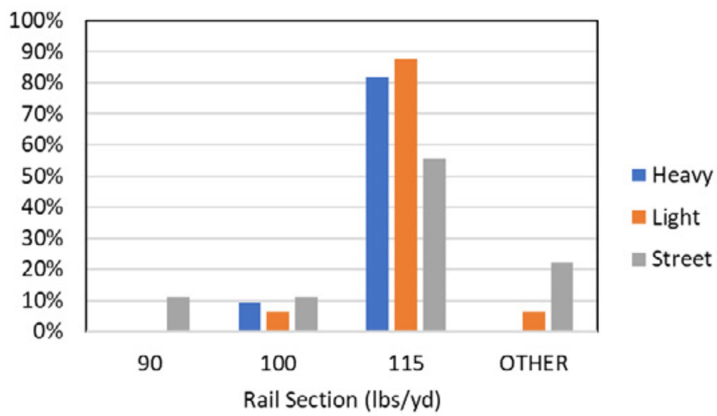

Figure 6-5 *Distribution of rail sections*

Figure 6-6 shows the distribution of wheel tread tapers by transportation mode. Wheel taper is the vertical slope on the wheel tread, away from the wheel flange throat.[8] It largely determines the angle at which the wheel contacts the rail on tangent track. A greater amount of taper causes the wheels to naturally make contact with the rail closer to the gage corner. A greater amount of taper can make the vehicle easier to steer in curves but tends to have negative effects as the train speed increases. A flat wheel tread taper generally improves higher speed stability for the wheelsets. Results show that the majority of tapers are 1/20, which is typical; wheel tread tapers of 1/30 and 1/40 are also used. These

[8] American Public Transportation Association, (2017), Standard for Definition and Measurement of Wheel Tread Taper, APTA PR-M0S0017-06.

more closely match the rail seat cants typically used. The goal of this is to align the tangent track wheel force vector with the centerline of the rail. Also, note that 20 percent of the heavy rail agencies use a flat taper.

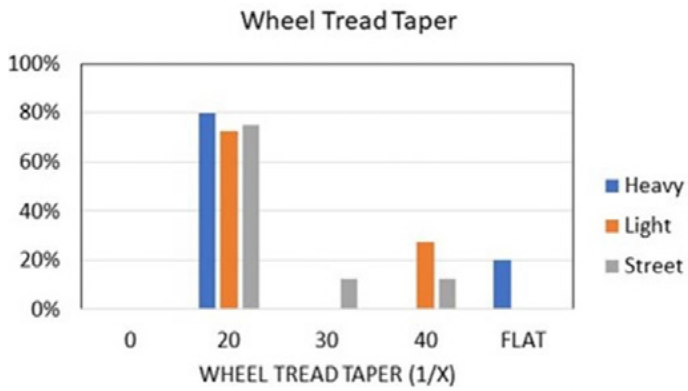

Figure 6-6 *Distribution of wheel tread tapers by transportation mode*

Figure 6-7 shows the distribution of wheel tread width by transportation mode. A wider wheel tread width allows for more lateral movement and, therefore, is more forgiving to track gage deviations. There was likely some confusion in answering the survey question which asked, "How wide is wheel tread?" Some agencies may have answered based on the total width of the wheel (tread plus flange); the range of wheel widths also may be due to the origins of the vehicles, as the transit vehicle manufacturing market is truly worldwide.

Results show a wide distribution of wheel tread widths., which could be a potential issue when trying to standardize track gage deviation limits across the various agencies. Itis likely more important for safety limits rather than maintenance limits. Ride quality considerations likely dominate maintenance limits. Results suggest there is potential for savings in standardizing wheels among various transit operators. However, this would be extremely difficult to implement on existing systems and likely makes mores economic sense for new operations.

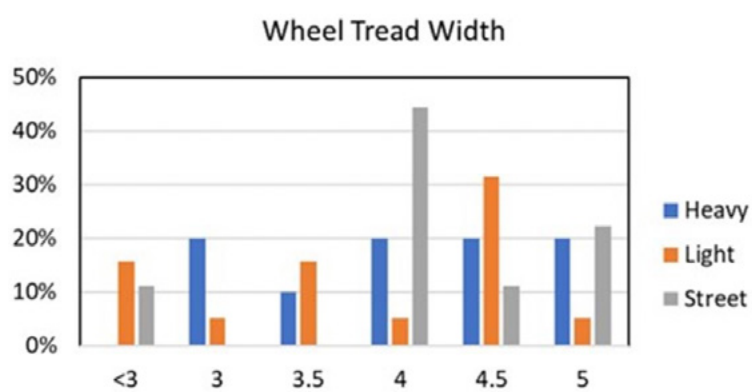

Figure 6-7 *Distribution of wheel tread width by transportation mode*

** Note: Tread widths greater than 4 in. may be total wheel widths.*

Track Inspection Methods and Technologies

This section covers track inspection methods and technology results, including minimum track safety standards, manual inspection frequency, automated inspection frequency, and existing track inspection tools and technologies.

Figure 6-8 shows the distribution of minimum track safety standards. Most responses show either FRA (29%) or agency standards (42%). The other was a state standard similar to the CPUC standard.

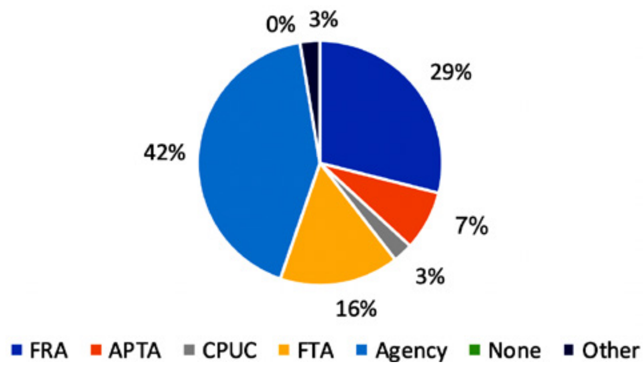

Figure 6-8 *Distribution of minimum track safety standards*

Figure 6-9 shows the range of open track and special trackwork inspection tools. All agencies use tape and track gauges, and many use profiling gauges for special trackwork.

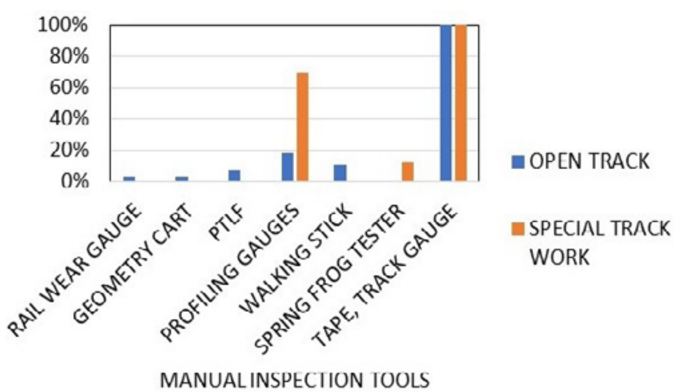

Figure 6-9 *Inspection tools used for open track and special trackwork*

Figure 6-10 shows the range of automated inspection technology used by transit agencies by response and agency. “Responses” equal 100%, and “Agencies” total greater than 100% because most agencies use more than one inspection technology. Results show that the majority use ultrasonic equipment for rail flaw detection and lasers for track geometry; a few agencies use LIDAR for clearances, GPR for substructure assessments, and other various technologies.

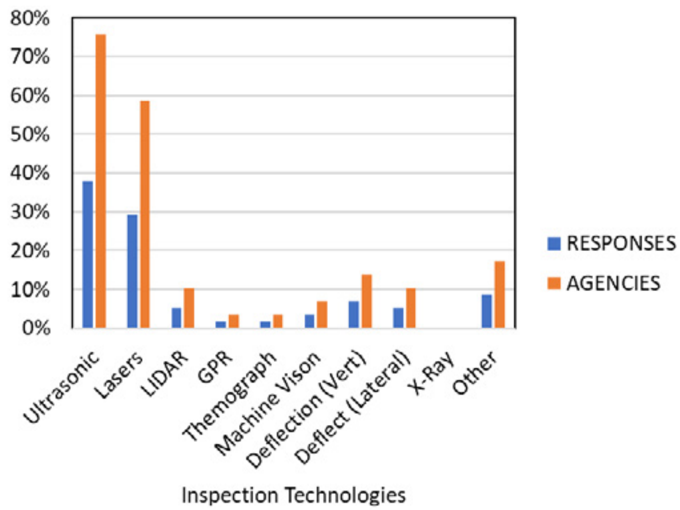

Figure 6-10 *Automated inspection technologies used by transit agencies*

Figure 6-11 shows the frequency of manual inspections for mainline track and turnouts. The required frequencies vary with the standard being used, traffic rates, and any additional commodities (e.g., hazardous materials) hauled on the line.

Results show a wide range of frequencies for mainline track, and the majority of turnout inspections occur once per month. The wide range of manual inspection frequencies likely is due to the wide range of traffic levels seen for the various transit agencies, whereas turnouts have an additional factor of wear related to the number of throws of a switch (e.g., activations). Often, an inspection with both track and signal maintainers is productive at keeping turnouts in good working order. The two groups working together can often optimize the operating condition of the turnout.

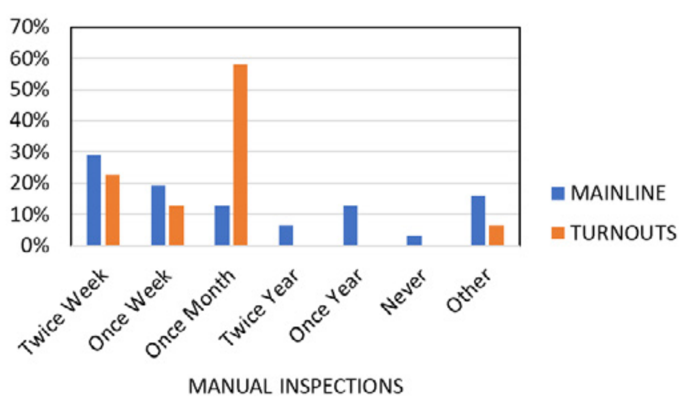

Figure 6-11 *Frequency of manual inspections on mainline track and turnouts*

Figure 6-12 shows the frequency of automated inspection with track geometry cars and rail flaw detectors. The minimum recommended frequencies in the standards are once per year on mainline track. Results show that the majority of automated inspections occur once per year. Agencies that never use automated inspections are generally streetcar agencies.

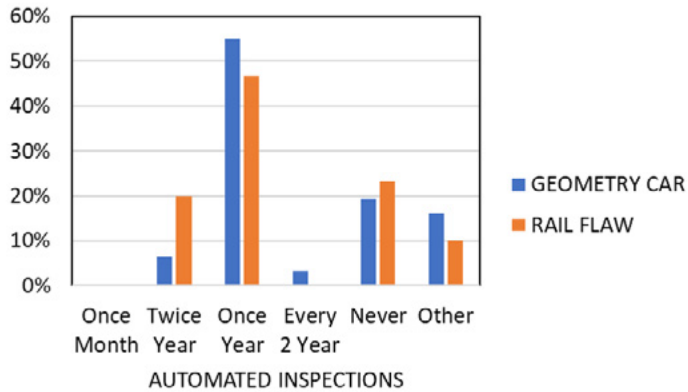

Figure 6-12 *Frequency of automated inspections*

Figure 6-13 shows agencies that use Personal Digital Assistants (PDAs) (handheld electronic devices) in the field. A PDA can streamline recordkeeping of inspection reports and also assists in filing reports to maintenance planners who update the maintenance schedule and prioritize necessary repairs. Results show the majority (80%) do not use PDAs.

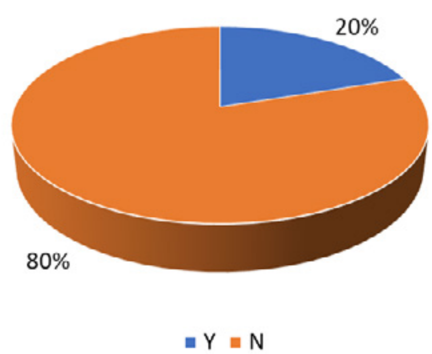

Figure 6-13 *Percentage of agencies that use PDAs in field*

Track Inspection Maintenance Philosophies

This section covers survey results related to track inspection methods and technology, including maintenance philosophy, maintenance schedule updates, and maintenance time windows.

Figures 6-14 and 6-15 show the distribution of maintenance philosophies by transportation mode. Figure 6-14 shows whether maintenance is scheduled or reactive. Results show that streetcar tracks have the most scheduled maintenance vs. light or heavy rail. This discrepancy is likely exists because streetcar tracks have less unexpected track service failures, so most maintenance can be scheduled in advance. Train speed, wheel loads, and traffic rates are the most likely factors contributing to lower service failure rates. Figure 6-15 shows whether track components are replaced individually as needed, through reliability metrics, or through overall track renewal. The percentages total above 100 percent because agencies use both maintenance philosophies. Most agencies do individual maintenance if a component unexpectedly fails, and the heavy rail agencies also perform maintenance using reliability metrics and track renewal schedules. The benefit of scheduled reliability metrics or track renewal is that an agency can stay ahead of maintenance instead of reacting to multiple failures across the whole system. Reliability-based philosophies can be cost-effective if performed correctly so it is desirable for agencies with large amounts of track.

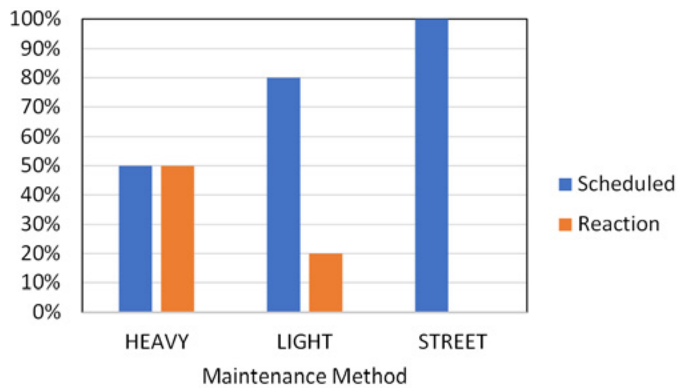

Figure 6-14 *Schedule or reactive maintenance by transportation mode*

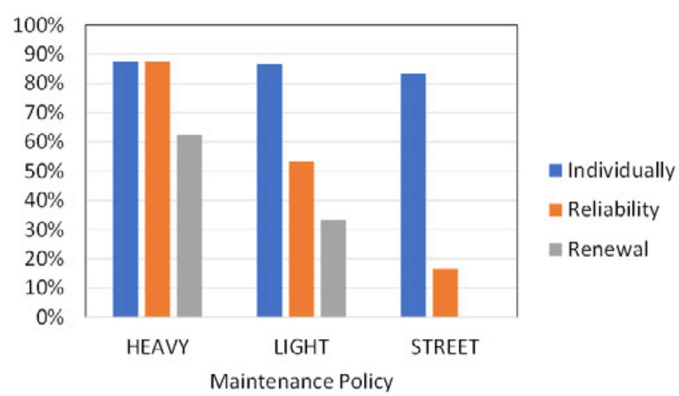

Figure 6-15 *Maintenance philosophy by transportation mode*

Figure 6-16 shows the time-frame at which transit agencies update track maintenance schedules. About half of respondents said their maintenance schedules are updated continuously; about 20% update the maintenance schedules daily or weekly, and 13% update maintenance schedules monthly.

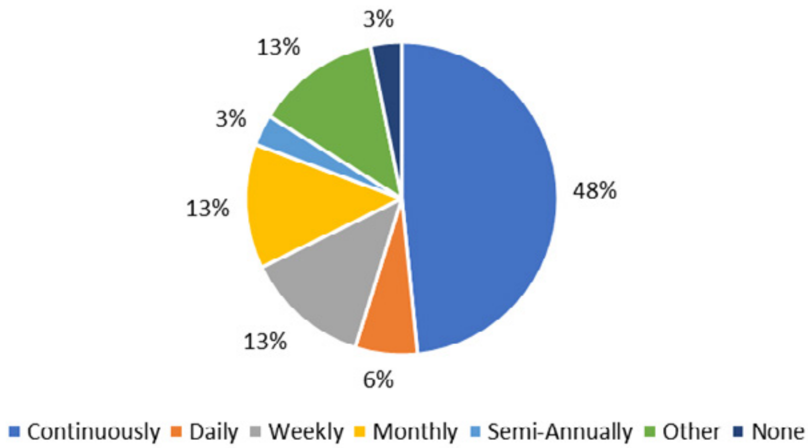

Figure 6-16 *Maintenance schedule update*

Figure 6-17 shows daily maintenance time periods. More than 50% of transit agencies have less than 4 hours per day to complete scheduled and spot maintenance, suggesting that limited time is a major inspection and maintenance constraint. Also, some track geometry vehicles are limited by their operating speed and lack of set-out tracks on a route and can operate only during non-revenue service hours.

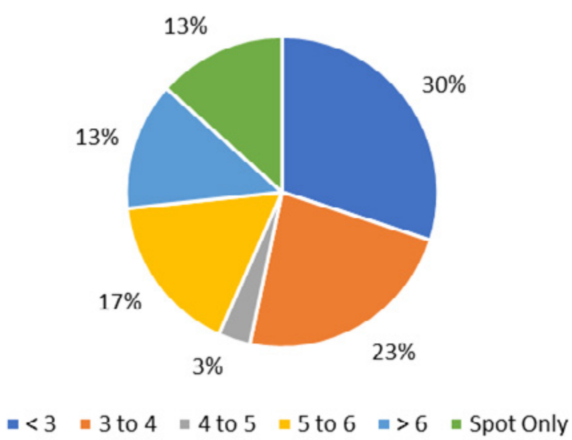

Figure 6-17 *Maintenance time window*

Industry Needs for Inspection and Maintenance

The section covers results regarding industry needs regarding inspection and maintenance. Due to the variety of transit agencies, needs depend on the specific operational characteristics of each transit agency. For example, a streetcar system with fewer than 10 miles of track has different maintenance needs than a heavy rail system with more than 200 miles and more frequent, faster service. Therefore, needs were analyzed based on maintenance time windows, track miles, and transportation mode. “Track miles” were determined to have the strongest correlation, so the data are shown based on whether an agency has more than 100 miles, between 10 and 100, or under 10 miles of track.

Figure 6-18 shows the results of whether new inspection tools or techniques would be viewed as useful to the agency. Results show a strong correlation based on the track miles in the system. Of the systems with more than 100 miles, 80% are interested in new inspection techniques and only 33% of smaller systems are interested. This interest gap is likely due to the large amount of track to inspect, often with short maintenance time windows.

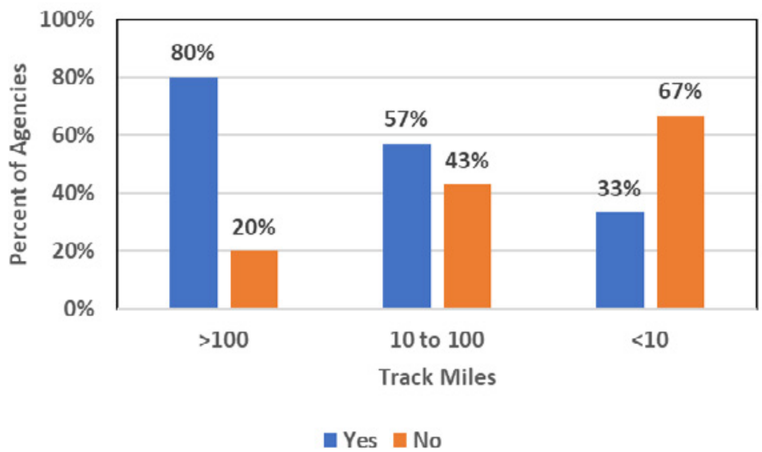

Figure 6-18 *Percentage of agencies interested in new inspection tools or techniques based on track miles*

Figure 6-19 shows the results of whether new maintenance techniques would be viewed as useful to the agency. Results show a similar correlation, with 90% of agencies with more than 100 miles and only 17% of agencies with less than 10 miles.

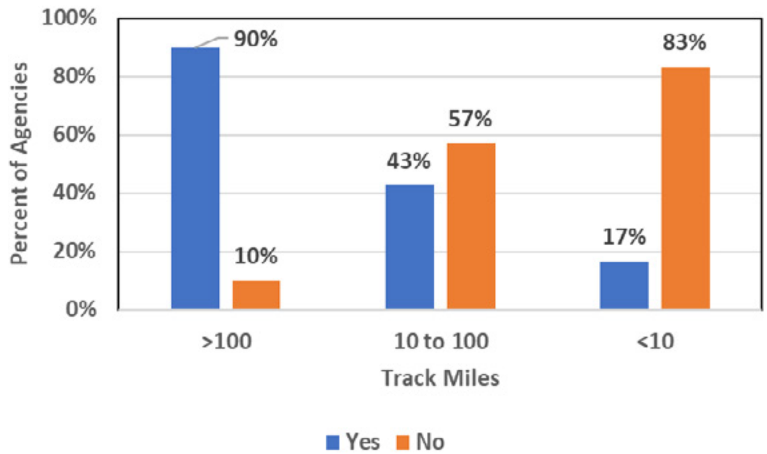

Figure 6-19 *Percentage of agencies interested in new maintenance techniques based on track miles*

Figure 6-20 shows results from the question about inspection items that would be viewed as most useful to the agency other than larger time windows. Some agencies gave more than one response, so the values are greater than 100%. Results show that agencies with more than 10 miles of track prefer automated inspection techniques, followed by training. Smaller agencies are more interested in non-automated tools and more training.

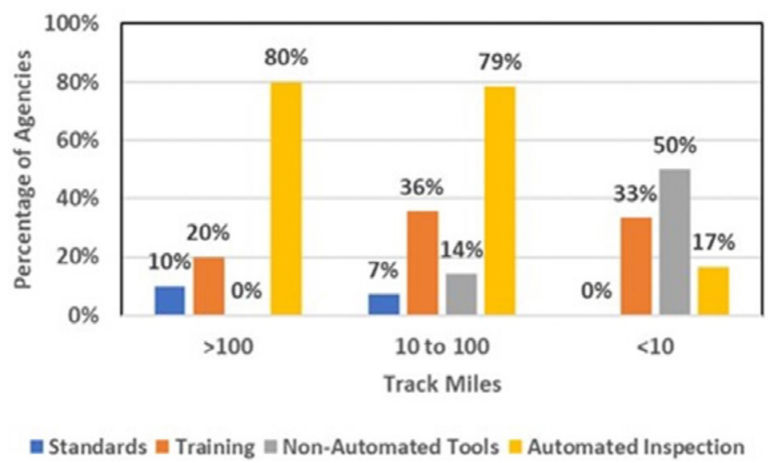

Figure 6-20 *Inspection needs of agencies based on track miles*

Figure 6-21 shows results from the question about what maintenance items would be the most useful to the agencies other than larger time windows. Some agencies responded with more than one response and other responded with none, so values may not add to 100%. Results show that maintenance techniques are more desirable for all sizes of system. Schedule needs increase in importance at agencies with larger track systems.

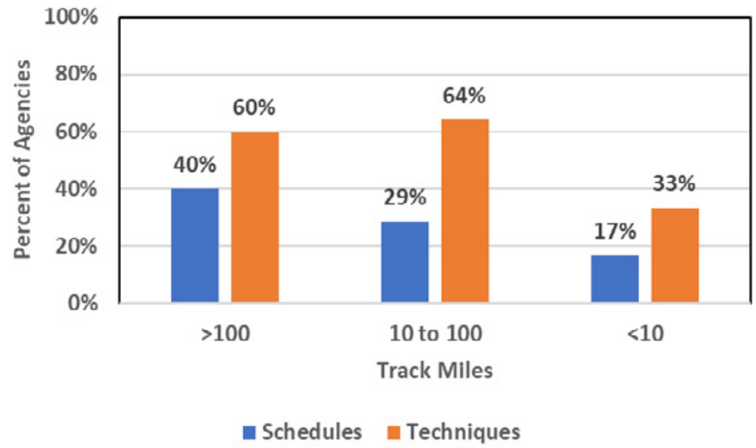

Figure 6-21 *Maintenance needs of agencies based on track miles*

Data Collection Summary

The results of the survey give insight into the practices of various rail transit agencies, with regard to inspection and maintenance. General remarks from analyzing the results are as follows:

- Transit agencies have a wide range of system infrastructure, inspection and maintenance practices, and needs.
- Uniform safety standards for wide gage will be difficult due to the range of wheel tread widths. Smaller widths will be more sensitive to track gage deviations and, therefore, will require stricter track geometry requirements than systems with wider wheel treads. For maintenance limits, ride quality is a major concern. Thus, more uniformity in maintenance limits is seen because wheel tread width is less important than track deviations from nominal dimensions.
- Most transit agencies use either FRA or APTA standards for track inspection. These standards are similar and broadly cover all the same topics. Some agencies have their own agency standards, which typically are based on historical knowledge and often are stricter than FRA or APTA standards.
- Most transit agencies use various gauges to measure geometry and frog health along with annual track geometry and rail flaw runs. Some agencies use additional tools and automated inspection tools and equipment.
- New inspection technologies are largely in the experimental or trial stage and may remain there for many more years. Implementing new technology is often hindered by a lack of information about the technology, training, institutional support, and initial cost. Demonstration projects often facilitate implementation of new technologies and methods beyond the

demonstrating organization. Information from credible sources is useful in steering new technology implementation.

- A wide range of maintenance philosophies is used, with smaller streetcar agencies using predictive maintenance planning and larger agencies in actual practice tending to be more reactive.
- Maintenance time windows vary extensively by agency, and about 50% of agencies have fewer than 4 hours per day to complete maintenance.
- The inspection and maintenance needs of agencies depend greatly on track miles and mode, which correlate to daily maintenance period variances. Agencies with higher track miles (>100) are more interested in automated inspection and new maintenance techniques to efficiently complete inspections and maintenance actions during shorter time windows. Smaller transit agencies (<10 miles) are less interested in automated inspections.

Section 7

Gap Analysis in Standards

The literature review references multiple standards and recommended practices available for transit track inspection. A gap analysis of the standards was conducted using accident data, a comparison of standards, and a scan of potential technologies. The areas of focus for the gap analysis were as follows:

- NTSB and NTD accident data:
  - Lack of causal factor explanations
  - Turnouts
  - Yard track
  - Non-revenue service accidents
- Inspection and maintenance standards comparisons:
  - Lower speed safety standards in North America are less restrictive than in other parts of the world
  - Vehicle speeds, weights, and capabilities should be accounted for in the track inspection and maintenance standards
- Technology implementation opportunities are available:
  - Greater use of automated inspection capabilities
  - More frequent inspections using less capable equipment that resides on revenue service equipment may be feasible

The following sections discuss each topic in more detail. The first phase of this project involved gathering and comparing information on track inspection and maintenance standards used by passenger operations. Standards data were supplemented with a review of relevant accident data and a survey of standards, current practices and technologies being used by participating agencies.

Gap Analysis Using Accident Data

TTCI conducted an analysis of the accident data available to help determine where there may be gaps in standards and maintenance practices. The analysis , including data from FRA, NTD, and SSOAs, aimed to identify root causes so potential improvements in inspection and maintenance standards, methods, and technologies can be identified. Four areas of focus were identified from the accident data analysis.

The first area involves reports, which often lack sufficient detail to assign track and mechanical causes. NTD and SSOA reports typically do not assign a cause to the accident, whereas FRA reports almost always assign a primary cause. Without cause-finding, data are of limited value in guiding research and development to reduce accidents. This finding suggests that the report forms should be revised to add data that will assist in cause-finding. Based on the lack of basic key derailment investigation information in the narrative sections of the reports, accident investigation training should be developed so current and revised reports will provide more useful information.

The second area of focus is turnouts. About two-thirds of track-caused accidents involved turnouts. This may reflect, in part, the lack of cause-finding in most reports. The high percentage of accidents involving turnouts suggests that improvements in inspection, maintenance, and operations are possible. Further analysis of turnout-related accidents show that switch point climb and split switch derailments are prominent among failure modes. Switch point climbs suggest that wheel/switch point profile mismatches are creating conditions that enable wheel climb derailments. Thus, inspection and maintenance standards in this area should be reviewed. Split switch derailments can be caused by human error such as throwing a switch under a train or switch condition deterioration that causes a lateral gap under traffic loading that allows wheels to go down the wrong route. The following recommendations are made for turnouts:

- Thorough review of turnout design considering vehicle wheel profiles, speeds, and weights is needed.
- Turnout designs should be appropriate for the service environment; they should be re-evaluated when designing and implementing new operating equipment.
- Switch point inspection procedures and criteria improvements are needed. It is highly unlikely that training of track inspectors will be successful without production of simple “go/no-go” gauges. Automated assessment of wheel/rail contact angle and/or standardized gauges that allow a quick assessment of wheel flange/ rail or switch point contact conditions are needed.
- The frequency of inspections under vehicle loads should be increased. Switches and frogs in turnouts perform quite differently when under load than they do when unloaded. Deflections in critical areas can make running surfaces and discontinuities adverse to good performance; for example, switches may gap only under dynamic loading.
- Operations training should be improved. Many turnout accidents involve run-throughs, a trailing point move opposite proper switch route, and split switches where a train is transitioning through a switch when it is thrown.

The third area of focus is yard track. Accident data show that yard track is disproportionately represented. Available NTD data show that 50% of track-related accidents occur in yards. Perhaps this is a natural consequence of risk management and maintenance prioritization, i.e., focusing maintenance effort in areas where the consequences are most severe. Thus, the same recommendations as those made for turnouts apply to all yard track. Operations training should include familiarization with yard tracks and devices and stress the importance of maintaining yard trackage to reduce derailments and resultant operational delays.

The fourth area of focus is non-revenue service operations and vehicles that can occur in yards or on regular rights-of-way. From the accident data, it is apparent that a significant number of accidents occur during non-revenue service operations. Review of 100 accident records showed that about 20% are from non-revenue service operations. Of these, 7% are regular revenue service equipment performing non-revenue service moves, e.g., switchman moved cars in the yard. The other 13% are non-revenue service vehicles, e.g., rail flaw inspection cars, ballast cars, etc., that are derailing while performing track inspections and maintenance. Further research is needed to better understand this phenomenon. Potential causes include:

- Track failure due to more severe loading than revenue service equipment
- Adverse wheel/rail contact conditions due to non-conformal wheels
- Non-familiarity with the territory and operations
- Maintenance standards and recommended practices

Gap Analysis of Inspection and Maintenance Standards

Manual inspection of track is similar between different forms of rail passenger operations. Progressive development of advanced technologies is occurring that will extend automation of the inspection processes. Advanced technologies and more automation of the inspection process were cited as a need by survey respondents.

Most, if not all, existing or developmental automated inspection technologies are for open, non-street track inspection. For track constructed in streets, the street surface covers track condition and traps water, sand, and dirt that has deleterious effects on track quality. It is prudent to promote advancements in technologies that can provide inspection information on hidden, under-street components so a full assessment of track condition can be made.

Comparing track FTA safety standards to other international standards and APTA recommendations, the main feature that differs is that FTA geometry standards are not speed- related. Increasing precision of track quality with increasing speeds has resulted in maintenance and safety standards for other international and domestic standards that demand stricter track standard measurements as the speed increases. FTA guidelines remain essentially the same as speed increases.

For light rail that is constructed in streets, initial construction is critical, as options for ongoing maintenance are limited because of the covering street pavement. For light rail operating on open track, the use of stricter standards with increased speeds would be consistent with heavy rail operations and would result in more consistent ride quality over time with periodic maintenance performed on the track.

Track safety standards used worldwide are similar for higher track speeds (e.g., speeds above 60 mph), as shown in the figures above. One difference noted between agencies in the track safety standards used is for lower speed track. North American low speed track safety standards tend to be less strict than international standards. Figure 7-1 shows the safety standards for Alignment, for example.

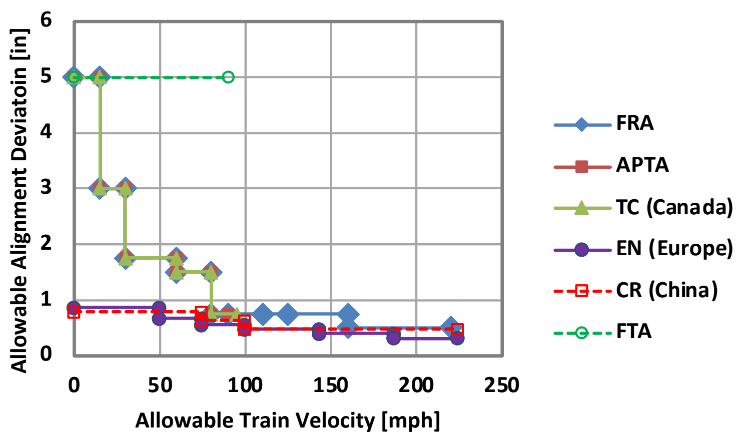

Figure 7-1 *Allowable alignment deviation*

In general, most transit agencies set maintenance limits above the corresponding safety limits that govern the track. In this way, the railroad always is maintained well above the safety limits. When a maintenance limit is exceeded, the track is still well within the safety limits for the set operating speeds. A rule of thumb for many systems that use FRA track limits is to set the maintenance limit at one track class above the safety limit. Thus, the maintenance limit for Class 3 track (60 mph) will be the safety standards for Class 4 track (80 mph). For example, Figure 7-2 shows the extent to which maintenance standards for cross level, the elevation difference between two rails at a given location, exceed the corresponding safety limit used by a sample of transit agencies. The sample size and data are from six agencies who provided their maintenance standards for this study.

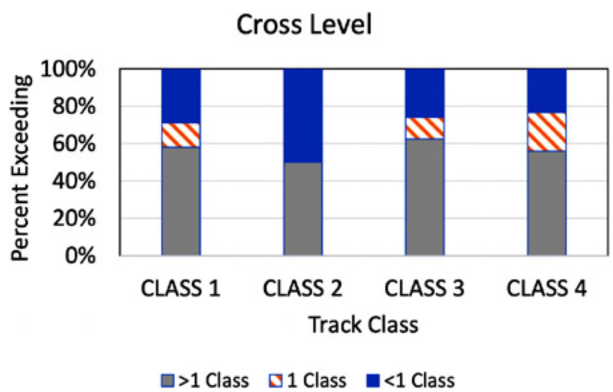

Figure 7-2 *Comparison of maintenance standards and safety standards*

Note that the majority of agencies have a maintenance standard that exceeds the safety standard by more than one track class. Also note the differences by track class; with track Class 2 (15–30 mph) being less restrictive above the safety limits than other track classes.

Maintenance recommended practices, as shown in AREMA's *Manual for Railway Engineering, AREMA Practical Guide to Railway Engineering* and the APTA handbook, offer useful information about best practices for performing maintenance of track and infrastructure. One example of the information found in the AREMA manual is the section on how to install CWR (American Railway Engineering and Maintenance of Way Association, 2017).[9] The manual gives a step-by-step procedure on how to install rail and covers why the procedure is done in this order and what the advantages are over other procedures. Such issues as tie condition and how ties should be replaced prior to new rail installation are also discussed.

Technology Gap Analysis

A review of the technologies currently being used for inspection and maintenance revealed some potential gaps, as described below.

Vehicle capability assessment tools are useful to determine truck and wheel performance and proactively identify defects. Agencies can work with integration companies and railcar manufacturers to determine rail-to-wheel interface performance requirements of new and legacy vehicles and then use the dataset and historical maintenance records to fine-tune condemning criteria. New vehicle acceptance tests should include performance of vehicles on yard track, for example.

[9] *Manual of Recommended Practices*, *2017*, American Railroad Engineering and Maintenance of Way Association, Washington DC.

Load measuring of revenue service vehicles for ride quality assessment is needed. Automated track geometry measurements that can be operated as a revenue service train or in the slot of a revenue service train is needed to provide timely information at a lower cost. Ride quality assessment is needed to determine conditions that are within all safety and maintenance limits but still could cause high dynamic forces and increase risk of derailment. Typically, these are combination defects in which a combination of track gage, cross level, and surface may cause a particular vehicle to generate unacceptably high dynamic forces or accelerations. These conditions can be vehicle type/design-specific and should be evaluated for the types of vehicles in use.

Automated assessment of wheel/rail contact angle and/or manual gauges allow quick assessment of wheel flange/rail or switch point contact conditions. Experienced personnel, who understand wheel/rail interaction, can accurately assess the potential risk of derailment at each switch point. Evaluating potential three-dimensional wheel/rail contact by inspecting only the switch point is difficult. It is highly unlikely that training of track inspectors will be successful without some simple “go-no-go” gauges. Implementation of a set of simple gauges will allow for accurate and consistent prioritization of safety critical switch maintenance. A set of switch point gauges was developed by the University of Delaware under an FRA research and development program.[10] Figure 7-2 shows a set of switch measurement gauges built by Norfolk Southern for the Delaware project. These may already be suitable for use or likely can be modified to serve the transit industry, depending on the wheel profiles used.

Figure 7-3 *Switch inspection gauges built by NS*

On-board rail inspection should be explored. Many rail flaws eventually progress to final failure from repeated wheel loads. Thus, the concept of a fleet

[10] Zarembski, Allan (June 2017), Switch Point Gauges to Prevent Wheel Climb Derails, RIVIT Conference, University of Illinois, Urbana, Il.

of revenue service inspection vehicles equipped to find large rail head defects at revenue service speeds has merit. Currently, ultrasonic rail flaw inspection is done at long time intervals, such as yearly. A detailed inspection is conducted using an inspection vehicle that operates at low travel speeds, typically 10 mph and below, which can complicate train operations.

Track inspection equipment can find transverse flaws as small as 3% of the rail head cross section area. The trade-off of finding small flaws is that there is a high probability of identifying good rail as having a flaw, i.e., a false positive indication. Also, detailed inspection requires large windows of track time because of relatively slow inspection speeds which greatly affects operational schedules and train throughput. As many rail flaws grow slowly under repeated transit wheel loads, it may be preferable to do more frequent but less discriminating inspections using revenue service vehicles. The key to this approach is that the revenue service vehicle inspections must reliably find larger flaws that are sufficiently sized below typical failure criteria. Failure criteria will need to be defined to assure proper safety margin.

Gap Analysis Findings

The gap analysis revealed several opportunities for potential improvements in track inspection and maintenance standards, methods, and technologies. These opportunities may produce improvements in the safety and efficiency of transit operations. The following results are offered to the industry:

- Railway operations, especially vehicle-track interaction, are a carefully balanced system. The effects of any track or equipment changes can have unintended consequences. Thus, any changes in track characteristics and vehicles should be evaluated for the potential effects on railway operations.
- Refine accident causal findings and reporting by improving the accident reporting process, databases, and enhanced track maintenance personnel accident investigation training.
- Specific suggestions for turnout inspections:
  - Thorough review of turnout design with respect to the vehicles and operating speeds.
  - Improvement of switch point inspection procedures and tooling; purpose-built gauges to assess wheel/rail contact should be used, and a project to develop gauges for the range of rail and wheel profile combinations should be conducted.
  - Frequency of inspections conducted while under vehicle load should be increased.

  - Operations training, including trainings on inspection and maintenance, should be improved; many reported derailments involve operational issues.
- Data show that there are opportunities to increase the quality and upkeep of yard track and switch equipment. Yard track is also disproportionately represented in incident/accident reports. Further investigation and emphasis can determine specific causes and prevention methods.
- A review of policies regarding track-work operations during revenue and non-revenue service times should be conducted. Accident data show that significant numbers of accidents and fatalities occur during these operations. Further research and possible policy improvements may mitigate serious consequences.
- Review the appropriateness of less restrictive, lower speed track safety standards when compared to international standards.
- Encourage the implementation of flaw detection inspection technologies to include the following:
  - Wider scale use of automated inspection and ride quality assessment tools on revenue service equipment
  - Use of manual wheel/rail contact inspection gauges for switches
  - Use of wayside truck performance detection devices to proactively identify poor wheel to rail interface characteristics

Based on results of the research and the feedback and suggestions of CUTR's Transit Safety Standards Working Group, the following findings are provided for consideration. As many of the findings are interrelated, it is possible that addressing some combination of findings will eliminate the need of other findings.

- **Finding 1**: Lower track speed safety standards (Class 1 track class) result in a higher number of yard accidents as shown by NTD data. Further investigation is needed to determine specific causes and prevention methods. Policy reviews and possible improvements may reduce non-revenue service operation and vehicle incidents. Based on accident data, it is apparent that a significant number of accidents occur with non-revenue service operations.
- **Finding 2**: Switch point inspection improvements can be made. Purpose-built gauges to assess wheel/rail contact can be developed specific to the agency track geometry will assist in inspections. An FTA or industry project to develop gauges for the range of rail and wheel profile combinations is an option.
- **Finding 3**: Training for turnout operations can reduce incidents, and APTA could consider revising its recommended practice on turnout inspections.

- **Finding 4**: The NTD data reporting system does not indicate derailment cause-finding reporting; inclusion of that data definer would assist in future data analysis efforts.
- **Finding 5**: Vehicle/track interaction plays a large role in derailment incidents. Track maintenance standards can be tailored to an agency's types and characteristics of vehicles. One standard defining requirements for track maintenance may not fit all agencies due to the differences in vehicle types, track gage, wheel profile, wheel back-to-back spacing, and more. Sister agencies that have the same vehicle, track, and operational characteristics may be able to confer and improve their inspection procedures and policies.
- **Finding 6**: Industry track geometry safety standards and recommended practices exist, including FRA Track Safety Standards (49 CFR Part 213); APTA Inspection and Maintenance Standard (RT-FS-S-002-02, Rev 1) (similar in scope to 49 CFR Part 213), which directly accounts for a variety of track gages found in rail transit; and APTA RT-FS-S-002-2 Rev 1, Rail Transit Track Inspection and Maintenance, which includes inspections under load. Loaded conditions flex track geometries and increasing the frequency of inspections can reduce incidents.
- **Finding 7**: New automated inspection technology developments may be worthy of demonstration/validation.
- **Finding 8**: A thorough review by the industry can improve turnout design with respect to the vehicles and operating speeds used in transit today.

Appendix

Transit Agency Data Collection Form

The following data collection form was sent out to various rail transit agencies in the U.S. to gain their input.

Rail Transit Inspection and Maintenance Practices

Transportation Technology Center, Inc. (TTCI), with support from the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF), was tasked by the Federal Transit Administration (FTA) to research standards and technologies for rail transit track inspection and maintenance. FTA provided TTCI with a list of State Safety Oversight (SSOA) program managers (through the Transit Safety Office) to contact about helping TTCI obtain Rail Transit Agency contacts that could help with this data collection effort.

If technical specifications can be provided in addition to the answers to the questions, please send them to david_davis@aar.com.

1. Agency Name: _____
2. About how many track miles (not route miles) are incorporated in your system? Do not include storage yards. (Please specify by mode, if more than one)

Miles of Track	Heavy Rail	Light Rail	Streetcar
a. <10			
b. 11-50			
c. 51-100			
d. 101-200			
e. 200+			

3. What year was the first segment of track opened within your system? _____
4. What is your top speed on mainline track?

Mainline Top Speed	Heavy Rail	Light Rail	Streetcar
a. <35 mph			
b. 45 mph			
c. 55 mph			
d. 60 mph			
e. >60 mph			

5. About how many miles of Embedded Track are in your System?

Miles of Embedded Track	Heavy Rail	Light Rail	Streetcar
a. Zero			
b. 1-3			
c. 4-10			
d. 11-50			
e. 50+			

6. About how many miles of Direct Fixation Track are in your System?

Miles of Direct Fixation Track	Heavy Rail	Light Rail	Streetcar
a. Zero			
b. 1-3			
c. 4-10			
d. 11-50			
e. 50+			

7. About how many miles of Ballasted Track are in your System?

Miles of Ballasted Track	Heavy Rail	Light Rail	Streetcar
a. Zero			
b. 1-3			
c. 4-10			
d. 11-50			
e. 50+			

8. About how many miles of Elevated Structures are in your System?

Miles of Elevated Structure Track	Heavy Rail	Light Rail	Streetcar
a. Zero			
b. 1-3			
c. 4-10			
d. 11-50			
e. 50+			

9. Is your track standard gage (56 1/2)?
   a. Yes
   b. No
   If no, what track gage is used? _______

10. Which wheel profile is used?

Wheel Profile	Heavy Rail	Light Rail	Streetcar
a. APTA 140			
b. APTA 340			
c. AAR 1-B			
d. AAR 1:20			
e. Other			

11. What is the width of your wheel tread?

Wheel Width	Heavy Rail	Light Rail	Streetcar
a. 3"			
b. 3 ½"			
c. 4"			
d. 4 ½"			
e. 5"			
f. Other			

12. Is your system governed by the FRA?
    a. All trackage is
    b. More than 50 percent
    c. Less than 50 percent
    d. None
13. What minimum Track Safety Standard is used for Track Maintenance?
    a. FRA
    b. APTA
    c. CA Utilities Commission
    d. FTA
    e. Agency Standard
    f. None
    g. Other_____
14. If you have your own agency standards, are they stricter than the Track Safety Standards?
    a. Yes
    b. No
15. If yes to 14, does it have a speed restriction based on severity of defect?
    a. Yes
    b. No
    c. N/A
16. Do you have a priority system related to track defects?
    a. Yes
    b. No
17. Does a Track Inspector have the authority to shut down the railroad?
    a. Yes
    b. No
    c. Depends
18. Do Track Inspectors file reports?
    a. Yes
    b. No
19. If yes to 18, are the reports audited?
    a. Yes
    b. No
20. How often is your maintenance schedule updated?
    a. Continuously
    b. Daily
    c. Weekly
    d. Monthly
    e. Semi-Annually
    f. Other _____
    g. No Maintenance Schedule

21. Is track maintenance scheduled or reactive?
    a. Mostly scheduled (predictive of reaching limit)
    b. Mostly reactive (work is scheduled after reaching limit)
22. What is the average time-window to perform maintenance per day?
    a. Less than 3 hours
    b. 3 to 4 hours
    c. 4 to 5 hours
    d. 5 to 6 hours
    e. More than 6 hours
    f. Spot maintenance Only
23. How is track maintained?
    a. Failed components individually (e.g., tie replacement)
    b. Triggered by track reliability measure (e.g., track blitz with identified rail, ties, fasteners, ballast, etc. being replaced)
    c. Track renewal (e.g., all components replaced)
24. How often do Inspectors perform a walking inspection of the mainline?
    a. Twice weekly
    b. Once weekly
    c. Once per month
    d. Twice per year
    e. Once per year
    f. Never
    g. Other_____
25. How often do Inspectors perform a walking inspection of mainline turnouts?
    a. Twice weekly
    b. Once weekly
    c. Once per month
    d. Twice per year
    e. Once per year
    f. Never
    g. Other _____
26. How often is a geometry car operated on the mainline?
    a. Once per month
    b. Twice per year
    c. Once per year
    d. Every two years
    e. Never
    f. Other _____

27. How often do you run a rail flaw detector car on your mainline?
    a. Once per month
    b. Twice per year
    c. Once per year
    d. Every two years
    e. Never
    f. Other _____
28. Do you have a CWR plan?
    a. Yes
    b. No
    c. Don't have any CWR
29. Does your agency use a formal track inspection/track foreman written qualification process?
    a. Yes
    b. No
30. If yes to 31, does it include a written exam?
    a. Yes
    b. No
    c. N/A
31. Do track maintenance workers and track inspectors have training requirements? (select all that apply)
    a. Roadway Worker once a year
    b. Roadway Worker once only
    c. Roadway Worker never
    d. Track Maintenance Standards (TMS) once per year
    e. TMS once only
    f. TMS never
    g. TMS twice per year
    h. Equipment Training

    Other Training, please list: _____
32. What is the predominant type of railroad ties used in your track?
    a. Wood
    b. Concrete
    c. Steel
    d. Rubber
    e. Tropical Hardwoods
    f. Others _____

33. What is the predominant rail used in your track?

Predominant Rail Section	Heavy Rail	Light Rail	Streetcar
a. 90 lb. section			
b. 100 lb. section			
c. 115 lb. section			
d. Other			

34. What is the hardness specification of rail used in track?

Predominant Hardness Specification	Heavy Rail	Light Rail	Streetcar
a. Standard (e.g., 300-320 BHN)			
b. Intermediate (e.g., 320-360 BHN)			
c. Premium (e.g., >360 BHN)			
d. Other			

35. Do you use computer hand-held devices for recording track defects?
    a. Yes
    b. No

36. Do you have any future plans to:
    a. Update or change existing standards
    b. Write a maintenance standard
    c. Write a CWR Plan
    d. Nothing, we are good

37. Can you share your inspection and maintenance standards with TTCI? (They will remain confidential).
    a. Yes
    b. No

38. Which non-automated inspection tools are used (besides tape measure, stringline, level board)?
    a. _____
    b. _____

39. Are hand-held gauges used to inspect turnouts?
    a. Yes, please describe _____
    b. No

40. Do you plan on using different non-automated inspection tools or techniques in the foreseeable future?
    a. Yes, please comment _____
    b. No

41. Do you plan on using different automated inspection tools or techniques in the foreseeable future?
    a. Yes, please comment _____
    b. No

42. Are the following technologies used for track inspection? If so, please list components inspected and typical frequency:

Inspection Technology	Track Component or Feature	Frequency
Example: LIDAR	Clearance	Annual
Ultrasonic		
Lasers		
LIDAR		
Ground Penetrating Radar		
Thermography		
Machine vision		
Deflection (vertical)		
Deflection (lateral)		
X-ray		
Other		
Other		

43. Would new inspection tools or techniques be useful to your agency?
    a. Yes, please comment _____
    b. No

44. Would new maintenance techniques be useful to your agency?
    a. Yes, please comment _____
    b. No

45. Accounting for non-negotiable constraints, i.e. limited time-windows, etc., which of the following do you feel would most benefit your agency with regards to inspection?
    a. New standards
    b. Improved training
    c. Non-automated inspection tools/techniques
    d. Automated inspection tools/techniques
    e. Other _____

46. Accounting for non-negotiable constraints, i.e. limited time-windows, etc., which of the following do you feel would most benefit your agency with regards to maintenance?
    a. Improved maintenance schedules
    b. New maintenance techniques
    c. Other _____

Please provide contact information in case TTCI has any technical questions regarding the specifications:

Name: _____
Phone: _____
Email: _____

U.S. Department of Transportation
Federal Transit Administration

U.S. Department of Transportation
Federal Transit Administration
East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
https://www.transit.dot.gov/about/research-innovation