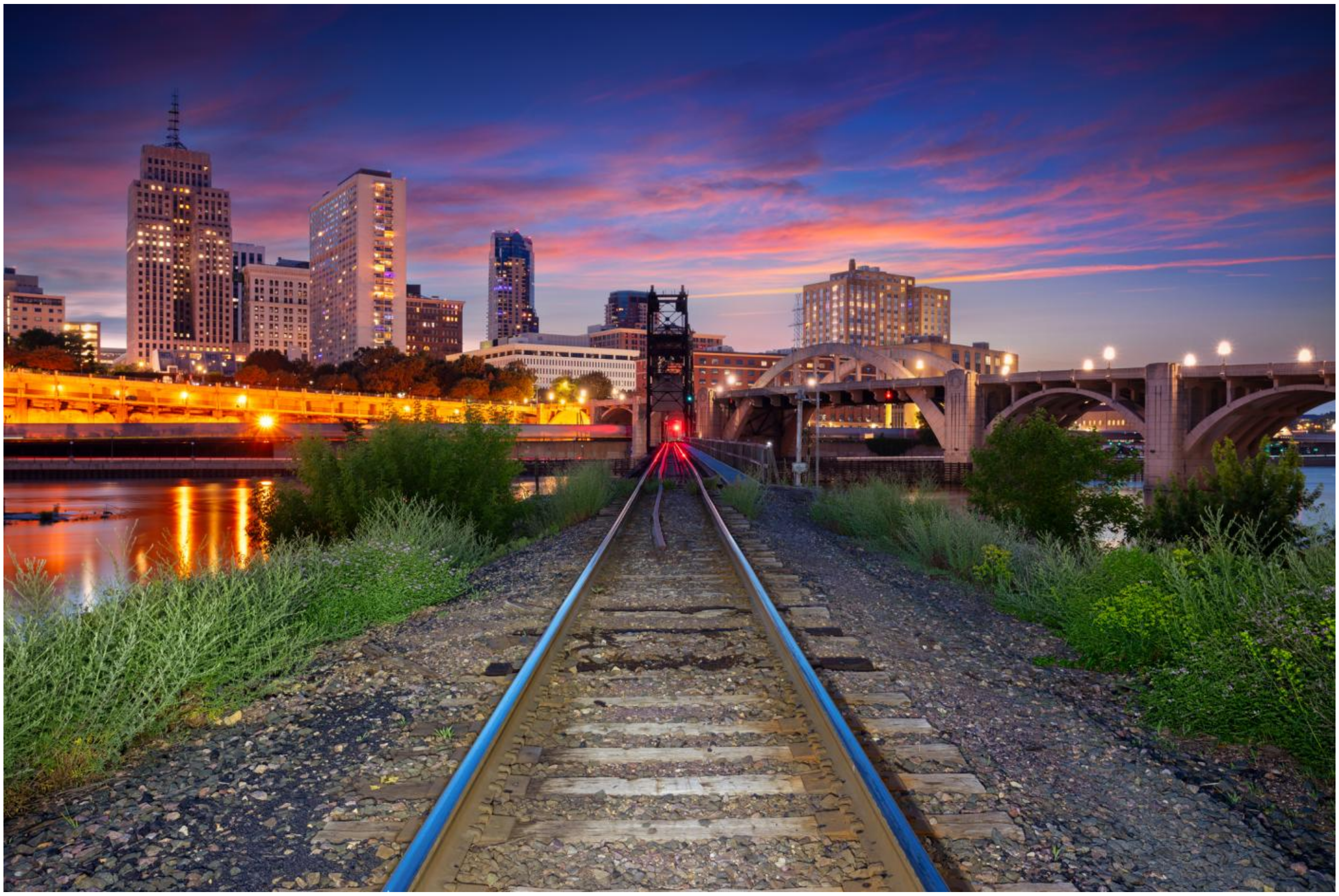
Wayside Detector System Study

March 2026



Prepared by: CPCS Transcom Inc.

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395 John Ireland Boulevard
Saint Paul, Minnesota 55155

March 20, 2026

The Honorable Brad Tabke, Co-Chair
House Transportation Finance & Policy Committee
5th Floor, Centennial Office Building
Saint Paul, MN 55155

The Honorable Jon Koznick, Co-Chair
House Transportation Finance & Policy Committee
2nd Floor, Centennial Office Building
Saint Paul, MN 55155

The Honorable Scott Dibble, Chair
Senate Transportation Committee
3107 Minnesota Senate Building
Saint Paul, MN 55155

The Honorable John Jasinski
Ranking Minority Member
Senate Transportation Committee
2227 Minnesota Senate Building
Saint Paul, MN 55

RE: 2025 Wayside Detector System Study

Dear Legislators,

The Minnesota Department of Transportation is pleased to present the Wayside Detector System Study, prepared in response to the directive outlined in 2024 Minn. Laws Chap. 127 Art. 3 Sec. 129. This report provides a comprehensive evaluation of wayside detector systems and other rail inspection technologies, including their deployment, performance, regulatory context, and potential impacts on Minnesota's freight rail network.

The study evaluates both deployed and emerging detector systems, including Hot Bearing Detectors, Wheel Impact Load Detectors, Dragging Equipment Detectors, and Acoustic Bearing Detectors. It also includes a federal preemption analysis, cost estimates for Class II and III railroads, and a review of potential funding mechanisms. Wayside detector systems can reduce derailment risks and support preventive rolling stock maintenance. Costs for detector installation and maintenance may pose challenges for Class II and III railroads. Several funding mechanisms, including federal CRISI grants and state programs, may support implementation.

MnDOT remains committed to advancing rail safety and supporting Minnesota's freight network. We appreciate the Legislature's leadership in initiating this study and welcome any questions or feedback.

Please let me know if you have questions. You can also contact Matthew Miller at matthew.2.miller@state.mn.us, or 651.334.4058

Sincerely,

Nancy Daubenberger

Nancy Daubenberger, P.E. (MN)
Commissioner

Table of Contents

List of Figures

List of Abbreviations

Abbreviation	Full Form
AAR	Association of American Railroads
ABD	Acoustic Bearing Detector
AEI	Automatic Equipment Identification
AVIS	Automatic Vehicle Inspection Systems
CCTV	Closed Circuit Television
CFS	Census Commodity Flow Survey
DAC	Digital Automatic Coupler
DED	Dragging Equipment Detector
DFOS	Distributed Fiber Optic Sensing
DDCT	Damaged and Defective Car Tracking
EHMS	Equipment Health Management System
ETCS	European Train Control System
EW	Early Warning
EHV	Equipment Health View
FDS	Fire Detection System
FRA	Federal Railroad Administration
HBD	Hot Box Detector / Hot Bearing Detector
HD	Hunting Detector
HVAC	Heating, Ventilation and Air Conditioning
HWD	Hot Wheel Detector
IQ	Inspection Quality
IoT	Internet of Things
LoS	Loss of Shunt
LiDAR	Light Detection and Ranging
MA	Maintenance Advisory
MnDOT	Minnesota Department of Transportation
MVA	Machine Vision Algorithm
NDIR	Non-dispersive Infrared
NTSB	National Transportation Safety Board
PIS	Passenger Information System
PTC	Positive Train Control
RCEP	Railroad Crossing Elimination Program
SA	Safety Advisory(ies)
SBB	Swiss Federal Railways
TBOGI	Truck Bogie Optical Geometry Inspection
THD	Truck Hunting Detector
TIPS	Train Inspection Portal System

TPD	Truck Performance Detector
UGMS	Unattended Track Geometry Measurement System
UMLER	Universal Machine Language Equipment Register
UOMS	Unattended Overhead Measurement System
USDA	United States Department of Agriculture
WCMS	Wheel Condition Monitoring Systems
WILD	Wheel Impact Load Detector
WIM	Weigh-In-Motion
WPD	Wheel Profile Detector
WPMS	Wheel Profile Measurement System
WTD	Wheel Temperature Detector

A glossary of technical terms is provided in the appendix.

Report Cost

The cost of producing this report was approximately $250,000.

2024 Minn. Laws Chap. 127 Art. 3 Sec. 129

(a) For purposes of this section, the following terms have the meanings given:

(1) "commissioner" means the commissioner of transportation; and

(2) "wayside detector" or "wayside detector system" means one or more electronic devices that:

(i) perform automated scanning of passing trains, rolling stock, and on-track equipment to detect defects or precursors to defects in equipment or component parts; and

(ii) provide notification to individuals of a defect or precursor to a defect.

(b) The commissioner must conduct a comprehensive study on wayside detector systems and other rail inspection technologies. The commissioner must engage with the governor's Council on Freight Rail under Executive Order 24-02 to consider and review issues related to wayside detectors, including analyzing existing federal regulations and guidance, incidents and performance data, safety complaints, and best practices.

(c) The study must:

(1) identify current practices for defect notification to train crews;

(2) identify current practices for wayside detector systems or other inspection technology deployment and maintenance;

(3) analyze deployed and emerging wayside detector system technology, including known detector types and quantities and may include but is not limited to the following inspection technologies:

(i) acoustic bearing detectors;

(ii) hot box detectors;

(iii) wheel tread inspection detectors;

(iv) wheel impact load detectors;

(v) wheel temperature detectors;

(vi) wheel profile detectors; and

(vii) machine vision systems;

(4) analyze wayside detector systems' impacts on railroad safety and identify accidents and incident trends of rolling stock or other conditions monitored by wayside detectors;

(5) estimate costs of requiring wayside detector systems for Class II and Class III railroads and rail carriers and identify potential state funding mechanisms to institute the requirements;

(6) include a federal preemption analysis of mandating wayside detector systems under state law that includes an analysis and examination of federal law, case law, and federal guidance;

(7) analyze the costs and impacts, if any, on the transport of goods on certain Minnesota industries and sectors, including agriculture, taconite mining, manufacturing, timber, retail, and automotive, if implementation of a wayside detector system is required in Minnesota; and

(8) review current and anticipated Federal Railroad Administration efforts to regulate wayside detector systems, including guidance from the federal Railroad Safety Advisory Committee on wayside detectors.

(d) By January 15, 2026, the commissioner must submit a joint report with the governor's Council on Freight Rail on the study to the chairs and ranking minority members of the legislative committees with jurisdiction over transportation, commerce, and civil law policy and finance.

EFFECTIVE DATE. This section is effective the day following final enactment.

Study Alignment with Minn. Laws Chap. 127 Art. 3 Sec. 129 Requirements

Legislative Requirement	How Addressed in Report
(b) Conduct a comprehensive study on wayside detector systems and other rail inspection technologies.	Chapters 2 provides a statewide review of deployed and Chapter 3 discusses emerging technologies.
(b) Engage with Governor's Council on Freight Rail; consider federal regulations, incidents, safety complaints, and best practices.	Section 1.3 documents stakeholder engagement; Chapters 4 and 5 review performance and safety considerations; Chapter 7 analyzes federal regulations.
(c)(1) Identify current practices for defect notification to train crews	Section 4.2 describes notification processes, including "talker" functionality and federal/industry guidance.
(c)(2) Identify current practices for deployment and maintenance	Section 2.2 outlines deployment practices; Section 4.1 covers site selection considerations for detectors; Section 4.2 addresses maintenance.
(c)(3) Analyze deployed and emerging wayside detector system technology, including known detector types and quantities and may include but is not limited to the following inspection technologies: (i) acoustic bearing detectors; (ii) hot box detectors; (iii) wheel tread inspection detectors; (iv) wheel impact load detectors; (v) wheel temperature detectors; (vi) wheel profile detectors; and (vii) machine vision systems	Chapters 2 and 3 describe these technologies, their deployment considerations and studied benefits. Minnesota-specific information, particularly detector locations and types, technology performance, and cost data are classified by carriers as sensitive for safety and security reasons and were therefore not provided for use within the study.
(c)(4) Analyze safety impacts and identify accident and incident trends	Chapter 5 presents FRA's rail equipment incident data and trends
(c)(5) Estimate costs for Class II and III railroads; identify potential state funding mechanisms.	Chapter 6 provides high-level cost estimates based on ranges of wayside detector system costs provided by technology vendors; Section 6.3 outlines funding programs that could be leveraged to cover the costs of wayside detector systems.
(c)(7) Analyze costs and impacts on Minnesota industries (agriculture, taconite mining, manufacturing, timber, retail, automotive).	Section 6.2 discusses potential impacts of wayside detector systems on listed sectors.
(c)(6) Federal preemption analysis of mandating wayside detector systems	Chapter 7 explains FRA's authority under FRSA and STB jurisdiction under ICCTA; the same Chapter includes case law and FRA guidance.
(c)(8) Review current and anticipated FRA efforts, including RSAC guidance	Chapter 7 summarizes FRA Safety Advisories (2023-01, 2023-04) and RSAC guidance.

Executive Summary

The purpose of the study is to provide the Minnesota policymakers with a clear understanding of the role and implications of wayside detector systems in Minnesota's rail network.

In response to Minnesota's legislative directive, Minnesota Department of Transportation (MnDOT) undertook a comprehensive assessment of the types of wayside detectors, their performance, deployment, and regulatory context. Wayside detector systems are defined in the legislation and for the purposes of this study as:

"one or more electronic devices that:

> (1) perform automated scanning of passing trains, rolling stock, and on-track equipment to detect defects or precursors to defects in equipment or component parts; and
>
> (2) provide notification to individuals of a defect or precursor to a defect."[1]

The present study addresses this legislative directive, by reviewing the detector types and emerging technologies, their safety impacts, deployment practices, costs, and regulatory context. It also evaluates the federal preemption, industry impacts, and potential funding mechanisms, as directed by the Legislature.

Deployed and Emerging Wayside Detector System Technologies

In North America, there are various types of wayside detector systems in use:

- Hot Bearing Detectors (HBDs) are the most widely deployed detector type, with more than 6,000 installed as of 2019. They are credited with reducing axle- and bearing-related accidents since their emergence in the early 1980s.[2]
- Wheel Impact Load Detectors (WILDs) and Dragging Equipment Detectors (DEDs) are also common on Class I corridors. They are often installed together along high-traffic corridors.
- Hot Wheel Detectors (HWDs) are also frequently paired with HBDs to monitor both wheel and bearing temperatures.
- Other advanced systems like machine vision portals are also in limited use nationally, and multiple railroads are exploring pilot deployments to evaluate their performance under local and corridor-level conditions.

The deployment of wayside technologies across Minnesota's rail network reflects national practice. During the stakeholder engagement portion of this study, railroads confirmed the presence of HBDs, WILDs, and DEDs within the state. They are typically installed on mainlines and hazardous material (hazmat) routes.

The following graphic provides a summary presentation of the wayside detector types reviewed in this study.

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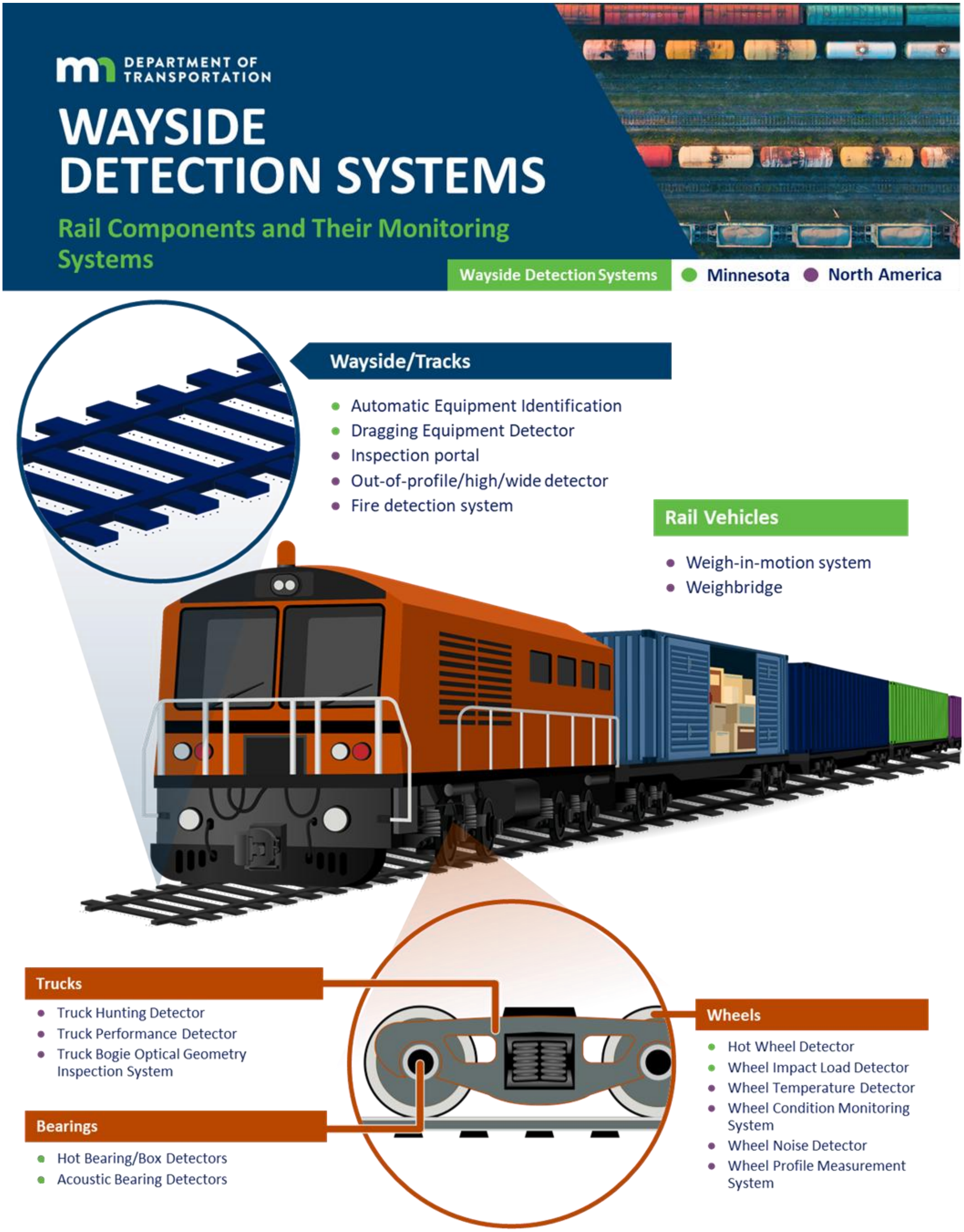
[1] Minnesota Senate File 3943, Section 1. https://www.revisor.mn.gov/bills/93/2024/0/SF/3943/versions/0/

[2] FRA, An Implementation Guide for Wayside Detector Systems, 2019.



DEPARTMENT OF TRANSPORTATION
WAYSIDE DETECTION SYSTEMS
Rail Components and Their Monitoring Systems
Wayside Detection Systems
Minnesota
North America
Wayside/Tracks
Automatic Equipment Identification
Dragging Equipment Detector
Inspection portal
Out-of-profile/high/wide detector
Fire detection system
Rail Vehicles
Weigh-in-motion system
Weighbridge
Trucks
Truck Hunting Detector
Truck Performance Detector
Truck Bogie Optical Geometry Inspection System
Bearings
Hot Bearing/Box Detectors
Acoustic Bearing Detectors
Wheels
Hot Wheel Detector
Wheel Impact Load Detector
Wheel Temperature Detector
Wheel Condition Monitoring System
Wheel Noise Detector
Wheel Profile Measurement System

Impacts of Wayside Detector System Technologies

When installed, calibrated, and maintained according to federal guidance and industry best practices, wayside detectors provide information that railroads can use to identify certain equipment conditions associated with derailment risk.

Wayside detection systems are designed to support risk reduction and safety monitoring across the rail network, including on corridors that carry hazardous materials or serve populated areas.

Federal Railroad Administration (FRA) studies indicate that wayside detector systems can help reduce the likelihood of specific types of equipment-related derailments by identifying defects before they progress:

- Potential **safety benefits** include reduced emergency response activity, decreased infrastructure damage associated with certain mechanical failures, and fewer manual inspections in locations where track access may present additional risk. FRA research shows that wayside detectors can identify specific mechanical anomalies linked to some equipment-related failures, supporting preventive maintenance efforts. Excluding the crossing related incidents, Minnesota's train accidents have declined overall since 2016, with cause patterns similar to national trends. Human-factor and track-related causes remain the largest factors leading to these incidents. Motive Power and Equipment causes (accidents attributed to mechanical or electrical failures in locomotives or railcars) represent approximately 10 percent of train accidents within Minnesota in recent years; about three accidents per year, which is consistent with national averages.
- **Operational benefits** relate to earlier detection of certain mechanical conditions, which can allow railroads to address issues before they result in service disruptions. This can reduce unplanned maintenance events, shorten service outages, and support more consistent asset utilization. Data collected from detectors such as Wheel Impact Load Detectors and acoustic bearing detectors can also be trended over time to identify deteriorating components. Deploying multiple detector types at a single site can, in some cases, improve diagnostic capability.
- **Economic benefits** can arise from improved service reliability, which can reduce delays and support more predictable freight movements. At the same time, FRA studies and industry input note that operational rules governing detector alarms must be calibrated appropriately, as unnecessary train stops can increase transit times and operating costs. Effective use of wayside detection therefore requires practices that support both safety and efficient train operations.

Wayside Detector System Deployment, Maintenance, and Notification Processes

Effective deployment of wayside detectors depends on selecting locations that support accurate measurements, predictable operating conditions, and safe maintenance access.

Site selection requires balancing geographic constraints, track geometry, ambient noise, and available right-of-way with operational factors such as traffic density, speed consistency, and routing patterns. Detector types also have specific technical needs, including speed thresholds, vibration tolerance, noise sensitivity, and spacing requirements that influence where installations are feasible. Co-locating multiple detector types is also a practice used to reduce infrastructure costs, streamline maintenance activity, and generate more comprehensive diagnostic information; however, it requires careful technology integration to avoid interference and ensure each system operates within its design limits.

Once installed, detector systems require ongoing calibration, inspection, and periodic repair to maintain accuracy and operational reliability.

Maintenance demands vary by detector type and depend on environmental conditions, vendor specifications, age of equipment, and site characteristics such as accessibility. Many installations require specialized calibration procedures that may necessitate rail vehicles passing over the detector. Railroads must also be prepared for unplanned maintenance, including system failures that need prompt response to minimize downtime.

Wayside detectors are most effective when paired with clear notification protocols and response procedures.

Detector alerts may be communicated through on-train “talker” systems, directly to railroad operations centers, or both, depending on the equipment type and setting. Thresholds for alerts are defined by industry standards, FRA guidance, and vendor recommendations, and often include multiple severity levels aligned with required inspection or repair actions.

Effective response requires coordinated communication between train crews and operations centers, timely ground inspections, documentation, and adherence to operating rules. These processes rely heavily on personnel training, data quality, and the ability to distinguish between true defects and non-actionable outliers.

Costs and Impacts of Wayside Detector Systems on Minnesota Industries

Wayside detector costs span equipment, installation, maintenance, calibration, training, and data systems with values varying by technology and site conditions.

These costs vary widely based on technology features and site conditions. For instance, technology vendors’ input has shown that HBDs can range from $200,000-$350,000 per site, WILDs around $150,000, with installation, calibration, and maintenance adding about $25,000 annually.

For Class II and III railroads, the costs of installing and maintaining wayside detector systems can exceed the quantifiable safety benefits in the initial years of deployment. These railroads operate on thin margins and rely on limited operating revenues, meaning that unfunded technology requirements would directly affect their financial capacity. Without external support, investment requirements could strain operating budgets and limit resources available for core maintenance and service needs. Industries reliant on rail shipments may experience pass-through effects if smaller carriers adjust their rates to manage expenses associated with technology investments.

The study identifies a few funding mechanisms that can support wayside detector deployment, including the federal Consolidated Rail Infrastructure and Safety Improvements (CRISI) program, which funds safety technologies and is accessible to Minnesota’s short lines through its rural set-aside.

FRA Guidance and Federal Preemption of Mandating Wayside Detector Systems

The Federal Railroad Safety Act (FRSA) and the Interstate Commerce Commission Termination Act (ICCTA) grant exclusive authority to the FRA and Surface Transportation Board (STB) over rail safety and operations.

As a result, federal law may preempt state regulation of wayside detection technologies. Despite the potential for federal preemption, some states have considered (such as California) or enacted (such as Ohio) state regulations for wayside detectors with the goal of improving safety.

Courts have previously addressed federal preemption of state rules requiring wayside detectors at 30-mile intervals, upholding California Public Utilities Commission requirements for wayside defect detectors against FRSA and locomotive-safety preemption in Union Pacific R. Co. v. California PUC, 109 F. Supp. 2d 1186 (N.D. Cal. 2000). However, as of late 2025, there are no reported cases specifically testing whether Ohio's current wayside detector statutes are preempted by federal regulations or guidance.

1 Introduction

1.1 Background

The Minnesota Legislature directed the Minnesota State Department of Transportation (MnDOT) to undertake a Wayside Detector Systems Study.[3]

Wayside detector systems are defined in the legislation and for the purposes of this study as, "one or more electronic devices that:

(1) perform automated scanning of passing trains, rolling stock, and on-track equipment to detect defects or precursors to defects in equipment or component parts; and

(2) provide notification to individuals of a defect or precursor to a defect."[4]

Following a derailment in 2023, the Federal Railroad Administration (FRA) issued Safety Advisories (SAs) and supplementary updates.

Safety Advisory 2023-01[5] identified burnt journal bearings as a contributing factor in multiple recent derailments. It recommended that railroads enhance the mechanical reliability of their rolling stock by reassessing inspection and maintenance policies and procedures, reviewing thresholds and detector trending logic using Hot Bearing Detector (HBD) data, utilizing real-time trend analysis to identify emerging issues, and ensuring proper training for personnel interacting with wayside detector systems.

Similarly, Safety Advisory 2023-04 addressed another mechanical risk where high-impact railcar wheels damaged the track and caused derailment. This advisory recommended railroads utilize a specific type of wayside detector system known as a Wheel Impact Load Detector (WILD) to properly identify and replace high-impact railcar wheels that could cause significant damage to rails and supporting track structures.[6]

Congress also introduced the Railway Safety Act of 2025 (RSA 2025) on February 4, 2025. The bill is currently in the House of Representatives, where there has been no action. The bill would require the U.S. Department of Transportation to issue regulations for wayside defect detectors.[7]

Figure 1 summarizes the existing FRA advisories concerning wayside detector systems. These advisories urge railroads to adopt better protocols for detector placement, defect threshold response, and trend analysis.

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[3] Minnesota House File 5242 (HF5242), Section 140. https://www.revisor.mn.gov/bills/93/2024/0/HF/5242/versions/ue/1/

[4] Minnesota Senate File 3943, Section 1. https://www.revisor.mn.gov/bills/93/2024/0/SF/3943/versions/0/

[5] Federal Register, Safety Advisory 2023-01; Evaluation of Policies and Procedures Related to the Use and Maintenance of Hot Bearing Wayside Detectors, 2023.

[6] Federal Register, Safety Advisory 2023-04; High-Impact Wheels Causing Damage to Rails and Track Structures, 2023.

[7] Congress.Gov, All Information (Except Text) for H.R.928 - Railway Safety Act of 2025, accessed October 2025. https://www.congress.gov/bill/119th-congress/house-bill/928/all-info

Figure 1: Summary of Existing FRA Advisories Regarding Wayside Detector Systems

Name	Description
SA 2023-01: Evaluation of Policies and Procedures Related to the Use and Maintenance of Hot Bearing Wayside Detectors	• **Recommends** inspection thresholds informed by HBD data. • Consider using real-time HBD trend analysis. • Train and qualify HBD maintenance staff. • Inspect rolling stock flagged by HBDs. • Promote safety-focused decision-making using HBD data.
SA 2023-01 Supplements	• **Recommends** using trend-based and comparative HBD temperature analysis. • Encourage cross-railroad data sharing and alert standardization. • Support the use of automated tools to flag temperature anomalies. • Advise adjusting train handling and inspection protocols based on alerts.
SA 2023-04: High-Impact Wheels Causing Damage to Rails and Track Structures	• **Recommends** using WILD systems to detect high-impact wheels. • Replace wheels that risk damaging track structures after the Gothenburg incident. • Emphasize WILD as a preventive tool against wheel-related derailments.

Source: CPCS review of FRA Safety Advisories as of June 2025.

In parallel with the federal advisories, the freight rail industry—led by the Association of American Railroads (AAR)—has voluntarily strengthened its own safety protocols. Following the East Palestine incident, all Class I railroads agreed to reduce the average spacing between wayside detector systems to approximately 15 miles, down from the previous 40-mile benchmark. It should be noted that exceptions apply to routes equipped with more advanced monitoring technologies. According to the AAR, this voluntary move has led the industry to install approximately 1,000 new detectors, expand support for first responders, and initiate actions based on a preliminary NTSB advisory. [8]

Under 49 U.S.C. § 20106, any later FRA rule (such as a nationwide detector spacing requirement) could override a stricter state standard unless the state demonstrates that its requirements are necessary to address a local safety hazard, are not incompatible with federal law, and do not unreasonably burden interstate commerce.[9]

[8] AAR, Industry to install approximately 1,000 new detectors, expand support for first responders and initiate actions based on preliminary NTSB advisory, March 8, 2023. https://www.aar.org/news/freight-railroads-announce-key-safety-measures-in-drive-to-zero-accidents/

[9] 49 U.S. Code § 20106 – Preemption, https://www.law.cornell.edu/uscode/text/49/20106

1.2 About This Report

This report evaluates both existing and emerging wayside detector systems, assessing their effectiveness, life-cycle costs, and broader industry impacts, to satisfy Minnesota's legislative mandate for a comprehensive analysis of these safety systems.

By providing a data-driven assessment of safety benefits, operational impacts, and implementation pathways, the report will help public agencies, railroads, and technology vendors align on good practice.

The report is organized as follows:

- Chapter 2 – Introduces the types of wayside detectors currently in service in Minnesota.
- Chapter 3 – Presents additional detector technologies implemented in North America and internationally to determine good practice and innovation trends.
- Chapter 4 – Assesses accuracy, reliability, detection rates, siting considerations, data management, and maintenance requirements for wayside detectors.
- Chapter 5 – Discusses safety benefits through statistical analysis of national and Minnesota-specific incident data.
- Chapter 6 – Details capital, operating, and maintenance cost ranges and benefits of wayside detectors, discusses industry impacts of wayside detector installation scenarios, and outlines federal and state funding or financing options.
- Chapter 7 – Examines federal preemption and FRA guidance on statewide wayside detector system deployment.

1.3 Methodology

This study applies a systematic review of MnDOT records, national research on wayside detectors and rail technology performance, railroad and technology vendor inputs, and interviews with other key rail industry stakeholders. These sources are used to catalog the wayside detection systems currently deployed across the state, identify best practices in preventive maintenance and rail safety monitoring outside of Minnesota, and assess performance metrics and costs associated with various wayside detector technologies.

The study draws on three complementary datasets:

1. **Network and Ownership:** MnDOT's railroad asset inventory provides a list of active rail lines, subdivisions, and associated ownership or operating rights. This ensures that each segment is attributed to the correct rail carrier.
2. **Hazmat Commodity Volumes:** The Census Commodity Flow Survey (CFS) 2022 serves as the most current public dataset for tracking the movement of rail cargo originating in, terminating in, or passing through Minnesota. It also includes a Hazmat Indicator that flags shipments regulated under 49 CFR, enabling an analysis of hazardous materials exposure. The commodity flow estimates based on CFS have been cross-checked against aggregate statistics presented in MnDOT's Minnesota Freight Network Optimization Tool (FNOT) and validated against hazmat incident and risk information published by FRA.
3. **Safety Performance:** The FRA Accident/Incident Database is used to analyze rail safety incidents that can potentially be prevented through the use of wayside detectors.

1.3.1 Limitations and Data Caveats

Railroads and industry organizations were invited to provide input throughout the study, including, but not limited to, the following:

- information on detector locations;
- technology cost-benefit specifications;
- installation practices;
- operating costs;
- alarm protocols; and
- safety performance.

Several of the railroads operating in Minnesota participated in interviews and reviewed draft materials; however, several categories of detailed, Minnesota-specific information, particularly detector locations and types, technology performance, and cost data are classified by carriers as sensitive for safety and security reasons and were therefore not provided for use within the study.

Due to the limitations on the railroads providing this data in disaggregated or site-specific form, the study relies on:

- **Publicly available studies and research**, particularly national level research, federal studies, and state planning documents (State Rail Plan, Minnesota Freight Plan, State Action Plan, and MnDOT rail-related resources inventories), and
- **Industry-standard ranges** from national associations, peer-reviewed studies, and vendor materials.

All assumptions are based on sources commonly used in state rail planning, rail-related federal grant applications, and high-level ranges shared by stakeholders during consultations. A full list of consulted entities is provided in Appendix B.

Additional data limitations to consider when reading this study:

- The FRA Accident/Incident Database includes only events exceeding the agency's annual equipment-damage reporting threshold (approximately $12,000 in 2025 dollars). As a result, minor derailments, internally detected defects, and near-miss incidents are underrepresented.
- Cost and installation ranges provided by equipment manufacturers may vary by up to ±20 percent, depending on site-specific conditions, system integration requirements, and purchase volume.
- MnDOT's rail-line inventory is the authoritative source for ownership and operating rights, but it may not reflect real-time changes such as lease transfers or embargoes.
- The datasets used, including hazard exposure (CFS 2022), safety performance (FRA 2014–2024), and detector inventories (2025), do not share identical timeframes.

Due to these data limitations, all quantitative results presented in this study should be interpreted as order-of-magnitude estimates, rather than precise counts.

2 Wayside Detector Systems in Minnesota

Key Chapter Takeaways

This Chapter summarizes the wayside detector systems currently in service on Minnesota's rail network and explains the underlying technology and general functions of each detector type. The information included within this section is current as of October 2025.

It is important to note that:

- While the study reviewed detector technologies, the exact number, type, and locations of wayside detectors in Minnesota could not be independently confirmed. Railroads classify this data as sensitive, since public disclosure could create security risks and reduce detector effectiveness. As a result, only broad descriptions of coverage were shared, consistent with industry protocols to protect rail network safety and reliability.
- Hot Bearing Detectors (HBDs), Wheel Impact Load Detectors (WILDs), and Dragging Equipment Detectors (DEDs) are the most deployed detector types statewide, often co-located to improve defect detection and reduce false positives through multi-sensor validation.

2.1 Wayside Detector Systems

Wayside detector systems perform intermittent, repeatable condition checks as rail vehicles pass by, but they do not offer continuous monitoring of any specific sub-system.

Each alert or notification generated by a detector is relayed to railroad personnel who may advance the issue and determine its cause. Follow-up actions are carried out according to each railroad's operating procedures and in alignment with industry guidance from the Federal Railroad Administration (FRA) and the Association of American Railroads (AAR). Additional details on applicable FRA and AAR protocols are provided in Chapter 4 of this report.

Most wayside detectors are equipped with Automatic Equipment Identification (AEI) functionality, which uses passive tags mounted on both sides of each railcar. AEI readers installed alongside the detectors enable rail vehicles to be identified and tracked throughout the North American rail network. Some detectors also include a "talker" function, which verbally communicates the inspection results to the train crew. These audio messages typically include the railroad name, milepost, track number, number of axles, and whether a defect has been detected. If a defect is present, the message may specify the affected axle and, when relevant, the temperature reading.

The following sections describe the wayside detector systems currently in service on Minnesota's rail network. As shown in Figure 2, five types of detector systems are in use. The figure also summarizes the primary functions, key technologies, and operational considerations associated with each system.

Figure 2: Active Wayside Detector Systems in Minnesota

Detector System	Primary Function	Technologies	Considerations
Hot Bearing Detectors	Monitor wheel bearing temperature	Infrared temperature sensors	Typically installed on mainlines
Hot Wheel Detectors	Monitor wheel temperature	Infrared temperature sensors	Typically combined with HBDs on mainlines
Dragging Equipment Detectors	Monitor for any loose or hanging parts from the rail vehicles	Acceleration sensors (vision camera is optional)	Typically installed on mainlines
Wheel Impact Load Detectors	Monitor wheel shape irregularities by measuring the vertical forces exerted	Accelerometers and strain gauges	Typically installed on mainlines
Acoustic Bearing Detectors	Identify internal bearing defects through acoustic signature analysis	Microphone arrays, acoustic emission sensors	Must be installed on straight track; varying performance at different operational speeds

Source: FRA, An Implementation Guide for Wayside Detector Systems, 2019.

2.1.1 Hot Bearing Detectors

Hot Bearing Detectors (HBDs)—often referred to as Hot Box Detectors—are a widely deployed wayside system across the North American rail network. These detectors identify abnormal bearing temperatures that may indicate defects that have the potential to develop and cause incidents such as train derailments. Using infrared thermal sensors positioned outside of the rail tracks, HBDs measure the heat emitted by bearings as trains pass.

To distinguish genuine bearing overheating from environmental or brake-related heat, HBDs rely on complex algorithms and threshold rules. For example, a bearing may be flagged if it exceeds ambient temperature by 170 °F (76.7 °C) or is 95 °F (35 °C) hotter than its mate on the same axle.[10] Some systems incorporate multi-scan modes to enhance reliability and reduce false positives. Many detectors also feature "talker" radios, which alert train crews of any issues detected in real-time with messages such as *"defect detector milepost 64.0, hotbox, north side axle 2-5-8. train speed 47*."

As widely noted in industry literature, HBDs are the most prevalent type of wayside detector and their broad use has been a key factor in reducing axle- and bearing-related accidents by 81 percent since the 1980s.[11] This reliance stems from the physics of bearing failure: once critical temperatures are reached, bearings can progress from normal operation to catastrophic failure in as little as three minutes.[12]

Beyond safety, HBDs also offer operational benefits. The systems generate valuable data on bearing performance, enabling railroads to implement predictive maintenance programs and optimize

[10] FRA, An Implementation Guide for Wayside Detector Systems, 2019

[11] FRA, An Implementation Guide for Wayside Detector Systems, 2019.

[12] CDL Railroad, Hot Box Detectors: What You Need to Know, 2023. https://cdlelectric.com/hot-box-detectors/

replacement schedules, improving reliability and reducing unplanned downtime.

2.1.2 Hot Wheel Detectors

Hot Wheel Detectors (HWDs) identify overheated wheels, which may result from conditions such as sticking brakes, unreleased hand brakes, or malfunctioning automatic brake systems. This type of detector uses infrared technology to measure wheel temperatures as trains pass by. HWDs are commonly co-located with Hot Bearing Detectors (HBDs) to provide complementary monitoring of thermal anomalies in both bearings and wheels, as shown in Figure 3.

Figure 3: An Example of a HBD System (Outer Detectors) and a HWD System (Inner Detectors)

Source: FRA, An Implementation Guide for Wayside Detector Systems, 2019.

2.1.3 Dragging Equipment Detectors

Dragging Equipment Detectors (DEDs) are wayside systems designed to identify loose or dragging components beneath moving trains. By detecting abnormal contact with the track structure, these systems help prevent catastrophic damage to rolling stock, cargo, and rail infrastructure. DEDs use a variety of detection methodologies to identify dragging hazards, including:[13]

- **Fixed Accelerometer Systems** are permanently installed units that use seismic sensors to measure vibration impacts. When dragging equipment strikes the track, accelerometers detect abnormal force patterns and trigger alarms.
- **Spring-Loaded Paddle Detectors** are mechanical arms that protrude between rails. Any contact with dragging objects depresses the paddle, immediately signaling an alarm.
- **Frangible Bar/Wire Systems** are single-use detectors with breakable stainless-steel wires or bars spanning the track. The impact fractures the component, breaking an electrical circuit to immediately alert crews. This type of DED requires manual resetting.
- **Third Rail Fouler** is a specialized system used in electrified commuter or subway systems to detect objects that intrude into the third rail clearance envelope..

The effectiveness of DED systems depends heavily on accurate calibration of detection thresholds and sensitivity levels. Systems must be adjusted to trigger alarms only for actual dragging equipment, avoiding false positives from benign sources such as rubber tires on high-rail vehicles.

DED systems also feature a “talker” function that communicates alarms directly to train crews via radio (for example, *"Stop train, dragging equipment detector alarm at milepost 42.3”*). To minimize false or redundant alerts, DEDs are configured to suppress repeated alarms unless specific criteria are

[13] FRA, An Implementation Guide for Wayside Detector Systems, 2019.

met, such as the closure and reopening of alarm contacts and the passage of at least three axles.

Figure 4: An Example of a Fixed Accelerometer Dragging Equipment Detector

Source: FRA, An Implementation Guide for Wayside Detector Systems, 2019.

2.1.4 Wheel Impact Load Detectors

The Wheel Impact Load Detector (WILD) system is used to detect wheel-related defects that can lead to derailments, infrastructure damage, and service disruptions. By measuring the wheel-rail contact force, WILD can identify tread defects such as flat spots, out-of-rounds, built-up treads, and shells.

The fundamental principle behind WILD technology stems from the recognition that defective wheels generate abnormally high impact forces when they come into contact with the rail. WILD systems (shown in Figure 5) consist of rail-mounted strain gauges that measure the vertical forces exerted by each wheel as a train passes. These readings are handled by processing units housed in nearby enclosures, which determine whether defective wheels are present in the rail vehicle consist. These systems are customizable to site conditions and can accurately detect and assess passing trains when they are moving at operational speed which may differ from the line speed for that section of track.

In addition to defect detection, some WILD systems can determine the weight of individual wheels, axles, bogies, and entire railcars while trains operate at normal speeds. This weigh-in-motion capability offers a cost-effective alternative to traditional static weighing facilities.[14]

Figure 5: An Example of a Wheel Impact Load Detector

Source: Nagory Foster, WILD 2025.

2.1.5 Acoustic Bearing Detectors

The Acoustic Bearing Detector (ABD) system identifies faults in railcar bearings by analyzing the unique acoustic signature produced by bearing components such as the cone, cup, and rollers. When a defect occurs, it generates specific structural vibrations that emit sound patterns that are distinctive to the fault. The microphone technology used within ABDs captures these acoustic signals, allowing the system to pinpoint the exact bearing component affected.

This method enables early-stage defect detection and supports the development of performance trends for each monitored bearing. Alarms are

[14] CPCS consultation with WILD technology vendor, June 2025.

triggered based on user-defined tolerance thresholds, which determine whether a bearing requires continued monitoring, maintenance, or replacement. ABD systems are installed for use at line speed but can be used for trains traversing at their required operational speed.

According to an FRA study in 2019, the two primary Acoustic Bearing Detection systems that are currently deployed in North America are:[15]

- Trackside Acoustic Detection System (TADS®): developed by the Transportation Technology Center, Inc. (TTCI). TADS® uses three microphone arrays spread over approximately 25 feet of tangent track, positioned at bearing height on both rails (shown in Figure 6). Its real-time signal processing algorithms filter out general train noise and isolate frequencies associated with damaged bearing components. To avoid false alarms, the unit must be installed on straight track segments where trains maintain speeds of at least 40 mph and are not braking, as braking noise can obscure defect signatures.[16]
- RailBAM®: developed by the Australian Rail Track Corporation and now manufactured by Wabtec Corporation. RailBAM® performs the same basic task but utilizes multiple beamforming microphone arrays, sleeper-mounted sensors, two trackside cabinets, and a dedicated electronics rack. This setup enables effective defect detection in a variety of environments, including mixed-traffic corridors and yard areas. RailBAM® can operate with trains moving as slowly as 15 mph.[17]

Figure 6: An Example of a TADS Acoustic Bearing Detector site

Source: TTX Company, 2025.

2.2 Wayside Detector System Distribution

Minnesota railroads operate over 4,534 total miles of active railroad track, ranking the state 8th nationally in rail infrastructure. The distribution of wayside detector systems across the Minnesota rail network enables rail carriers to monitor equipment health, detecting defects, and preventing derailments before they occur.

Minnesota's freight rail system serves as a critical transportation backbone, moving 25 percent of the state's freight tonnage, equivalent to 99.1 million tons of goods annually. It supports key industries such as agriculture, mining, and construction by moving large volumes of goods over long distances.

[15] Federal Railroad Administration, An Implementation Guide for Wayside Detector Systems, 2019.
[16] Federal Railroad Administration, An Implementation Guide for Wayside Detector Systems, 2019.
[17] Wabtec website, RailBAM, accessed July 2025. https://www.wabteccorp.com/digital-intelligence/condition-monitoring/kinetix-inspection-technologies/wayside/railbam

Top commodities by tonnage and value include cereal grains, metallic ores, coal, crude petroleum, and food products.[18]

The following presents an overview of key railroads in the state (Figure 7):[19]

- BNSF (Burlington Northern Santa Fe) Railway has the largest share of rail mileage in Minnesota, with 1,712 miles of track. Its network connects farmers to domestic and international markets via a link between Seattle and Chicago on BNSF's northern transcontinental route. BNSF also moves significant volumes of taconite, industrial products and consumer goods within Minnesota.
- CPKC (Canadian Pacific Kansas City) railroad maintains 1,701 miles of track, making it the second largest rail operator in the state. CPKC moves agricultural goods across Minnesota, including along the Detroit Lakes subdivision, and connects to five grain terminals in that area and the Shoreham Facility in Minneapolis.
- UP (Union Pacific) railroad manages 644 miles of track in southeastern Minnesota and the Twin Cities. UP's shipments focus on grain, oils, biofuels, sweeteners, and intermodal goods.
- CN (Canadian National) railroad operates 378 miles of track in northeastern Minnesota. This route is part of CN's intermodal corridor between the Port of Prince Rupert in British Columbia and Chicago.
- Regional (Class II) and short line (Class III) railroads together operate 984 miles of track. These carriers provide critical first- and last-mile freight services across the state.

2.2.1 Wayside Detector Types and Distribution

The placement, type, and density of wayside detectors are determined by the railroads, applying route-level data and risk modelling to determine where, and which, wayside detectors are most effective.

Nationally, the FRA estimates that detector spacing averages about 25 miles. Class I railroads are working to reduce this to 15-mile intervals as part of recent safety initiatives.[20]

The study reviewed detector technologies, but Minnesota's exact detector counts, types, and locations could not be independently verified. Class I railroads treat locations as sensitive infrastructure; public disclosure could create security risks, operational vulnerabilities, and diminish detector effectiveness. Accordingly, only generalized coverage and deployment practices are presented, consistent with industry security protocols that protect rail safety and reliability.

Consultations with Class I railroads in Minnesota (conducted in 2025) indicate that wayside detectors are in service across their networks, while Genesee & Wyoming (G&W) is the only short line operator in the state to deploy such systems. Reported detector

[18] MnDOT, State Rail Plan, Railroad Chapter, 2024. https://www.minnesotago.org/application/files/6217/2425/6225/2024_Minnesota_State_Freight_Plan_Draft-Chapter3.pdf

[19] MnDOT, State Rail Plan, Railroad Chapter, 2024. https://www.minnesotago.org/application/files/6217/2425/6225/2024_Minnesota_State_Freight_Plan_Draft-Chapter3.pdf

[20] FreightWaves, There are no federal regulations on key rail sensors, 2023. https://www.freightwaves.com/news/there-are-no-federal-regulations-on-key-rail-sensors

types include HBDs, HWDs, DEDs, WILDs, and ABDs. Nearly all HBDs are paired with DEDs.

2.2.2 Hazmat Transportation on Minnesota's Rail Network

The placement of wayside detectors along a corridor depends on several factors, including operational train speed, geographic conditions, and the types of commodities transported. Railroads strategically place wayside detectors to realize safety benefits in a cost-effective manner. According to the FRA implementation guidelines, detectors—particularly those used in higher-speed operations—should be installed on flat, tangent track segments with sufficient distance from grade crossings to ensure accurate readings. Hazardous material (hazmat) flows are another key consideration, as the volume and type of hazmat transported directly influences the intensity of monitoring required.[21]

Minnesota's rail network is a core component of the state's hazardous materials supply chain, moving commodities such as crude oil, refined petroleum products, fertilizers, and other chemicals that are essential to the operations of Minnesota's agricultural, manufacturing, construction, and utility sectors.[22]

Under AAR Circular OT-55-R (2022), a track segment is designated as a "Key Route" if it carries either 10,000 carloads or intermodal portable tank loads of hazmat, or 4,000 carloads of toxic or highly explosive materials (for example, nuclear fuel) over a one-year period. For Key Routes, AAR previously recommended detectors be spaced no more than 40 miles apart.[23]

Following the East Palestine derailment, the prevailing industry standard has shifted to 15 to 20-mile spacing for Class I railroads to enhance early detection capabilities. The AAR recommendations are voluntary, and it is the individual railroad's responsibility to implement the recommendations, but this is not regulated.

Figure 8 shows the annual movement of hazardous materials across Minnesota's freight rail network, including corridors with higher volumes. The map reflects data analysis based on national sources and validated using MnDOT's Freight Network Optimization Tool. However, railroad personnel and labor groups note that hazardous materials may move on nearly all Minnesota rail lines with various frequencies, and therefore the mapped flows may not capture all movements. Ensuring adequate detector coverage along corridors that carry hazardous materials is a prevailing industry practice for managing risks associated with braking, wheel impacts, and structural loads. For hazardous materials in particular, even small mechanical failures can have significant safety implications. FRA's Safety Advisory 2023-04 underscores these points by recommending broader use of WILD detectors to identify problems before they escalate.[24]

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[21] FRA, Implementation Guide for Wayside Detector Systems, 2019.
[22] MnDOT, State Freight Plan, 2024.
[23] AAR, Circular No. OT-55-R, 2022. https://www.aar.org/wp-content/uploads/2022/07/2022-07-01-OT-55-R-CPC-KBD.pdf
[24] FRA, SA 2023-04; High-Impact Wheels Causing Damage to Rails and Track Structures, Federal Register, published September 11, 2023.

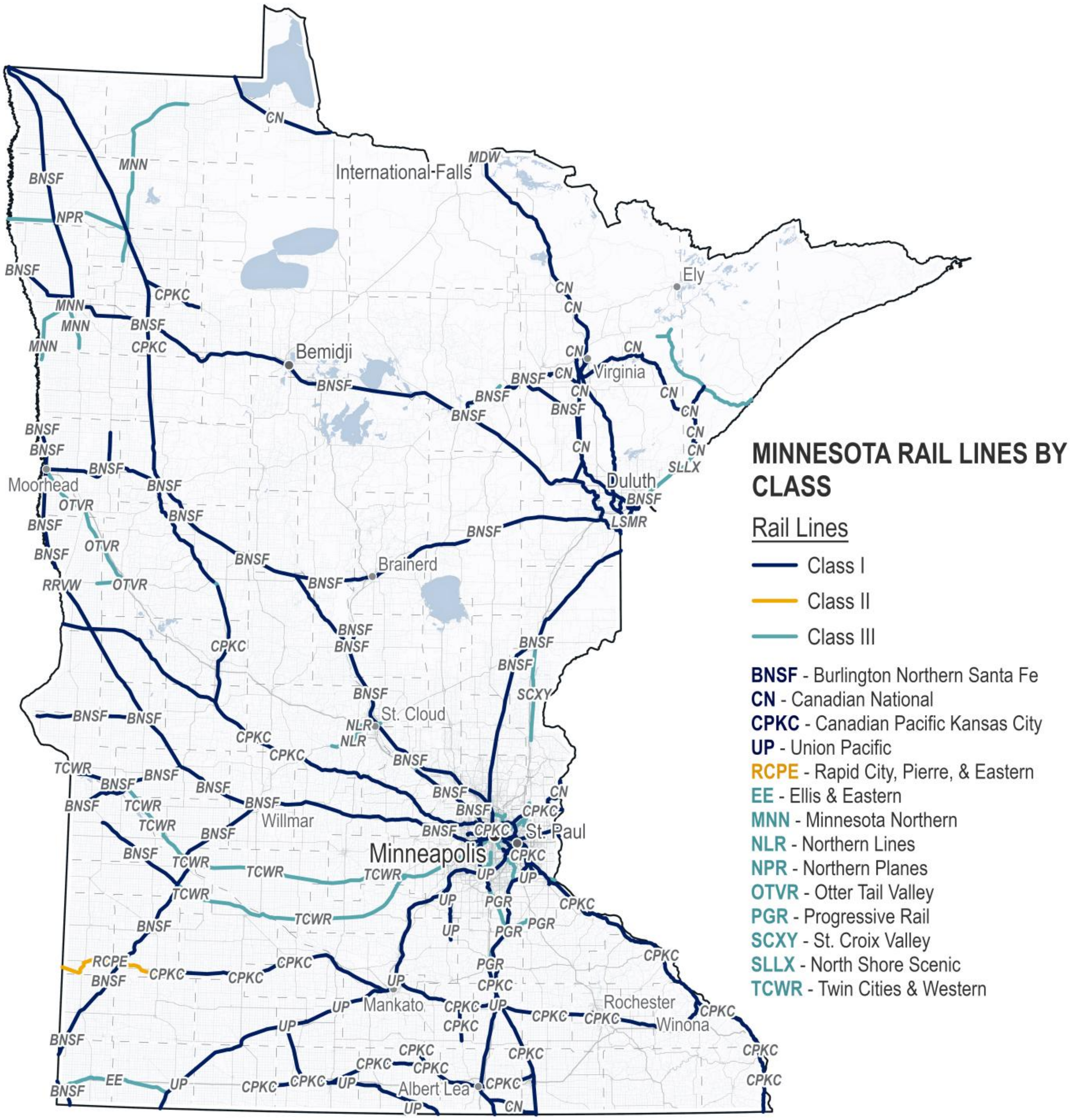
Additionally, AAR recommends a maximum speed of 50 mph on Key Routes that carry hazardous materials. If a wayside detector reports a bearing defect on a Key Train but a visual inspection does not confirm the issue, the train must not exceed 30 mph until it either passes the next detector or reaches a terminal for mechanical inspection.

Figure 9 shows the maximum train speed allowances across Minnesota's freight rail network. Most Class I mainlines allow speeds between 41 and 79 mph (highlighted in red). In contrast, all other routes operate at lower speeds, which inherently reduces the risk of derailment and damage in the event of an undetected mechanical defect.

Source: istock, 2025.

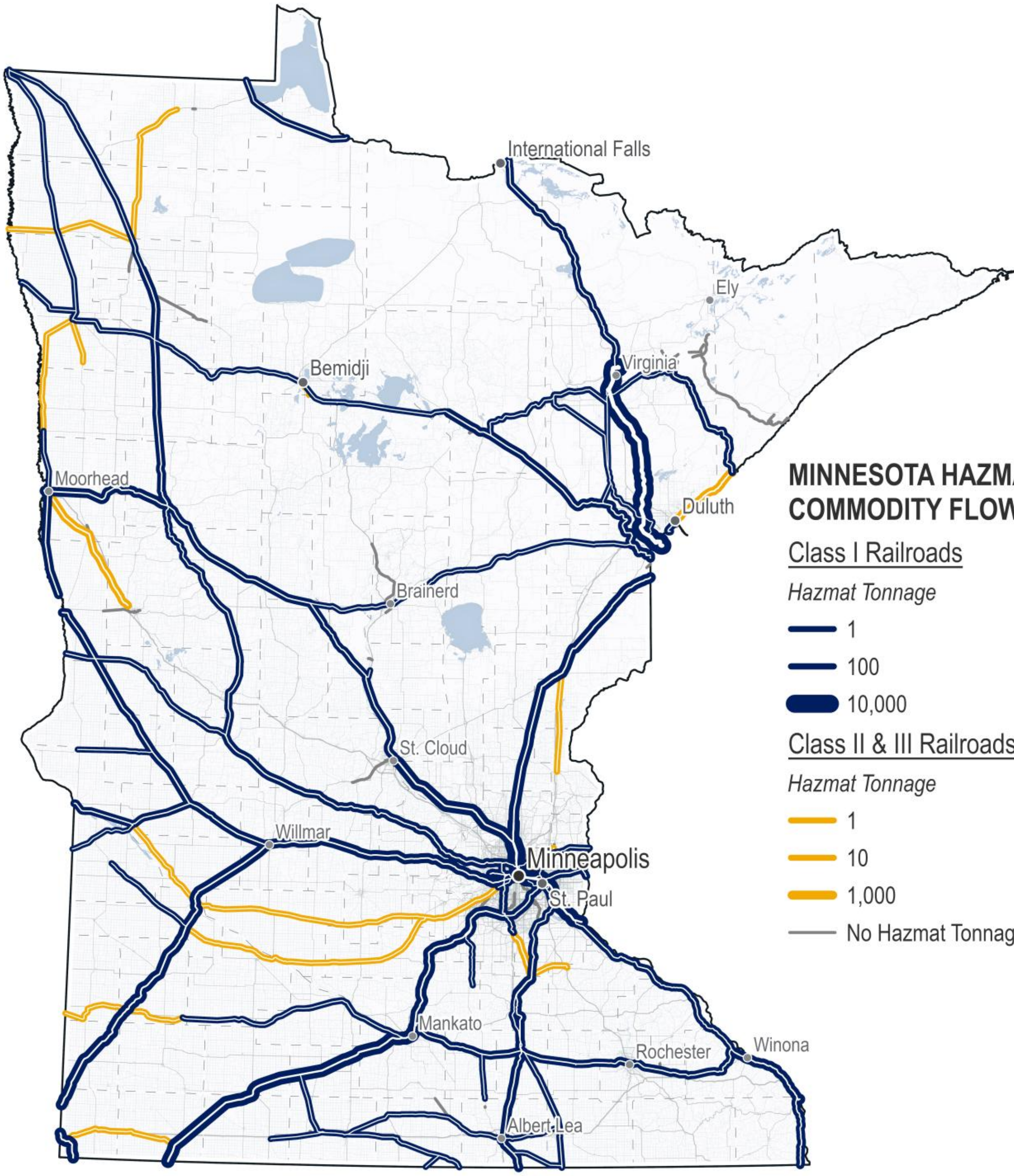
https://www.federalregister.gov/documents/2023/09/12/2023-19677/safety-advisory-2023-04-high-impact-wheels-causing-damage-to-rails-and-track-structures

Figure 7: Minnesota State Rail Freight System



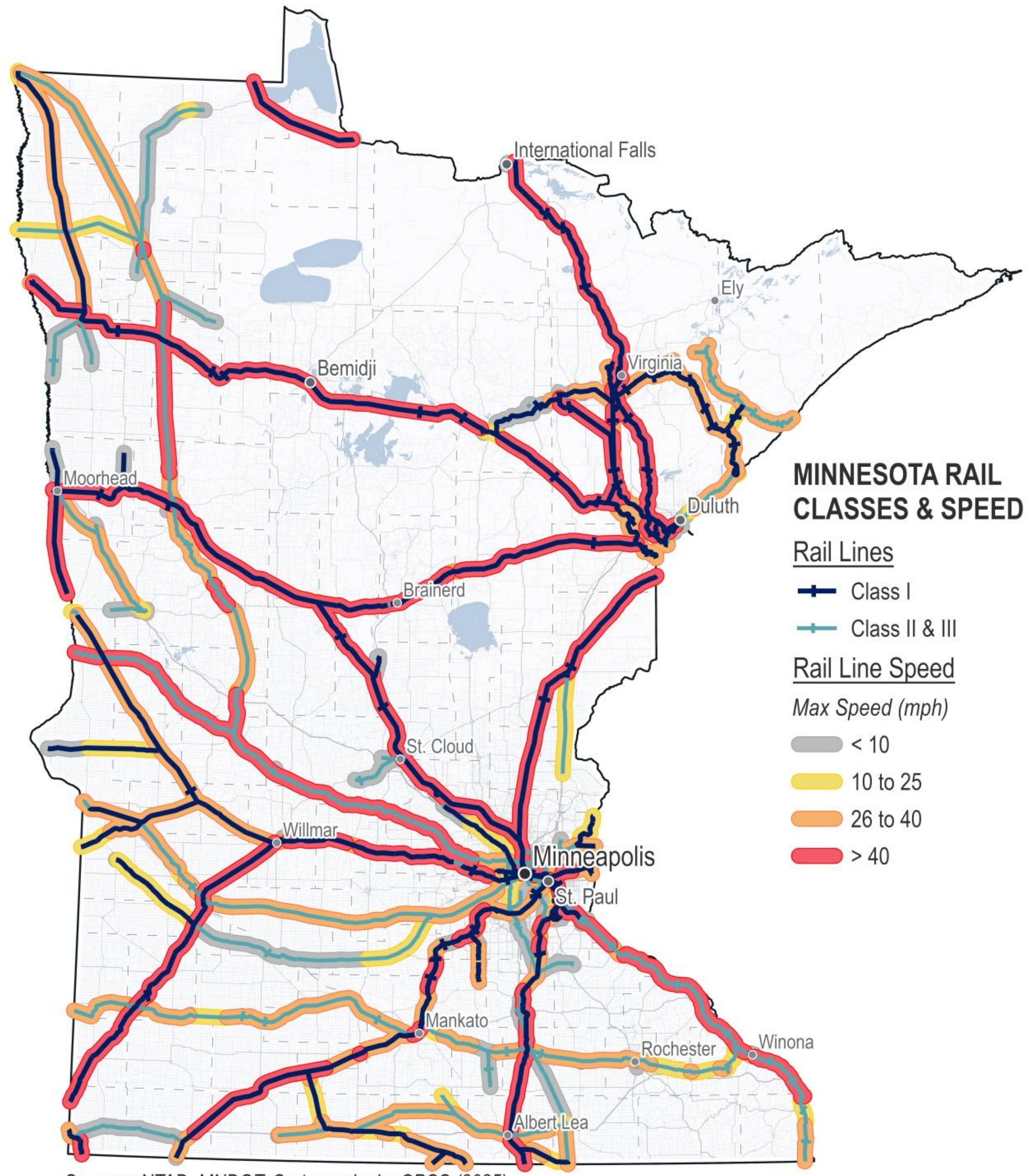
Sources: NTAD, MNDOT. Cartography by CPCS (2025).

Figure 8: Map of Hazmat Commodity Flows in Minnesota



Sources: NTAD, MNDOT, US Census CFS. Cartography by CPCS (2025).

Figure 9: Map of Rail Line Speed Allowances in Minnesota



Sources: NTAD, MNDOT. Cartography by CPCS (2025).

3 Rail Safety Technology

Key Chapter Takeaways:

This Chapter reviews the rail monitoring technologies currently in use outside of Minnesota, both across the US and internationally. For each technology, a brief description of functionality, benefits, and application considerations in Minnesota are provided. The material is drawn from FRA guidance, AAR standards, vendor technical data, and operating railroad case studies.

Key findings from this review include:

- Emerging wayside detector technologies can provide information on different sub-systems and components, assisting in providing a holistic view of the condition of the full train.
- Several advanced detector systems are still in earlier stages of deployment given integration cost, complexity, and infrastructure constraints; pilot schemes and scaling efforts are ongoing.
- Onboard technology such as monitoring capabilities, axle-powered sensors, and forward-facing cameras stream continuous data, can help railroads move from time-based maintenance to a more predictive and proactive maintenance approach.
- Advanced software links real-time data to individual vehicles using AEI tags, therefore, repairs can be prioritized by severity, and pushes work orders directly into asset systems, reducing manual triage.
- Environmental monitoring systems such as flood gauges and rockfall detectors give dispatchers early warnings so they can reroute or reduce the speed of trains before hazards threaten safety.

3.1 Wayside Detector Systems in Use Outside of Minnesota

Railroads in the U.S. and internationally use wayside detector systems to identify certain mechanical conditions before they lead to failures. The technologies in common use today represent only a portion of the systems currently being developed and tested. Several advanced detection and monitoring tools designed to identify defects earlier in their lifecycle are in various stages of maturation.

This section describes both the types of wayside detector systems that are widely used elsewhere in the U.S. but not currently deployed in Minnesota, and a set of newer, advanced systems that are in use on Class I corridors in the U.S. and Canada and on selected rail networks in Mexico and Europe.

Although these technologies have demonstrated potential benefits, their use across the US remains limited, and they are not currently deployed on Minnesota's rail system. Factors such as capital cost, maintenance requirements, and site-specific installation needs may contribute to the limited adoption.

Like the more conventional detectors described in Chapter 2, these emerging and advanced systems can provide repeatable condition checks as railcars pass by, linking each data point to a unique vehicle ID that can be tracked across North America.

The following table summarizes the technologies reviewed, including their primary functions and key technologies.

Figure 10: Wayside Detector Systems in Use Outside of Minnesota

Detector System	Primary Function	Technologies
Wheel Condition Monitoring System	Captures detailed wheel geometry data to report on the overall wheel health condition	Laser-based technologies, rail-mounted accelerometers, and load-cells
Wheel Noise Detector	Identifies wheel defects through acoustic signature analysis	Acoustic sensors
Wheel Temperature Detector	Captures temperature readings of the rim and brake disc of each wheelset, used for both hot and cold wheel detection	Infrared scanners
Wheel Profile Measurement Systems	Measures the wheel profile to identify defects	Lased-based technologies, high-speed cameras
Weighbridge	Measures the weight of a rail vehicle and its contents	Load-cells
Weigh-In-Motion System	Measures the weight of the vehicle while it remains in motion and can identify weight-related issues such as axle overloads, transverse and longitudinal imbalances	Load-cells
Truck Hunting Detector	Evaluates truck hunting behavior	Strain gauges or laser-based technologies
Truck Performance Detector	Evaluates the suspension performance of vehicles along a S-curve section of track	Strain gauges or laser-based technologies
Truck Bogie Optical Geometry Inspection	Measures the performance of the vehicle axles and wheel suspension	Laser-based technologies, high-speed cameras
Fire Detection System	Identification of combustion gases such as CO and CO_2	Infrared absorption spectroscopy
Out-of-Profile and High-Wide Detector	Evaluate whether rail vehicles comply with the rail track's clearance profile and can identify oversized and/or overloaded vehicles	Laser-based technologies, infrared sensors

Source: FRA, An Implementation Guide for Wayside Detector Systems, 2019; CPCS review of wayside detector technologies including railroad and technology vendor inputs and interviews with other rail industry stakeholders, 2025.

3.1.1 Wheel Condition Monitoring System

Wheel Condition Monitoring Systems (WCMS) rely on precision laser scanning methods that capture detailed wheel geometry data to report on the overall wheel surface health condition.

WCMS detectors are typically installed on plain line track so that the approach, instrumented, and departure sections share identical track geometry, preventing track irregularities from distorting the data. WCMS units typically use rail-mounted accelerometers and load cells to detect tread defects such as flats, spalls, roughness, and out-of-round wheels. They also identify loading issues, including overloading and imbalances. Many WCMS also integrate Wheel Impact Load Detectors (WILDs) and Weigh-In-Motion (WIM) functions into the system.

WCMS can also be combined with vision-based systems, adding high-speed cameras and 3-D laser scanning to inspect the tread, flange, and plate at operational line speed; image-processing software then highlights surface abnormalities.

For cracked wheels and other sub-surface flaws, operators will either utilize vision tools that detect internal damage, or they will use ultrasonic transducers, in conjunction with a couplant (a substance that facilitates the transmission of sound waves) and are typically used at low speeds in yard environments, to scan each wheel directly.

Integration of WCMS with railroad communication systems enables immediate notification of critical wheel defects to train crews and maintenance personnel through existing radio networks and data management systems.

WCMS technology is now deployed across Europe, Asia, Australia, and North America, with Europe leading the way after extensive in-service validation. Major passenger rail operators such as Deutsche Bahn in Germany, ÖBB in Austria, SBB in Switzerland, and SNCF in France have embedded WCMS into their rolling-stock maintenance programs. On the freight side, carriers such as BNSF in North America are adopting machine-vision and AI-enhanced WCMS to strengthen wheel monitoring and move further toward predictive maintenance.[25]

3.1.2 Wheel Noise Detector

Railway operations produce many distinct noise types. For example, the sound produced by wheel-rail contact on a straight (tangent) track differs from the sound made on a tightly curved track. There are three characteristic sounds: wheel squeal, flanging, and graunching. Wayside acoustic sensors capture these distinct sounds and use sophisticated software to classify the patterns, particularly the high-frequency squeal, to identify wheel defects before they escalate into serious safety risks or cause track damage. Once defects are identified, railroads can address them by adjusting wheel and rail geometry, optimizing rail profiles, and otherwise reducing lateral slip at the wheel-rail interface.

There have also been correlations drawn between squeal noises and the rail vehicle wheels' tracking position and angle-of-attack. In some cases, acoustic monitoring is used alongside track geometry monitoring to provide a fuller picture of the wheel/rail interface.

To minimize false alarms, some noise detector systems use accelerometers mounted on the rail or in the track bed to detect impact vibrations caused by wheel flats or out-of-round conditions. These vibrations are analyzed to distinguish between normal operation and defect-induced noise. When a defect is detected, the system can automatically notify railroad personnel or train crews, often integrating with other wayside diagnostic systems for comprehensive monitoring.

3.1.3 Wheel Temperature Detectors

Wheel Temperature Detectors (WTDs) (shown in Figure 11 and Figure 12) are track-side infrared scanners that measure the rim and brake-disc temperatures of each wheelset as a train passes by. It is common for there to be two WTDs in the same vicinity. The first is situated at a non-braking site and the second is situated at a location where the

[25] BNSF Rail Talk Newsletter, August 2024. https://www.bnsf.com/news-media/railtalk/safety/wheels-defects.html

train is expected to brake. By comparing the readings obtained against preset thresholds, WTDs flag both overheated components (often a sign of bearing failure, dragging brake shoes, or locked hand brakes) and abnormally cold wheels, which can indicate ineffective or inoperative brakes.

Figure 11: Cold Wheel Detector Example

Source: BNSF News, accessed 2025.

Early alerts provide an indication of the overall brake health effectiveness of vehicles, preventing equipment damage such as wheel flats and ultimately derailments.

As of 2013, approximately 700 WTD units were deployed on North American freight lines. Under AAR Standard S-6031, each detector evaluates four criteria to judge braking performance: the truck temperature ratio, absolute wheel temperature, average wheel temperature, and evidence of normal heat generation. Any deviation from expected profiles triggers an alarm for immediate inspection, allowing railroads to intervene before minor brake issues escalate into major safety hazards.[26]

[26] FRA, An Implementation Guide for Wayside Detector Systems, 2019.

Figure 12: An Example of a Wheel Temperature Detector

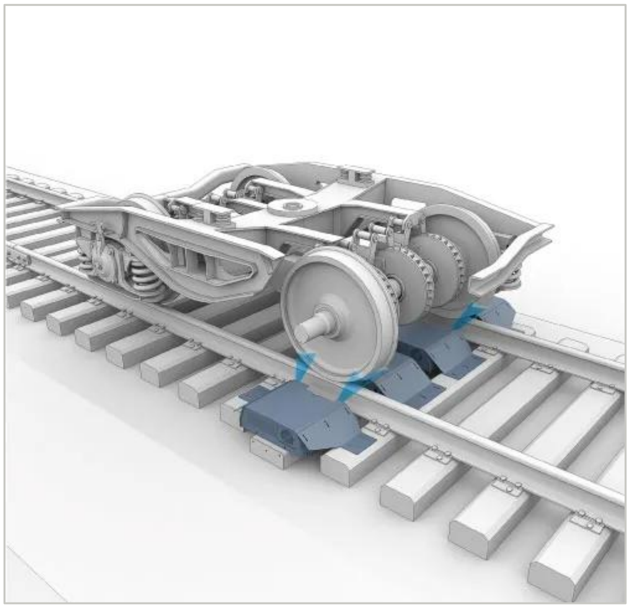
Source: FRA, An Implementation Guide for Wayside Detector Systems, 2019.

3.1.4 Wheel Profile Measurement Systems

Wheel Profile Measurement Systems, also called Wheel Profile Detectors (WPD), use laser-based, high-resolution vision technology to capture and quantify wheel geometry as trains pass at operational line speed. A typical setup places two cameras inside the rail and two outside, giving a full 360-degree view that records flange height and thickness, rim thickness, tread wear, and hollow tread defects. The raw images are processed automatically, converted into standard geometric parameters.

To ensure accurate, repeatable measurements, the cameras must maintain a fixed standoff from the wheel; instruments are therefore mounted in a dedicated sleeper or similar rigid structure. WPMS installations can operate on main lines or, for greater precision, in yards at lower speeds, depending on system design and operator needs. The processed data is then analyzed to flag any profile irregularities that warrant maintenance attention. Figure 13 shows an example of a Wheel Profile Measurement System.

Figure 13: Example of a Wheel Profile Measurement System



Source: Wabtec WheelView® schematic, 2025.

3.1.5 Weighbridge

A railroad scale is a heavy-duty platform scale, typically mounted permanently on a concrete foundation, used to determine the weight of a vehicle and its contents to ensure compliance with weight restrictions and regulations, and to monitor safe transportation of bulk goods.

A scale can be either static or in-motion and load cells are used to measure the weight of the vehicle. Static scales measure the weight of each axle, or set of axles, when the vehicle is stationary. In-motion scales measure vehicles as they pass over the platform at a constant speed, typically below 15km/h which equals approximately 9.3 mph.[27]

Scales can be integrated with existing railway infrastructure but do require regular calibration. Typically, scales are installed where freight cargo originates from, such as industrial plants, mines, ports, and railyards.

3.1.6 Weigh-In-Motion System

The Weigh-In-Motion (WIM) system is a wayside detector that measures the weight of a rail vehicle in motion, via the vertical load, and identifies weight-related issues such as axle overloads, transverse (side-to-side) and longitudinal (end-to-end) imbalances (as shown in Figure 14). WIM can operate as a standalone system or in conjunction with Wheel Impact Load Detectors (WILD) or Wheel Defect Detectors.[28] The system typically operates at mainline operational speed, although some will be more suited to low-level speeds. WIM systems are highly accurate and typically use load cells installed directly onto the rails.

These systems may also include self-diagnostic features that notify users of sensor or system failures. For instance, Union Pacific Railroad reported that between July 2005 and September 2006, 13 WIM units monitored over 11 million vehicles, with only 439 exceeding the maximum load limit by more than 10 percent, demonstrating

[27] Libra Weighing, Trapper Rail Weighbridge. Accessed August 2025. https://libraweighing.co.uk/products/train-weighers/trapper-rail-weighbridge/

[28] Voestalpine, zentrak Wheel Defect Detection/Weighin in Motion. Accessed August 2025. https://www.voestalpine.com/railway-systems/es/products/zentrak-weighing-in-motion-wheel-defect-detection/#:~:text=zentrak%20Weighing%20In%20Motion%20(WIM)%20*%20WIM,vehicle%20weight%20and%20train%20weight%20are%20determined.

the system's effectiveness in monitoring freight safety.[29]

Figure 14: An Example of a Weigh-In Motion Detector

Source: FRA, An Implementation Guide for Wayside Detector Systems, 2019.

3.1.7 Truck Hunting Detector

Hunting is a condition where freight trucks exhibit a dynamic instability. The Truck Hunting Detector (THD) evaluates the ability to maintain the centerline of the rail at speed. This is particularly problematic for empty or lightly loaded vehicles, and for vehicles with worn wheels.

There are typically two different types of Truck Hunting Detectors, and both types use the truck Hunting Index (HI) to determine the degree of hunting occurring and whether intervention is required. The first system uses a series of strain gauges which measure and analyze the vertical and lateral wheel forces in a truck for a pattern of oscillation that is characteristic of truck hunting. The strain gauges are applied to the rails and require periodic recalibration. Frequently, these types of Truck Hunting Detectors are co-located with Weigh-In-Motion or Wheel Impact Load Detectors.

Alternatively, laser-based Truck Hunting Detectors are used, and information on the trajectory of the wheelset is collected via an emitter and receiver for the laser beam. The data is generated based on the speed, amplitude, and frequency of the laser beam as it is received.

An example of a Truck Hunting Detector system is shown in Figure 15.

Figure 15: Example Truck Hunting Detector System with Strain Gauges

Source: LB Foster Truck Hunting Detector System, 2025.

3.1.8 Truck Performance Detector

A Truck Performance Detector (TPD) (shown in Figure 16) is a system that evaluates the suspension performance of trucks by measuring the vertical and lateral forces generated by the vehicles' wheels as they move over the wayside detectors.

Similar to the Truck Hunting Detector, there are two different types of Truck Performance Detectors. The first uses a series of strain gauges and the second is a laser-based system. TPDs that use strain gauge

[29] FRA, An Implementation Guide for Wayside Detector Systems, 2019.

technology are installed in track locations with reverse curves and measure the lateral loads on the track under left and right curving conditions. This allows for evaluation of the truck's "dynamic" performance by checking left and right rotation, as well as the ability to return to a neutral tracking position in the tangent section between the curves. Analysis is then undertaken to determine the axle misalignment or poor suspension conditions.

TPDs that use laser-based technology are installed on plain line track and measurements are taken via an emitter and receiver for the laser beam.

Truck Performance Detectors can identify worn friction wedges, broken suspension springs, twisted car bodies, mismatched side frames, hollow/worn wheels, and tight side bearings.

Figure 16: Example of a Truck Performance Detector with Strain Gauges

Source: International Engineering, Monitoring Systems Examples, 2025.

3.1.9 Truck Bogie Optical Geometry Inspection

A Truck Bogie Optical Geometry Inspection (TBOGI) system measures the performance of the vehicle axles and wheel suspension using laser-based technology, combined with high-speed cameras along a tangent section of track (shown in Figure 17). TBOGI systems are often combined with hunting detectors to create a comprehensive TBOGI-HD system that provides both geometric assessment and lateral stability monitoring capabilities.

Figure 17: Truck Bogie Optical Geometry Inspection System

Source: Wayside Inspection Devices, 2025.

The TBOGI system measures two critical parameters for each axle:

- The angle of attack, which is the angle between the track radial line and the centerline of the wheel set axle, a crucial parameter that affects wheel-rail contact forces, wear patterns, and vehicle stability; and
- The tracking position, which is the lateral shift distance between the track centerline and the midpoint of the axle, indicating how far the axle has shifted laterally from its ideal centered position on the track.

The TBOGI system calculates several derived parameters that characterize bogie performance, including:

- The inter-axle misalignment which is measured through the angle misalignment between the two wheelsets of the bogie and is calculated as the difference between the angle of attack of the leading wheel set and the trailing wheel set;

- The tracking error, which is the lateral distance between the midpoints of the two axles of the bogie, is calculated as the difference between the tracking position of the leading wheel set and the trailing wheel set;
- The angle of the bogie, also referred to as "rotation" and defined as the average of the angle of attacks of the leading and trailing axles; and
- The shift, is calculated as the average of the tracking positions of the leading and trailing axles.

If an additional Hunting Detector is integrated with TBOGI, hunting peak-to-peak can be calculated using the tracking position measurements of multiple TBOGI sensors. This is the maximum distance travelled laterally by a truck.

TBOGI systems access the in-service condition of wheels and bogies, providing highly repeatable measurements that enable trending analysis over time to determine asset degradation patterns.

3.1.10 Fire Detection System

Fire Detection Systems represent a category of wayside detector technology designed specifically to protect critical railroad infrastructure through early identification of combustion gases (CO and CO_2). These systems utilize advanced infrared absorption spectroscopy to detect the smallest concentrations of characteristic combustion gases, primarily carbon monoxide (CO) and carbon dioxide (CO2), before trains enter critical areas such as tunnels, bridges, or other confined spaces.

Two combined measurement systems are required, positioned 0.2 miles apart on the approach to the infrastructure requiring protection. The system provides a reading within 20 seconds of a train passing through the monitoring stations and estimates thermal power based on the concentration change, velocity, and tunnel cross-section.

The most comprehensive deployment of this technology is operated by Swiss Federal Railways (SBB), which maintains 30 fire detection systems in approach tunnels protecting critical routes. The SBB system has processed 1.8 million train measurements annually with fewer than 10 fire alerts per year, demonstrating both the system's sensitivity and its low false alarm rate.[30]

3.1.11 Out-of-Profile and High-Wide Detectors

The out-of-profile detectors check, at normal operational speed, whether rail vehicles are complying with the clearance profile and detect objects which may be close to the contact line. The system measures the train's profile with a laser scanner and compares the measured profile with the target profile. The measured profile is reconstructed as a 3D model to help assess whether an alert should be activated. In addition to the laser scan of the vehicle, the system also records

[30] SBB CFF FFS, Wayside train monitoring systems (WTMS), accessed July 2025. https://www.hastema.com/wp-content/uploads/2020/12/sbb_Train_Monitoring_Systems.pdf

instances, via cameras, when the clearance gauge has been exceeded.[31]

The benefit of this system is the ability to detect whether the train profile has exceeded the allowable profile due to an incorrectly loaded or defective vehicle. It is used to prevent collisions with railway infrastructure and passing trains, as well as preventing fires or material damage resulting from a vehicle touching the contact wire.

Similarly, High-Wide/Shifted Load Detectors are designed to protect rail infrastructure by identifying oversized or shifted loads before they pose a threat. These systems use infrared sensors mounted on a portal (structure that spans across the track) and are positioned depending on the loading gauge of the line.[32] In North America, the AAR publishes clearance diagrams which define the maximum dimensions (width and height) for railcars to navigate various routes and structures on the network.

3.2 Emerging Rail Technologies

Beyond traditional wayside detectors, new innovations are emerging that expand the ability to monitor, predict, and prevent risks across the rail network. The following sections explore these emerging technologies across six key areas:

- Onboard Monitoring
- Derailment Detection
- Machine Vision Systems
- Infrastructure Monitoring
- Environment Monitoring
- Grade Crossing Technology

These technologies are described as "emerging" because their adoption across the national freight rail network remains in the early stages, often limited to pilot projects, demonstration sites, and select corridors. Broad implementation is hindered by challenges such as regulatory approval, integration with legacy systems, cost considerations, and the need for proven reliability and standardized deployment models.

For example, machine vision portals and onboard sensor systems have only recently begun appearing on major railroads, while other innovations —such as real-time environment monitoring and advanced AI-based derailment detection—are still undergoing active testing and evaluation for scalability. Until rigorous national standards and frameworks for deployment are established, these solutions will continue to be considered "emerging," except in regions or railroads that have proactively initiated pilot programs.

3.2.1 Onboard Monitoring Technology

In recent years, advances in rolling stock technology have allowed for the drastic increase in onboard monitoring capabilities. This approach allows for continuous, real-time, and in-service monitoring and diagnostics, which provides an accurate representation of the assets. This can increase the availability of the vehicles due to more efficient

[31] SBB CFF FFS, Train Monitoring and Measuring Systems. Accessed August 2025. https://bahninfrastruktur.sbb.ch/en/products-and-services/bahnbetrieb/train-monitoring-systems/measuring-systems.html#:~:text=Out%2Dof%2Dprofile%20and%20antenna,close%20to%20the%20contact%20line

[32] Progress Rail, HIWL – High Wide Load Detector System. Accessed August 2025. https://www.progressrail.com/en/Segments/Infrastructure/Signaling/ECM/InspectionandDiagnostic/HWL.html

maintenance management and decreased down time for maintenance activities.

Passenger Rolling Stock

Passenger rolling stock commonly features onboard sensors that monitor a wide range of systems. The types of sensors include, but are not limited to, accelerometers, gyroscopes, proximity sensors, pressure sensors, and vibration sensors. This includes both locomotive-hauled vehicles and multiple units with sensors tracking sub-system components such as doors, HVAC systems, toilets, compressors, batteries, lighting, Passenger Information Systems (PIS), CCTV, brakes, and axle boxes. In some cases, onboard systems can monitor up to 200 parameters, taking readings every 30 seconds.[33] The data is then stored onboard, but can also be shared in real-time via cellular networks to facilitate predictive maintenance and performance optimization.

Unattended Measurement Systems

In addition to specific monitoring devices, it is also becoming increasingly common for revenue vehicles to have unattended measurement systems installed. These systems can continuously monitor the condition of specific assets without requiring human intervention. One benefit of using this type of system includes the increased volume of repeatable data due to the ability to survey heavily used lines without the interruption in normal traffic flow posed by engineering measurement train surveys. The data captured can then be used to compare how the asset deteriorates over time, quantify the success of maintenance and predict when maintenance interventions will be required by comparing the data against historic datasets and identifying trends.

One example is an Unattended Geometry Measurement System (UGMS). This system collects data on various track parameters such as gauge, cross-level, twist, warp, and surface profile. Another example is an Unattended Overhead Measurement System (UOMS). This system uses sensors, cameras, and algorithms to collect data on various aspects of the overhead contact system, including wire position, contact force, and electrical parameters. The data collected by these systems is transmitted via cellular networks and requires connection to an appropriate access point.

Forward-Facing Cameras

Forward-facing cameras installed in the cab of rolling stock provide an additional source of safety and operational information. Positioned as close as practicable to the driver's viewpoint, without obstructing their line of sight, the cameras record the track environment from the driver's perspective.

In some systems, the driver can manually flag an event, creating a marker within the video recording. These flagged segments are then available for later review by railroad personnel to confirm the driver's observations or determine whether follow-up action is required.

Beyond manual review, video footage can be paired with Artificial Intelligence (AI) and machine learning

[33] Alstom, HealthHub – The Intelligent Way to Improve Maintenance. Accessed August 2025. https://www.alstom.com/press-releases-news/2023/2/healthhub-intelligent-way-improve-maintenance

tools to automatically identify track conditions or potential hazards.

For example, forward-facing cameras can detect vegetation encroachment that may compromise a driver's view of signals or grade crossings. This enables more targeted maintenance interventions and reduces the time needed to locate problem areas.

Freight Trains and Rail Cars

Advances in technology and a focus on making rail freight more efficient have enabled freight railcars to be equipped with a variety of sensors to monitor parameters such as the temperature of the axle boxes, load monitoring and dynamic derailment detection.[34]

Other examples of advancements in technology include the ability for brake condition monitoring, axle lock detection and wheel flat prevention monitoring.[35] These types of sensors are frequently powered by axle-end power generators, as opposed to each sensor requiring batteries. The information from these systems is then transmitted wirelessly in real-time to the relevant stakeholders, including drivers and control centers, who can then proactively organize maintenance activities before incidents occur.

In North America, this shift towards digitalization is demonstrated by Rail Pulse[36], a coalition of railcar owners working to develop a standardized, end-to-end digital platform for tracking the location, condition and health of railcars across the supply chain. The platform will support the entire rail industry, including shippers, Class I and short line railroads and railcar operating lessors, with benefits including improved operational insights through monitored systems, improved asset health and safety through better understanding of the condition of assets and accurate monitoring of railcar locations, including arrival times.

Furthermore, onboard locomotive monitoring is now commonplace, and it provides the ability to monitor locomotive faults and operating parameters in real-time, providing diagnostics and the ability to deliver the appropriate level of intervention before issues escalate. Various train components such as engines, traction motors and brakes can be monitored, alongside sensors for temperature and air quality. Fuel consumption can also be monitored, as can the operational state of the vehicle, such as when it is moving, when it is stopped and when the vehicle is idling.

Digital Automatic Coupler

In Europe, a program is underway to develop a Digital Automatic Coupler (DAC) for freight trains.[37] This would allow for the automatic coupling and decoupling of freight trains both physically (the mechanical connection and the air line for braking) and digitally (the electrical power and data connection). This will remove the requirement for coupling to be undertaken manually, which will enhance the performance and safety of rail freight. It will increase efficiency by reducing manual interventions, and by having the ability to transmit data and power through the freight train consist.

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[34] PJM, WaggonTracker. Accessed August 2025. https://pjm.co.at/en/waggontracker/
[35] VTG, iWagon. Accessed August 2025. https://uk.vtg.com/products-and-services/iwagon
[36] Rail Pulse. Accessed August 2025. https://railpulse.com/
[37] Europe's Rail, Digital Automatic Coupler (DAC). Accessed August 2025. https://rail-research.europa.eu/european-dac-delivery-programme/

The ability to monitor railcar components such as brakes, wheels, air continuity, and load positioning will be invaluable with respect to maintenance planning but also by notifying the driver of any issues that occur during service. By having continuous data connections throughout the entire freight train, trains can become longer and carry heavier cargo as they can generate vital train integrity data. This capability strengthens the rail freight business model, making it more competitive with road transport. Additionally, the ability to generate train integrity data supports future signaling upgrades, such as the implementation of the European Train Control System (ETCS).

Related to ETCS, the ability to generate train integrity data is essential for the system as it manages and controls the entire train movement process. This includes the signal control process, automatic train protection, and communications between the train and the control center. ETCS, as part of the broader European Rail Traffic Management System, aims to enhance safety, improve operational efficiency, and enable greater interoperability across national rail networks. In contrast, Positive Train Control (PTC) is primarily focused on safety enforcement in North America, ensuring compliance with speed limits and movement authorities to prevent collisions and other incidents.

3.2.2 Derailment Detection Technology

Derailment detection technology is another area that has progressed in recent years. Both wayside and onboard technology is available and in use across the global rail industry.

There are several types of wayside derailment detection technology. One type of detector uses an iron bar installed through, and perpendicular, to the track. When this bar is broken by derailed wheelsets or dragging equipment, the electronic circuit is interrupted, and an alarm is triggered. This type of system requires manual intervention to reset the frangible engagement bar.[38]

Alternative wayside derailment detectors use a sensor assembly that is securely clamped between the rails and is protected by deflector plates that shield it from dragging equipment. When a wheel derails, it impacts the deflector plates and triggers the sensors which provide a notification to the dispatcher. Some systems are equipped with automated supervision capabilities that allow them to differentiate between actual derailments and other issues that may affect the detector functionality. [39]

Onboard derailment detection systems are currently seen as a complement to prevention systems such as the wayside detectors described throughout this study for the rail freight industry.[40]

[38] Erico, Derailment Detector DED Rail Kit, Last Accessed June 2025. https://www.nvent.com/sites/default/files/acquiadam/assets/R1172S-LAEN.pdf

[39] Voestalpine, zentrak Derailment Detection, Last Accessed June 2025. https://cdnstoreapp.blob.core.windows.net/image-container/792619/original/railwaysystems_factsheet_DRD_en.pdf

[40] European Railway Agency, Prevention and Mitigation of Freight Train Derailments at Short and Medium Terms, Last Accessed June 2025.

However, new technology is currently being deployed within the United Kingdom for a derailment detector that can recognize the sudden change to a vehicle's vertical movement caused by a derailment and will immediately vent the main air brake pipe, ensuring a rapid, complete emergency brake application.[41] The passive pneumatic/mechanical unit can be retrofitted to vehicles and allows for easy identification of which car triggered the brake application. The activation parameters for the unit can be adjusted to the individual railcar ensuring they only respond when a derailment may have occurred and not when the train passed over a section of infrastructure that causes rough riding. [42]

3.2.3 Machine Vision Systems

Automatic Vehicle Inspection System (AVIS), also referred to as Train Inspection Portal System (TIPS), are becoming an essential tool used by railway operators and owners to perform more accurate and efficient inspections of their vehicles. The data and insights gained support a shift from traditional time-based maintenance to a more proactive, condition-based approach, allowing for targeted interventions and improved asset reliability.

AVIS typically uses high-sensitivity, short exposure, and high frame-rate cameras and optical laser sensors to capture data from rolling stock. Successful deployment of the AVIS system relies on image quality being independent of environmental conditions such as lighting, temperature, and precipitation. Typically, there are multiple cameras or sensors allowing for optimized and consistent image quality.

The inspection portals are frequently modular in nature, allowing for customization depending on their intended use. Areas which can be inspected include wheels, brakes, pantographs, and underframes. Vehicles are typically identified using AEI passive tags which allow for the data captured to be assigned to individual vehicles.

AVIS can be installed in locations such as yards, or on mainline tracks. When installed in yards, this allows inspections to be carried out as vehicles arrive for servicing, integrating the process into routine maintenance procedures. If they are installed on mainline tracks, trains pass by at operational line speed and the data is captured via the high-performance cameras.

The captured information from the AVIS is then processed using Machine Vision Algorithms (MVAs). The condition information is calculated for the identified components and relevant information is then extracted and used to measure objects such as wheel profile. The condition of components can also be evaluated using MVAs. This may include identifying if components are missing or have been distorted in shape. The images taken can also be assembled to provide a continuous view of the entire consist.

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https://www.era.europa.eu/system/files/2022-10/Agency%E2%80%99s%20final%20report%20on%20the%20%E2%80%9CPrevention%20and%20mitigation%20of%20freight%20train%20derailments%20at%20short%20and%20medium%20terms%E2%80%9D.pdf

[41] Rail Freight Group, Derailment Detector set to make a significant impact on freight train safety. Last Accessed August 2025. https://rfg.org.uk/derailment-detector-set-to-make-a-significant-impact-on-freight-train-safety/

[42] Knorr Bremse, EDT 101 Pneumatic Derailment Detector, Last Accessed June 2025. https://rail.knorr-bremse.com/media/2000_products/2900d_product_broschures/p-1216_edt101.pdf

In addition to processing captured data, some systems also support integration with maintenance asset management platforms, enabling automatic generation of work orders when issues are identified during inspections. Integrating inspection, data processing, and actionable outputs into a seamless end-to-end process is essential for realizing the full benefits of the system.

Transport Canada's Machine Vision Rail Inspection Study

Transport Canada, CPKC, the University of Alberta, and the National Research Council Canada partnered on the Automated Machine Vision Inspection Systems (AMVIS) project. Launched in 2021, the study evaluated CPKC's Train Inspection Portal System (TIPS) (shown below) to test the effectiveness of machine vision technologies for detecting railcar safety defects.

Located in Saskatchewan, the TIPS portal uses over 35 infrared cameras to capture 72 high-resolution images of every railcar at speeds up to 100 km/h. The system provides 360-degree coverage, including hard-to-inspect undercarriage components, and transmits images to remote offices in real-time.

- The TIPS achieved a 70 percent defect recall rate and enabled inspections without halting train operations.
- The system provided superior imaging of brake rigging, couplers, and draft gear under load.
- Environmental challenges, such as snow and ice, were found to affect image quality in a small number of cases.
- Human factors played a significant role and it was found that experienced inspectors produced more accurate results, when compared to the TIPS outputs.
- AI models (YOLOv5, Faster R-CNN) showed strong potential for automating defect detection.

The project demonstrated that machine vision can identify in-service defects previously missed by manual inspection, including one safety-critical wheel defect that prompted an immediate train stoppage. The findings provide a foundation for integrating AI and machine vision into Canada's regulatory framework, setting a path for safer, more reliable rail operations.

Source: Transport Canada, Assessing the Effectiveness of Vision technologies for Railcar Inspection, modified 2025. https://tc.canada.ca/en/innovation-centre/priority-reports/assessing-effectiveness-vision-technologies-railcar-inspection

3.2.4 Infrastructure Monitoring

The standard practice for infrastructure monitoring is combining in-person inspection activities with inspections carried out using specialized rolling stock that is fitted with monitoring and measurement equipment. In recent years, infrastructure monitoring is also being supplemented by newer technology such as aerial vehicles and remote condition monitoring.

Infrastructure Monitoring Vehicles

Monitoring and measurement equipment can be installed on individual vehicles, which may operate as locomotive-hauled inspection trains or be integrated into regular consists. This includes equipment fitted to locomotives, converted railcars, road-rail vehicles, or self-propelled units.

The monitoring and measurement equipment can include ultrasonic test equipment to detect faults within the rails, lasers, and cameras that monitor and record track geometry, or systems for monitoring the overhead line equipment, including force measurement systems and temperature sensors.

Traditionally, inspection vehicles are manned, however autonomous track inspection is a growing trend across the global rail industry. This allows the monitoring and measurement equipment to function without human intervention. The captured data is then transmitted in near-real-time to the server for analysis via machine learning systems and review by competent engineers. There are several benefits to autonomous inspection, as it reduces costs, increases survey intervals and ultimately identifies defects that require rectification.

These specialized trains operate on mainline tracks, amongst standard traffic, and are scheduled into available routes within the planned timetable. The frequency of inspection depends on the line-of-route and includes factors such as the typical speed and usage statistics.

It should be noted that the rail infrastructure manager within the United Kingdom, Network Rail, have recently begun the process for a £1.2 billion replacement of its rail infrastructure monitoring service. Network Rail has indicated that they are "…agnostic to the method of data collection and believes that, over time, this could evolve into a hybrid approach combining both train and non-train borne collection methods. We are particularly interested in understanding new and innovative non-train borne methods for monitoring railway infrastructure, both now and in the future. This could include, but is not limited to, railroad vehicles, drones, robots and satellite."[43] By not limiting the procurement to a certain type of technology, Network Rail is embracing the opportunities that advances in monitoring technology can provide.

Aerial Vehicles

More recently, aerial vehicles have been trialed and introduced as a form of infrastructure monitoring. The aerial vehicles typically include helicopters and drones or unmanned aircraft systems. One benefit of using aerial vehicles for inspections is that it removes any potential direct impact on the railway. For example, there are no disruptions to normal railway operations and there are no timetable

[43] Gov Find a Tender, Rail Infrastructure Monitoring Service Replacement. Access August 2025. https://www.find-tender.service.gov.uk/Notice/019963-2025

requirements or work sites required for activities such as inspections of electrical equipment.

Aerial vehicles can be used in a variety of ways to monitor the railway. These include undertaking thermal image surveys which can pinpoint potential damage of electrical assets and ensure that assets such as points heaters are working as expected. The aerial vehicles can also survey the rail network more efficiently after adverse weather conditions to identify any locations where damage has occurred and provide exact locations for the maintenance representatives.

Another example of how aerial vehicles can assist in railway operations is by undertaking photographic surveys. These can include surveys after incidents, such as derailments or large-scale renewal works.

In the UK, the Infrastructure Manager, Network Rail, has recently begun trials of "beyond visual line of sight" aerial operations on the railway. These types of drones have the technological capability to cover more miles of track than the Visual Line of Sight equivalents, which will increase the efficiency of undertaking surveys safely from above.[44]

Remote Condition Monitoring

Infrastructure monitoring is also conducted using remote condition monitoring. By installing wireless Internet of Things (IoT) sensors, establishing a communications platform, and deploying an online data portal, infrastructure systems can be made intelligent. The ability to wirelessly and remotely monitor infrastructure not only provides a fuller picture of the condition of the monitored asset but also reduces the risks associated with people working on the tracks. Typical applications include measuring changes in track geometry and monitoring the condition of rail structures such as bridges and tunnels. This process allows Infrastructure Managers to move from manual planning and maintenance schedules to a more proactive approach using "predict and prevent" development.

Furthermore, research and developments in technology have created solutions to the problem of powering remote sensors. This allows the sensors to be self-powered and not require a battery that will need to be replaced periodically. This means a reduction in the number of trackside visits required and enables opportunities for wider deployment.[45]

3.2.5 Environment Monitoring

As climate change alters weather patterns across the world, environmental monitoring is becoming a key consideration in the rail industry.

Weather Monitoring Stations

Weather monitoring stations are becoming more common along the trackside of railways. The stations can be solar powered and provide real-time data for parameters such as wind speed and direction, air temperature, rainfall totals, including precipitation rate and accumulation, and relative humidity. The data gathered from these stations

[44] Network Rail Media Centre, Network Rail Trials Revolutionary Approach to Aerial Operations with British Drone Companies. Accessed August 2025. https://www.networkrailmediacentre.co.uk/news/network-rail-trials-revolutionary-approach-to-aerial-operations-with-british-drone-companies

[45] Unipart Rail, New Collaboration to Drive Sustainable, Game-changing IoT Solution. Accessed August 2025. https://www.unipartrail.com/blog/news/new-collaboration-to-drive-sustainable-game-changing-iot-solution/

can allow for analysis on which area(s) of rail networks are more susceptible to inclement weather that has the potential to cause service disrupting incidents.

Flood Monitoring

Flood monitoring allows railway operators to detect early signs of flooding and respond in an appropriate manner, such as running trains at a reduced speed or stopping trains until it is safe to resume their journey. There are several approaches currently on the market and in use across the global rail industry, including flood poles[46] and water level monitors. Typically, the systems allow for continuous monitoring, and they can determine multiple alert thresholds from an initial warning of increased water level to a flood water alarm. The systems are remote and are self-powered, with options to include solar-powered cameras in some instances. More sophisticated systems make use of IoT sensors and data modelling to better predict weather events and effectively manage railway assets during sever weather events.[47]

Ground Movement Monitoring

Ground movement monitoring has enabled operators to make decisions in advance of incidents occurring. For example, being able to remotely monitor embankments or slopes adjacent to the railway replaces the need for an in-person inspection to identify failures such as ground movement or landslides. With the ability to receive warnings about these types of events, it allows for early interventions such as stopping trains in advance and reducing the chance of derailments. In some cases, the monitoring equipment is integrated with the signaling system and will prohibit train movement authority until the area has been confirmed as clear and safe for trains to pass.

Typically, ground movement is detected using IoT sensors such as triaxial tiltmeter sensors. The sensors are then connected to each other and the internet via a communication platform. The system may also include cameras which are triggered to send photos of the site in the event of movement outside of pre-set thresholds.[48]

Similarly, rockfall is another example of the positive contribution of remote monitoring to the maintenance and management process. Traditionally, visual inspections and the use of catchfences provide a degree of protection but do not provide any warnings for potential rockfall events. Installing a system similar to the ground movement monitoring system allows for continuous, near real-time data that enables early detection of potential hazards without compromising on safety.

Slide fences, or rockslide detectors, are a series of wires suspended from poles to form a fence. They provide the most common method of detecting rockfall. If rockfall or debris movement breaks one of the wires, the resulting disruption to the electrical circuit triggers a signal restriction in the area. This automatically prevents trains from entering the potentially obstructed zone. This method is solely focused on detection and requires on-site inspections to determine if the rockfall has

[46] LB Foster, Flood Monitoring. Last accessed August 2025. https://lbfoster.com/en-gb/rail/total-track-monitoring/flood-monitoring

[47] Rail Sense, Reduce the Incidence of Flooding on the Rail Network. Last accessed August 2025. https://railsense.co.uk/trackwater/

[48] Senceive, InfraGuard. Access August 2025. https://www.senceive.com/products/infraguard

landed on the tracks or has caused damage to any rail assets that will prohibit traffic moving through the area until maintenance teams can rectify the damage.

Another technological option for ground monitoring such as landslide and rockfall detection uses fiber-optic cables.[49] The system converts a standard single mode telecoms fiber-optic cable into an array of distributed sensors capable of detecting rockfall, landslide and significant ground movement events. The application of distributed fiber-optic sensing technology (DFOS) allows for continuous monitoring along the entire length of the fiber, instead of at discrete points where sensors would typically be installed.

LiDAR technology is deployed in various applications across the railway industry. One usage which can be implemented in different scenarios is the ability to detect obstacles on the tracks. The obstacles could be foreign objects, such as rocks from rockfall, people, or other obstructions on the tracks.

In using LiDAR for rockfall monitoring, the greatest benefit comes from knowing if the rocks remain on track, as opposed to other rockfall monitoring systems where it is only known that rockfall has occurred rather than indicating if it has resulted in obstruction or damage to the rail assets.[50]

3.2.6 Grade Crossing Technology

Grade crossings are a critical element of overall rail safety; however, detailed evaluation of grade crossing technologies and treatments is outside the scope of this study, which focuses on rolling-stock condition monitoring and related wayside detector systems. The report acknowledges the importance of and continued support for grade crossing programs (such as crossing elimination, upgrades to active warning devices, and other engineering, enforcement, and education measures) as complementary strategies to enhance safety for all users. Detailed assessment of grade crossing technologies and program options should be addressed through existing roadway–rail grade crossing programs and processes.

[49] Luna, OptaSense, Railway Monitoring. Accessed August 2025. https://www.optasense.com/transportation/rail-monitoring/#:~:text=Rockfall%20and%20Landslide%20Monitoring%20Falling%20rocks%20and,threat%20and%20cause%20significant%20problems%20for%20railways

[50] LB Foster, Rockfall Monitoring. Accessed August 2025. https://lbfoster.com/en-gb/rail/total-track-monitoring/rockfall-monitoring

4 Performance Analysis

Key Chapter Takeaways

This Chapter presents the current state of performance for wayside detector technologies, their deployment practices, and the opportunities for Minnesota to strengthen rail safety through more advanced systems and better integration. It emphasizes not only the hardware itself, but also the importance of site selection, data management, and training to ensure these systems deliver meaningful safety outcomes.

Key Findings from this analysis include:

- Wayside detectors are one of several tools used to support rail safety, and as FRA's studies have shown, their performance depends on appropriate site selection, spacing, and integration of the relevant technologies.
- Site-selection rules and detector pairings come from proven field practice rather than laboratory theory.
- Co-locating detectors offers efficiency gains and detailed diagnostic data.
- Data management, notification protocols, trends analysis, and crew response procedures are as important as detector hardware.
- Expanding training and standardized practices will be essential to realizing the full safety and economic benefits of wayside detector investments.

4.1 Wayside Detector Site Considerations

Identifying appropriate locations for wayside detector systems and establishing clear installation and operating practices can support consistent system performance and effective monitoring.

The following section examines the practical considerations that determine whether wayside detectors achieve their intended safety outcomes. Topics include site selection criteria, co-location of detector types, and the balance between geographic, operational, and technological constraints.

4.1.1 Site Selection Criteria

The selection of a site to install any wayside detector must be carefully considered. There are several key considerations that can be grouped together into the following categories:

- Geographic constraints
- Track characteristics
- Accessibility
- Operational considerations
- Technology constraints

Geographic Constraints

Geographic conditions, both natural and man-made features, may affect the accuracy of wayfinding detection technologies.

Natural features such as changes in elevation, bodies of water and the accessibility of the site can all affect detector suitability. For instance, elevation shifts may affect train braking behavior, which in turn can compromise the accuracy of detector readings.

Man-made features, including urban development near rail corridors, may introduce ambient noise that interferes with certain detector types.

Additionally, limited space within railroad right of way can restrict the installation of equipment housing and associated infrastructure. It is essential that sufficient clearance is available to accommodate all necessary components. Proximity to other wayside equipment should be avoided to minimize interference. While the footprint of wayside detector equipment is typically modest, associated infrastructure such as bungalows must be installed within a defined range of the instrument area.

Track Characteristics

The track characteristics play an important role in determining the suitability of a location.

Most detectors, including the widely implemented HBD, require tangent, plain track with minimal grade variation and a consistent speed profile to ensure accurate readings. Ride quality is also important, as some sensors are sensitive to vibration and require a stable operating environment. This allows for the standardization of vehicle running and removes the likelihood of any potential ambiguities, which in turn will provide accurate readings from the detectors.

However, certain detectors such as TBOGI (described in Section 3.1.9) and TPD (described in Section 3.1.8) may require specific track geometries, such as an "S" curve segment with a curvature of between 4 and 6 degrees. Others, like WILD systems (described in Section 0), require installation on concrete ties. This ensures consistency across the measurement site and reduces any potential ambiguities being introduced to the measurements being taken.

In general, detectors should be placed away from tunnels, bridges, and grade crossings, and ideally in areas with low ambient noise.

Accessibility

The selected site must allow for safe and efficient access for installation, commissioning, routine inspections, and maintenance activities.

The presence of communication infrastructure and power sources is highly beneficial and can reduce installation costs. Where such infrastructure is not already available, it must be provisioned as part of the installation process.

Operational Considerations

Operational factors and traffic dynamics, such as routing patterns, vehicle frequency, and overall density, are important considerations when determining suitable locations.

Detectors are generally installed away from train stop locations such as stations, yards, and maintenance facilities due to the changes in speed profile that occur near these areas. However, installing detectors on routes leading to maintenance facilities can be advantageous, provided the site is located far enough from the facility to ensure consistent train speed.

Locations with high traffic volumes enable more comprehensive data to be captured across a larger portion of the fleet. This facilitates more robust trend analysis and enhances the effectiveness of condition monitoring. Additionally, the nature of the cargo being transported is a relevant consideration. In cases where trains carry hazardous materials, strategically placed detectors can provide critical safety insights and support timely interventions.

A holistic assessment of existing detector infrastructure should be undertaken to identify opportunities for optimizing system spacing. This approach can strengthen network-wide safety capabilities and ensure that coverage is both efficient and effective.

Technology Constraints

Site selection for wayside detectors must also account for the technical requirements and limitations of each system to ensure accurate performance and long-term reliability.

Environmental tolerance is a primary consideration. Although detectors are engineered for outdoor use, each system has defined temperature, moisture, and vibration ratings. Potential sites should be evaluated to ensure that local environmental conditions fall within the detector's specified operating range.

Each detector type also has minimum and maximum speed thresholds within which measurements are valid. As such, the chosen location must support operating speeds that align with the detector's design parameters. This requires reviewing posted track speeds and typical train operating behavior to confirm compatibility.

Certain detectors have functional constraints related to braking conditions or noise sensitivity. For example, some systems require a consistent pass-by speed, while others can collect data during brake application. Likewise, technologies such as acoustic detectors perform best in areas with limited ambient noise. These factors should be considered when identifying suitable candidate sites.

Spacing requirements are also important. Spacing decisions should draw on route-level data and risk assessments to determine where additional coverage provides the greatest benefit. Some detectors operate in paired or sequential configurations; for example, paired wheel temperature detectors or sequential hot bearing detectors, requiring placement that supports their intended diagnostic function.

Finally, detector manufacturers may provide site-specific guidance based on system capabilities and prior field performance. Incorporating vendor recommendations can help ensure that installations meet technical specifications and operate reliably.

4.1.2 Wayside Detector Co-location

The co-location of different types of wayside detector systems is common throughout North America.

There are several benefits to co-locating different types of wayside detector systems, these are typically related to efficiency, both during installation and maintenance activities, as well as during the operational phase.

The types of detectors that are co-located often use the same technology and do not create any interference issues. For example, Hot Bearing Detectors and Hot Wheel Detectors both use infrared technology. As shown in Figure 18, HBD and HWD can co-locate without creating any interference with each other. HWD are most often co-located with HBD's, as opposed to being installed in standalone locations.

Figure 18: Hot Bearing (Outer) and Hot Wheel (Inner) Detector Co-location

Source: Future Systems, 2025.

It is also common for HBD, HWD, and Dragging Equipment Detectors (DED) to be integrated as part of the same installation.

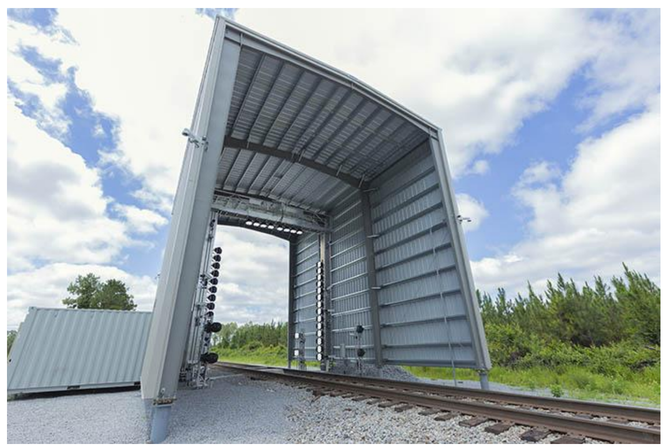
Another example is the use of Wheel Impact Load Detectors to not only provide data relating to the wheel forces imparted on the rail, but some WILD systems are also capable of offering weigh-in-motion and truck hunting monitoring. This combination provides the opportunity to report on train weight and speed, wheel impacts, lateral forces, and truck hunting from a single source, which can then be used for comprehensive data analysis.

Within North America, Wheel Impact Load Detectors (WILDs) and Acoustic Bearing Detectors (ABDs) have also been installed together at the same location.

In another instance, WILDs and ABDs have been installed alongside Truck Performance Detectors and Hot Bearing Detectors. This provides the opportunity to correlate data collected in the same instance with a view to improving diagnostic confidence. For example, ABDs and HBDs both measure characteristics of bearing health but in different forms – the acoustic signature of bearing components and the temperature of the journal bearings, respectively. By using the data collected from both types of detectors, it may be possible to recognize an early-stage fault through the acoustic measurements before the bearing demonstrates the overheating typically associated with late-stage bearing failure. The combination of these detectors not only increases confidence in identifying the issue but also helps identify the root cause of the issue and the specific components responsible.

Automated vehicle inspection technology is another example where having multiple sensors in a single location can provide a more efficient way to gather consistent measurement data. Inspection portals (shown in Figure 19) combine high-sensitivity cameras and optical laser sensors to capture and analyze data from multiple onboard components such as brakes and wheels, and can also carry out full vehicle inspections, including underframes.

Figure 19: Duos Technology Railcar Inspection Portal



Source: Duos Technology, 2025.

There are a variety of benefits in combining the locations of multiple wayside detectors, such as reduced overall deployment costs by sharing infrastructure. For example, power supply and communication equipment can be located at a single site, as opposed to multiple.

Maintenance inspections and associated activities may also become more efficient due to the centralized location, enabling further savings over the lifetime of the detectors. This may also reduce any downtime associated with faulty detectors.

With regards to data collection, combining multiple sensors provides a more comprehensive view of the current condition of specific components and provides a holistic view of the vehicles' condition. By combining proactive detectors with reactive detectors, such as Acoustic Bearing Detectors and Hot Bearing Detectors respectively, the condition of components can be determined from data obtained from the ABD, with a view to identify potential faults before the HBD detects them in service. This type of process can enhance the efficiency of fault detection and rectification.

4.2 Wayside Detector Maintenance

Maintenance and calibration requirements present important considerations when installing and using wayside detectors. Each detector system will have individual maintenance and calibration requirements which should be considered when developing the appropriate processes and procedures. Key areas that will inform the processes and procedures include vendor requirements and recommendations, environmental conditions at the site location, track conditions, and the age of the instrumentation.

Each system will require calibration both at installation and throughout its operational life. Calibration of the sensors is required to ensure that all measurements are accurate, reliable, and consistent. This prevents errors that could compromise the readings. Calibration requirements and frequency are typically based on the type of detector system and the functionality. Calibration activities may also require confirmation of the detector system operating accurately, and within defined ranges, which may require rail vehicles to pass by.

Maintenance and calibration processes and procedures need to consider the logistics of the detector site. This includes general site access and furthermore, whether the site is positioned on a congested rail corridor which may lead to limited opportunity to access the detector and perform the required procedures.

Maintenance and calibration activities can be performed by a number of different parties. This includes the railroads themselves, or the technology vendor. The technology vendor may offer a service contract which could include maintenance and/or calibration activities.

Railroads will also have to prepare for unplanned maintenance of the detector systems. This may involve monitoring the health of the system remotely and reacting as appropriate to fix any identified issues, which may include partial or whole failure of the system. Railroads try to minimize downtime for detector systems. Response times to detector failures typically range from 24 to 48 hours. Thus, the downtime for detector systems is minimized as much as possible.

4.3 Detector Notification Process and Response

Any technological implementation involves the technology itself, the people who operate and maintain it, and the processes and procedures that guide its use.

This section explores the threshold and measurement considerations required for wayside detector systems, along with the associated notification and response procedures.

While certain aspects of these processes are generally consistent across the industry, others vary by railroad depending on internal policies, technology platforms, and organizational structures.

The description provided here reflects typical processes and is intended for illustrative purposes; actual practices may differ among railroads.

As noted previously, FRA Safety Advisories have also included recommendations for the processes and procedures relating to wayside detector data.

4.3.1 Detector Thresholds and Measurement Considerations

With regard to thresholds that trigger the alerts and subsequently require interventions, there are several sources of information that railroads should consult when developing their own threshold values. They include:

- AAR Manual of Standards and Recommended Practices.
- AAR's Equipment Health Management System, which includes centralized information, operating tests, and training materials.
- FRA Safety Advisories and extensive guidance provided in the Wayside Detector Implementation Guide (2019), and Rail Safety Advisory Committee's (RSAC) [51]ongoing work.
- AREMA Manual Part 11.5.1 on environmental requirements for electrical and electronic railroad signal system equipment, which includes operating and storage temperature thresholds.
- International Union of Railways standards for broken rail detection and other wayside systems that include threshold specifications.
- Equipment supplier (vendor) specific manufacturer-recommended thresholds and calibration procedures for each detector type as well as vendor-specific operational guidance based on field experience and technological capabilities.

System thresholds will depend on the type of wayside detector and can include temperate based, load based, dimension based, laser or acoustic pre-determined metrics. Wayside detector systems must also incorporate logic to determine the difference between true, factual readings and those that are outliers, or influenced by external factors.

The thresholds are typically divided into multiple levels, increasing in severity. At a high-level, the stages equate to a low-level alert advising that some degradation has occurred and action may be required, a mid-level alert advising the equipment owner to schedule repairs before damage occurs, a high-level alert advising that repairs are needed and shops should take action and finally, a severe-level alert where the vehicle should be pulled from service and repaired immediately. Further information on the standard alert levels is included within Section 4.3.1.

Using the example of Hot Bearing Detectors, there are several classifications used to identify defects. The classification WM50 refers to a temperature reading of at least 170°F above the ambient temperature. The measurement at this temperature must then be manually confirmed to be hotter than the next hottest bearing on the same side of the

[51] Rail Safety Advisory Committee's (RSAC) activity is currently paused but expected to resume.

equipment to ensure that the correct bearing has been identified.

The same classification can also apply if the bearing temperature is read by the HBD as being at least 95°F above the temperature of the mate bearing on the same axle. The measurement must be manually confirmed to be hotter than the next hottest bearing on the same side of the equipment to ensure that the correct bearing has been identified.

Classifications WM51 and WM52 are described in the AAR "Manual of Standards and Recommended Practices – Sensors, Bearing Temperature Performance Standard S-6001." These classifications relate to the K values of the train and equipment. The K value is the statistical indicator that defines the relative variation of one measurement to the population. With respect to WM51, temperature only readings are used, whereas WM52 uses a combination of temperature and acoustic bearing detectors to determine whether an intervention is required.

It is also important for railroads to consider the implications of single measurements from HBD systems, alongside multiple measurements in a temperature trend analysis scenario. Therefore, thresholds should be established for single measurements, as well as multiple measurements of individual bearings to enable temperature trend analysis.

To ensure the wayside detector systems deliver accurate, actionable readings, it is essential that the systems themselves are properly maintained and calibrated in accordance with each vendor's specific maintenance and operation guidelines.

4.3.2 Detector Notification Process

Wayside detector systems provide notifications in several different ways. The notification can be direct to the train crew on board the vehicle, or direct to the Railroad Operations Center, but more typically it is a combination of the two. The description provided here reflects typical processes and is intended for illustrative purposes; actual practices may differ among railroads.

For wayside detector systems that contain "talker" functionality, the train crew receives an audible radio announcement shortly after passing over a detector. Systems with "talker" functionality include, but are not limited to, hot bearing detectors, hot wheel detectors, and dragging equipment detectors.

These announcements can provide information including the following:

- Railroad name
- Milepost
- Track number
- Number of axles from the full consist of railcars
- Whether a defect has been detected, if so, details on the affected axle and when relevant, the associated temperature reading. If no defect has been detected, this will also be communicated.

Railroads typically use the "talker" functionality to notify train crew if the detector notification is above a defined threshold. This ensures that train crews do not experience notification fatigue.

The "talker" functionality assists train crew in determining the next steps, for example if a Dragging Equipment Detector is activated, the radio message alerts the train crew to stop the train. The train crew will then follow the relevant detector response process.

Alternatively, detector systems that do not contain the "talker" functionality, report directly to the Railroad Operations Center. In this case, the information gathered from the detector can be used in two different ways. Firstly, it can be used to identify actions that should be carried out as soon as possible by the train crew and secondly, the information may be used for trend analysis, which allows railroads to monitor components, and systems over time. This aligns with the previously discussed reactive and proactive detectors respectively.

The Railroad Operations Center will be in direct communication with the train crew and will guide them through the next steps once a wayside detector has noticed that there is a defect in a railcar. They will have access to previous data from the same components and detectors and will be able to validate the detector readings to determine the reliability of the reading and the appropriate actions that are required.

4.3.3 Detector Response Process

As described in the previous section, there is a significant amount of information available from the detectors, which allows for the appropriate response to be undertaken. This usually includes input from the wayside detector, the train crew, and the Railroad Operations Center.

The train crew is notified in near real-time, allowing them to undertake the appropriate response actions, as described in the railroad's operating procedures, almost immediately after a defect has been detected. The train crew will be in direct communication with the Railroad Operations Center to determine the best course of action.

Promptly after a wayside detector system provides a notification regarding a defect, railroads must follow established response procedures that vary based on the type of defect, train composition, and applicable operating rules. The following procedures are based on industry best practices derived from FRA guidance, AAR standards, and railroad operating procedures:

1. **Train control and safety procedures:** upon receiving a wayside detector alert, train crews must follow their railroad's applicable safety procedures for train control, which, depending on the alert may include stopping the train in a safe manner consistent with safe train handling procedures at the location.
2. **Ground inspection:** reported defective equipment is inspected from a position on the ground. For certain alerts, this may require a two-sided inspection of the entire train, focused axle checks for signs of bearing overheating, grease leaks, or physical damage, and roll-by inspections following consecutive detector failures.
3. **Safety and repair determination:** inspection findings determine whether a train can move. If the train is unsafe, repairs must be made before movement. If defects are confirmed but the train can still operate safely, movement may continue under speed restrictions. Railroads may impose additional restrictions depending on defect type and operating conditions.[52]
4. **Documentation:** train crews prepare written inspection reports within established timeframes. Reports typically include detector location and alert details, inspection findings,

[52] Special considerations according to AAR Circular No. OT-55-R: in single-track territory, trains with hot wheel defects may continue at 30 mph only to the next siding, multiple tracks, or yard for inspection. Further restrictions may apply if crews experience erratic train operation. See: https://www.aar.org/wp-content/uploads/2023/09/2023-10-01-OT-55-R-Draft.pdf

actions taken, condition and disposition of the equipment, and any speed restrictions or operational limitations applied.

The inspection of the identified location may include looking at discoloration of components from overheating, leaking grease, physical abnormalities, grinding in motion and flat spots. The inspection may also require checking for sticking brakes and issues with hand brakes, depending on the alert received.

Specifically relating to the transportation of hazardous materials, the Association of American Railroads Recommended Railroad Operating Practices for Transportation of Hazardous Materials, describes the Road Operating Practices whereby a "Key Train" is any train with:[53]

- One tank carload of Poison of Toxic Inhalation Hazard (PIH or TIH) (Hazard Zone A, B, C, or D), anhydrous ammonia (UN1005), or ammonia solutions (UN3318), or;
- 20 carloads or intermodal portable tank loads of any combination of hazardous material, or;
- One or more carloads of Spent Nuclear Fuel (SNF), High Level Radioactive Waste (HLRW).

The restrictions that the operating practices describe include the following:

- Maximum speed of "Key Train" is 50mph.
- Unless siding of auxiliary track meets FRA Class 2 standards, a Key Train will hold main track at meeting or passing points, where practicable.
- Only cars equipped with roller bearings will be allowed in a "Key Train."
- If a defect in a "Key Train" bearing is reported by a wayside detector, but a visual inspection fails to confirm evidence of a defect, the train will not exceed 30mph until it has passed over the next wayside detector or delivered to a terminal for a mechanical inspection. If the same car again sets off the next detector, or is found to be defective, it must be set out from the train.

4.4 Data Processing and Management

The following section will explore the Railinc Corporation products and how wayside detector information is captured and used within these systems. Furthermore, it will describe how else the data can be used to undertake further analysis and assist with railroad's maintenance approach.

4.4.1 Ownership Models and Data Governance

Railinc Corporation is a wholly owned subsidiary of the Association of American Railroads. It was established in the late 1990s to deliver secure, centralized, and interoperable data systems for the rail industry. Railinc supports everything from asset tracking and maintenance planning to interline commerce and real-time operations. Its platforms are integral to daily rail activity, connecting Class I railroads, short lines, equipment owners, and suppliers.

Railinc has a large number of products and services that are web-based for ease of access. The Equipment Health View (EHV) consolidates railcar

[53] AAR, Recommended Railroad Operating Practices for Transportation of Hazardous Materials, Circular OT-55-R Effective July 1, 2022. https://www.aar.org/wp-content/uploads/2022/07/2022-07-01-OT-55-R-CPC-KBD.pdf

health-related information from multiple Railinc systems including the following:

- Universal Machine Language Equipment Register (UMLER): The industry's central repository for registered rail and intermodal equipment in North America. It contains vital data about freight cars, locomotives, and other rail assets, serving as a foundational tool for safe and efficient operations.
- Equipment Health Management System (EHMS): Plays a key role in identifying potential mechanical issues before they lead to costly delays or safety incidents. Railroads use this data-driven approach for asset health to adopt proactive maintenance practices.
- Damaged and Defective Car Tracking (DDCT): Allows for the reporting, documentation, and management of defective equipment.

Users can view equipment-level information such as open Early Warning (EW) and Maintenance Advisory (MA) notices, EHMS alert levels, open data summaries, open DDCT incidents, and UMLER component registry and inspection data. If a user wants to act on information that they see on the dashboard, EHV enables them to report repairs and/or inspections to these systems. EHV also provides fleet-level statistics for equipment linked to the Car Mark Owner's Company ID.

The UMLER system is the industry data and government publications for rail equipment information in North America. UMLER contains vital data about freight cars, locomotives, and other rail assets, serving as a foundational tool for safe and efficient operations. Railroads, equipment owners, agents, shippers, ports, suppliers, industry consultants, government agencies, and railcar service providers use UMLER for the safe and efficient placement, movement, and interchange of railcars.

The Damaged and Defective Car Tracking system allows users to update, retrieve, and share information in a timely manner. DDCT interfaces with many of Railinc's products that facilitate better equipment management, improve rail safety, and reduce administrative costs. Damaged cars are handled in accordance with AAR Interchange Rule 107, and defective cars are handled in accordance with AAR Interchange Rules 1, 96 and 108. AAR Interchange Rule 95 is used for any damaged equipment that can be returned to service.

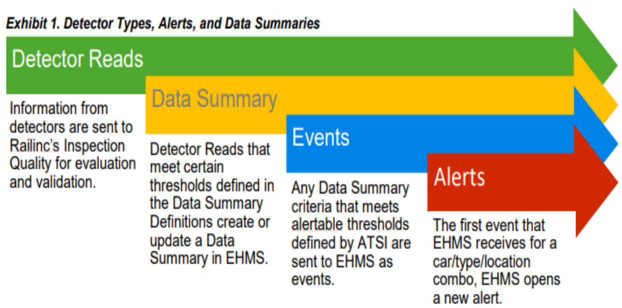
Equipment Health Management System (EHMS) aggregates data collected from wayside detectors throughout North America to monitor the condition of rail equipment. It identifies emerging mechanical issues, communicates equipment status, and generates alerts and data summaries for responsible parties when maintenance is required. While alerts indicate actionable issues, the data summaries are informational only, providing insight into equipment condition—even if it has not yet reached the threshold for an alert. Alerts may be actionable by repair shops depending on their severity. EHMS also enables car owners, railroads, and equipment maintenance providers to report equipment repairs and collect repair history data.

Early detection enables proactive remediation to potentially save time, money, and more serious equipment damage. Equipment condition data is evaluated, and if it indicates the equipment condition has deteriorated beyond certain industry-defined thresholds, an alert is opened.

Data from wayside detectors is sent to Railinc's Inspection Quality (IQ) system, which captures equipment condition readings and event information. Once readings exceed certain industry-defined thresholds, IQ opens alerts and sends the information to EHMS. EHMS displays the applicable alert for the unit and distributes information about equipment to rail carriers, car owners, and other interested parties.

All of these automatic alerts enhance car inspections by providing insight into problems that might otherwise go undetected. The workflow of EHMS can be seen in Figure 20.

Figure 20: Railinc Equipment Health Management System (EHMS) Workflow



Source: Railinc, Equipment Health Management System (EHMS) User Guide, 2025.

Each detector type has defined alert levels which are based on industry-defined thresholds. The alert level corresponds to the severity of the mechanical problem and the urgency in which repairs are required.

The EHMS manages the communication of this information to all equipment owners and provides the mechanism for reporting repairs, allowing for the closeout of alerts. The closeout action depends on the specific wayside detector. For example, Truck Hunting Detector alerts can be closed by inspection but not repair. They can also be automatically closed as a result of several consecutive non-elevated readings from wayside detectors.

However, EHMS does not have the capabilities to accept input data from all wayside detector systems. Therefore, it is the responsibility of the railroad to maintain the appropriate tools to manage, store, and utilize the data appropriately.

The system generates alerts from wayside detectors and categorizes them as shown in Figure 21.

Figure 22 describes the various wayside detector types and the available industry alert levels.

Figure 21: Industry Alert Levels

Industry Alert Level	Description
Window Open EHMS Code W Level 1	This **lowest-level alert** advises that some degradation has started. An alert at this level is primarily a notice to the car owner/operator that a potential problem exists on the car and to allow the car owner to get the car into the shop of their choice.
AAR A2 EHMA Code O Level 2	This **mid-level alert** offers the equipment owner a chance to schedule repairs before damage starts, for example if the equipment is in a shop for any other reason. Units with an AAR A2 level fall under AAR rules and may be repaired if they are in the shop for any other reason.
AAR A1 EHMS Code C Level 3	This **high-level alert** notifies shops that wheels need to be replaced. Units with alerts at this level may be pulled into the shop specifically for this repair.
Mandatory EHMS Code M Level 4	This **severe-level alert** advises railroads/car owners that high stresses are being placed on rails requiring immediate action. A unit with a Mandatory Alert should be immediately reviewed by a shop and repaired.

Source: Railinc, Equipment Health Management System (EHMS) User Guide, 2025.

Figure 22: Wayside Detector Type and their Industry Alert Level(s)

Detector Type	Industry Alert Level(s)
Acoustic Bearing Detector (ABD)	AAR A1
Automatic Equipment Identification Detector	Window Open AAR A2
Brake Health (Wheel Temperature Detector – WTD (Car Level))	Window Open
Brake Health (Wheel Temperature Detector – WTD (Truck Level))	Window Open
Hot Bearing Detector	AAR A1
Machine Vision	Window Open
Truck Geometry Detectors	None – Data Summary only
Truck Geometry Detectors	Window Open AAR A1
Truck Performance Detectors	AAR A1
Wheel Impact Load Detectors	Window Open AAR A2 AAR A1
Wheel Impact Load Detector and Wheel Profile Detector	Window Open
Wheel Profile Detector	Window Open

Source: Railinc, Equipment Health Management System (EHMS) User Guide, 2025.

4.4.2 Data Outputs

Once the data has been analyzed and arranged into a usable format, the opportunities to benefit from the data are vast.

The data collected can be used to undertake further investigations into different sub-systems, down to the component level. For example, investigating brake health over longer periods of time can allow maintainers to delve deeper into the data and draw correlations from different variables such as the age and type of different components.

In analyzing the data beyond the standard metrics, there is the opportunity to identify and create a "watch list" of vehicles or components that may have the potential to develop into service affecting failures. In monitoring specific vehicles or components closely over a period of time, this creates the opportunity to facilitate the required maintenance at a suitable time and/or location, for example when the vehicles are next scheduled to be in the shop. It also creates the potential to monitor components of the same type across the fleet. This may lead to identification of systemic issues, where components require widespread maintenance, or replacement.

A step further would be aggregating the data from multiple detectors to provide a holistic view of the vehicles. In doing this, it provides the opportunity to draw correlations between different sub-systems and components. For example, brakes create issues with wheels. In viewing these issues individually, the root cause may not be identified.

Some analysis applications allow for connections to asset and maintenance management systems, which allows the continuation of data flow and provides a more efficient maintenance system. This can include automatic and customizable defect reporting and the ability to raise work orders for components that have measured defects.

Other uses for the data include establishing models such as digital twins. A digital twin is a virtual representation of a physical object, system, or process that mirrors its real-world counterpart and is connected through a continuous stream of data. Information gathered from detection and monitoring activities provides inputs to the model, which can then be used to simulate, test, monitor, and maintain the physical asset. The global rail industry is embracing this technology, with applications in railway operations, major infrastructure projects, and rolling stock maintenance.

4.4.3 Maintenance Approach

The international rail industry is embracing the greater availability of asset condition data. This data is made available through the increased monitoring of assets, including both rail vehicles and infrastructure. The benefits are two-fold – increased awareness of asset condition, allowing for greater accuracy in maintenance activities, including planning and implementation, and as a result, the operational railway becomes a safer environment.

With regards to asset condition and maintenance planning, in recent years there has been a pivot from time-based maintenance practices, based on asset age, usage rates and in person inspections, to a more tailored and predictive approach, based on asset condition and data obtained through monitoring activities. This approach has been facilitated through the advances in monitoring technology and the associated applications in the rail industry.

To be able to undertake maintenance based on asset conditions, the workflow of data is key. The data needs to be acquired from the detectors and monitoring equipment, it then needs to be processed, including aggregating the data, and then the data can be analyzed. In analyzing the data, it then becomes useful, and decisions can be made, with actionable outputs assigned, such as those described in Section 4.3.2.

With respect to wayside detectors, they can assist with the ability to predict potential faults and issues, allowing for a proactive approach to maintenance. The information gathered from the detectors falls into two categories, information that requires immediate action and information that can be used to enhance the maintainers' knowledge of the assets over time. This aligns with describing wayside detectors as either proactive detectors or reactive detectors.

Proactive detectors allow for the trending and analysis of data which can then be used to proactively identify and monitor components that have the potential to fail in-service. This allows for interventions to be carried out prior to failure, and the rectification of issues before they become service impacting. Examples of this type of detector include Truck Bogie Optical Geometry Inspection systems or Wheel Impact Load Detectors. The monitoring and trending of data from these types of systems will be carried out over longer periods, such as weeks and months, to determine the condition of the component and how it is deteriorating.

In contrast, reactive detectors identify issues as they are occurring and require immediate intervention. For example, Hot Bearing Detectors will identify if a bearing is above a certain temperature that requires an action to be carried out, such as a speed reduction or removing the vehicle from service. Although the data captured from HBD's can also be used to proactively monitor bearings that are still within the acceptance temperature range, the time period available for monitoring is often too short to be used to make proactive maintenance decisions.

In continuing to use and expand upon the installation of different types of wayside detectors, the rail industry can make a step change in the approach to maintenance. In using the data collected from wayside detector systems to inform maintenance decisions alongside using the data to identify faults that require immediate rectification, the railway will become a safe environment to operate in. The combination of proactive and reactive systems and combining the data collected will provide a holistic view of the assets and enable maintainers to make informed maintenance decisions.

4.5 Training

Effective use of wayside detectors depends not only on technology, but on the associated people and process. The railroad personnel must be able to interpret the data, respond to alerts, and maintain the equipment. This can only be done through applicable training and the associated process and procedures. Training is therefore a critical element of any detector program.

4.5.1 Training Programs

Class I railroads typically provide detector training as part of broader mechanical and operating programs. Training programs emphasize:

- **Detector function and limitations,** ensuring crews and maintainers understand what each system can and cannot detect.
- **Notification and response protocols,** familiarizing train crews, dispatchers, and shop

personnel with alarm levels, communication procedures, and required actions.

- **System maintenance**, equipping signal and mechanical staff with the skills to inspect, calibrate, and repair detectors to manufacturer specifications.
- **Data interpretation,** developing proficiency in reading trending data, identifying false positives, and correlating detector outputs with other condition reports.

Industry input from railroads and technology vendors indicates that efforts are underway to expand the range of detector types and to transition older systems to more advanced, data-driven technologies. As a result, training programs should evolve beyond the traditional focus on widely used systems (such as HBD/DED) to incorporate newer technologies such as acoustic, optical, and machine-vision detectors.

Specialized training is particularly important in the following three areas:

- **Cross-system analysis,** equipping staff to interpret and correlate outputs from co-located detectors, where multiple detectors provide complementary data.
- **Data governance and interoperability,** ensuring personnel can effectively use national platforms such as Railinc's EHMS while managing and integrating locally collected data.
- **Emergency response integration,** preparing train crews and first responders to apply detector alerts in managing incidents, particularly those involving hazardous materials.

5 Safety Impact Evaluation

Key Chapter Takeaways:

This Chapter examines recent rail safety trends in Minnesota using Federal Railroad Administration (FRA) accident data. It is limited to train accidents occurring on railroad property and excludes highway-rail grade crossing incidents.

Key findings from this review include:

- Minnesota's train accidents have declined overall since 2016, with cause patterns similar to national trends. Human-factor and track-related causes remain the largest categories.
- Equipment-related accidents are a smaller, stable share of incidents in Minnesota, about three accidents per year which is consistent with national averages.
- FRA research shows that wayside detectors can identify specific mechanical anomalies linked to some equipment-related failures, supporting preventive maintenance efforts.
- Wayside detector performance depends on maintenance, calibration, and response practices. FRA inspections and advisories highlight the need for consistent processes, procedures, and training.
- Wayside detectors complement, but do not replace, other inspection methods such as visual inspections, onboard monitoring, and track infrastructure maintenance.

5.1 Safety Trends Overview

Wayside detector deployment can be associated with a reduction in certain rail equipment incidents, as shown in several national and federal studies highlighted in this Chapter.

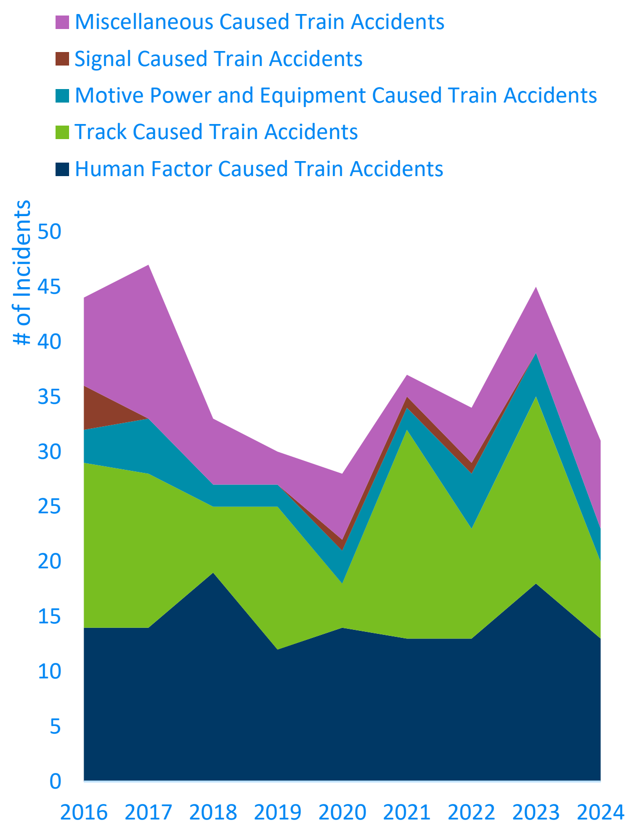
The Federal Railroad Administration's (FRA's) safety data indicates that nationwide train accidents, not occurring at highway-rail crossings, fluctuated between 2016 and 2024, with year-on-year variation. However, there was no single consistent directional trend across the period. In Minnesota, FRA records show a decrease in these types of accidents over the same timeframe, from 44 in 2016 to 31 in 2024.

FRA incident cause codes, across both Minnesota and the U.S., show that human factors and track-related causes are the two largest categories of train accidents. Motive Power and Equipment causes (accidents attributed to mechanical or electrical failures in locomotives or railcars) represent approximately 10 percent of train accidents both nationally and within Minnesota in recent years.

Figure 23 presents the total number of reportable rail equipment-related incidents in Minnesota between 2016 and 2024. This analysis is conducted based on FRA's rail incident data with a focus on rail equipment incidents. The data show year-on-year variation and an overall decrease over the period, including a decline from 45 total incidents in 2023 to 31 in 2024.

As shown in Figure 23, human-factor causes consistently represent the largest share of rail equipment-related accidents in Minnesota, followed by miscellaneous causes and track-related categories. Motive Power and Equipment-related accidents have remained relatively stable, averaging roughly three per year over the nine-year period, with normal year-on-year variation consistent with FRA national patterns.

Figure 23: FRA Rail Equipment Incident Data for MN (2016-24)



Source: Federal Railroad Administration Office of Safety Analysis, Rail Accident Data 2016-2024.

5.2 Wayside Detector Effectiveness

FRA's research indicates that wayside detector systems can assist railroads in identifying certain mechanical conditions that contribute to equipment-related train accidents. These systems monitor characteristics such as bearing temperature, wheel impact forces, and truck performance, and generate alerts when readings fall outside expected ranges. Their effectiveness depends on the type of defect, detector technology, maintenance practices, and railroad operating processes and procedures. [54]

Another FRA-led study focused on evaluation of industry data through the AAR InteRRIS® system (2008–2012) found that wheel impact load detectors (WILD), truck performance detectors (TPD), and truck hunting detectors (THD) were effective in identifying conditions associated with wheel defects, bearing distress, and truck instability. FRA reported that the use of these types of detectors supported preventive maintenance activities and contributed to reductions in certain derailment types where the primary cause was related to wheels, bearings, or truck components.

FRA also notes that wayside systems are not capable of identifying all mechanical defects. Some types of failures such as internal brake malfunctions, sudden coupler failures, or locomotive-specific mechanical issues may not produce detectable external signatures and require other inspection methods.[55]

Detector reliability depends on how consistently systems are maintained and calibrated. In its High-Hazard Flammable Train Route Assessment (2024), FRA inspected more than 2,600 wayside detectors across multiple Class I railroads and identified maintenance-related issues at approximately 4.6 percent of locations. These included alignment problems, calibration drift, and sensor configuration

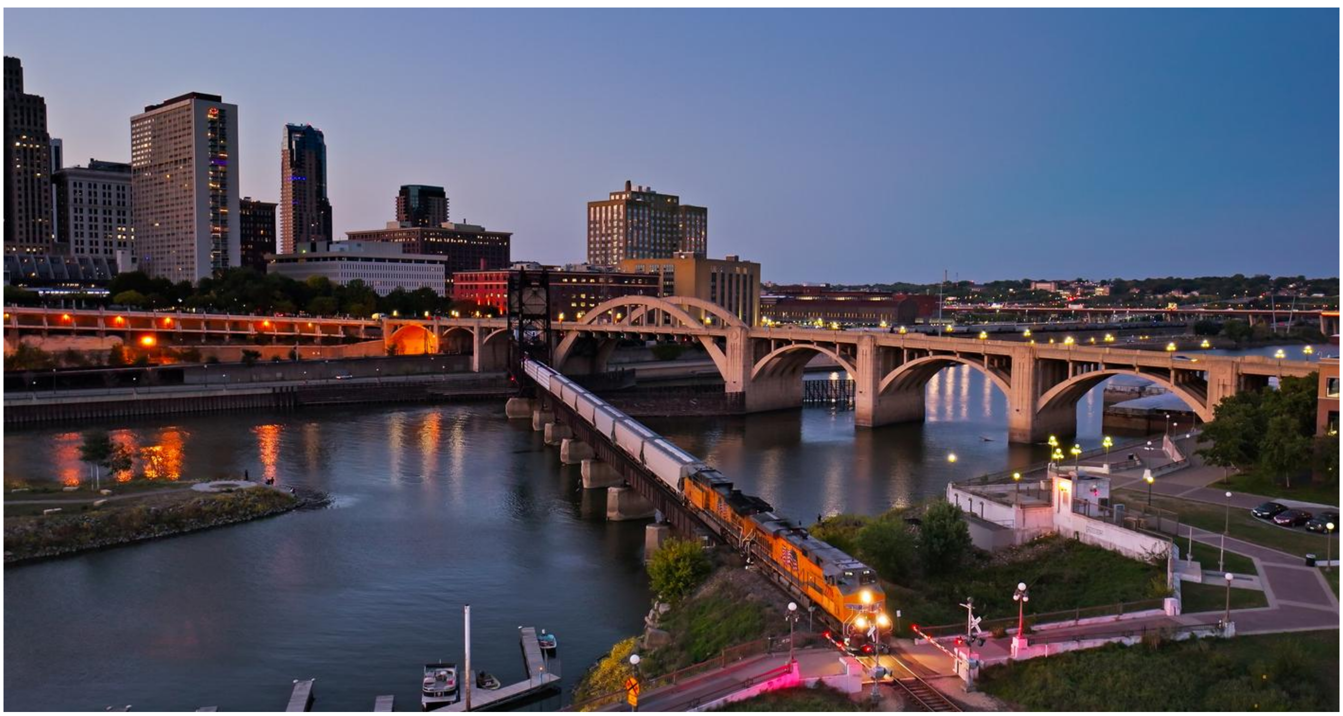
[54] FRA, An Implementation Guide to Wayside Detector Systems, 2019.

[55] FRA, Effectiveness of Wayside Detector Technologies on Train Operation Safety, 2022.

issues. FRA indicated that these conditions can generally be corrected through routine inspection and maintenance and highlighted the importance of documented procedures and clear lines of responsibility.[56]

FRA has also issued additional guidance through Safety Advisory 2023-01, recommending practices to support consistent and reliable performance. These include regular calibration and verification of detector equipment, recurring training for personnel responsible for installation and inspection, review of alarm thresholds and trending logic, and timely communication of alerts to operating crews and dispatchers.

Overall, FRA's findings show that wayside detectors are a component of a broader safety and inspection framework. They provide useful information on specific mechanical conditions and support preventive maintenance programs, while other inspection methods, such as visual inspections, onboard monitoring, and track inspections, remain necessary to address defect types not suited to trackside detection.



[56] FRA, High-Hazard Flammable Train Route Assessment & Legacy Tank Car Focused Inspection Program, 2024.

6 Economic and Industry Impacts

Key Chapter Takeaways:

This Chapter provides a high-level assessment of the potential costs, benefits, and economic impacts associated with wayside detector deployment on Minnesota's Class II and III railroads, as directed by state legislation. It draws on federal sources, state planning documents, and industry input to outline how detector requirements may interact with railroad financial considerations and, as a result, impacts the state's rail-reliant industries such as agriculture and manufacturing.

Key findings from this review include:

- Detector costs span equipment, installation, maintenance, calibration, training, and data systems with values varying by technology and site conditions.
- For Class II and III railroads, the costs of installing and maintaining wayside detector systems can exceed the quantifiable safety benefits in the initial years of deployment. These railroads operate on limited margins and rely on limited operating revenues, meaning that unfunded technology requirements would directly affect their financial capacity. Without external support, investment requirements could strain operating budgets and limit resources available for core maintenance and service needs.
- Industries reliant on rail shipments may experience pass-through effects if smaller carriers adjust their rates to manage expenses associated with technology investments.

6.1 Analysis Context

While wayside detection technologies have demonstrated clear safety benefits, their deployment involves substantial capital, operating, and maintenance costs. Understanding the financial and economic impacts can inform public policy around wayside systems and the impacts on carriers.

Minnesota law directs the Commissioner of Transportation to "estimate costs of requiring wayside detector systems for Class II and Class III railroads and rail carriers and identify potential state funding mechanisms to institute the requirements," and to "analyze the costs and impacts, if any, on the transport of goods on certain Minnesota industries and sectors."

This chapter responds to that direction at a high level, focusing on:

- The role that Minnesota's Class II and III railroads play in supporting key industries;
- The major types of costs associated with wayside detector deployment and ongoing operations;
- Potential funding and cost-sharing mechanisms that could support implementation; and
- How additional costs could affect Minnesota industries and shippers, such as agriculture, mining, manufacturing, timber, retail, and automotive sectors.

The analysis relies on sources such as the Minnesota State Freight Plan, the State Rail Plan, legislative fiscal notes, FRA studies, and other national rail industry data.

6.2 Role of Class II and III Railroads in Minnesota's Economy

Class II and III railroads (short lines and regional railroads) play an important role in Minnesota's freight system relative to their size. They account for roughly one-fifth of the state's rail track miles, much of it in rural areas that lack alternative rail options.[57] These railroads connect elevators, mines, mills, processors, and manufacturers to Class I railroads, ports, and national markets.

State and federal analyses show that short lines support thousands of direct and indirect jobs and help sustain economic activity in agriculture, taconite mining, forest products, chemicals, and manufacturing.

Additionally, Class II and III railroads provide the first and last mile for many of Minnesota's rail-reliant industries. Where truck alternatives exist, they are often more expensive and can increase pressures on rural highways and bridges. Where alternatives do not exist, reliable short lines and regional rail services can be a precondition for local production and investment.

This context informs the understanding of how any new safety requirements, including wayside detector mandates, interact with the financial capacity of these railroads and the industries they serve.

6.3 Cost Elements of Wayside Detectors

As highlighted earlier in this report, detailed, state-specific data of detector locations, numbers, and types, as well as cost data are classified by carriers as sensitive and were therefore not provided for use within the study.

Additionally, industry input indicates that unit costs and maintenance costs can vary by technology type, vendor, and site conditions, and that some earlier estimates (on both costs and benefits) may not reflect real-world experience on small railroads.

As a result, rather than assigning a single point estimate, this study describes ranges for the main cost components of wayside detector deployment based on FRA studies and industry input. These costs fall into several categories:

- **Capital Costs (Per Detector):** include equipment purchase, site preparation, access to power and communications equipment, and training.
- **Installation and Integration:** include installation labor and testing, and integration with existing signaling, communications, or back-office systems.
- **Ongoing Operating and Maintenance Costs:** include routine inspections, calibration, and component replacement, software licensing, data hosting, analytics platforms, training of staff in interpreting alarms and maintaining equipment.
- **Operational Impacts:** include time and cost associated with responding to detector alerts, including train stops and inspections.

[57] MnDOT, State Freight Plan, 2024.

The following provides the key assumptions used related to these cost categories:

- **Equipment:** Approximately $200,000 per detector, assuming HBD and single-track installation.[58]
- **Installation:** Applied as a percentage (12 - 15%) of equipment cost consistent with industry standards; about $25,000 per detector for the purpose of this analysis.[59]
- **Annual Maintenance:** A range of $12,000 to $15,000 per detector is recommended by the technology providers annually for routine upkeep, plus at least $5,000 for calibration/testing.
- **Personnel Training:** Estimated at one-third of annual maintenance costs, aligned with standard industry practice for budgeting recurring training programs; about $5,000 for the purpose of this study.
- **Data Systems, Communications Software and Compliance:** FRA analysis and vendor input place these expenses in the range of $8,000 to $15,000 annually.

6.4 Benefit Elements of Wayside Detectors

The benefits of wayside detector deployment are estimated as **safety benefits**, quantified by the expected reduction in derailments attributable to expanded detector coverage.

The baseline derailment frequency and associated costs require careful examination given the variation between incident types, railroad classes, and severity levels. National derailment rates for all U.S. railroads average approximately 1,200-1,300 incidents annually, with Class I railroads experiencing approximately two derailments per million train-miles in 2022. The derailment rate has declined 30 percent since 2000 across all railroads.[60] For equipment-related causes specifically (the category most relevant to wayside detector effectiveness) bearing failures, broken wheels, and truck component defects represent the primary mechanical causes on mainlines.

A recent study in Pennsylvania estimated a median derailment cost of $44,456 for derailments, reflecting that most of these events are low-speed yard incidents with minimal damage.[61] Recent major incidents, such as the East Palestine derailment, with costs exceeding hundreds of millions of dollars, dramatically inflate average costs but represent rare, high-severity outliers rather than typical preventable equipment failures.

As a result of these assumptions, the benefit calculation therefore applies the formula: (Carloads ÷ 80,000) × $44,456 × Estimated Reduction Rate in Derailments.

Operational Benefits from wayside detector systems are described qualitatively as there is no peer-reviewed basis for estimating specific figures. FRA's study of wayside detector effectiveness and

[58] TRB Circular E-C085, Rail Operational Safety, 2006. https://onlinepubs.trb.org/onlinepubs/circulars/ec085.pdf

[59] Bridgelall, P. et al., Benefit Cost Analysis of Railroad Track Monitoring Using Sensors Onboard Revenue Service Trains, MPC-549, 2021. https://rosap.ntl.bts.gov/view/dot/61622/dot_61622_DS1.pdf

[60] AAR Fact Sheets, Freight Train Derailments: Key Facts, accessed 2025.

[61] Center for Rural Pennsylvania, Train Derailments in Rural and Urban Pennsylvania, 2018 to 2022.

benefit–cost analysis similarly emphasizes qualitative categories for detector benefits (for example, fewer in-service failures, reduced unscheduled repairs, extended component life, and better workforce utilization) without specifying standard dollar savings per track mile or per carload.

Additionally, Minnesota's "Pathways to Decarbonizing Transportation" initiative, and related statewide multimodal planning efforts recognize rail as an important strategy for **reducing on-road emissions**.[62] Rail contributes to decarbonization primarily by lowering heavy-truck vehicle miles traveled through viable rail alternatives and by improving overall freight system efficiency. The Federal Rail Energy and Emissions Action Plan underscores that, because rail is significantly more energy-efficient than trucking, expanding freight-rail access through short lines can help reduce total system-wide energy demand and emissions associated with the projected growth in truck tonnage.[63]

6.5 Sensitivity Assessment

To reflect uncertainty in the underlying cost and benefit assumptions, the analysis models three scenarios based on the distance between detectors: 10-mile, 15-miles, and 20-miles. These scenarios vary key inputs such as equipment and installation costs, detector performance, operating expenses, derailment frequency, and estimated safety benefits. **The intent is to provide an illustrative set of high-level estimates.**

The sensitivity analysis also incorporates the total Class II and Class III track mileage in Minnesota. According to the State Rail Plan, approximately 984 miles of track are operated by Class II and III railroads.[64] Applying different spacing assumptions to this mileage yields varying estimates of the number of detectors that would be required and, therefore, the likely range of potential costs.

Figure 24: Statewide Class II and Class III Cost-Benefit Sensitivity Scenarios (High-Level Estimates)

Category	*10-miles*	*15-miles*	*20-miles*
Total Track Miles	984	984	984
Detector Spacing	Every 10 miles	Every 15 miles	Every 20 miles
Detectors Needed	98	65	49

[62] MnDOT, Pathways to Decarbonizing Transportation In Minnesota, August 2019.
[63] DOE & FRA, An Action Plan for Rail Energy and Emissions Innovation, 2024.
[64] Operating mileage is used as a proxy for actual track mileage because railroads may operate over track owned by other entities under trackage rights, and detailed ownership-specific mileage data were not available for this analysis.

One-Time Upfront Costs:

Cost Component	*10-miles*	*15-miles*	*20-miles*
Equipment Cost	$19,600,000	$13,000,000	$9,800,000
Installation Cost	$2,400,000	$1,630,000	$1,230,000
Total Capital Cost	**$22,000,000**	**$14,630,000**	**$11,030,000**

Annual Costs:

O&M Component	*10-miles*	*15-miles*	*20-miles*
Maintenance	$1,176,000	$877,500	$735,000
Calibration/Testing	$490,000	$325,000	$245,000
Data/Compliance	$784,000	$780,000	$735,000
Total Annual O&M Cost	**$2,450,000**	**$1,982,500**	**$1,715,000**

Annual Safety Benefits:

Benefit Component	*10-miles*	*15-miles*	*20-miles*
Derailment Reduction Benefit	$9,169	$18,338	$27,506

Source: CPCS analysis, 2025.

These results show how upfront capital costs and recurring annual operating costs scale with the number of detectors assumed in each scenario. Equipment and installation costs represent the one-time capital investment, while annual maintenance, calibration, and data-related expenses make up the ongoing costs. Because detector spacing assumptions vary across scenarios, the total number of units, and associated costs differ accordingly.

The table is intended to illustrate how different assumptions influence potential costs and benefits at a statewide level. These estimates do not represent any specific railroad or corridor and should be interpreted as high-level, order-of-magnitude indicators based on available national data and the mileage of Minnesota's Class II and III network.

Extending these scenarios over a 10-year period provides additional context for understanding long-term implications. The one-time capital cost remains fixed, while annual operating and maintenance costs and safety benefits recur each year.

Under the current assumptions, recurring annual operating costs can exceed the quantified safety benefits, resulting in a negative cumulative net impact over the 10-year period. However, the balance could shift if key assumptions change, for example, if derailment costs increase, if additional operational benefits are quantified in future research, if traffic levels change, or if technology and maintenance costs decline over time.

External funding support or cost-sharing mechanisms could also alter the long-term financial picture for individual carriers. Over a 10-year horizon, therefore, results remain sensitive to baseline assumptions, available resources, and evolving operational conditions.

6.6 Sectoral Impacts of Wayside Detector Deployment

Although the estimated net systemwide annual impact of wayside detector deployment may be modest in aggregate, higher capital and operating costs can be challenging for smaller railroads that already operate with constrained revenues and legacy infrastructure.

Minnesota's State Rail Plan observes that many short lines have relatively poor track and structure conditions compared with Class I railroads, including limitations in carload weights served by tracks and poor tie and ballast conditions which constrain speeds and limit their ability to absorb additional unfunded investment. The plan further notes that short lines often serve lower-density markets with narrow margins, and that some have had to defer maintenance investments. In this context, new technology requirements, if not paired with support, may create pressures that may ultimately be passed on to shippers through higher rates, fees, or reduced service levels.[65]

Minnesota's statewide and district level freight plans consistently identify **agriculture** and related rural industries as highly dependent on rail, particularly for bulk commodities. The State Freight Plan shows that cereal grains are one of the top rail commodities by tonnage in Minnesota. By value, cereal grains, crude petroleum, and other foodstuffs are the top three rail-reliant commodities.[66]

The State Rail Plan explains that short lines perform a critical role for smaller agricultural and industrial product shippers, providing connections to Class I mainlines and generating significant revenue for larger carriers by aggregating rural traffic.

State materials prepared in support of the Minnesota Short Line Railroad Modernization (SLIM) Tax Credit further highlight the role of short lines in agricultural and rural economies. The same document notes that many short lines operate on legacy infrastructure suited only for 263,000-pound railcars and require substantial investment to accommodate modern 286,000-pound cars.[67]

Heavy industries such as **mining and construction** are also traditionally associated with rail transport for moving large volumes over long distances. The State Freight Plan identifies metallic ores as the second-largest rail commodity by tonnage in Minnesota, reflecting the importance of rail service to the state's taconite and related mining operations. The State Rail Plan also notes that Class I railroads focus on bulk freight including coal and ore, while short lines and regional railroads connect mines and processing facilities to these mainline networks.[68]

Because metallic ores and construction materials are heavy, relatively low-value commodities, transportation costs comprise a significant share of delivered price, and rail is often the only cost-effective mode for long-distance shipment.

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[65] MnDOT, State Rail Plan, 2025. https://www.dot.state.mn.us/planning/railplan/

[66] MnDOT, State Freight Plan, 2024. https://www.dot.state.mn.us/planning/freightplan/index.html

[67] Minnesota Regional Railroad Association, Short Line Railroad Modernization (SLIM) Tax Credit.

[68] MnDOT, State Rail Plan, 2025; MnDOT, State Freight Plan, 2024.

The State Rail Plan emphasizes that improvements to freight rail infrastructure (which would include safety and reliability investments) benefit the mining sector by enhancing network efficiency and helping short lines accommodate modern equipment. Conversely, if smaller carriers face difficulty financing any required technology investments, the resulting constraints could limit capacity or increase costs on corridors critical to Minnesota's mining and construction products supply chains.

Minnesota's freight plans also highlight **manufacturing, food processing, and related industrial activities** as key users of rail for both inbound raw materials and outbound finished goods.

State policy documents and the State Freight Plan frame one of Minnesota's core freight objectives as improving the contribution of the freight system to economic efficiency, productivity, and competitiveness and ensuring that critical multimodal segments remain in a state of good repair. The State Rail Plan notes that short lines are vital to the economic growth of communities they serve and that local investment in short line railroads can have significant local impact by preserving or enhancing rail-served industrial sites.

In this context, wayside detectors and related safety technologies can support key freight industries in the state by improving reliability and reducing derailment risk, while the associated costs may still present challenges for carriers with relatively smaller operations.

6.7 Existing Funding Mechanisms for Wayside Detectors

This section identifies a few funding mechanisms that can support deployment of wayside detector systems.

6.7.1 Consolidated Rail Infrastructure and Safety Improvements (CRISI) Federal Grants

The CRISI program is the most directly applicable federal source for wayside detector deployment because federal statute explicitly lists "deployment of railroad safety technology, including … rail integrity inspection systems" as an eligible project type. Under 49 U.S.C. § 22907, eligible recipients include states, local governments, Class II and III railroads, port authorities, and a range of other public and nonprofit entities. CRISI funds projects that improve the safety, efficiency, and reliability of freight and passenger rail, and recent notices of funding opportunity highlight safety technologies, condition monitoring, and risk-reduction projects as priority areas . CRISI also includes a rural set-aside of at least 25 percent, which increases accessibility for Minnesota's short line operators and others serving rural communities.[69]

6.7.2 Minnesota Short Line Railroad Infrastructure Modernization (SLIM) Tax Credit

The SLIM tax credit, codified at Minn. Stat. § 290.0695, provides an income tax credit equal to 50

[69] 49 U.S. Code § 22907 (2021), https://www.govregs.com/uscode/title49_subtitleV_partB_chapter229_section22907

percent of qualified expenditures by eligible short line railroads for the maintenance, reconstruction, or replacement of railroad infrastructure in Minnesota. Eligible infrastructure includes "track, roadbed, bridges, industrial leads and sidings, and track-related structures," with the credit capped at $3,000 per mile of track owned or leased in the state and available for expenditures between January 1, 2023, and December 31, 2030.

Because the statute is framed around physical infrastructure and does not mention safety equipment, communications systems, or wayside technologies, wayside detectors are not clearly within the current definition of qualified expenditures and would likely require clarification or legislative amendment to be eligible.[70]

6.7.3 Minnesota Rail Service Improvement Program (MRSI)

Established in 1976, the MRSI Grants program is the state's primary tool for preserving and enhancing freight rail service on lines that might otherwise be at risk of disinvestment or abandonment. The program provides grants, low- or no-interest loans, loan guarantees, and rail bank support for projects such as rail line rehabilitation, capital improvements, rail purchase assistance, industrial spur expansion, and improved loading/unloading facilities that strengthen freight rail service and support economic development. Program guidance does not list wayside detectors explicitly but focuses on freight rail service improvement and preservation; detector installation could potentially be eligible if framed as a capital improvement that enhances safety and long-term viability of freight service on a line, subject to MnDOT's project-by-project eligibility review.[71]

6.7.4 Other State and Local Tools

In addition to MRSI and SLIM, Minnesota and local governments may use broader economic development tools, such as state bonding for freight rail projects, local tax increment financing, or site-specific development incentives, to support rail infrastructure improvements that are integral to retaining or expanding major employers.

The State Rail Plan also notes that freight rail investments can be packaged with other public and private funds to support industrial development and preserve rail-served sites, particularly in rural communities where short line service is critical to economic competitiveness.[72]

While these programs are not dedicated to wayside detector funding sources, they provide potential avenues for co-funding detector deployment when the technology is part of a broader rail infrastructure or site-readiness project that satisfies existing statutory purposes.

[70] Minnesota Statutes § 290.0695 (2023), "Short Line Railroad Infrastructure Modernization Credit," accessed September 2025. https://www.revisor.mn.gov/statutes/cite/290.0695

[71] MnDOT, Minnesota Rail Service Improvement Program (MSRI), 2025. https://mndot.net/ofrw/railroad/mrsi-program-description.html

[72] MnDOT, State Rail Plan, 2025.

7 Federal Regulation and Pre-emption

Key Chapter Takeaways:

This Chapter discusses how the Federal Railroad Safety Act (FRSA) and the Interstate Commerce Commission Termination Act (ICCTA) govern rail safety and operations.

Both statutes are designed to ensure consistent national rules and to prevent a patchwork of conflicting state requirements for railroads that operate across state lines.

Neither law requires detectors nor sets minimum spacing, though the FRA has issued safety advisories regarding detector use.

7.1 Federal Railroad Safety Act Pre-emption

The Federal Railroad Safety Act (FRSA) of 1970 establishes uniform national safety standards for railroads. To achieve uniformity, federal law preempts state law whenever federal and state laws cover the same subject matter. This helps prevent a collection of different standards in different states that would be difficult for railways to abide by.

Specifically, **FRSA, 49 U.S.C. § 20106** states:

(a) National Uniformity of Regulation. —

> ***(1)*** *Laws, regulations, and orders related to railroad safety and laws, regulations, and orders related to railroad security shall be nationally uniform to the extent practicable.*
>
> ***(2)*** *A State may adopt or continue in force a law, regulation, or order related to railroad safety or security until the Secretary of Transportation (with respect to railroad safety matters), or the Secretary of Homeland Security (with respect to railroad security matters), prescribes a regulation or issues an order covering the subject matter of the State requirement. A State may adopt or continue in force an additional or more stringent law, regulation, or order related to railroad safety or security when the law, regulation, or order—*
>
> > ***(A)*** *is necessary to eliminate or reduce an essentially local safety or security hazard;*
> >
> > ***(B)*** *is not incompatible with a law, regulation, or order of the United States Government; and*
> >
> > ***(C)*** *does not unreasonably burden interstate commerce.*

The FRSA only permits state regulation related to railroad safety in two limited circumstances: (1) if the Secretary of Transportation has not yet regulated the subject matter of the state regulation; or (2) if the regulation is necessary to eliminate an essentially local safety or security hazard.[73]

FRA has issued several safety advisories in response to recent safety incidents:

- **Safety Advisory 2023-01** recommends railroads set inspection thresholds based on HBD data, train and qualify HBD maintenance staff, inspect rolling stock flagged by HBD's and promote safety-focused decision-making using HBD data.
- **Safety Advisory 2023-01 Supplements** recommend using trend-based and comparative HBD temperature analysis, encourage data sharing and alert standardization among different railroads, support the use of automated tools to flag temperature anomalies, and advise adjusting train handling and inspection protocols based on alerts.
- **Safety Advisory 2023-04** recommends the use of WILD systems to detect high-impact wheels, replacing wheels that risk damaging track structures, and emphasizes WILD as a preventive tool against wheel-related derailments.

7.1.1 Example Case Laws of Federal Preemption

Two notable cases involving interpretations of the federal preemption under the FRSA have reached the Supreme Court: *CSX Transp., Inc. v. Easterwood* and *Norfolk So. Ry. Co. v. Shanklin*, and in both cases, the court held that FRSA preempted common law tort duties.

CSX v. Easterwood (1993): In the case of Easterwood, a truck driver was killed in Cartersville, Georgia in 1988 when a CSX train collided with his truck at a grade crossing. The driver's widow brought an action against CSX alleging that the railroad was negligent under Georgia law for traveling at excessive speeds and failing to have adequate warning devices at the crossing. Because federal regulations established a maximum train speed of 60 miles per hour for that stretch of track based on its classification, and because the train in question was compliant with federal regulations, the excessive speed claim was preempted. The court did conclude, however, that the negligence claim based on the absence of warning devices was not preempted.

Norfolk Southern v. Shanklin (1999): In the case of Shanklin, a man was killed when a Norfolk Southern train struck his car at a grade crossing in western Tennessee. The man's widow brought a case against Norfolk Southern alleging inadequate warning devices at the crossing. The Supreme Court ruled that the claim of inadequate warning devices was preempted because the warning devices – reflective 'cross buck' signs – had been installed using federal funds. As a result, "the federal standard for adequacy set forth in the applicable regulations displaced state statutory and

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[73] U.S. Court of Appeals for the Sixth Circuit - 283 F.3d 812, 6th Cir., 2002. https://law.justia.com/cases/federal/appellate-courts/F3/283/812/484511/

common law addressing the same subject matter resulting in preemption of the claim."[74]

It should be noted that, while FRA has not made regulations specific to wayside detectors, FRA has made regulations pertaining to related subject matter of overheated wheels and to defective roller bearings; 49 C.F.R. § 215 states that a railroad is prohibited from placing a rail car into service in situations where "[a] wheel on the car shows signs of having been overheated[.]"

7.2 Interstate Commerce Commission Termination Act Preemption

Federal law may also preempt state regulations regarding wayside detector systems due to the Interstate Commerce Commission Termination Act (ICCTA) of 1995. ICCTA vests the federal Surface Transportation Board (STB) with exclusive jurisdiction over transportation by rail carriers and operation of their facilities and preempts other remedies under federal or state law. The STB broadly regulates the economic and operational aspects of rail and complements the FRA's jurisdiction over rail safety.

As per **49 U.S.C. §§ 10101(b)** The STB has jurisdiction over:

(1) *Transportation by rail carriers, and the remedies provided in this part with respect to rates, classification, rules (including car service, interchange, and other operating rules), practices, routes, services, and facilities of such carriers; and* ***(2)*** *the construction, acquisition, operation, abandonment, or discontinuance or spur, industrial, team, switching, or sidetracks, or facilities, even if the tracks are located, or intended to be located, entirely in one State.*

Numerous state mandates have been preempted due to ICCTA, including laws not specifically targeted at rail operations but which may impact national rail uniformity. A proposed California regulation mandating a maximum age for locomotives for environmental reasons was withdrawn after it was determined this would not be allowed under ICCTA. In *BNSF Ry. Co. v. City of Edmond*, it was found that a state regulation seeking to regulate the time a train can occupy a grade crossing was preempted by ICCTA.

7.3 FRA Safety Waivers

Under **49 U.S.C. § 20103(d)**, FRA may grant safety waivers, exemptions from federal safety regulations, when such relief is in the public interest and consistent with railroad safety. Over the past decade, waivers have increasingly reflected the imbalance between rapid technological change and the regulatory process.

Key trends related to FRA safety waivers between 2015 and 2025 include:

- **Technology-driven waivers:** Most notable requests involve advanced inspection and monitoring systems, such as Automated Track Inspection systems, highlighting the industry's push to modernize inspection practices.
- **Mixed outcomes:** Some waivers, such as Amtrak's shunt enhancement program which looked to install shunt enhancer antennas to reduce the Loss of Shunt (LoS) at grade

[74] Preemption is Not Dead: The Continued Vitality of Preemption unde.pdf

crossings, have been approved with conditions, while others related to Positive Train Control, have been denied as overly broad.

- **Growing delays and litigation:** Railroads have challenged the FRA in federal court for failing to act on waiver requests in a timely manner, with courts occasionally overturning FRA denials as arbitrary.
- **Labor-management dynamics**: Stakeholder positions on waivers vary. Unions have often opposed waivers that they view as reducing manual inspections or affecting staffing; in other instances, labor and carriers have jointly supported technology-focused waivers.
- **Policy uncertainty:** Recent attempts to reform the waiver process, including proposals for expanded labor review and stricter justification standards, have added further uncertainty.

Any state-level rail safety regulation should be mindful of FRA's waiver authority and the federal trends shaping its use. State rules may either complement national safety efforts or, if not carefully aligned, risk conflict with FRA decisions and evolving federal standards.

Detailed case examples of Automated Track Inspection waivers, PTC waiver denials, Amtrak's shunt enhancement program, Metra (Northeast Illinois Regional Commuter Railroad Corporation) extensions, and current waiver litigation are provided in the appendix.

7.4 Experience from other states

Despite the potential for federal preemption, some states have considered or enacted state regulations for wayside detectors with the goal of improving safety, including Ohio, Colorado, and California examples highlighted below.

7.4.1 Ohio

Ohio is currently the only state in the country to require railroads to install wayside detectors every 10-15 miles with the passage of the state budget in 2023. Then, in 2025, House Bill 54 updated state regulations by mandating upgrades to wayside detector systems, including the replacement of any outdated or nonfunctional systems with systems that adhere to current industry standards. It also established an enforcement mechanism, empowering the state's Public Utilities Commission and Department of Transportation to scrutinize a railroad company's safety practices if a railroad fails to cooperate with safety investigations.

Specifically, Section 4955.50 of Ohio's code, Wayside detector systems,[75] states:

(C) If a railroad company refuses to work or otherwise cooperate with the public utilities commission and the department of transportation in good faith in accordance with this section, the commission and department shall investigate that railroad company's safety practices and standards in accordance with 49 C.F.R. Part 212. The commission and department shall determine whether the

[75] Ohio Revised Code § 4955.50 (2024) - Wayside Detector Systems. :: 2024 Ohio Revised Code :: U.S. Codes and Statutes :: U.S. Law :: Justia

company appears to be in compliance with federal railroad safety laws, as defined in 49 C.F.R. Part 209.

(D) (1) If a railroad company does not appear to be in compliance with the applicable federal standards based on an investigation conducted under division (C) of this section, not later than sixty days after the conclusion of the investigation, the commission and department shall make a report to the federal railroad administration. The report shall detail the results of the investigation and recommend that the administration take enforcement action in accordance with its authority against the railroad company for the safety violations discovered through that investigation. (2) The commission and department shall send a copy of the report to the governor, the president of the senate, the speaker of the house of representatives, and the minority leaders of both the senate and the house of representatives.

7.4.2 Colorado

Colorado's recently adopted regulations take a different approach from Ohio's, in that they do not mandate specific spacing requirements or any specific standard for how often detectors must be maintained. Instead, railroads operating on main lines in Colorado are required to make an annual public report with respect to their wayside detector systems. Key required elements in the report include[76]:

- Types of wayside detectors, their general locations, and spacing between them.
- A description of how the wayside detector system promotes safety, including plans for adjustments or improvements.
- How defects or detections are managed: the process of notifying train operators and what procedures exist.
- What percentage of time each type of detector was operational in the prior year.

Colorado's recent laws also established an Office of Rail Safety within the state's Public Utilities Commission to impose fines for violations of reporting requirements.

Colorado's laws emphasize transparency, reporting, and accountability, and explicitly acknowledge that federal regulations recommend, but do not require, space for wayside detectors.

7.4.3 California

California has authorized numerous safety-related regulations for railroads. For example, in 1992, the California Public Utilities Commission required that railroads install trackside defect detectors at 30-mile intervals, in addition to other safety measures, after two train derailments involving hazardous materials.[77]

More recently, in 2025, proposed Senate Bill 667, considered regulating wayside detectors, along with maximum train length. The bill did not become law because it did not meet legislative deadlines. However, if passed, SB 667 would have required railroads to install wayside detectors every 10-15 miles, restricted freight trains speeds to less than 10

[76] Find Law, Colorado Revised Statutes Title 40. Utilities § 40-20-303. Wayside detector systems--obstructions at public crossings--reports—definitions, 2022. https://codes.findlaw.com/co/title-40-utilities/co-rev-st-sect-40-20-303/?utm_source=chatgpt.com

[77] Justia, Union Pacific R. Co. v. California Pub. Utilities Commission, 109 F. Supp. 2d 1186 (N.D. Cal. 2000), 2000. https://law.justia.com/cases/federal/district-courts/FSupp2/109/1186/2522909/

mph on tracks without the sensors, and specified actions to be taken in the event of a defect being detected.[78]

Industry Standards and Best Practices

While the Federal Railroad Administration guidance and rules around equipment and rail safety currently govern detector use, the rail industry has issued guidelines and made commitments on wayside detection systems with the goal of improving safety.

As noted in Chapter 2, the AAR previously recommended detectors be spaced no more than 40 miles apart on "Key Routes", a designation for routes that carry over 10,000 carloads or intermodal portable tank loads of hazmat, or over 4,000 carloads of toxic or highly explosive materials (such as nuclear fuel) over a one-year period (AAR Circular OT-55-R (2022)). However, following the East Palestine derailment, AAR now recommends 15- to 20-mile detector spacing for Class I railroads. All Class I railroads voluntarily agreed to begin installing additional detectors along Key Routes to achieve 15-mile spacing, or up to 20 miles where corridors are equipped with advanced technologies such as acoustic bearing detection or similar systems.

In addition to committing to wayside detector spacing, AAR Class I railroad members committed to stopping trains and inspecting bearings whenever the temperature reading from an HBD exceeds 170°F above ambient temperature, developing a standard for shared trending analysis, encouraging confidential close call reporting, and strengthening training of first responders on accident mitigation.

Class I railroads have made public statements committing to adding HBDs to their railroads to comply with AAR's recommendations. However, there is no comprehensive public dataset yet that shows exact spacing, therefore external verification of network-wide spacing from public sources is not feasible. Similarly, because detailed outage and repair data are typically treated as security sensitive operational information, public data on the number and duration of out-of-service detectors are limited.

Source: AAR Circular No. OT-55-R, 2024. https://www.aar.org/wp-content/uploads/2024/12/2022-07-01-OT-55-R-CPC-KBD.pdf

[78] Bill Text: CA SB667, Regular Session, Amended 2025-2026. https://legiscan.com/CA/text/SB667/id/3206046?utm_source=chatgpt.com

Appendices Table of Contents

Appendix A: Glossary of Terms

Bearings	There are two types of bearings: **Journal Bearings** and **Roller Bearings**. A **Journal Bearing** is a traditional type used in older railcars and supports rotating shafts—such as axles in rail vehicles—by allowing smooth rotation while carrying loads. A **Roller Bearing** is commonly used in modern railcars and similarly provides support to rotating parts, except that it uses cylindrical rollers to reduce friction, thereby requiring less maintenance than journal bearings.
Bungalow	A small, weatherproof structure, typically metal or concrete, that houses vital signaling and communication equipment.
Clearance Gauge	A clearance gauge refers to the standardized envelope or profile that defines the maximum dimensions a train or rail vehicle can have to safely pass through tunnels, bridges, platforms, and other trackside structures.
Consist	Refers to the set or arrangement of rail vehicles that make up a train.
Cross-level	The relative height difference between the two rails of a track at a given location, typically measured across the track at a right angle.
Digital Twin	A digital twin is a virtual representation of a physical asset, system, or process that is continuously updated with real-time data from sensors and other sources.
Emissivity	A measure of how efficiently a surface emits thermal radiation compared to a perfect blackbody (which has an emissivity of 1.0). It's a dimensionless value between 0 and 1, and it plays a critical role in infrared thermography, thermal imaging, and heat transfer calculations.
Envelope	There are three types of **envelopes** used in rail terminology: **Vehicle Envelope, Clearance Envelope, and Infrastructure Envelope**. A **Vehicle Envelope** refers to the outer dimensions of a train or railcar, including dynamic movement (sway, tilt). A **Clearance Envelope** is the space required around the vehicle to ensure safe passage through tunnels, bridges, platforms, etc. An **Infrastructure Envelope** refers to the physical limits of structures that trains must pass through.
Flange	The raised edge or lip on the inside of a train wheel that helps keep the wheel aligned on the track.
Flat Spots	Localized areas on a train wheel that have become flattened due to skidding or sliding rather than rolling, usually a result of emergency braking (when wheels are locked into position and prevented from rolling), an imbalance or overloading of a truck, or malfunction in the braking system.
Hot Bearing Detectors (HBDs)	Identify abnormal bearing temperatures that may signal defects using infrared thermal sensors positioned outside the rail tracks, HBDs measure the heat emitted by bearings using thermal sensors positioned outside the rail tracks.
Key Route	AAR defines a track segment as a "**Key Route**" if it carries either 10,000 carloads or intermodal portable tank loads of hazmat, or 4,000 carloads of toxic or highly explosive materials (e.g., nuclear fuel) over a one-year period.
Light Detection	**LiDAR** is a remote sensing technology that uses laser light to measure distances and create high-resolution maps of surfaces.

and Ranging (LiDAR)	
Line	A line typically refers to a specific stretch or route of railway track used for train operations. Types of lines include: **Main Line**, the primary route used for long-distance or high-priority trains; **Branch Line**, a secondary route that connects to the main line, often serving local or industrial areas; **Freight Line**, which is dedicated to cargo transport; **Passenger Line**, primarily used for commuter or intercity passenger services; and **High-Speed Line,** designed for high-speed trains with specialized infrastructure.
Loading Gauge	A loading gauge defines the maximum height and width that a rail vehicle and its load can have to safely pass through infrastructure like tunnels, bridges, platforms, and signals.
Mainline	Refers to the primary track or route used for long-distance or high-priority train movements.
Metra	Northeast Illinois Regional Commuter Railroad Corporation
NDIR Spectroscopy	Non-dispersive Infrared (NDIR) spectroscopy, a type of advanced infrared absorption spectroscopy used to detect concentrations of characteristic combustion gases for detection of fires.
Out-of-Round	Refers to a condition where a wheel (or another rotating component like a brake disc or bearing surface) is not perfectly circular, which can result in vibration or noise, uneven wear, reduced ride quality for passengers, potential safety risks, and false positives in wheel defect detection systems. These irregularities can be caused by thermal stresses, impact damage, or flat spots from emergency breaking.
Pantograph	A device mounted on the roof of electric trains, trams, or electric buses that collects power from overhead wires. It maintains contact with the overhead catenary system and transfers electricity to the vehicle's electrical systems, enabling propulsion and onboard functions.
Portal	Describes the frame or gantry structure that spans across the track and holds the infrared sensors used for detecting out-of-profile or shifted loads. This is similar to how portals are used in tunnel entrances or overhead scanning systems.
Rolling Stock	**Rolling stock** refers to all vehicles that move on a railway, including both powered and unpowered units. This encompasses locomotives, passenger coaches, freight wagons, and maintenance vehicles. The term is used to distinguish mobile rail assets from fixed infrastructure such as tracks, signals, and stations.
Shunt	Refers to the process of moving train cars from one track to another, often within a rail yard- it is used to organize trains, prepare them for departure, or move them for loading/unloading.
Spalling	Spalling occurs when small pieces of metal flake off due to thermal stress, rolling contact fatigue, or impact. This can happen on wheels, the railhead (near welds or high-impact zones) or bearings.
Strain, Strain Gauge	In general engineering terms, strain is the deformation or displacement of material that results from an applied force or load. A **Strain Gauge** is used to monitor the structural integrity and performance of components under stress. Strain is measured on components like axles, rails, bogies, and brake systems to detect fatigue, overloads, or structural weaknesses.

Surface Profile	The vertical alignment of the rails, including dips, bumps, and undulations along the track.
Transducer	A device that converts one form of energy into another. In engineering and rail contexts, transducers are commonly used to convert physical phenomena (like pressure, force, temperature, or vibration) into electrical signals that can be measured, monitored, or recorded.
Triaxial Tiltmeter Sensors	Triaxial tiltmeter sensors are a specialized type of tilt sensor used for high-precision monitoring of angular changes in three dimensions (X, Y, and Z axes); they measure angular displacement or tilt in three orthogonal directions. They typically use MEMS (Micro-Electro-Mechanical Systems) accelerometers to detect changes in orientation relative to gravity.
Truck, Bogie, or Truck Bogie	The framework underneath a rail vehicle that holds the wheelsets and allows the vehicle to roll, steer, and absorb vibrations caused by track irregularities. **Regional terminology variations**: "truck", "bogie", "truck bogie" are all used to refer to refer to the assembly component beneath a railcar. "Truck" is commonly used in North America, whereas "bogie" is used in Europe, Asia and other regions.
Truck Performance Detector (TPD)	A comprehensive system that measures the curving performance of railroad trucks as they navigate specific track configurations.
Truck Hunting	Hunting is a condition where freight trucks exhibit a dynamic instability.
Twist	The difference in cross-level between two points on the track, typically measured over a short distance (e.g., 3 meters or 10 feet).
Universal Machine Language Equipment Register (UMLER)	A centralized database maintained by Railinc that contains detailed information on more than two million pieces of rail equipment in North America.
Warp	A broader term that describes distortion or unevenness in the track plane, often involving both vertical and lateral irregularities.
Wayside Detector Systems	Trackside sensors that continuously monitor critical components such as wheelsets, bearings, and axles.

Appendix B: Federal Railroad Administration Safety Waivers

The Federal Railroad Administration (FRA) may grant waivers from regulatory requirements "if such waiver is in the public interest and consistent with railroad safety."[1] The FRA has granted numerous railroad safety waivers over the past decade, spanning several key categories that reflect both technological advancement and operational challenges. These waivers demonstrate the ongoing evolution of railroad safety regulations and the industry's efforts to implement innovative solutions while maintaining safety standards. Potential Minnesota wayside detector regulations have the potential to conflict with or complement existing and future safety waivers. The following sections summarize safety waivers granted over the past several years by the federal government and trends that should be considered as Minnesota determines wayside detector regulations.

Automated Track Inspection Waivers

Some of the most significant and controversial waivers have involved Automated Track Inspection (ATI) systems, which allow railroads to reduce manual visual inspections by using advanced sensor technology to detect track defects in real time.

BNSF Railway ATI Program (2018-Present)

In November 2018, BNSF received the first major ATI waiver for its Powder River Division (1,348 miles), reducing required visual inspections from daily to 2–3 times per week based on track class.

In January 2021, FRA granted partial approval for BNSF to extend its ATI program to 46,35 miles along its high-traffic Southern Transcon route between Chicago and Los Angeles. However, FRA denied a further expansion request (4,717 miles) in March 2022.[2]

In June 2024, the Fifth Circuit Court of Appeals ruled in BNSF's favor, ordering FRA to approve the expansion. The court found the denial "arbitrary and capricious," noting ATI detected 200 defects for every one found by visual inspection and significantly improved safety outcomes.[3]

Other Class I ATI Waivers

Following BNSF's initial success, other major railroads sought similar waivers:

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[1] 49 USC §20103. https://uscode.house.gov/view.xhtml?req=granuleid:USC-2012-title49-section20103&num=0&edition=2012

[2] Trains.com, Federal court orders FRA to allow BNSF Railway to expand track inspection program, 2025. https://www.trains.com/pro/regulatory/federal-court-orders-fra-to-allow-bnsf-railway-to-expand-track-inspection-program/

[3] Fifth Circuit, *BNSF Railway Company v. Federal Railroad Administration*, No. 22-60217 (5th Cir. June 21, 2024). https://www.ca5.uscourts.gov/opinions/pub/22/22-60217-CV1.pdf (accessed September 2025).

- Norfolk Southern received ATI testing program approval in 2020 but had its waiver request denied in March 2022.[4]
- Union Pacific, CSX, and additional carriers have filed multiple ATI-related waiver requests that remain pending.[5]

Positive Train Control (PTC) Waiver Denials

In August 2024, FRA denied PTC waiver requests from five carriers seeking relief from certain compliance requirements:[6]

- BNSF Railway
- Norfolk Southern
- South Florida Regional Transportation Authority
- Caltrain
- New Mexico Rail Runner Express

FRA described the requests as "overly broad and indefinite" and sided with union arguments that such changes should be addressed through formal rulemaking—not waivers.

Recent Waiver Extensions and Modifications

Metra Extensions (2025)
The Northern Illinois Commuter Railroad Corporation (Metra) has received multiple waiver extensions in 2025:

- Participation in the FRA's Confidential Close Call Reporting System (C3RS) Program
- Signal system modification approvals for various routes

The Northern Illinois Commuter Railroad Corporation (Metra) has recently filed petitions with FRA in 2025 that relate to waiver- or signal-system matters:

- Metra has petitioned for an extension of its waiver relating to the Confidential Close Call Reporting System (C3RS).[7]

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[4] Freight Waves, FRA slows Class I railroad implementation of improved track and train inspections, 2024. https://www.freightwaves.com/news/fra-slows-class-i-railroad-implementation-of-improved-track-and-train-inspections
[5] RT&S, Norfolk Southern Comments on AAR Petition for Waiver of Compliance with FRA Visual Track Inspection Rules, 2024. https://www.rtands.com/freight/class-1/norfolk-southern-comments-on-aar-petition-for-waiver-of-compliance-with-fra-visual-track-inspection-rules/
[6] FRA, *Five Railroads' Joint Request to Amend Their Positive Train Control Safety Plans – Denial Without Prejudice* (August 27, 2024). https://www.regulations.gov/document/FRA-2010-0056-0645
[7] FRA, *Metra Commuter Railroad – Petition (Docket No. FRA-2015-0011)*, 2025. https://www.regulations.gov/docket/FRA-2015-0011

- Metra has also submitted an application for approval to modify or discontinue portions of a signal system.[8]

Current Waiver Processing Challenges

Litigation and Delays

As of November 2024, multiple Class I railroads filed federal lawsuits against the FRA for failing to act on pending waiver requests within the required nine-month timeframe:[9]

- BNSF filed suit over three delayed waiver requests
- Union Pacific challenged two pending applications
- CSX contested one overdue waiver decision

Some waiver requests have been pending for over two years, leading to industry accusations of regulatory dysfunction and systematic inaction.

Policy Changes and Regulatory Uncertainty

The FRA had proposed several policy changes affecting waiver processing in October 2024:[10]

- Increased labor involvement in waiver review processes
- Enhanced public comment periods for safety-related waivers
- Stricter justification requirements for technology-based relief

In December 2024, the FRA withdrew the proposal, citing the need for further review.[11]

Summary of Waiver Trends (2015-2025)

The decade from 2015-2025 has been characterized by several key trends in FRA waiver activity:

- Technology-Driven Requests: The majority of high-profile waivers have involved advanced safety technologies, particularly automated inspection systems that promise improved defect detection while reducing manual inspection requirements.

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[8] FRA, *Notice of Application for Approval of Discontinuance or Modification of a Railroad Signal System (Docket No. FRA-2025-0053),* 2025. https://www.regulations.gov/document/FRA-2025-0053-0002

[9] Trains.com, Railroads ask federal courts to order FRA to take action on waylaid safety waivers, 2025. https://www.trains.com/pro/regulatory/railroads-ask-federal-courts-to-order-fra-to-take-action-on-waylaid-safety-waivers/

[10] FRA, *Federal Railroad Administration's Procedures for Waivers and Safety-Related Proceedings,* 2024. https://www.federalregister.gov/documents/2024/10/29/2024-24586/federal-railroad-administrations-procedures-for-waivers-and-safety-related-proceedings

[11] FRA, *Federal Railroad Administration's Procedures for Waivers and Safety-Related Proceedings; Withdrawal,* 2024. Federal Register: Federal Railroad Administration's Procedures for Waivers and Safety-Related Proceedings; Withdrawal

- Emergency Response Flexibility: The COVID-19 pandemic demonstrated the FRA's ability to grant comprehensive emergency relief quickly when circumstances warrant, affecting virtually every aspect of railroad operations.
- Increased Scrutiny and Delays: Processing times have significantly increased, with many applications exceeding regulatory deadlines and requiring federal court intervention to compel decisions.
- Labor-Management Tensions: Most controversial waivers involve technologies that could affect employment, leading to systematic opposition from railroad unions and increasingly political decision-making processes.
- Legal Challenges: The waiver process has become increasingly litigious, with courts ultimately ordering the FRA to approve several denied applications and finding agency actions "arbitrary and capricious."

Appendix C: Engagement Log

This study benefited from the insights, expertise, and thoughtful feedback of many individuals and organizations across the rail industry. The project team extends its sincere appreciation to the following partners who provided direct input through consultations and technical correspondence:

- Association of American Railroads (AAR)
- Railinc Corporation
- Short Line Safety Institute (SLSI)
- American Short Line and Regional Railroad Association (ASLRRA)
- SMART Transportation Division (SMART-TD) Minnesota State Legislative Board
- Brotherhood of Locomotive Engineers and Trainmen Minnesota State Legislative Board
- BNSF Railway
- Union Pacific Railroad (UP)
- Genesee & Wyoming Inc. (G&W)
- L.B. Foster Company
- Pavemetrics Systems Inc.
- Southern Technologies Corporation
- Wabtec Corporation
- Wayside Inspection Devices Inc.

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