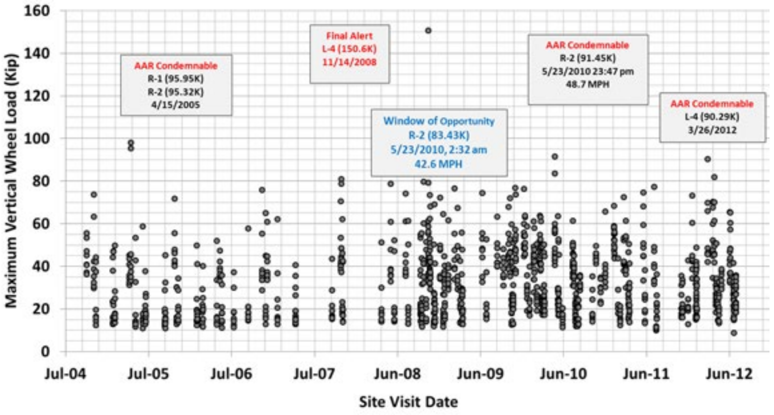
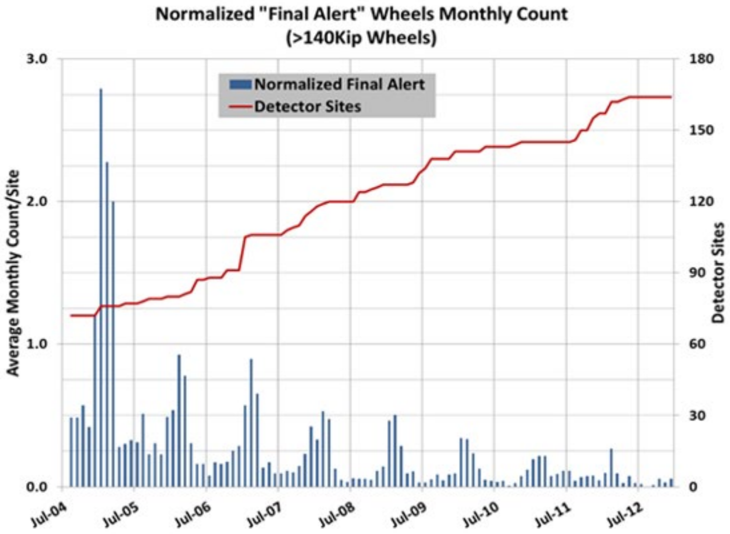
U.S. Department
of Transportation

**Federal Railroad
Administration**

**Office of Research,
Development and Technology
Washington, DC 20590**

Effectiveness of Wayside Detector Technologies on Train Operation Safety





DOT/FRA/ORD-22/19

Final Report | May 2022

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 2022	3. REPORT TYPE AND DATES COVERED Technical Report September 5, 2008–December 31, 2012

4. TITLE AND SUBTITLE Effectiveness of Wayside Detector Technologies on Train Operation Safety	5. FUNDING NUMBERS TO DTFR54-07-D-00002 TO 12
6. AUTHOR(S) Som P. Singh: 0000-0002-6076-6839	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Sharma & Associates, Inc. 100 W. Plainfield Road Countryside, IL 60525	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development Office of Research, Development and Technology Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-22/19

11. SUPPLEMENTARY NOTES
COR: Monique Ferguson Stewart

12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the FRA website.	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Under the safety mandate for wayside detection technology, the Federal Railroad Administration (FRA) has contributed to the development and deployment of various such technologies under its wayside detection research program. The goal of this project was to assess the state of major wayside detection system installations in the US rail network and their effectiveness in derailment incidents reduction. A secondary objective was to identify the derailment causes which require FRA's attention to encourage technology development to address these areas and promote deployment of the proven detection systems.
The Association of American Railroads' (AAR) Integrated Railway Remote Information Service (InteRRIS®) database was accessed to gather data on detector system installation growth and vehicle performance indices data. The FRA derailment database was queried to determine derailment trends, associated causes and costs. The reported analysis shows a strong correlation between the growth in installation of Wheel Impact Load (WILD), Truck Performance Detectors (TPD) and Truck Hunting Detectors (THD), and the reduction in the number of derailments. The trends show that the railroads have improved operational safety through proactive wayside monitoring and detection of vehicle performance. The analysis shows that the major derailment causes that still require detection technology innovation are broken wheel rim and transverse/compound fissure of rail.

14. SUBJECT TERMS Advanced Technology Safety Initiative, ATSI, derailment cause, final alert, high impact wheel loads, Truck Hunting Detector, THD, wayside detection, Wheel Impact Load Detector, WILD, Truck Performance Detector, TPD, rolling stock, derailments, accidents	15. NUMBER OF PAGES 61
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

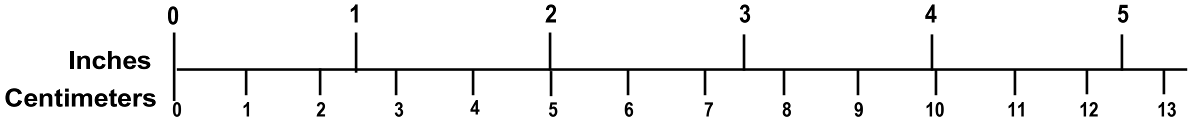
VOLUME (APPROXIMATE)

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

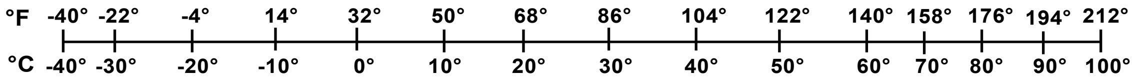
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

Contents

Illustrations

Tables

Executive Summary

The Federal Railroad Administration (FRA) focuses its research and development resources on promoting innovations in the railroad industry which have a potential to improve railroad operational safety, reduce the risk of accidents due to poorly performing railroad equipment, and improve the safety of railroad personnel and the public.

During 2009 to 2012, the research team carried out the work at their engineering offices, near Chicago, IL.

Under the Federally mandated Rail Safety Improvement Act of 2008 (Public Law 110-432, Div. A, Oct 16, 2008), FRA has supported the railroad industry's efforts on research, development and deployment of wayside detection systems.

The primary goal of FRA's wayside detection research program is to promote improved railroad safety and performance through the appropriate and optimal application of automated detection/inspection technologies to detect defects and precursors to safety critical defects in railroad rolling stock. Other secondary goals are to identify key enabling technologies for automated vehicle inspection and to maintain an awareness of the current state-of-the-art and the potential for advancements or breakthroughs, which may be valuable to the railroad industry to address future safety improvement needs.

For this study, FRA funded Sharma & Associates (SA) to analyze retrieved data with limited access from the Association of American Railroads' Equipment Health Monitoring System (EHMS) Integrated Railway Remote Information Service (InteRRIS®) database that has been maintained since 2004. SA's approach was to determine the impact on safety and operational economics and to identify technology gaps where innovations are required to further improve railroad operation safety. An additional approach used in this research included a brief review of the wayside detection systems in North America, and an acquisition of representative sample data from the EHMS InteRRIS® database. This access included wheel impact load, truck hunting and truck gauge spreading force data for 133,000 cars out of the total North American railroad fleet of 1,309,000 cars.[1] To protect information considered proprietary, AAR assigned pseudo identification codes for these cars.

The goal of this project had a focus on demonstrating the impact and effectiveness of various wayside detection systems installed in the North American railroad network. These detectors are designed to reduce the risk in railroad operations by identifying poorly performing equipment before the defects reach a critical threshold and lead to incidents/accidents.

Overall, the work reported here shows that the wayside detection systems have performed as expected in improving the railroad fleet performance and operational safety reflected in reduction in derailment incidences.

---

[1] Railroad Facts 2011 Edition, Copyright © 2011 by the Association of American Railroads.

1. Introduction

One of the primary roles of the Federal Railroad Administration (FRA) is to promote improvements in safety, efficiency and innovation in the railroad industry. To improve the safety of both railroad operating personnel and the public, FRA focuses its resources on research activities that have a potential to reduce the risk of derailments due to poor performance of railroad equipment.

The Rail Safety Improvement Act of 2008 (Public Law 110-432, Div. A, October 16, 2008) mandated a regulatory requirement for a railroad safety risk reduction program in approximately 4 years after its enactment.[2]

Under this mandate, FRA has funded efforts to support the development of wayside detection systems for equipment performance monitoring and, in some cases, promoted and supported the railroads' efforts to deploy detectors such as Wheel Impact Load Detectors (WILD) and Truck Hunting Detectors (THD). This report discusses the work performed by Sharma & Associates (SA) to analyze wayside detection system data from the Association of American Railroads' (AAR) Equipment Health Monitoring System (EHMS) Integrated Railway Remote Information Service (InteRRIS®) database.

Appendix A includes a brief description of various detector systems.

1.1 Background

Over the years, the railroads have developed and deployed Truck Performance Detectors (TPD), Truck Alignment Detectors (TAD) and Acoustic Bearing Detectors (ABD) in the North American rail network through the Association of American Railroads' (AAR) research activities. Other wayside systems, such as Hot Box Detectors (HBD), Wheel Profile Measurement System (WPMS), Dragging Equipment Detector and Low Air Hose Detectors, have also been developed and deployed in the past decade. The railroad industry is also investigating implementation of machine vision system based detection of missing and/or worn system components and safety appliances. Currently, the AAR's Equipment Health Monitoring System (EHMS) stores data only from WILD, TPD, THD and ABD systems in the InteRRIS® database.

The first detector system to be integrated in the railway network was the WILD system. Since 2004, all WILD systems communicate wheel impact load data to EHMS. Currently, the data is warehoused in the InteRRIS® database. Although truck-hunting detectors were installed by several railroads beginning in the late 1990s, the truck hunting indices data collection for the EHMS in InteRRIS® database system was formalized and implemented in 2007.

As of August 2013, AAR reported a total of 171 WILDs, 78 THDs, 27 TPDs, and 21 TADs installed and providing data for InteRRIS® and EHMS purposes. These detectors are spread over the North American railroad system that includes U.S., Canada, and Mexico (Figure 1).

---

[2] 49 U.S.C. 20156 - Railroad safety risk reduction program.

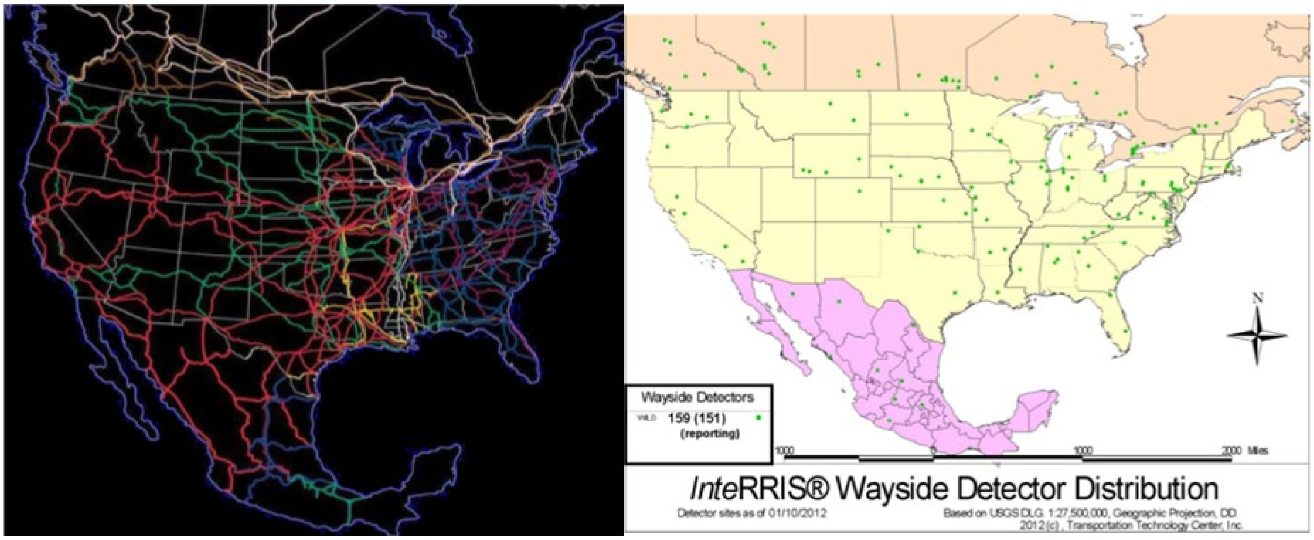


Figure 1. North American Rail Network and WILD Installations circa January 2012 (Courtesy of AAR-TTCI)

1.2 Objectives

To assess the impact of wayside detection systems on railroad safety, FRA needed to review accident data from 2004 to 2012 to identify the leading causes of accidents, and incidents.

Overall, the objectives for this project include the following:

- Access AAR's InteRRIS® database for querying representative sample data on the performance of the North American interchange fleet as related to high impact load, truck hunting and poorly performing/steering trucks
- Store the queried data for future access and analyses for wayside detection research needs
- Trend analysis of WILD, THD and TPD data to determine a reduction in high impact vertical wheel loads, truck hunting and trucks exhibiting high lateral forces
- Analyze a reduction in derailments due to wayside detection systems
- Analyze the impact of detectors on derailment costs
- Identify major derailment causes unaffected by the existing detector systems and technologies to help FRA formulate and provide a focus for future wayside detection research

1.3 Overall Approach

The most important task for was to obtain access to AAR's InteRRIS® and EHMS wayside detection database, which is further discussed in Section 2. Another task was to query FRA's derailment database from 2004 to 2012 for the incidences attributed to mechanical equipment and rail break derailment causes. The mechanical equipment and track causes which are likely to be affected by the HBD, TPD, THD and WILD systems, respectively were identified.

1.4 Scope

The scope of the reported effort included accessing the AAR's InteRRIS® database for wayside detectors data, studying the growth in various wayside detectors installed in the rail network and conducting analysis to establish any relationship between the detectors growth and railroad derailments.

1.5 Organization of the Report

The research was performed to provide data and results, as well as and possible recommendations for future wayside detector systems in the following six sections:

Section 2 documents how SA obtained access to AAR's EHMS InteRRIS® database to conduct further research for this work.

Section 3 provides a history on detector installation and vehicle performance modeling.

Section 4 details the trends of wayside detector system effectiveness.

Section 5 describes the impacts of the implementation of detectors on safety and economics.

Section 6 documents the impact of an increased number of detectors on derailments.

Section 7 summarizes the data and findings from this research project.

2. Wayside Detection Data Access and Queried Performance Data

The first task of this project was to obtain access to AAR's InteRRIS® database in which SA was given limited login privileges to develop a warehousing mechanism for the data to be downloaded to local servers. Three of the most widely implemented wayside systems were queried from the database: WILD, THD, and TPD.

There are dual purposes for these detectors when installed, such as detecting vehicle performance that poses an immediate risk to safe operations, and monitoring vehicle performance deterioration over time. This permits the equipment owners to be proactive in planning for repair and maintenance. For example, the WILD system has four performance indices as part of the detector system. The THD system has three performance indices and TPD has one performance index to flag a wheel, a truck and a car for action.

The performance indices for the three detector systems are shown in Table 1 through Table 3, respectively.

Table 1. Performance Indices for Wheel Impact Load Detection

Index*	Description
WindowOpen_65-80Kip	The car owner can choose to shop the car and make wheel repairs to eliminate defects causing high dynamic loads.
OpportunisticRepair_80-90Kip	If a car is shopped for any non-wheel related repairs, the repair facility is permitted to make wheel repairs to eliminate defects causing high dynamic loads and recover the costs from the car owner under AAR's Interchange Car Repair Billing system.
AARCondemnable_90-140Kip	The operating railroad is required to shop the car for repair as soon as the car reaches the destination.
FinalAlert_140Kip	The operating railroad is required to inspect the train and move it at slow speed (below 30 mph) to set out the affected car for repair.

* AAR - Field Manual Rule 41(r)

Table 2. Performance Indices Used in the Truck Hunting Detection

Index	Description
AARWindowOpen_HTD_0.20#	Hunting Index <=0.2, the car owner can choose to shop the car and make truck repairs to eliminate hunting.
AARCondemnable_HTD_50_2*0.35 (Post January 2011)	A single reading of Hunting Index of >0.5 or two values >0.35 in 12 months requires the car to be scheduled and routed to shop for truck repair.

Index	**Description**
AARCondemnable_HTD_55_2*0.40 (July 2007–December 2010)	A single reading of Hunting Index of >0.55 or two values >0.40 in 12 months requires the car to be scheduled and routed to the shop for truck repair.

AAR - Field Manual Rule 46(h)

Table 3. Performance Indices Used in the Truck Performance Detection

Index*	**Site Curvature (degrees)**
TGSF (Truck Gauge Spreading Force, kips)	
28	< 4.0
33	≥ 4.0 < 5.0
38	≥ 5.0 < 6.0
43	≥ 6.0 < 7.0
48	≥ 7.0 < 8.0
53	≥ 8.0 < 9.0
58	≥ 9.0
Index	**TPD Site**
LAHRLV (Leading Axle High Rail, L/V)	
1.05	2 events 12 months moving window

*AAR - Field Manual Rule 46 (i)

System access permitted downloading data of the WILD, THDs, and TPD for approximately 130,000 cars. The car identities were masked by assigning pseudo reporting identification marks to safeguard any proprietary information. According to AAR's Railroad Fact Edition 2011 (see footnote 1), the North American rail vehicle fleet had 1,309,030 cars in 2010, with the distribution of car types shown in Table 4.

Table 4. Car Types Distribution in the Queried Dataset

AAR Car Type	**Description**	**Number in Queried Dataset**
A	Equipped Box Cars	19,627
B	Unequipped Box Cars	311
C	Covered Hoppers	23,908
D	Locomotives	2,314
E	Equipped Gondolas	15,522
F	Flat Cars	3,392
G	Unequipped Gondolas	684

AAR Car Type	Description	Number in Queried Dataset
H	Unequipped Hoppers	7,001
J	Gondolas	6,508
K	Equipped Hoppers	2,056
L	Special Types	11
M	MOW Cars	1,018
P	Conventional Intermodals	195
R	Refrigerated Cars	760
S	Stack Cars	2,499
T	Tank Cars	43,078
V	Autoracks	663

Direct information on the car types was not included with SA's access on WILD or THD queried parameters to determine the distribution of car population. However, car type data was available through ancillary queries. The WILD, THD, and car type query data were stored in a local database for analyses. The analysis algorithm was then used to develop the car type distribution of the queried car population.

Table 4 lists the distribution of car types in the population allowed for data access. For a comparison as to how representative this sample is of the car types in the North American fleet, Figure 2 shows percentage distribution for the cars in the queried data and for the North American fleet. It is clear that the queried population has a higher percentage of tank and box cars and a lower percentage of hopper cars. The percentage of gondolas is very similar to the industry fleet.

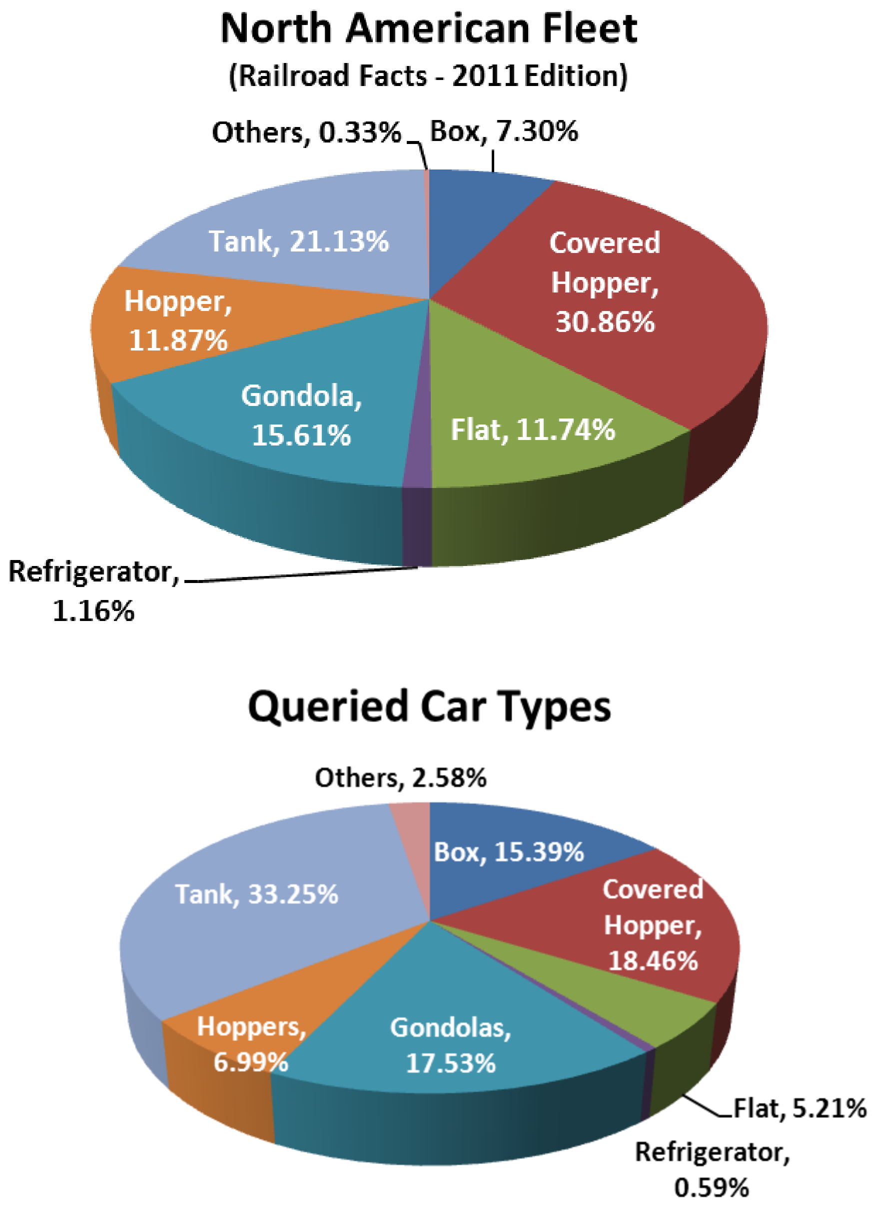


Figure 2. Car Types Distribution – North American Fleet vs Queried Data Set

3. Detector Installation History and Vehicle Performance Monitoring

WILD systems were developed in the 1990's and railroads began to install them on individual routes. A common approach to institutionalize the performance criteria and gather the data from these detectors was implemented by AAR in the form of EHMS to centralize the data from the WILD systems in 2004.

Similarly, THD systems were developed in the early 2000s. Most of them were installed and co-located with the WILD systems. THD data were incorporated into the EHMS' InteRRIS® system in 2007. TPD data were integrated into the InteRRIS® in 2008.

One of the project goals was the evaluation of the impact of detector growth on the defect detection rate, and on reduction in derailments due to equipment performance monitoring and proactive maintenance by the railroads. To evaluate these factors, the implementation history of these three detector systems was obtained from AAR.

Figure 3 depicts the growth of WILD installations in the years 2000 through 2012 and Figure 4 depicts the growth of THD installations in the years 2000 through 2012.

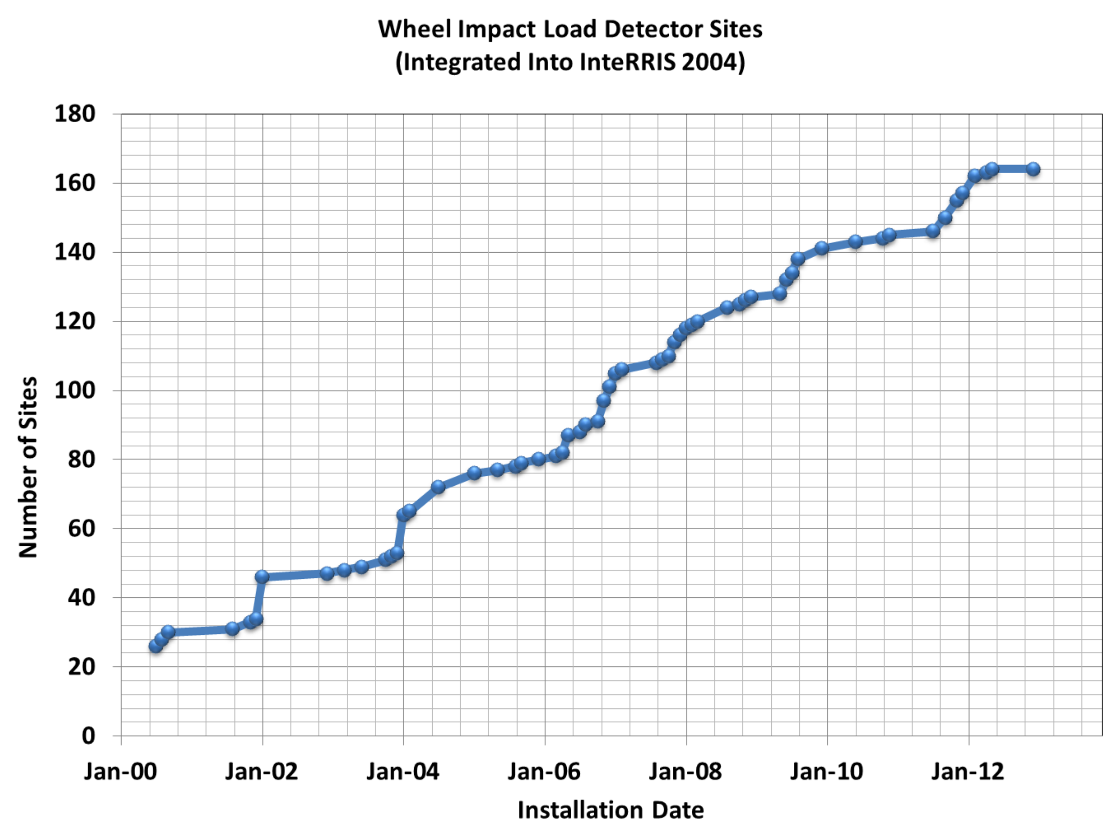


Figure 3. WILD Installations from 2000–2012

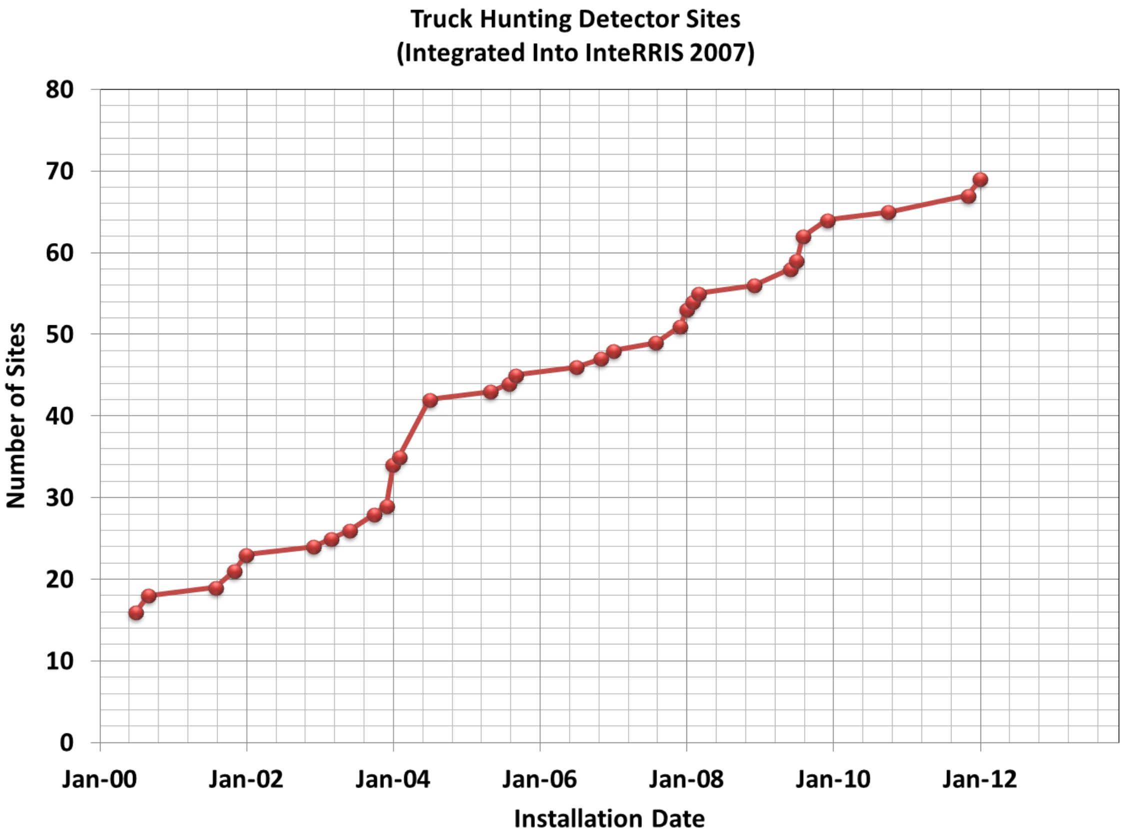


Figure 4. THD Installations from 2000–2012

As shown in Figure 3, the number of WILD sites increased from 26 in July 2000 to 164 in December 2012.

Similarly, as shown in Figure 4, the number of THD sites increased from 16 in July 2000 to 69 in December 2011, while most of the THDs are co-located with the WILD sites.

The growth of TPDs is shown in Figure 5. The TPDs are not deployed widely. The number of TPD sites has gradually increased from 3 in July 2000 to 27 in late 2008. Since no new TPDs have been installed.

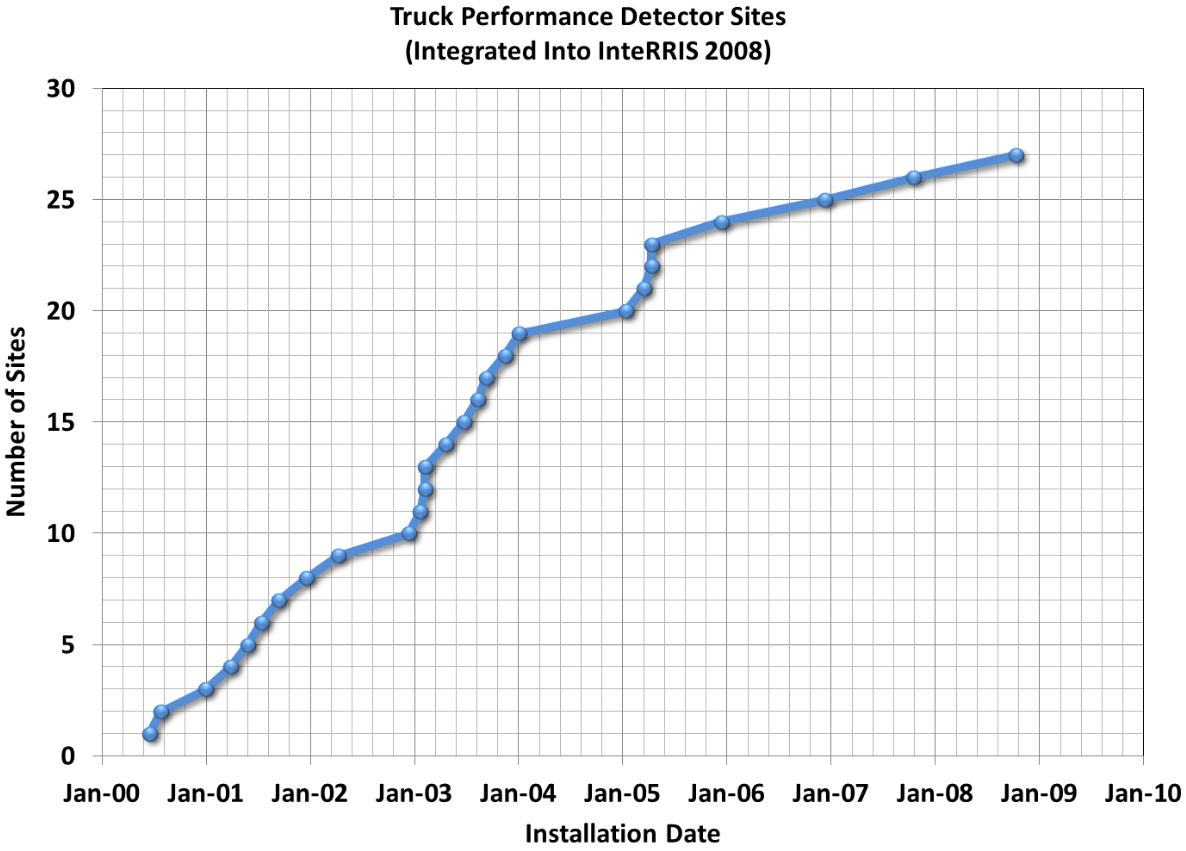


Figure 5. TPD Installations from 2000–2012

Performance indices data were queried for years 2004–2012 for WILD, years 2007–2012 for THD, and years 2008–2012 for TPD. Since the WILD systems are widely deployed and the threshold for WindowOpen_65-80Kip is relatively low, on a given day many wheels exceed the detection criterion. To ensure data is gathered on all wheels while also keeping the queried result data file size manageable, WILD data queries for WindowOpen_60-80Kip were conducted for 24-hour periods at a time.

3.1 Detector Site Train Speed

WILD systems are designed to provide optimal detections at train speeds in the range of 20 mph to 60 mph. Although most WILD systems are located such that the train speed is generally within this range, often other operating conditions may lead to speeds being outside this range at the time of detection.

To determine whether train speeds over a detector site are generally within the optimal range, several queries were made to extract train speeds. These queries were essentially for a 24-hour period for cars that triggered various criteria in the Yellow Table[3] of InteRRIS® database.

---

[3] Yellow Table consists of a summary of all cars that trigger any of the indices of various detectors. This then allows the car owner to retrieve detail history on a specific car for further investigation and action.

From these queries, one 100-ton 4-axle car was selected for trending its history for the period of 2004 through 2012. During this period the car passed 156 times over detectors at various speeds. The queried data were then analyzed to extract train speeds at the time of passing the detectors. The distribution of speeds at the time of detection for this car is shown in Figure 6.

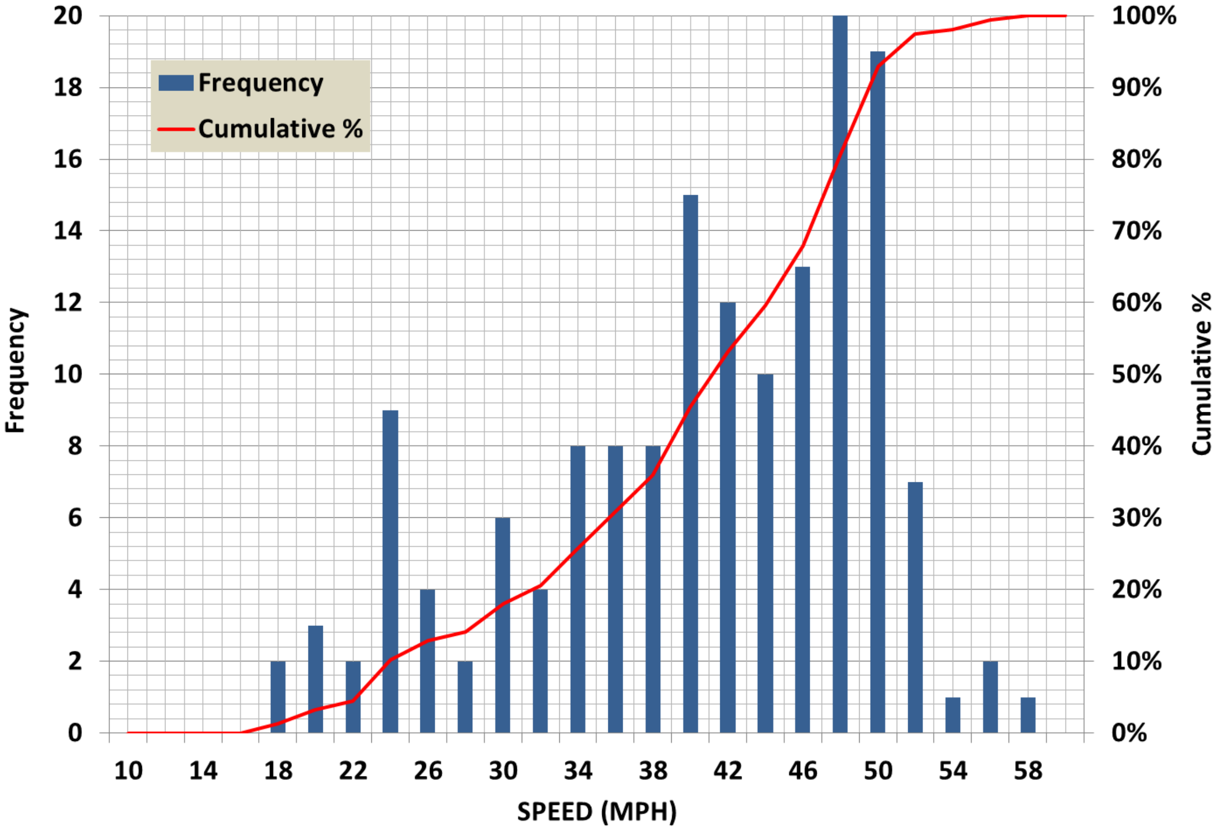


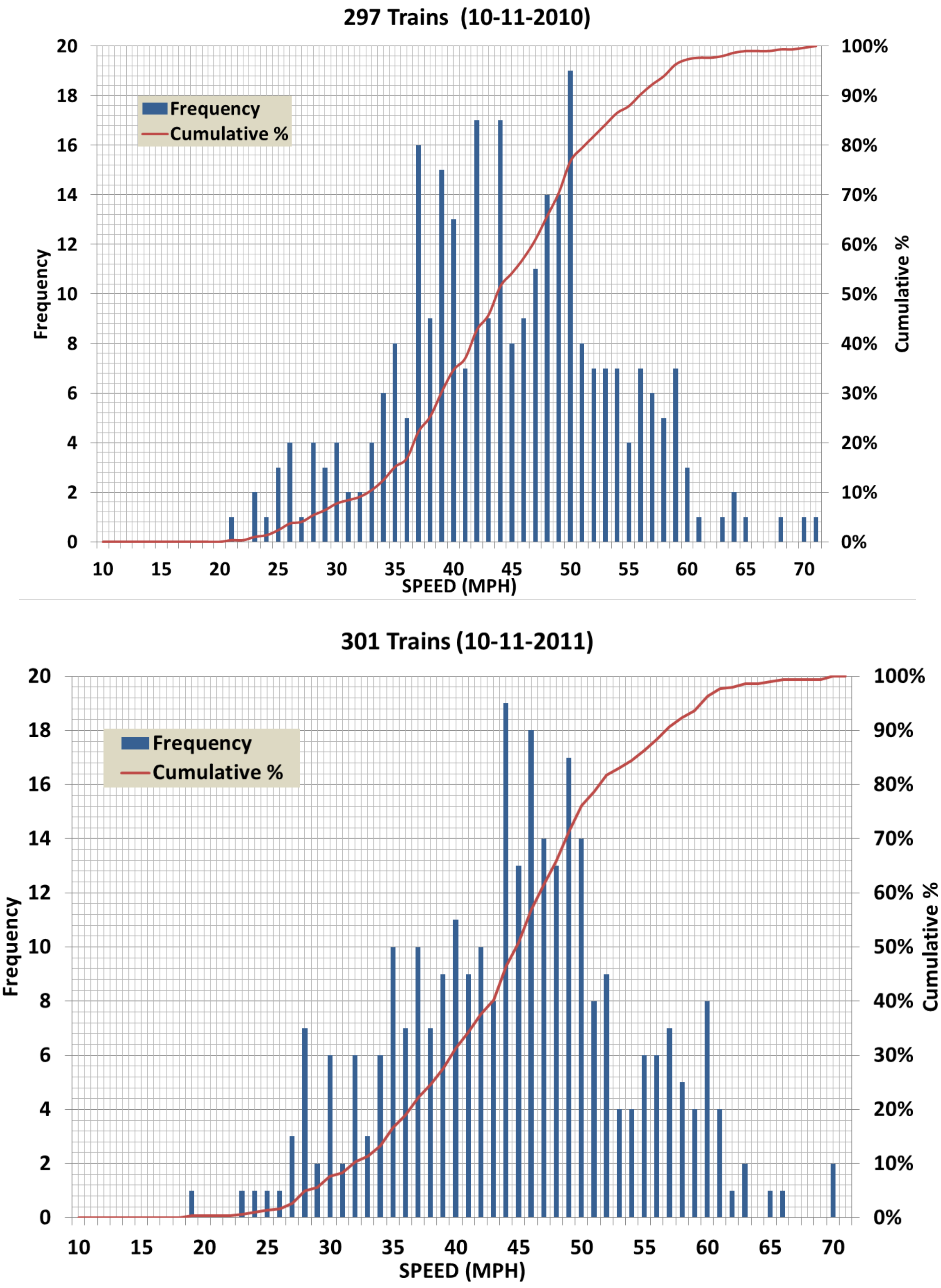
Figure 6. WILD Detection Speed Distribution for a 100-Ton 4-Axle Car from 2004–2012

Figure 6 shows that ~97 percent of the times that this car passed over a detector; it was traveling in the 20 mph to 60 mph speed range. Only 3 percent of the time speed was below 20 mph and never exceeded the 60 mph. The 20 mph to 60 mph speed range is desirable for effective detection of wheel defects.[4]

To further investigate the train speeds over detector sites, Yellow Table queries were made for train speeds on four separate days over a 24-hour period for each case of the queries. These queries for a day in October in each of the years 2010, 2011, 2012, and 2013 yielded 297, 301, 319 and 294 trains, respectively, which were traversing various WILD detectors in the network. The speed distributions for these four sets of trains are shown in Figure 7 and Figure 8.

---

[4] Wheel Impact Load Detector Tests and Development of Wheel-Flat Specification, Report No. R-829, AAR



297 Trains (10-11-2010)

301 Trains (10-11-2011)

Figure 7. Distribution of Train Speeds Passing WILD Sites (October 11, 2010, & 2011)

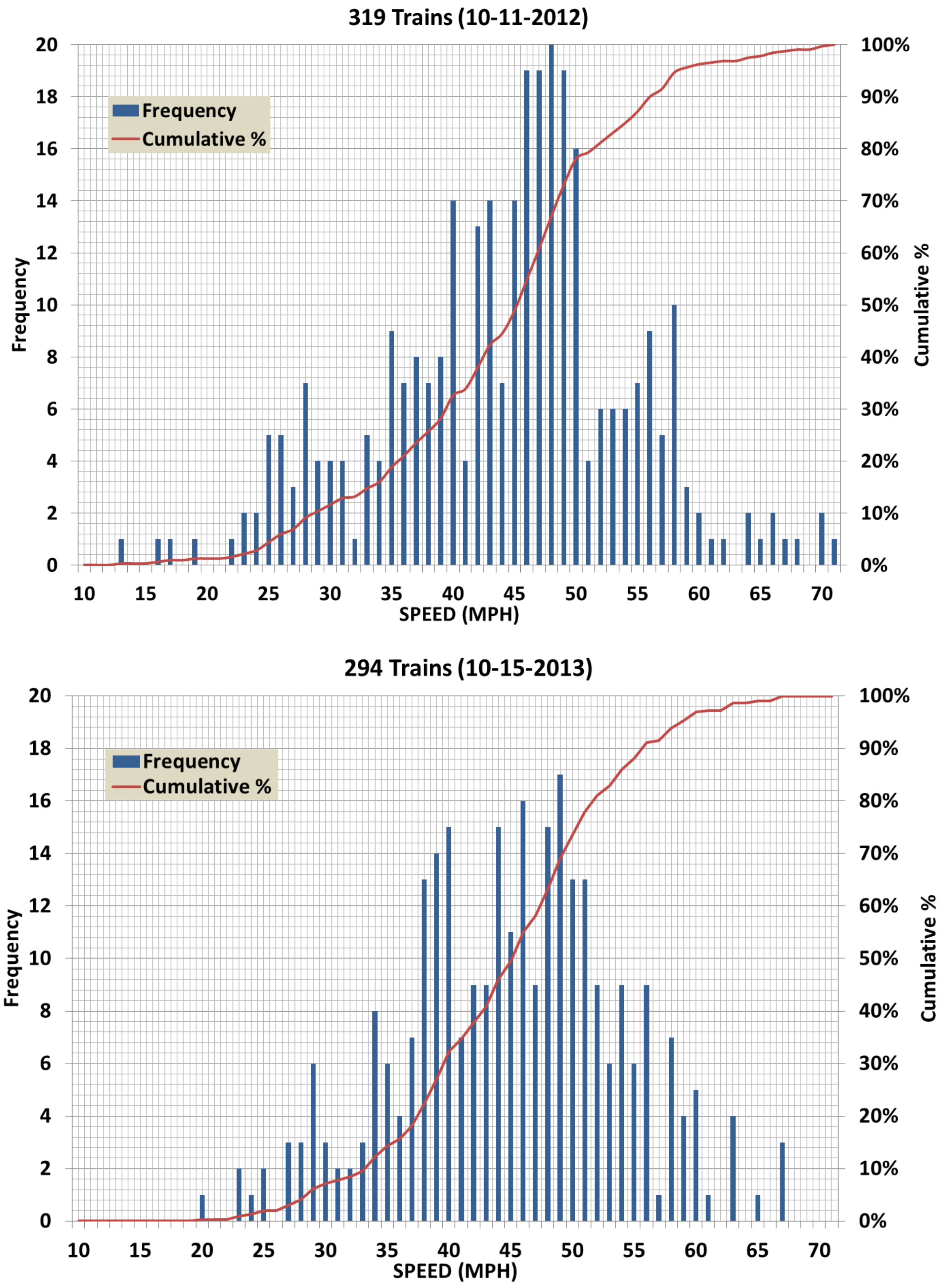
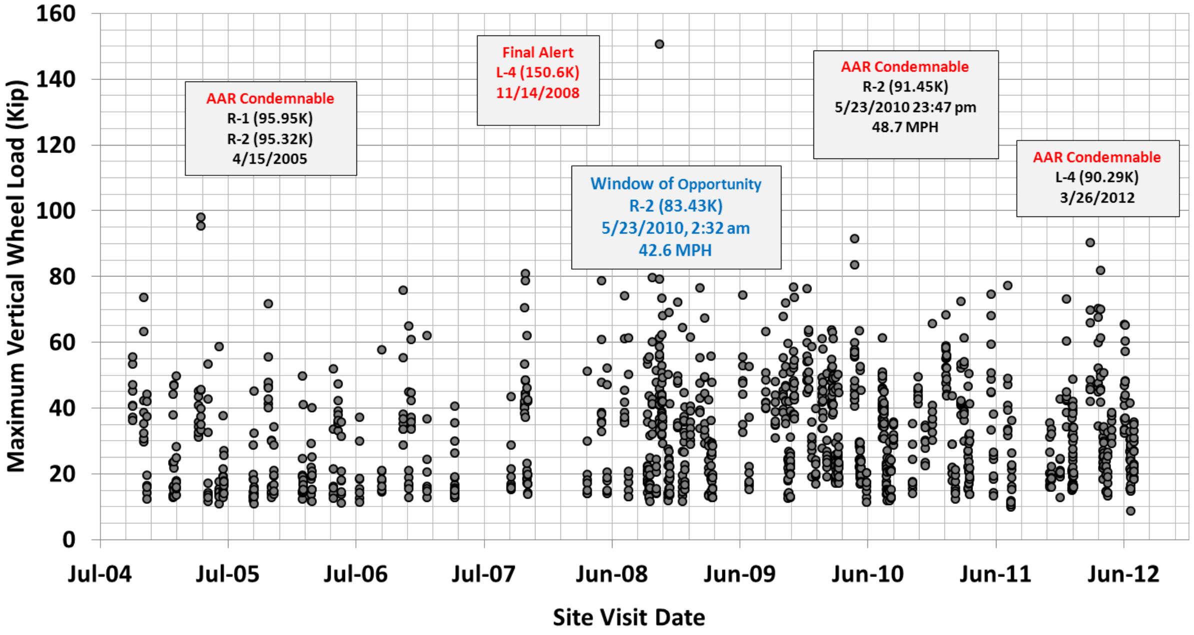


Figure 8. Distribution of Train Speeds Passing WILD Sites (October 11, 2012, & October 15, 2013)

The speed distributions for these trains are like the percentage shown in Figure 6. The percentages of speeds in the 20 to 60 mph range for the four trains are ~97, ~96, ~95, and ~96.5 percent, respectively. In aggregate, these speed distributions indicate that by the time a train passes three detector sites, the probability of the train speed passing at least one of the sites at a speed between the 20 and 60 mph range is 99.98 percent. This provides a high degree of confidence that the detector systems are effective in flagging the wheels with defects causing high vertical wheel impact loads.

3.2 Car Performance Monitoring and Maintenance Actions

To demonstrate the implementation and execution of the wayside performance detection indices for high impact vertical wheel loads, WILD data time history of wheel loads on a 100-ton 4-axle car was queried from InteRRIS® for July 2004 through December 2012. This car, over a period of 8 1/2 years, passed over WILD sites 156 times, i.e., ~18 times per year on average.



AAR Condemnable
R-1 (95.95K)
R-2 (95.32K)
4/15/2005

Final Alert
L-4 (150.6K)
11/14/2008

Window of Opportunity
R-2 (83.43K)
5/23/2010, 2:32 am
42.6 MPH

AAR Condemnable
R-2 (91.45K)
5/23/2010 23:47 pm
48.7 MPH

AAR Condemnable
L-4 (90.29K)
3/26/2012

Figure 9. Maximum Loads Time History of a 100-Ton 4-Axle Car Wheels—Empty and Loaded Conditions—2004–2012

Figure 9 shows the time history of maximum wheel loads for the queried car. The loads are shown for all eight wheels of the car and include both empty and loaded car conditions. The wheel loads that result in removal due to “AAR Condemnable” or “Final Alert” conditions are observed for loaded car conditions.

The car owners can monitor wheels under empty car conditions as well using other criteria, such as dynamic ratio and dynamic increment. Dynamic ratio greater than or equal to 3.5 and dynamic increment greater than or equal to 30,000 lbs are in the Yellow Table and allow the car owners to plan for car inspection and repair. For any proactive car repair measures the car owners can access Yellow Table data.

From Figure 9, this car had wheels removed three times due to AAR Condemnable criteria and one time due to Final Alert.

The first wheel removal event was triggered by AAR Condemnable limit on wheels R1 and R2 (right wheels on B-end axles) on April 15, 2005. Then, the car ran free of high impact wheel load detections for over 3 years until November 11, 2008. In this case the Final Alert level was exceeded on wheel L4 with no precursor seen in the wheel load history. The same wheel was detected 3.5 years later on March 26, 2012, where it experienced a vertical load of 90.29K exceeding the AAR Condemnable limit of 90K.

In one case of wheel removal due AAR Condemnable criteria, the wheel load of 83.43K on R2, right side wheel on axle 2, triggered ‘Opportunistic Repair’ at 2:32 am on May 23, 2010, and then AAR Condemnable criteria at a wheel load of 91.45K later the same day, ~21 hours later at 23:47 pm. Further investigation revealed that the only difference between these two cases was train speed. The train passed the WILD site one night at a speed of 48.7 mph, whereas the previous night, it passed the WILD site at a speed of 42.6 mph, only ~6 mph lower speed.

These observations show that alert triggers at a WILD site are somewhat speed-dependent. However, as discussed in Section 3.1, if a car ends up passing several detectors during a trip at a speed between 20–60 mph, a wheel producing high vertical impact load is likely to be quickly detected and flagged.

4. Wayside Detector Systems Effectiveness Trend

The railroad industry adopted wayside detection systems to detect aspects of vehicle performance related to track interaction that would contribute to derailments. A derailment can be attributed to a vehicle if it is not able to follow the track due to a poor suspension system or worn-out or broken components. Poor performance and component defects also lead to higher vertical and lateral loads imposed on the track which promotes deterioration of track alignment, profile, and gauge geometry. High vertical wheel loads accelerate rail defect growth and result in accelerated fatigue and premature suspension and truck component failures. Derailments due to broken rails can be catastrophic because a broken rail is a relatively sharp object and can easily puncture most cars' super structure.

As described in Section 3, InteRRIS® warehouses the railroads' fleet performance data as collected by various detector systems. The most widely deployed wayside detection systems are WILD, TPD, and THD. To investigate the effectiveness of the WILD, THD and TPD systems, the InteRRIS® database was queried to investigate whether detection of various vehicle performance indices has improved fleet performance.

4.1 Wheel Impact Load Detector System

Figure 10 shows the monthly counts for wheels detected with 65–80 kips impact loads as reported from all active WILD sites for the period of July 2004 (i.e., beginning of the detector data being warehoused under AAR's Advanced Technology Safety Initiative [ATSI]) through December 2012. In Figure 10, along with the performance index 'Window Open' data, the number of WILD site installations is also plotted.

As the number of detector sites has increased, the overall number of wheels flagged under this performance index is relatively constant. The trend does capture the reduced amount of railroad business as affected by the major economic crisis beginning in 2008. Figure 11 depicts the same data in a normalized form, i.e., the monthly high impact wheel counts were divided by the number of detectors active during that month to provide a true picture of the detection trend.

As shown by the linear trend line in Figure 11, there is a noticeable reduction in the count of "Window Open" detections between July 2004 and December 2012 and this trend is coincident with an increase in WILD site installations. If the WILD systems did not have any significant impact, one would expect the total monthly counts to increase in the same proportion as the increase in WILD site installations and the normalized counts to remain constant. The fact that the total count has remained relatively constant and the normalized count has decreased clearly shows that WILD systems have significantly contributed to preventive maintenance efforts undertaken by the industry and, on a normalized basis, fewer wheels are being detected with the 'Window Open' index.

Figure 12 and Figure 13 depict the total monthly counts and the normalized monthly counts, respectively, for wheels detected with 80–90 kips impact loads. These are considered Opportunistic Repair detections. As described in Table 1, if a car is shopped for any non-wheel related repairs, the repair facility is permitted to check if the car has been flagged for Opportunistic Repair and if so, is authorized to make wheel repairs to eliminate defects causing high dynamic loads and recover the costs from the car owner under AAR's Interchange Car Repair Billing system.

Given that the car population used for querying the reported data is constant and consists of the same cars for all queries, the number of wheels detected with the Opportunistic Window index is approximately one-fourth of those detected with the "Window Open" index.

The normalized counts (Figure 13) clearly show that the number of wheels qualifying for Opportunistic Repair has steadily trended down as the number of detector installations have grown in the railroad network.

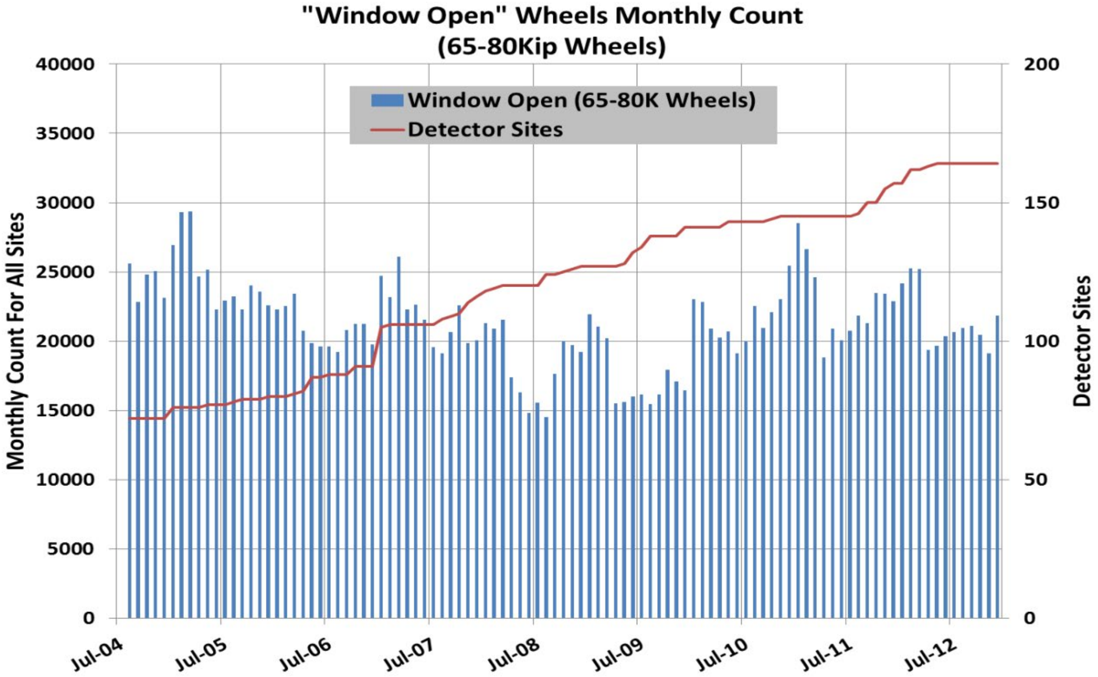


Figure 10. "Window Open" Wheels—Monthly Count

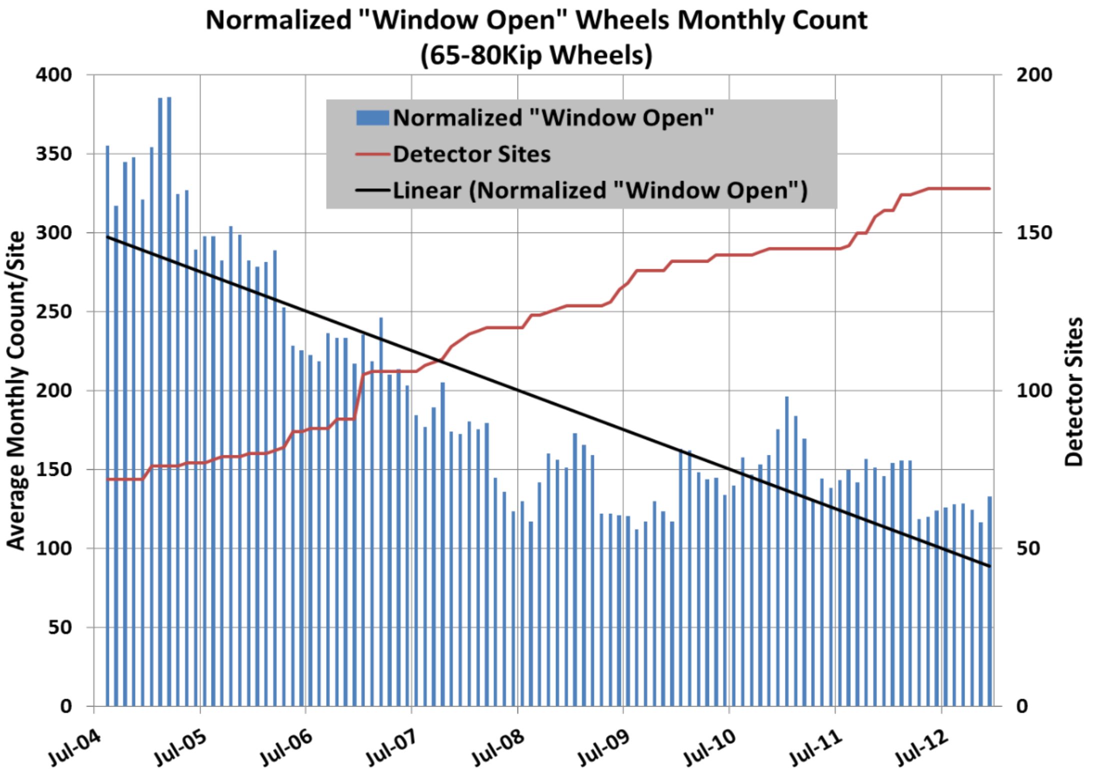


Figure 11. “Window Open” Wheels—Normalized Monthly Counts

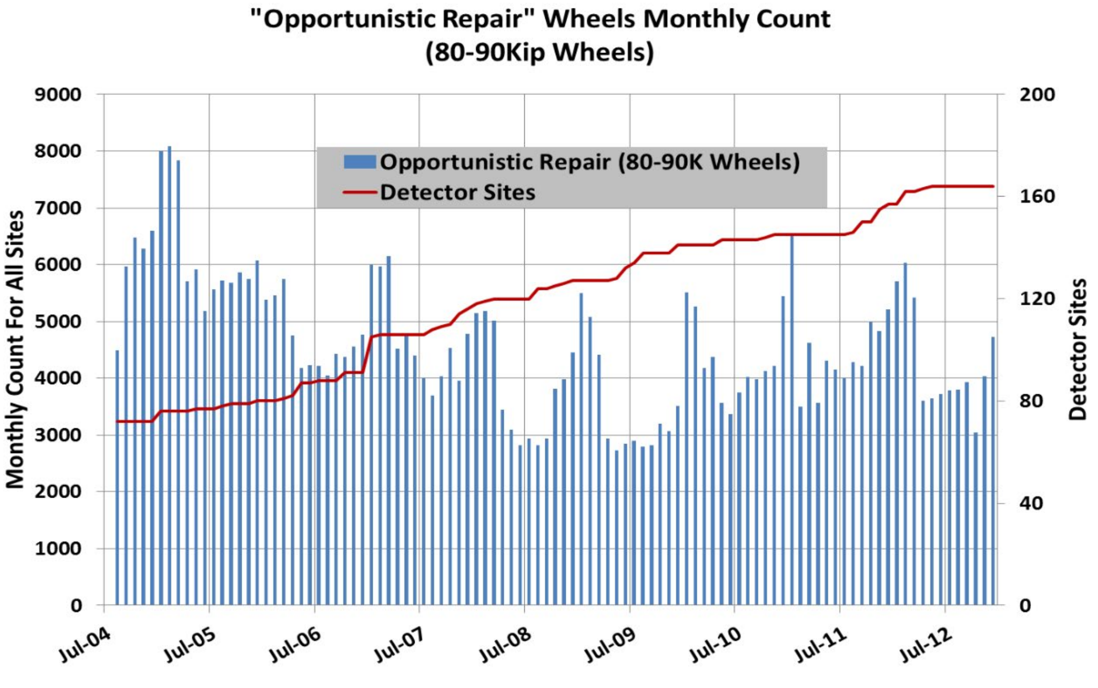


Figure 12. “Opportunistic Repair” Wheels—Monthly Count

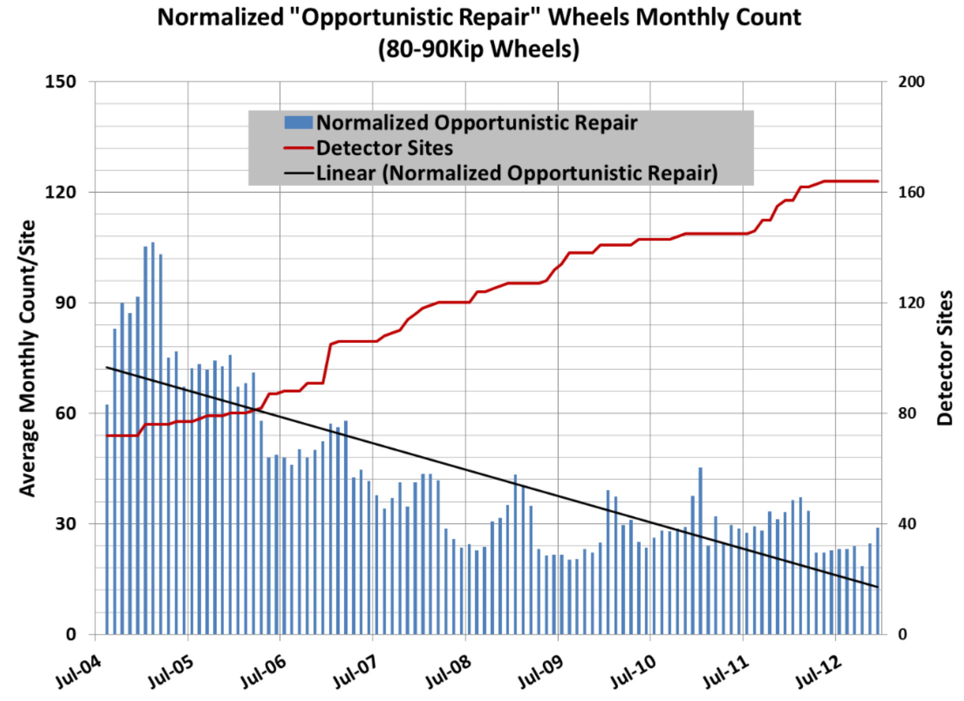


Figure 13. "Opportunistic Repair" Wheels—Normalized Monthly Count

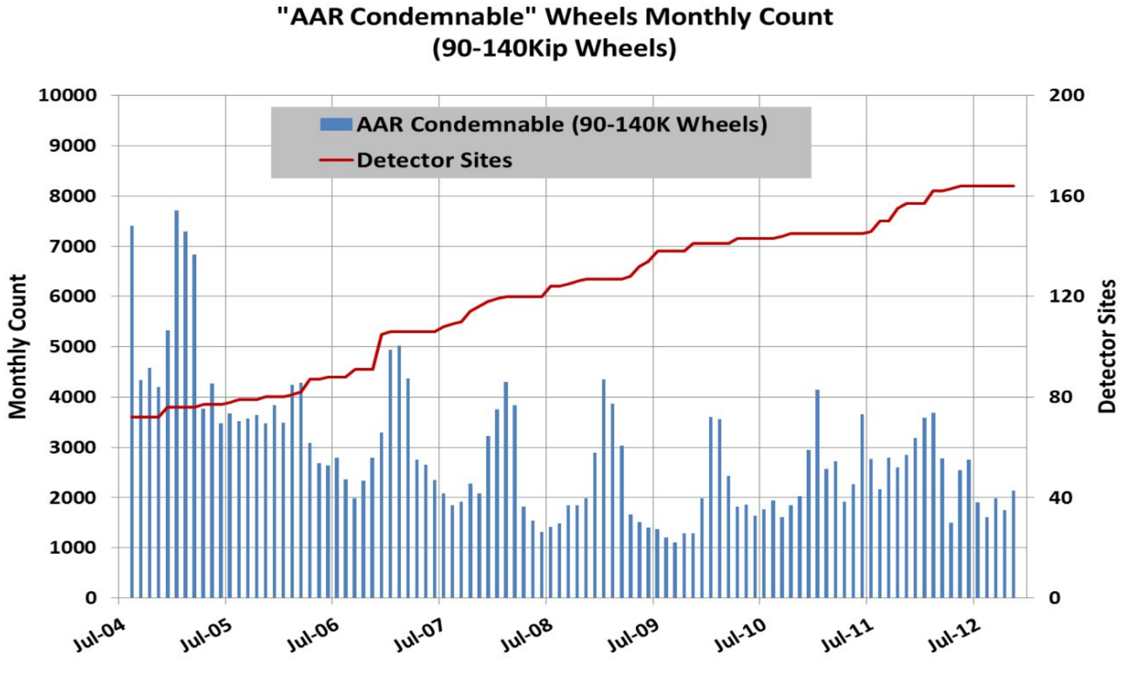


Figure 14. "AAR Condemnable" Wheels—Monthly Count

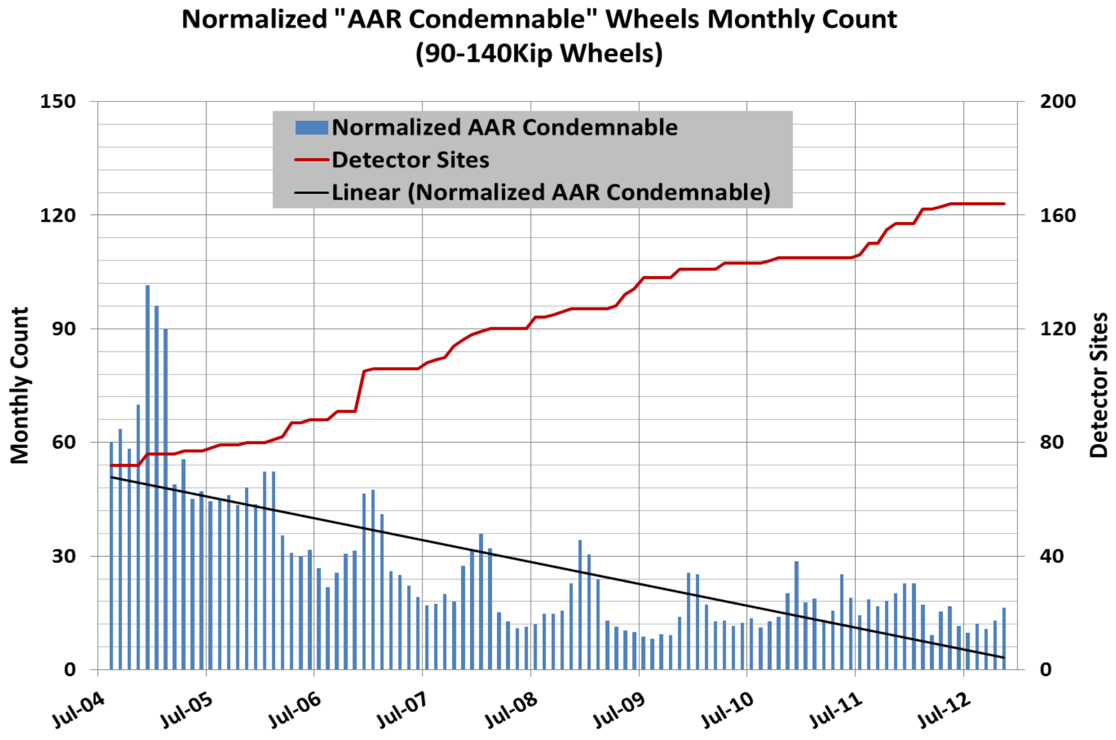


Figure 15. “AAR Condemnable” Wheels—Normalized Monthly Count

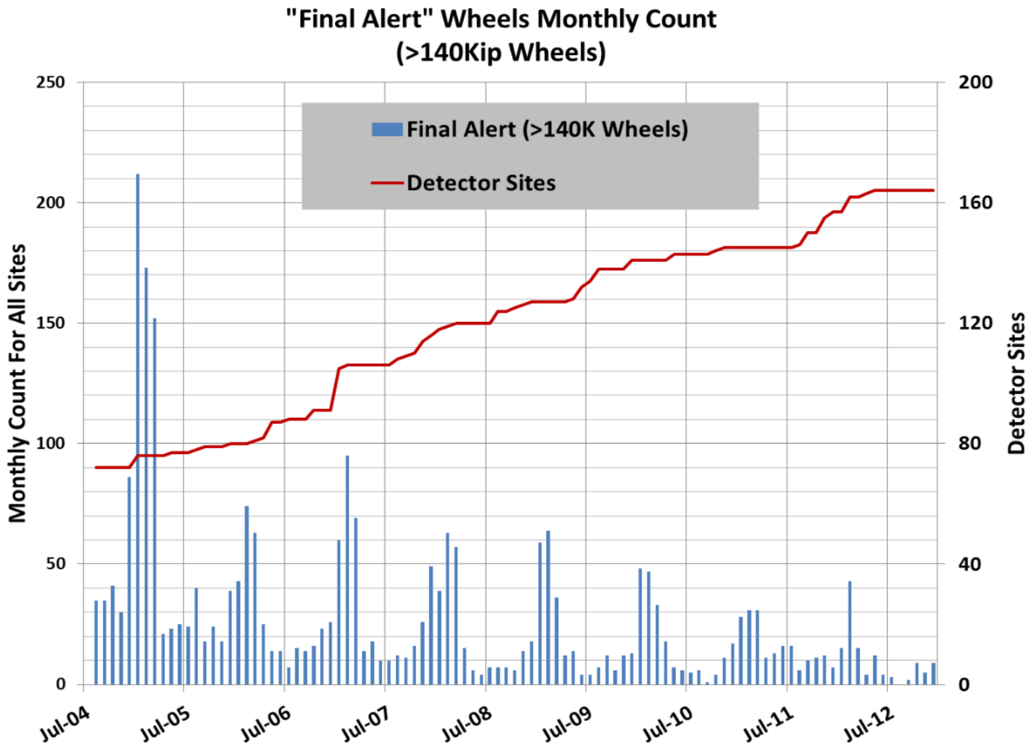


Figure 16. “Final Alert” Wheels—Monthly Count

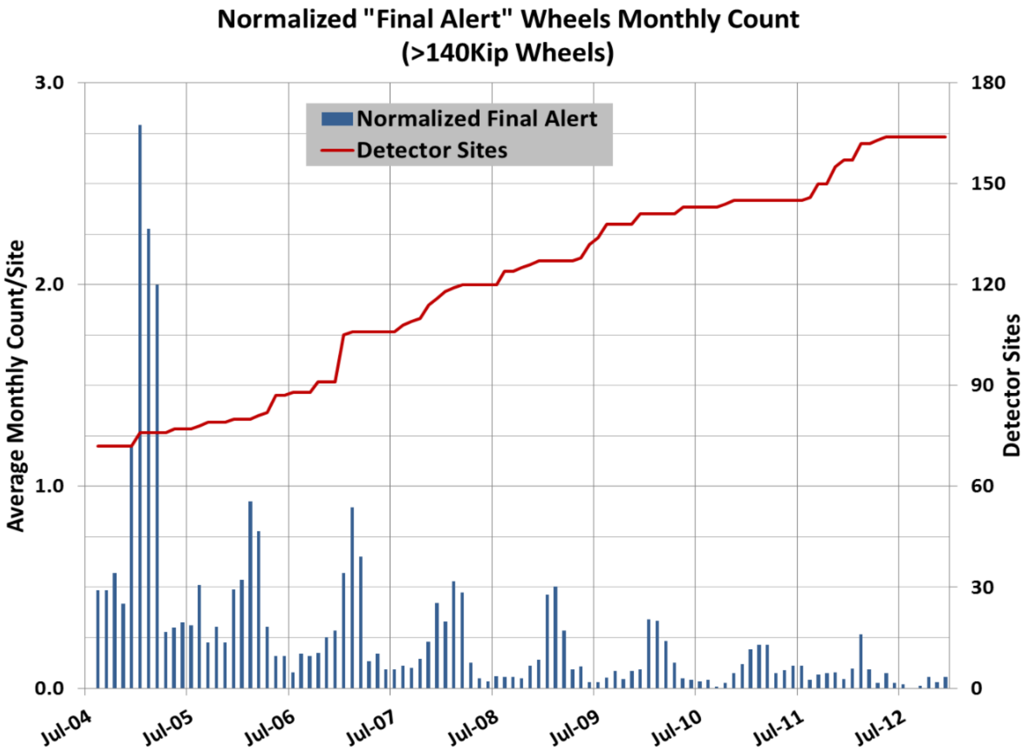


Figure 17. “Final Alert” Wheels—Normalized Monthly Count

Figure 14 and Figure 15 depict the total monthly counts and normalized monthly counts, respectively, for wheels detected with 90–140 kips impact loads. These are considered “AAR Condemnable” detections and under AAR’s Rule 41, r(1),[5] the corresponding cars must be flagged for immediate repairs. The trends in both the total monthly counts (Figure 14) and the normalized counts (Figure 15) show a drastic reduction in number of wheels detected with 90–140 kips impact loads. As discussed in Section 3.2, any wheel flagged under the “AAR Condemnable” criteria are immediately replaced as soon as the car reaches its destination. These trends clearly show the positive impact of the WILD systems on overall improvements in wheel conditions.

Finally, Figure 16 and Figure 17 depict the total monthly counts and normalized monthly counts, respectively, for wheels detected with greater than 140 kips impact loads. These are considered “Final Alert” detections. For such wheels, the operating railroad is required to inspect the train and move it at a slow speed below 30 mph to set out the affected car for repair at the first available track siding/repair site.

These figures also show a dramatic impact of WILD installations on the number of wheels that produce track damaging vertical loads. Whereas, for the queried car population, there were over 250 wheel counts at “Final Alert”—highest in winter months—level per month in 2004 with half the number of detectors in the network, that count has dwindled to only 5–6 per month in 2012.[6]

---

[5] Field Manual of the AAR – Interchange Rules, 2011, page 306.

[6] These counts are based on the queried car population ~130,000 cars. There are ~ 1,3000,000 cars in the North American fleet.

Thus, with a significant number of detectors in the network, the wheels dangerous to rail life have become rare. In fact, the trend shows that additional detectors might produce only marginal gains.

4.1.1 Seasonal Pattern in High Impact Load Wheel Counts

Figure 12, Figure 14 and Figure 16 exhibit a consistent pattern in the number of wheel counts that tend to be significantly higher in winter months. For both the "AAR Condemnable" index of wheel load ≥ 90K (Figure 14) and "Final Alert" index of wheel load ≥ 140K (Figure 16), the monthly counts are approximately 80–300 percent higher in winter months than the rest of year.

Initially, it was thought that this increase is largely due to ballast and track structure becoming stiffer due to cold temperature and leads to higher track stiffness resulting in increased dynamic wheel loads. However, the research effort reported under the AAR's Wheel Defect Prevention Research Consortium (Dedmon, S. L., et al., 2007) program shows that wheels tend to develop more shelling in winter which in turn is reflected in higher counts of high impact load wheels. The reported analytical research shows that this is more pronounced when trains are operating under snow conditions. As a point on the wheel moves from ambient temperature condition to the wheel/rail contact area where contact stresses are high and the wheel temperature is also relatively higher due to slippage in the contact patch, the snow sticking to the rail surface quickly melts and migrates into the cracks. When that point on the wheel moves away from contact, the condition changes from the wheel/rail contact conditions to ambient conditions and the melted snow freezes inside the cracks, thus propagating the cracks. This process repeats over each revolution of the wheel, thus accelerating crack growth and ultimately shelling of the tread.

4.2 Truck Hunting Detector (THD) Data Trend Analysis

As discussed in Section 3, railroads had begun to install truck hunting detectors in the network almost at the same time as WILD systems. In fact, most THDs are co-located with the WILD sites.

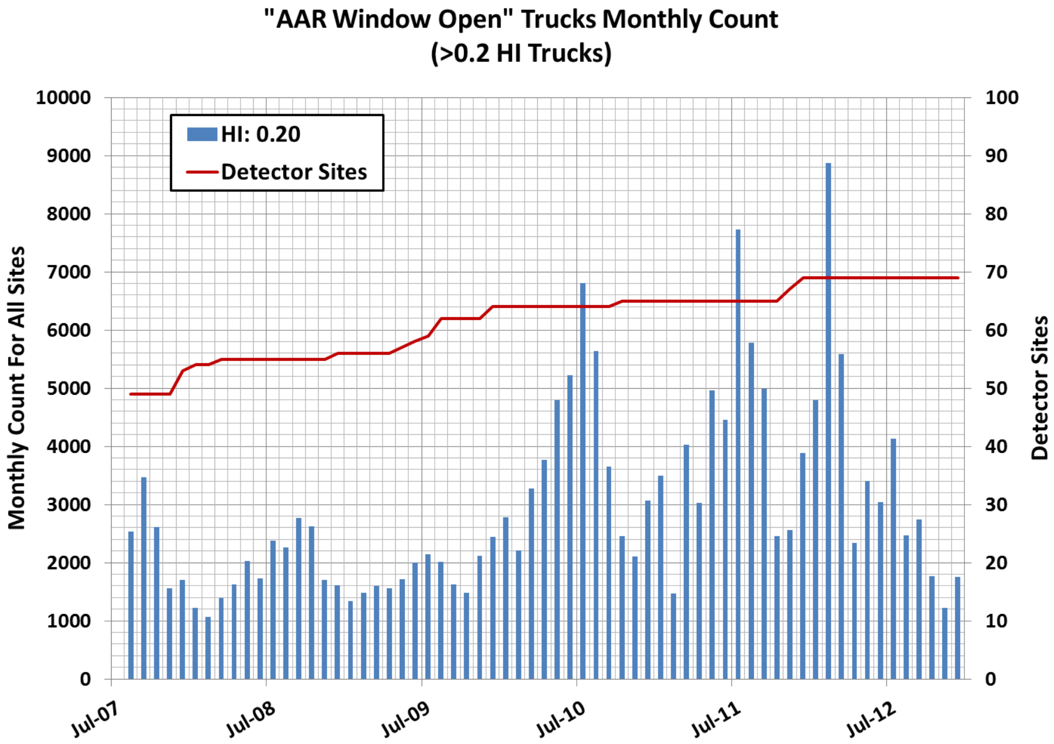
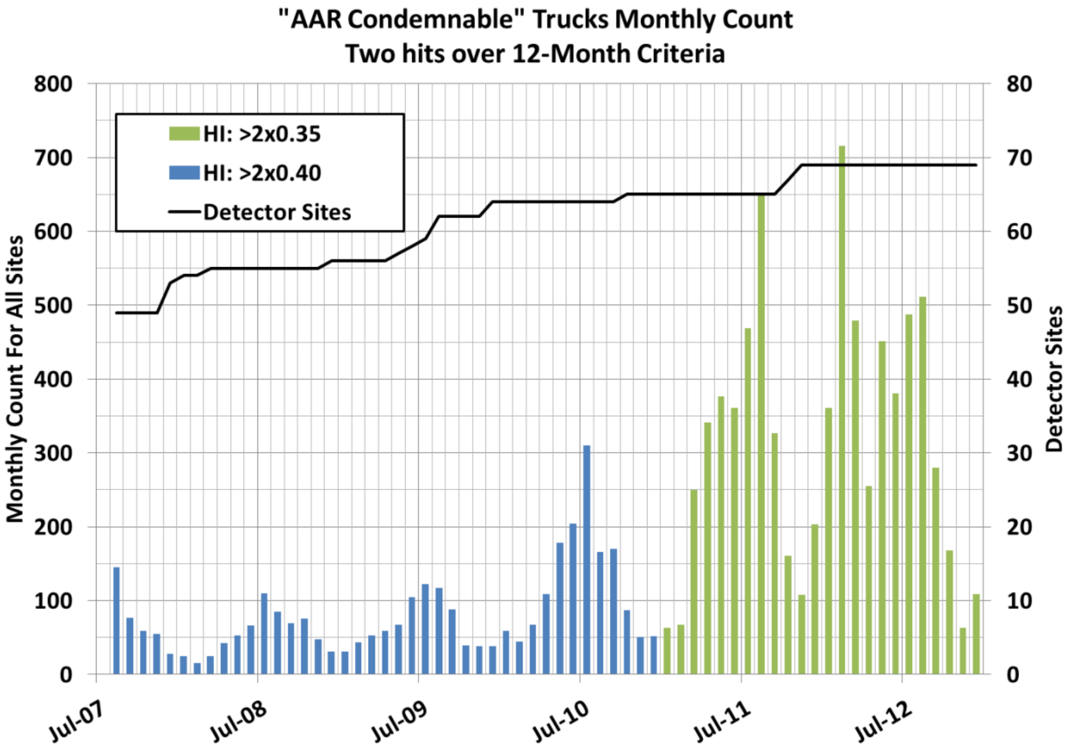


Figure 18. “AAR Window Open” Trucks—Monthly Count



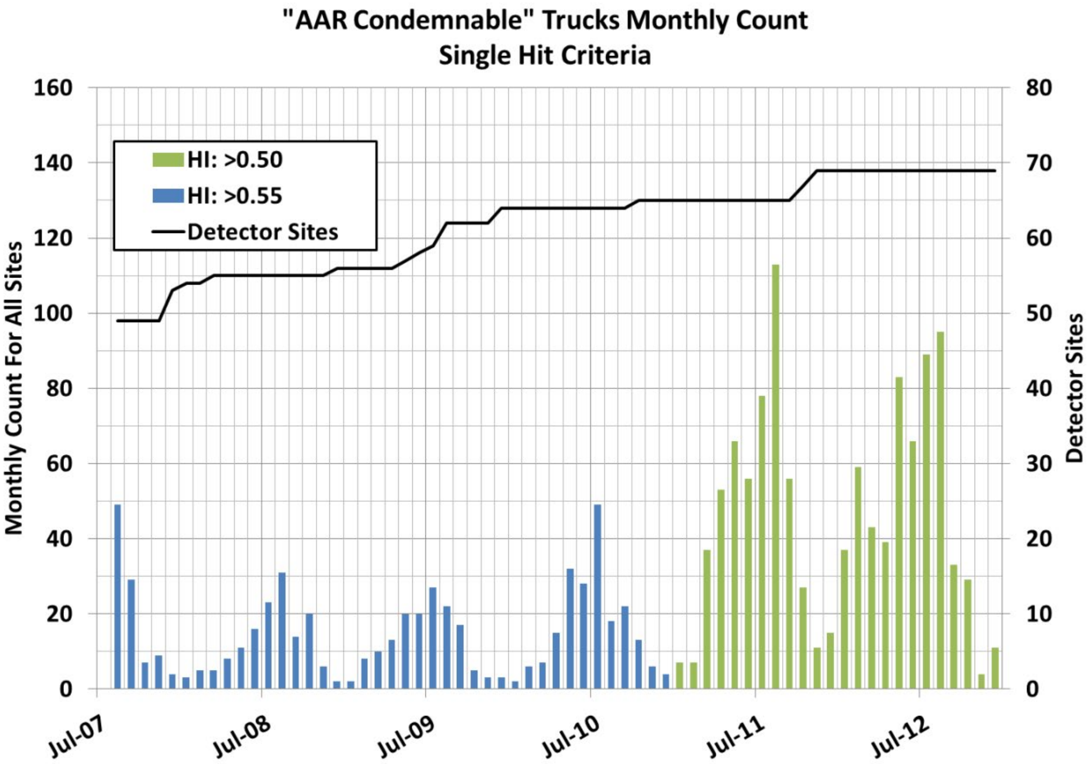


Figure 19. “AAR Condemnable” Trucks—Monthly Count from Truck Hunting Detectors

Whereas, AAR had established wheel impact load detection performance indices in the initial phase of the WILD systems deployment and formalized data warehousing in InteRRIS® by 2004, the detection criteria for truck hunting were developed later. In 2007, AAR, under its ATSI program, integrated the truck hunting detectors data into InteRRIS® database system.

There are two major truck hunting detector systems: one is based on lateral track forces and the other is based on lateral axle movement and rotation (yaw). These indices are related to the absolute lateral carbody and truck acceleration criteria used by AAR in its freight car certification process.[7] To accommodate the two systems, AAR has normalized the measured parameters relative to the lateral carbody/truck acceleration of its track-worthiness criteria and validated these two systems for use (Transportation Technology Center, Inc., 2007).

A measured hunting index (HI) of 0.20 or greater is considered for “AAR Window Open” detection. Figure 18 depicts the monthly counts for trucks detected with a HI greater than or equal to 0.20, that beginning in 2010, there is a marked increase in the number of trucks triggering the “AAR Window Open” criterion. Figure 19 depicts the monthly counts for trucks detected with the “AAR Condemnable” condition.

As described in Table 2, there are two criteria to be met for these detections. Prior to 2011, the two conditions were:

---

[7] Table 11.1, Chapter 11. Service-Worthiness Tests and Analyses for New Freight Cars, Manual of Standards and Recommended Practices, Section C-Part II, Association of American Railroads.

a. HI > 0.55 **or** **b.** Two instances of HI > 0.40

Since early 2011, when the railroad industry collectively decided to lower the hunting criteria, the following limits have been enforced:

a. HI > 0.50 **or** **b.** Two instances of HI > 0.35

The lowering of these limits has resulted in a higher number of trucks being flagged for hunting. Figure 19 shows the increase in the counts triggered by the 2 x '>0.40' and 2 x '>0.35' criteria. Although there was an increase in the number of detectors from 65 in 2010 to 69 in 2011, while most of the increase in the number of detections is likely due to lowering of the limiting criteria. A similar trend is seen for the '>0.55' and '>0.50' criteria.

4.2.1 Seasonal Pattern in Truck Hunting Counts

Also, a close inspection of the THD counts in Figure 18 and Figure 19 shows a seasonal pattern, albeit not as pronounced as in the WILD counts. The THD counts tend to increase in the middle of the summer season. During this period, generally, rail and wheel conditions are relatively dry and result in a higher coefficient of friction at the wheel/rail interface. A higher coefficient of friction tends to lower the truck hunting speed and also increases the amplitude of lateral truck motions and accelerations, as shown in Figure 20, thus leading to a higher count of truck hunting for the summer months.

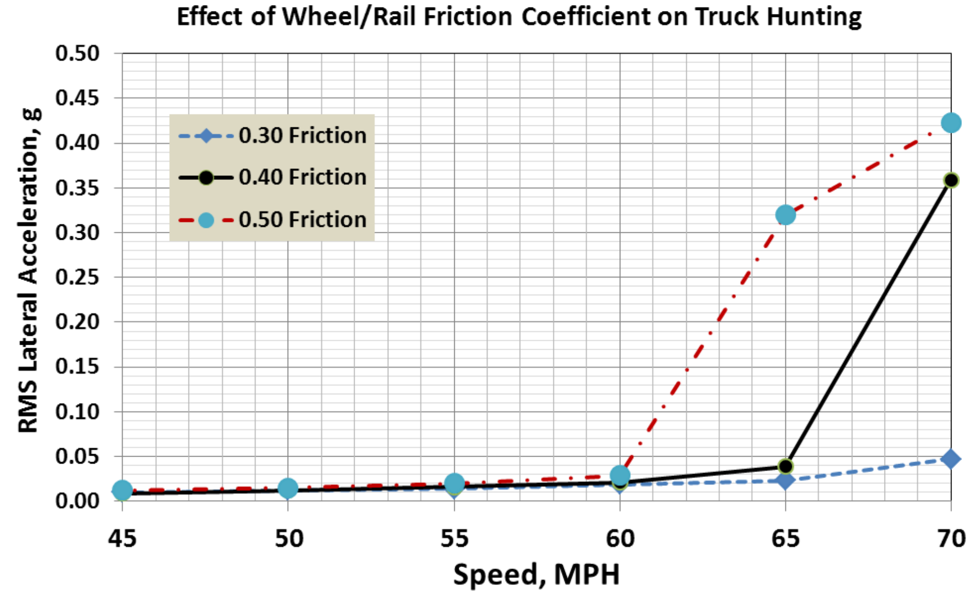


Figure 20. Simulated-Effect of Wheel/Rail Interface Friction Coefficient on Truck Hunting

4.3 Truck Performance Detector Systems (TPD)

The TPD systems have been installed to flag trucks that exhibit poor steering characteristics. Worn/degraded suspension, excessive wear or mismatch of wheel diameters, improperly installed or damaged constant side bearings and mismatched side frames can cause these trucks to track improperly, tending to curve poorly and produce high lateral forces.

The TPDs are located on track locations with reverse curves. By measuring the lateral loads on the track under left and right curving conditions, inferences are drawn to determine the axle misalignment or poor suspension conditions. A well behaving truck would steer similarly in both the sections of the reverse curve. A misaligned truck would exhibit higher than normally expected lateral forces. In addition, the forces on the first curve of the TPD site would show differing force levels compared to those on the subsequent curve.

Although railroads were beginning to install TPDs in 1999–2000, it was only in 2008 that the TPD criteria were developed and formally integrated into the InteRRIS® database. Even today, the number of installed TPDs compared to the WILD and THD systems in the railroad network is relatively small. As of August 2013, there are a total of 28 TPD systems installed and not all of them are integrated into the InteRRIS® database.

For TPD systems, two criteria, listed in Table 3 (Section 2), are used for detection, which are truck gauge spreading force (TGSF) and lead axle high rail lateral/vertical (L/V) Ratio (LAHRLV).

4.3.1 Truck Gauge Spreading Force (TGSF)

The history of truck gauge spreading force data for the period of 2008–2012 are shown in Figure 21. As shown in Figure 5, there are a total of 28 truck performance detectors in the rail network. However, a detailed analysis of the queried data for truck performance indices showed that all the exceedances shown in Figure 21 are reported from a total of five detector sites. It appears that of the 28 detectors in the network, several have not been integrated into InteRRIS®. It should be noted, however, that several of these detectors are active and the railroads are using the data on a proprietary basis and sharing with the car owners. Therefore, the lack of data in the InteRRIS® system does not imply that these detectors are not providing the safety improvements they are deployed for.

It is seen that the detectors were quite effective in flagging poorly performing trucks. Over last 5 years, there have been only a small number of trucks that triggered the TPD criteria on the integrated sites. All data queried showed the Truck Gauge Spreading Force levels higher than the limiting criteria of 28 kips, which implies that these detectors are deployed in curved sections with a curvature of four degrees or higher (see Table 3 for TGSF criterion.)

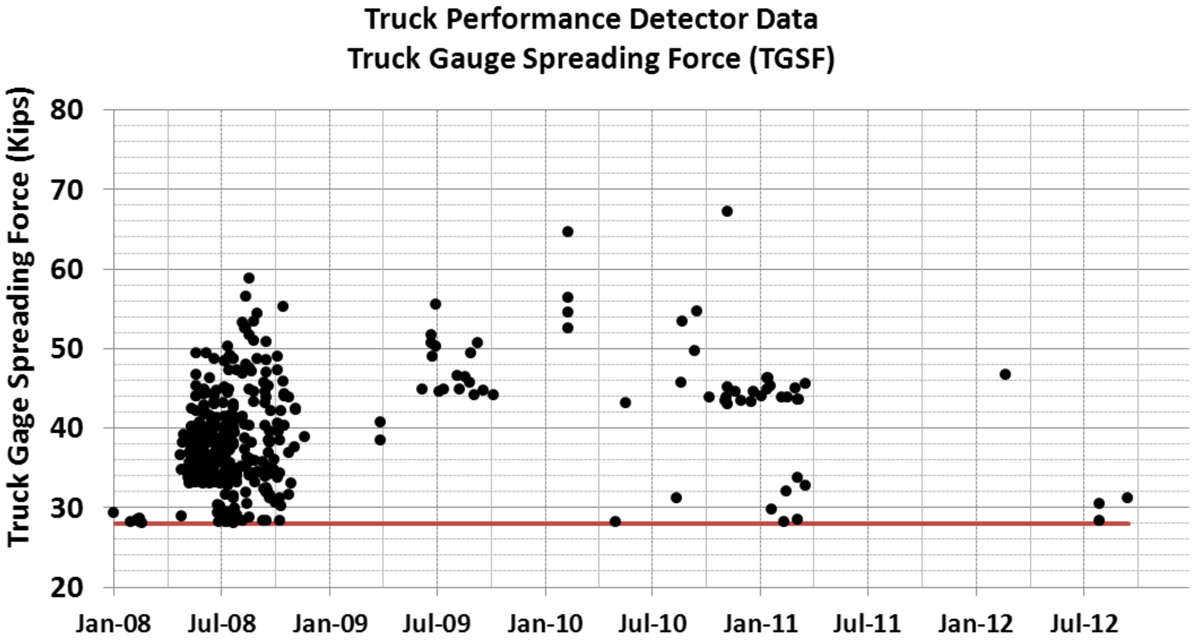


Figure 21. Truck Gauge Spread Force History

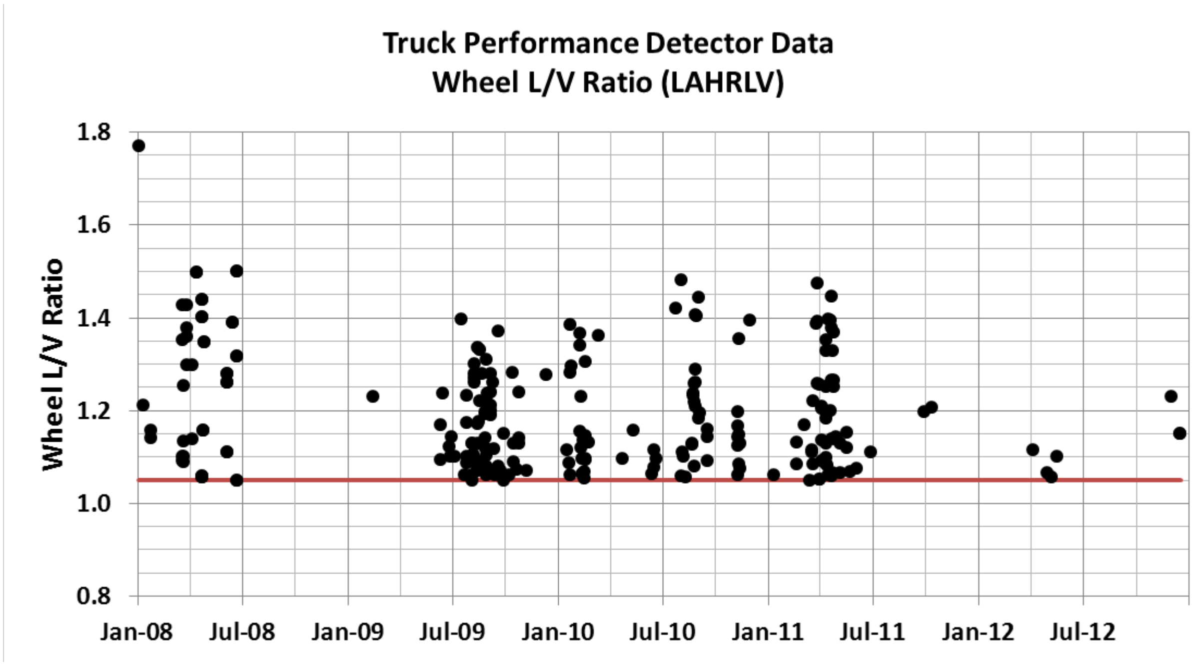


Figure 22. Lead Axle High Rail L/V Ratio History

4.3.2 Lead Axle High Rail L/V Ratio

The leading axle high rail L/V data from the TPD are shown in Figure 22. These data are also reported from the same TPD sites as the ones reporting TGSF. Since there is a small number of reporting detectors, it is difficult to draw any definite trending conclusions. However, the nonreporting detectors are still providing data to the owner railroads and would likely have an impact on the number of derailments attributed to poor truck performance as discussed in Section 5.

5. Impact Detector Implementation on Safety and Economics

In Section 4, it was shown that there has been a drastic reduction in the number of wheels exceeding the extremely high vertical wheel load (> 140 kips, Figure 16) and the number of trucks producing high lateral forces.

Not only have WILD, THD, and TPD sites helped in monitoring vehicle conditions that result in track and equipment damage, they also have led to improved safety against railway incidents.

In this section, the impact of WILD, THD, and TPD installations on track and vehicles/mechanical equipment is analyzed from the perspective of reduction in derailments and associated equipment and track damage costs.

FRA requires reporting of railroad incidents (e.g., derailments, collisions, etc.) that exceed a certain threshold of damage in terms of equipment and/or track. This reporting is done using FRA's F 6180.54 form, which includes the cause of the incident.

Furthermore, FRA's Office of Railroad Safety developed a list of valid cause codes that should be used by the reporting railroads to categorize the reported incident (Office of Railroad Safety, 2011). The data reported in F 6180.54 are collected by FRA and maintained in a publicly accessible database,[8] available at the time of this writing. For the current analysis, the FRA database was queried for incidents attributed to mechanical and track related causes, which were likely to be impacted by the introduction of WILD, THD, and TPD systems. The queries used for the two corresponding cause codes are listed in Table 5.

Table 5. Queries Used to Download Mechanical and Track Related Derailment Data from FRA's Office of Railroad Safety Database

MAJOR CAUSE = Equipment
Selections: Railroad - ALL
State - ALL, County - ALL
Derailment / All TRACK TYPES / E-ALL-Mechanical and Electrical Failures
MAJOR CAUSE = Track
Selections: Railroad - ALL
State - ALL, County - ALL
ALL ACCIDENT TYPES / MAIN / T - Rail, Joint Bar and Rail Anchoring

5.1 Derailment Cause Codes—Equipment

In the FRA incident database, the 'ALL-Mechanical and Electrical Failures' query includes 112 cause codes. The THD and TPD systems are specifically developed to detect the performance of freight cars, not locomotives. Although the queried data consisted of all the cause codes, only

---

[8] Federal Railroad Administration, Office of Safety Analysis, public database.

those freight car related cause codes—that can in some manner be affected by the THD and TPD systems—were selected for analysis.

There is a large number of HBDs (~6,000) and a smaller number of ABDs (26) installed in the North American rail network. The HBDs measure the temperature of the bearings directly, whereas the ABDs measure the acoustic signature of the bearings. They work, respectively, on the principles that a defective bearing will generate higher temperatures and have a unique acoustic signature for various defects, i.e., inner race, outer race, roller spalled, etc. AAR's Field Manual Rules 36(4) and 36(15) permit the removal of trucks from service due to defective bearings from service based on HBD and ABD readings.

It should be noted that, for this project, AAR provided access only to the WILD, THD, and TPD data, while data on HBD and ABD detections were not available. However, since most of the HBDs are installed, and do flag overheated bearings, the hot bearing derailment cause codes listed in Table 6, were retained as a part of this analysis.

Table 6. Relevant Mechanical Related Causes Used for Derailment Incident Query

Code	Description
E23C	Center plate broken or defective
E24C	Center plate disengaged from truck
E25C	Center pin broken or missing
E40C	Side bearing clearance insufficient
E41C	Side bearing clearance excessive
E42C	Side bearing(s) broken
E43C	Side bearing(s) missing
E44C	Truck bolster broken
E45C	Side frame broken
E46C	Truck bolster stiff
E47C	Defective snubbing
E48C	Broken, missing, or defective springs
E49C	Other truck component defects, (CAR)
E4AC	Gib Clearance (lateral motion excessive)
E4BC	Truck bolster stiff (failure to skew)
E4TC	Truck hunting
E52C	Journal (plain) failure from overheat
E53C	Journal (roller bearing) overheating
E59C	Other axle/journal bearing defect car
E60C	Broken flange
E61C	Broken rim
E62C	Broken plate
E99C	Other mechanical/electrical failures

5.1.1 Trend Analysis of Equipment Caused Derailments

For trend analysis of derailments related to equipment causes, queries were made for the period of 2003–2012. These data, plotted in Figure 23, show a year-wise breakdown of each of the top

10, and all other causes for the queried period of 10 years. The total number of derailments due to these causes over the queried period is shown in Table 7.

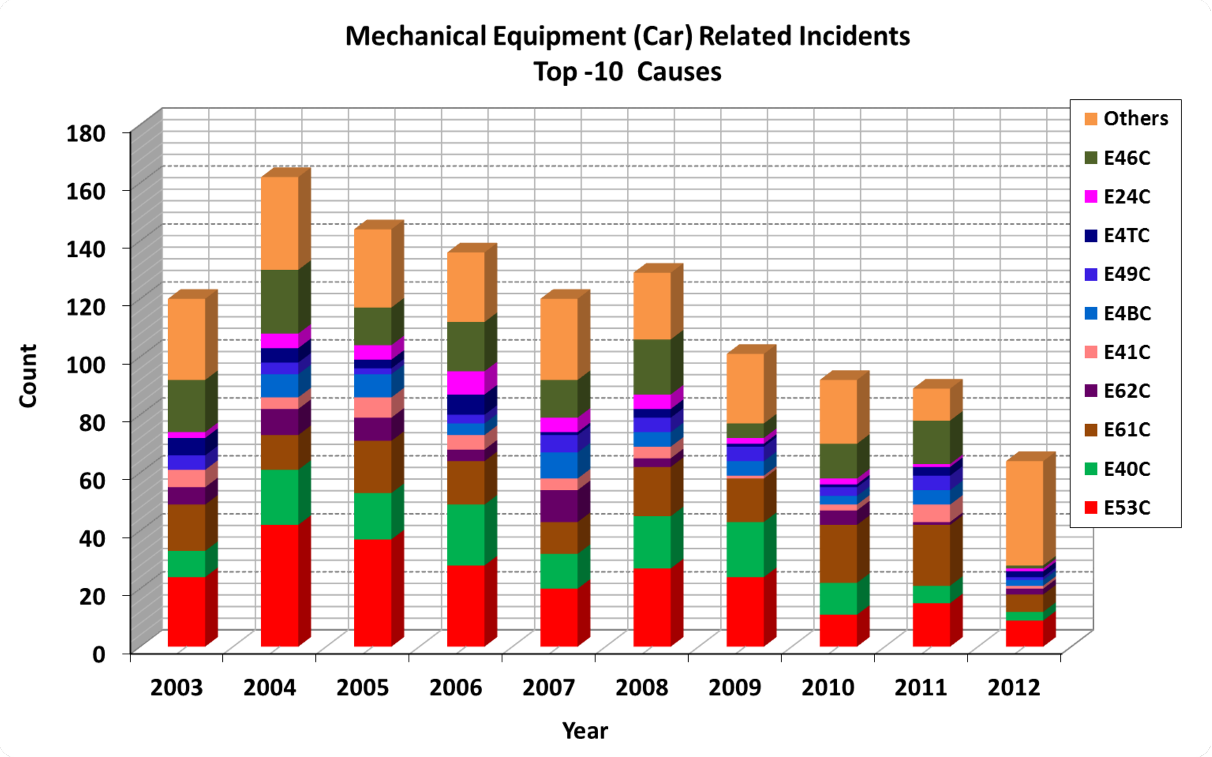


Figure 23. Derailments Due to Top 10 and Others Equipment Cause Codes (Freight Cars Only)

Table 7. Total Number of Derailments Due to Top 10 and Other Equipment Cause Codes

Code	Description of Cause	No. of Derailments (2003–2012)	% of All Derailments
E53C	Journal (roller bearing) overheating	237	20.48%
E61C	Broken rim	151	13.05%
E46C	Truck bolster stiff	135	11.67%
E40C	Side bearing clearance insufficient	134	11.58%
E62C	Broken plate	49	4.24%
E4BC	Truck bolster stiff (failure to slew)	49	4.24%
E41C	Side bearing clearance excessive	40	3.46%
E49C	Other truck component defects, (CAR)	39	3.37%
E24C	Center plate disengaged from truck	36	3.11%
E4TC	Truck hunting	32	2.77%
Others	(22 causes combined)	255	22.04%
	Total	**1,157**	

Two important observations may be made from the data shown in Figure 23 and Table 7. First, there is a definite downward trend in the overall number of derailments. Second, the top four leading derailment causes are:

E53C - Journal (roller bearing) Overheating (20.48%)

E61C - Broken Rim (13.05%)

E46C - Truck Bolster Stiff (11.67%) and

E40C - Side Bearing Clearance Insufficient (11.58%)

These four causes constitute ~57 percent of freight car related derailments. The percentage distribution values of the causes for the period of 2003–2012 are shown in Figure 24.

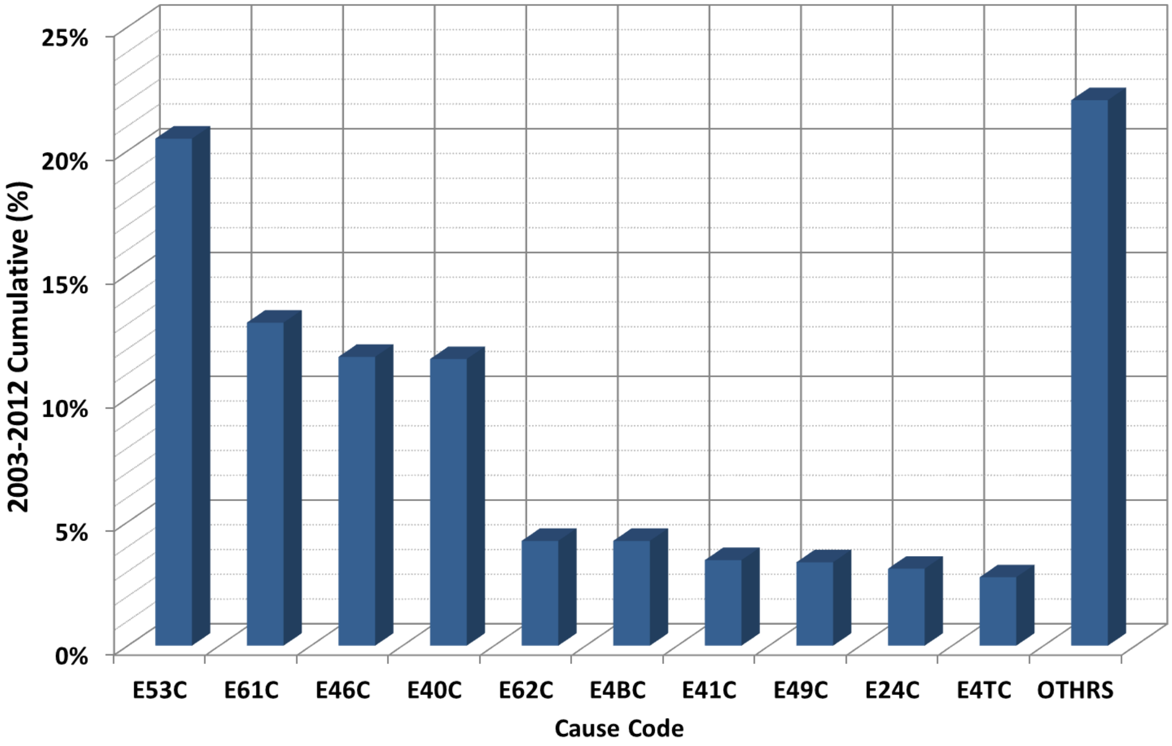


Figure 24. 2003–2012 Derailment Cause Codes (Equipment)—Percentage Distribution

The E53C cause code (Journal/roller bearing, Overheating) has the largest reduction, over the period considered. The next cause code with a large reduction is E46C (Truck Bolster Stiff). This condition refers to a truck with severely degraded steering behavior, and such a behavior is detected by TPDs. The third largest reduction trend is evident for E40C (Side Bearing Clearance Insufficient), another indicator of a truck is not being able to steer properly. This truck condition is also flagged by a TPD. The cited reductions are shown in Figure 25.

The only cause code not showing a reduction trend is E61C (Broken Rim). Over the queried period of 10 years, it ranks second with 151 derailments (Table 7). The broken rim is a result of relatively large portions of wheel treads falling off due to internal cracks which originate from material defects (e.g., voids and inclusions). These cracks initiate and propagate under cyclic loading of wheels.

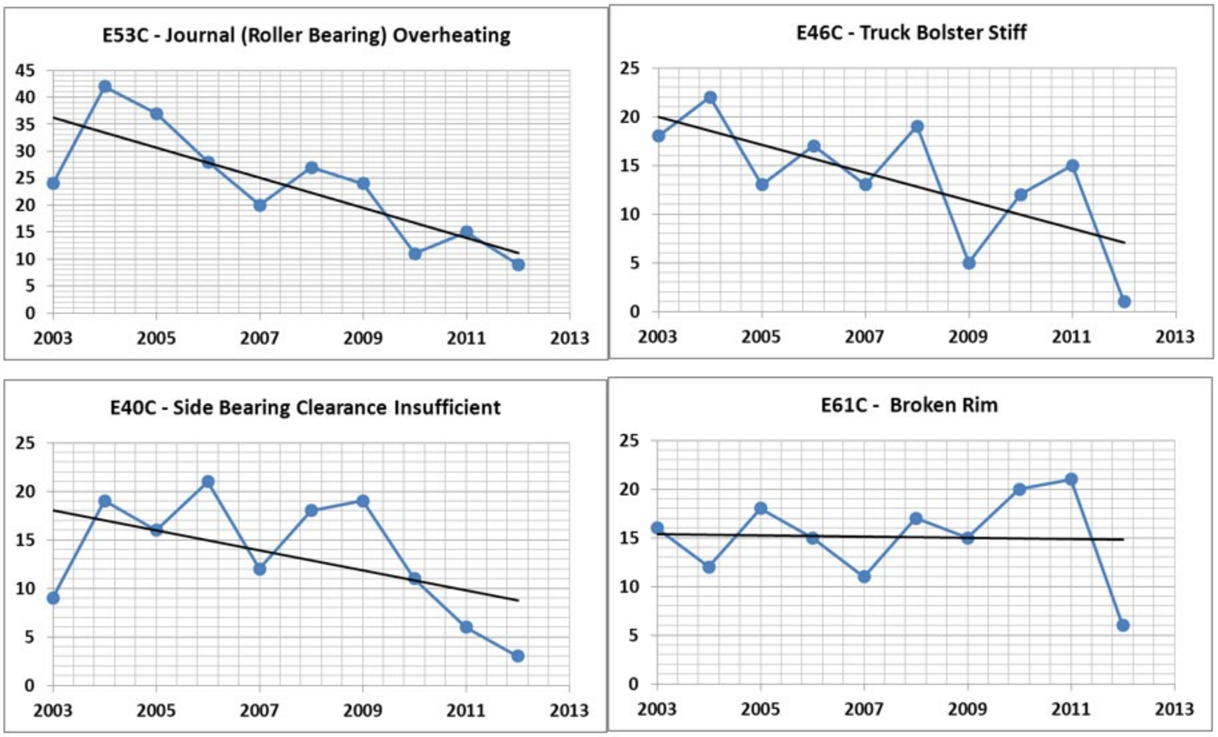


Figure 25. Derailments due to Top Four Mechanical Equipment Cause Codes

Trend line analysis, shown in Figure 25, of the top four mechanical causes—Journal (roller bearing) Overheating (E53C), Truck Bolster Stiff (E64C), Side Bearing Clearance Insufficient (E40C) and Broken Rim (E61C)—leading to the highest number of derailments shows a 69, 65, 50 , and 6.3 percent reduction in their respective trendlines, over the period of 2004–2012. Overall, the number of derailments due to these four causes combined has reduced from a total of 67 in 2003 down to 19 in 2012, a 71.5 percent reduction.

Whereas derailments due to Broken Rim (E61C) remained almost unchanged, recent deployment of an ultrasonic wheel crack detection system on one of the major railroads seems quite promising.

None of the detectors deployed currently (as of 2012) are designed to detect the presence of internal defects in a wheel rim. Recently, Union Pacific Railroad (UP) has installed an ultrasonic wheel rim defect detection facility at North Platte, NE. At this location, coal trains are controlled to roll by at 5 mph with the wheel flange riding on the rail, thus allowing the wheel tread to be submerged in a water trough to provide water as couplant for ultrasonic detection. According to UP,[9] since this facility was put into service, no broken rim related derailments have been reported on those trains. Queries in the FRA derailment database for comparative periods in 2005–2007 and 2011–2013 for the entire UP railroad fleet showed the derailments due to Broken Rim (E-61C) reduced from 22 in 2005–2007 to 12 in 2011–2013.

---

[9] Progressive Railroading, June 2012, "Since the railroad implemented the system, there have been no coal train derailments caused by wheel failure."

Further reduction in the number of hot bearing related derailments is under scrutiny via AAR's ATSI and there is a focus on developing a bearing temperature trending criterion for industry-wide acceptance.

5.1.2 Economic Impact of HBD, THD, and TPD Detectors on Derailment Costs

As discussed in Section 5.1.1, as a result of various wayside detectors, there has been a significant reduction in the number of derailment incidents. This reduction has a direct impact on the railroads' operating costs. As a part of the analysis, derailment costs for the mechanical causes were queried from the RAIRS database for the same period as the derailment incidences. The cumulative costs, by cause, for the period 2003–2013 are shown in Table 8 for all causes with top 10 broken out. A yearly distribution of these costs for various causes is shown in Figure 26.

Table 8. Total Damage due to Top 10 Equipment Cause Codes, 2003–2012

Cause Code	Description of Cause	Damage ($Million) (2003–2012)	% of Total Cost
E61C	Broken Rim	$80.2	28.8%
E53C	Journal (roller bearing) Overheating	$63.8	22.9%
E62C	Broken Plate	$17.1	6.1%
E40C	Side Bearing Clearance Insufficient	$12.8	4.6%
E46C	Truck Bolster Stiff	$12.8	4.6%
E47C	Defective Snubbing	$10.9	3.9%
E4TC	Truck Hunting	$10.0	3.6%
E60C	Broken Flange	$8.8	3.2%
E45C	Side Frame Broken	$8.5	3.1%
E59C	Other axle/journal bearing defect car	$5.2	1.9%
Others		$48.1	17.3%
	Total	**$278.20**	

It is worth noting that although Broken Rim (E61C) resulted in ~36 percent fewer (151 vs. 237) derailments compared to Journal Overheating (E53C), that resulted in ~26 percent ($80.2M vs. $63.8M) higher derailment costs when compared to Journal Overheating related derailments.

This shows that, on average over the 10-year period studied, a derailment caused by a broken rim was two times costlier than a derailment caused by a hot bearing.

A better indicator of downward trend in overall derailment cost is seen in Figure 27, where costs have been converted to 2012 dollars. It is seen that for all categories except for the Broken Rim, there has been a downward trend in derailment costs consistent with the derailment incidents shown in Figure 23.

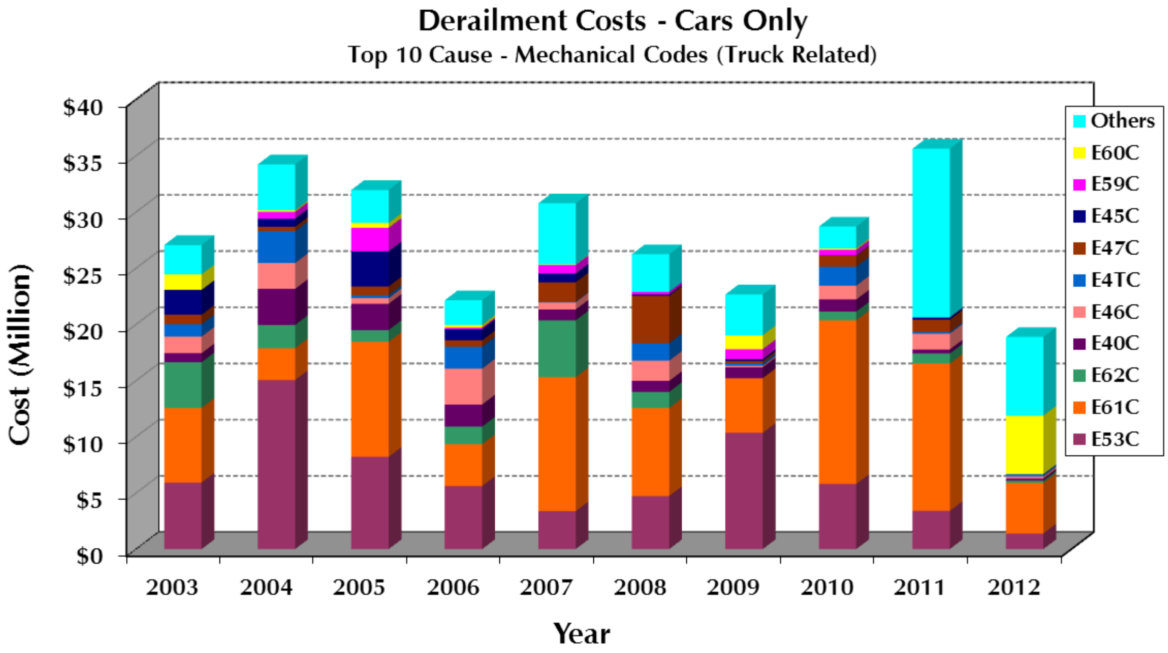


Figure 26. Equipment Related Derailment Costs, Top 10 Causes

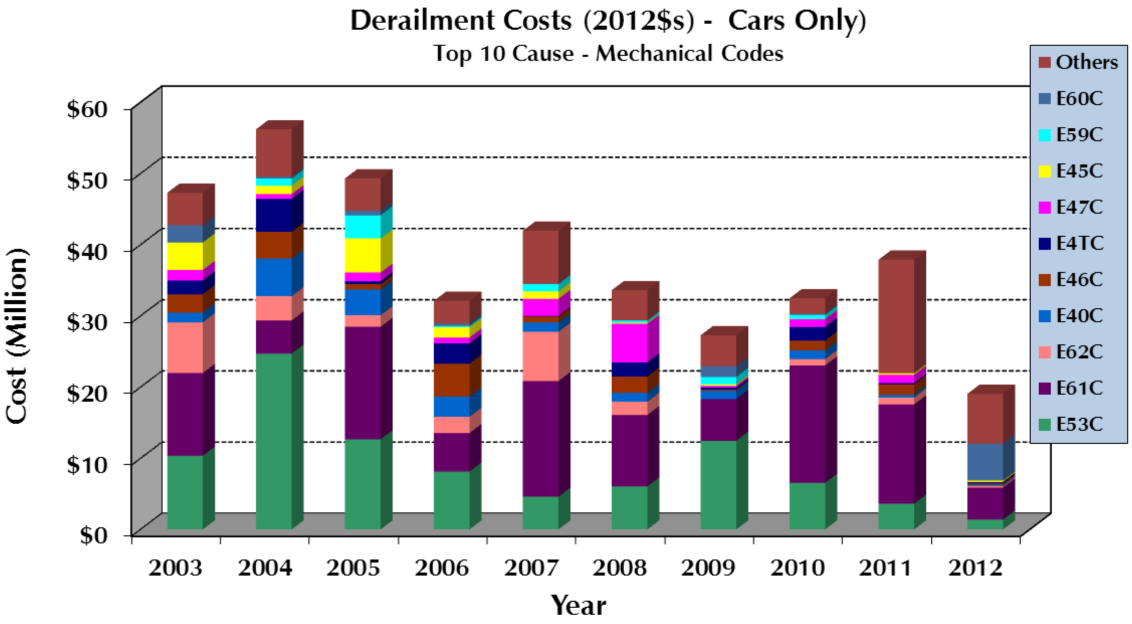


Figure 27. Equipment Related Derailment Costs in 2012 Dollars, Top 10 Causes

5.2 Derailment Cause Codes—Track

As shown in Table 5, the FRA incident database, the category ‘ALL ACCIDENT TYPES / MAIN / T - Rail, Joint Bar and Rail Anchoring’ query captures track related derailment cause codes and includes a total of 42 causes.

The WILD system is designed to identify wheels producing high vertical impact loads. Only those causes that would be affected by elimination or reduction of high vertical impact wheel loads are shown in Table 9.

Table 9. Track Related Causes Used for Derailment Incident Query

Code	Description
T201	Bolt hole crack or break
T202	Broken base of rail
T203	Broken weld (plant)
T204	Broken weld (field)
T205	Defective or missing crossties
T206	Defect/missing spike-other rail fastener
T207	Detail fracture—shelling/head check
T208	Engine burn fracture
T210	Head and web separation (outside joint bar limit)
T211	Head & web separation-in joint bar limit
T212	Horizontal split head
T213	Joint bar broken (compromise)
T214	Joint bar broken (insulated)
T215	Joint bar broken (non-insulated)
T216	Joint bolts, broken, or missing
T217	Mismatched rail-head contour
T218	Piped rail
T219	Rail defect with joint bar repair
T220	Transverse/compound fissure
T221	Vertical split head
T222	Worn rail
T299	Other rail and joint bar defects

Although WILD systems formally were organized by AAR under its ATSI program beginning in 2004, some versions of these systems were deployed in the rail network earlier than 2004. Therefore, the derailment database was queried for the 2003–2012 period. Downloaded data for the pertinent causes were then sorted and analyzed for top 10 causes.

5.2.1 Trend Analysis of Track Caused Derailments

Derailments related to track causes, for the period 2003–2012 are plotted in Figure 28, which shows a year-wise breakdown for each of the top 10 causes. The total number of derailments due to these causes over the queried period is shown in Table 10 for all causes with the top 10 broken out.

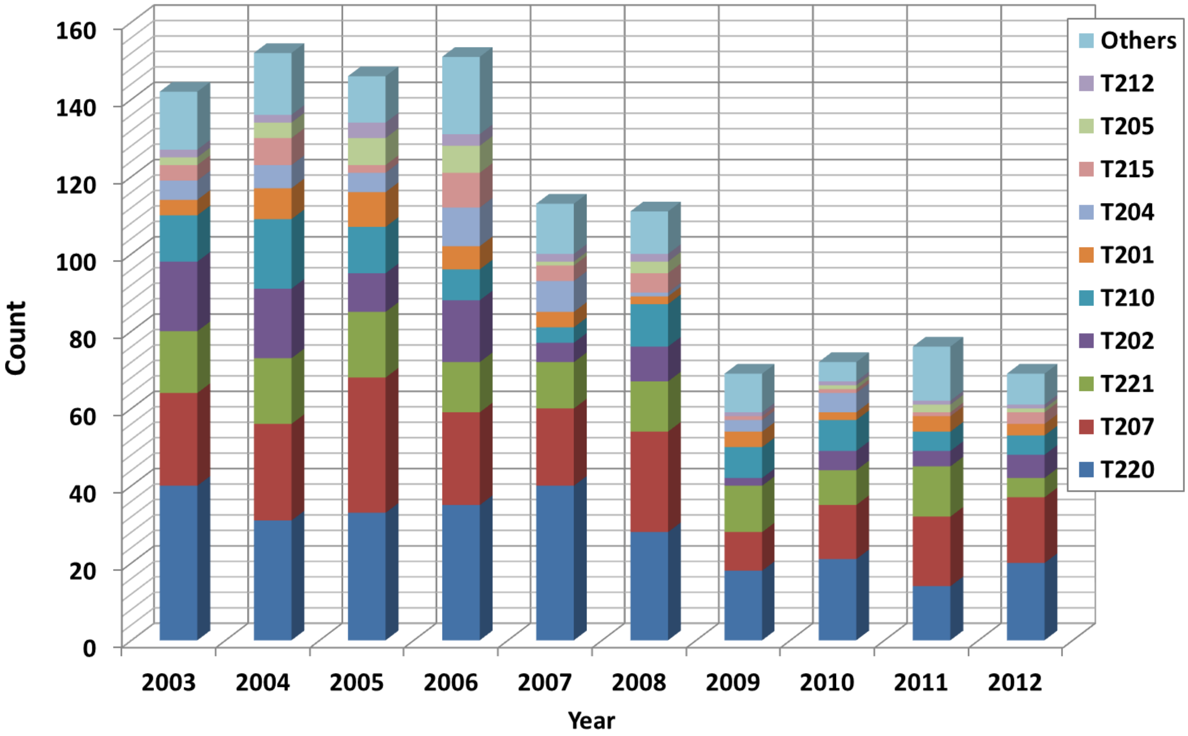


Figure 28. Top 10 Track Cause Codes, Number of Derailments

Table 10. Total Number of Derailments Due to the Top 10 Track Cause Codes

Cause Code	**Description of Cause**	**No. of Derailments (2003–2012)**	**(%) of Total Derailments**
T220	Transverse/compound fissure	280	26.7%
T207	Detail fracture - shelling/head check	213	20.3%
T221	Vertical split head	127	12.1%
T202	Broken base of rail	93	8.9%
T210	Head and web separation (outside joint bar limit)	91	8.7%
T201	Bolt hole crack or break	46	4.4%
T204	Broken weld (field)	43	4.1%
T215	Joint bar broken (non-insulated)	37	3.5%
T205	Defective or missing crossties	28	2.7%
T212	Horizontal split head	19	1.8%
Others	(12 Cause Codes Combined)	71	6.8%
	Total	**1,048**	

Two important observations may be made from the data shown in Figure 28 and Table 10.

First, there is a definite and significant downward trend in the overall number of derailments. Second, the top five leading derailment causes are:

T220 - Transverse/compound fissure (26.7%)

T207 - Detail fracture - shelling/head check (20.3%)

T221 -Vertical split head (12.1%)

T202 - Broken base of rail (8.9%)

T210 - Head and web separation (outside joint bar limit) (8.7%)

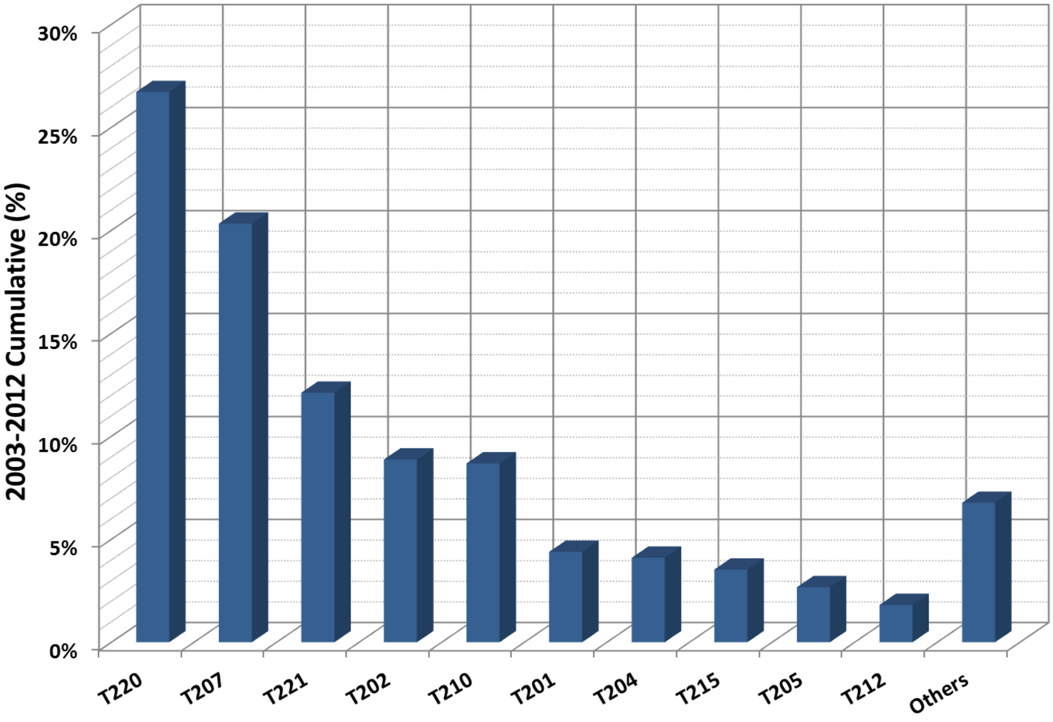


Figure 29. Top 10 Track Cause Codes—Percentage Distribution, 2003–2012

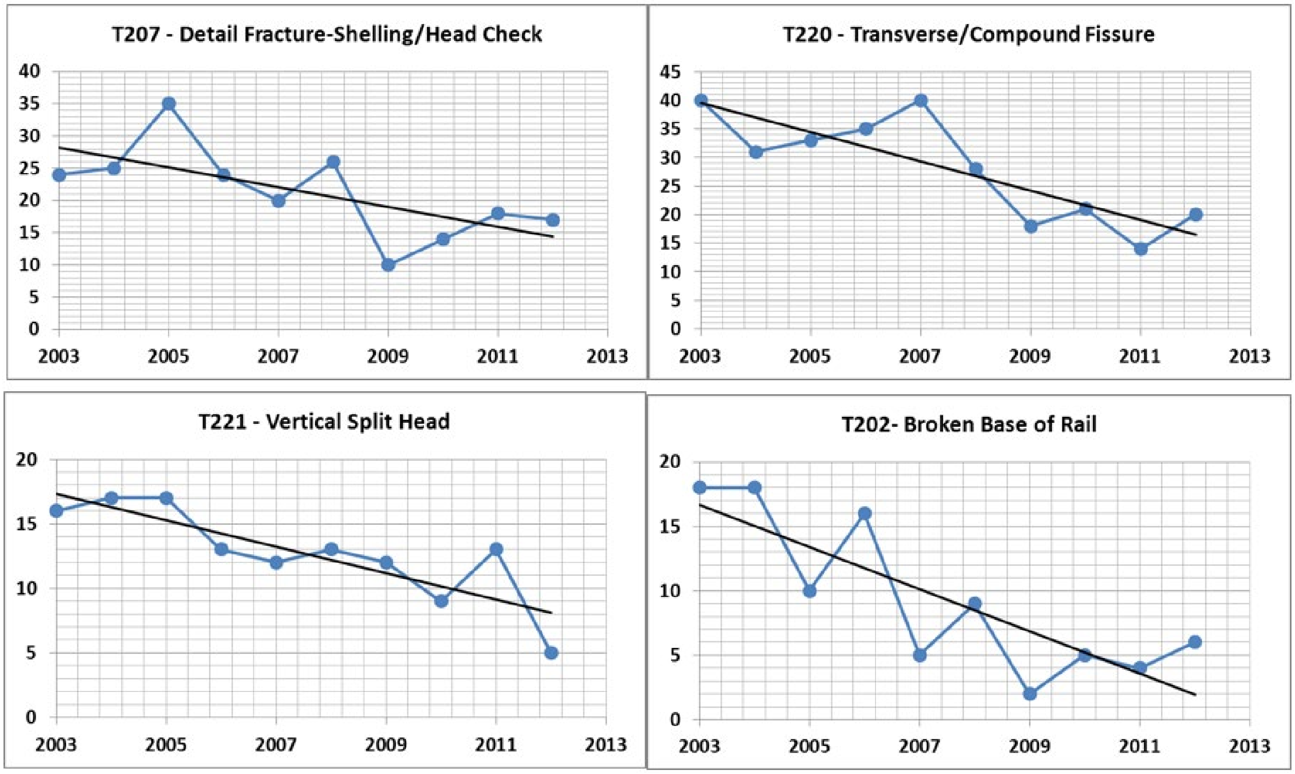


Figure 30. Top Four Track Derailment Cause Codes, 2003–2012

These five causes constitute ~76.7 percent of track related derailments. The percentage distribution values of the top 10 causes for the period of 2003–2013 are shown in Figure 28 and Figure 29.

A trend analysis for the highest four causes is shown in Figure 30.The T220 cause code (Transverse/compound fissure), in terms of number of derailments shows the largest reduction. It should be noted that the highest number of derailments during the queried period were assigned to this cause. Although even in 2012, it has the maximum number (20) of derailments; it went from a high of 40 in 2003 to 20 in 2012.

The next two causes with significant reductions are T207 (Detail Fracture - Shelling/ Head check) and T202 (Broken base of rail). T207 is the cause which showed the second highest number derailments for the 10-year period queried. The next cause to see a significant reduction trend is T221 (Vertical Split Head).

The transverse/compound fissures originate from internal defects and grow under traffic due to cyclic loading from wheels. Any wheel load higher than normal is likely to accelerate the growth of cracks in the rail, regardless of how the crack originated (i.e., internal defects or surface fatigue). Even normal wheel loads contribute to crack growth. Therefore, if the high impact vertical wheel load cycles are reduced, crack growth would be slower and thus delay the breakage of rail, thereby leading to reduced incidents from such causes.

The top four track related causes of derailments: Transverse /Compound Fissure (T220), Detail Fracture-Shelling/Head Check (T207), Broken Base of Rail (T202) and Vertical Split Head (T221) show a reduction of 57.5, 48, 75, and 53 percent, respectively, over the period of 2003–2012. Overall, these 4 causes combined, show a reduction from a total of 98 derailments in 2003 down to 48 in 2012, a 51 percent reduction.

In the track related area, the Transverse/Compound Fissure (T220) and Vertical Split Head (T221) are still the top derailment causes, 20 and 17 respectively, in 2012. The effectiveness of WILD systems in reducing the high impact wheel loads in the queried car population is seen in Figure 14 and Figure 16. In Figure 14, >90 kips wheels have reduced from a high winter months count of 7,708/month to 3,688/month, almost a 50 percent reduction. Similarly, in Figure 16, the high winter month count for >140 kips wheels was reduced from 212/month in 2005 to 43/month in 2012, an 80 percent reduction. The near asymptotic trend for AAR Condemnable and Final Alert wheel counts in Figure 15 and Figure 17 shows that any further reduction for the T220 and T221 causes would come with more effective detection of critical internal rail defects before they grow to an unsafe level under service wheel loads rather than adding more WILD sites.

Although cause code T220 is showing the largest reduction, it remains the top cause for track related derailments. Along with a reduction in number of high vertical wheel load cycles, the rail-flaw detection program is an important mechanism employed by the railroads to further reduce the incidences of derailment due to the cause codes T220 and T207.

5.2.2 Economic Impact of WILD Detectors on Derailment Costs

Like the derailment costs for the mechanical causes, queries were conducted for track cause related derailment incident costs for 2003–2012 and these costs are shown in Table 11 with the top 10 causes, broken out.

It is seen in Table 11 that ~60 percent of all track related derailment costs over the 10 year period were due to T220, Transverse/compound fissure (26.3%), T207, Detail fracture–shelling/head check (22%), T204, Broken weld (field) (6.1%), and T221, Vertical split head (6.1%).

Table 11. Total Damage due to Top 10 Track Cause Codes

Code	Description	Damage ($Million) (2003–2012)	Cause %
T207	Detail fracture–shelling/head check	$133.42	26.3%
T220	Transverse/compound fissure	$113.27	22.3%
T204	Broken weld (field)	$31.09	6.1%
T221	Vertical split head	$30.84	6.1%
T215	Joint bar broken (non-insulated)	$29.94	5.9%
T201	Bolt hole crack or break	$25.53	5.0%
T202	Broken base of rail	$24.70	4.9%

Code	Description	Damage ($Million) (2003–2012)	Cause %
T214	Joint bar broken (insulated)	$18.68	3.7%
T210	Head and web sep (outside jt bar limit)	$18.25	3.6%
T213	Joint bar broken (compromise)	$13.11	2.6%
T299	Other rail and joint bar defects	$68.04	13.4%
	Total	**$506.87**	

For the queried period of 2003–2012, a breakdown of the derailment costs for the top 10 track causes is plotted in Figure 31.

A better indicator of the downward trend in derailment cost is seen in Figure 32, where costs have been converted to 2012 dollars.

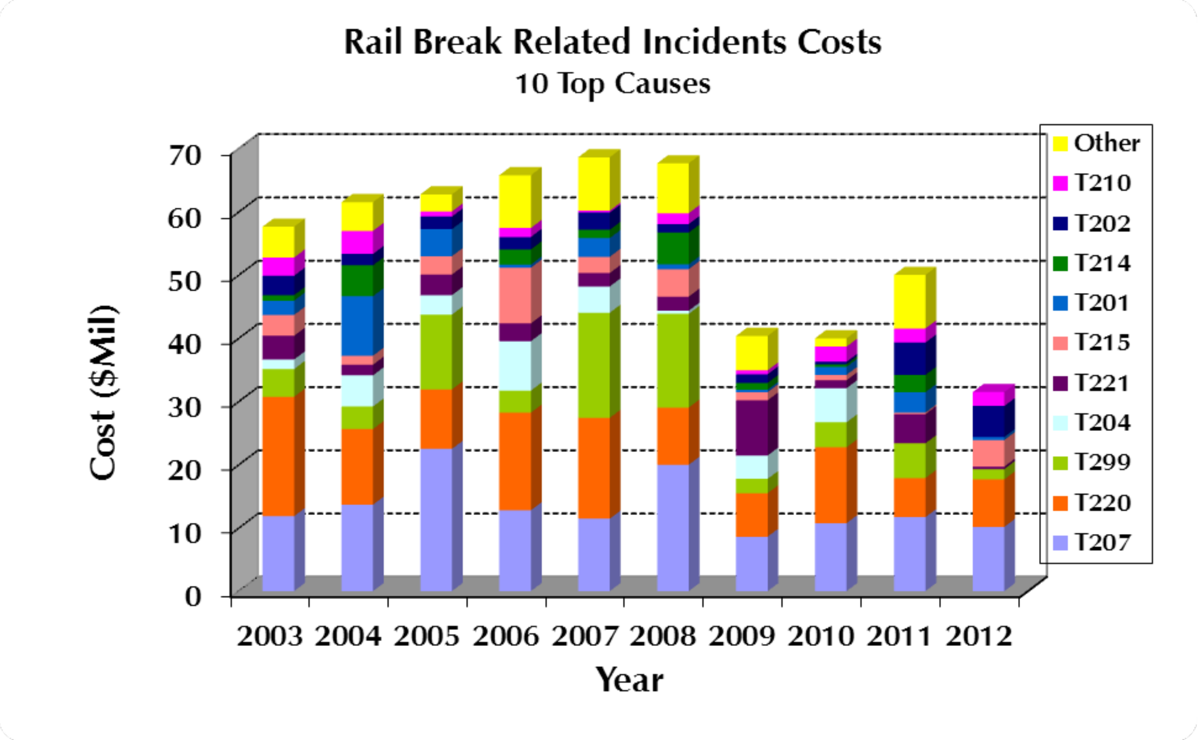


Figure 31. Track Related Derailment Costs—Top 10 Causes

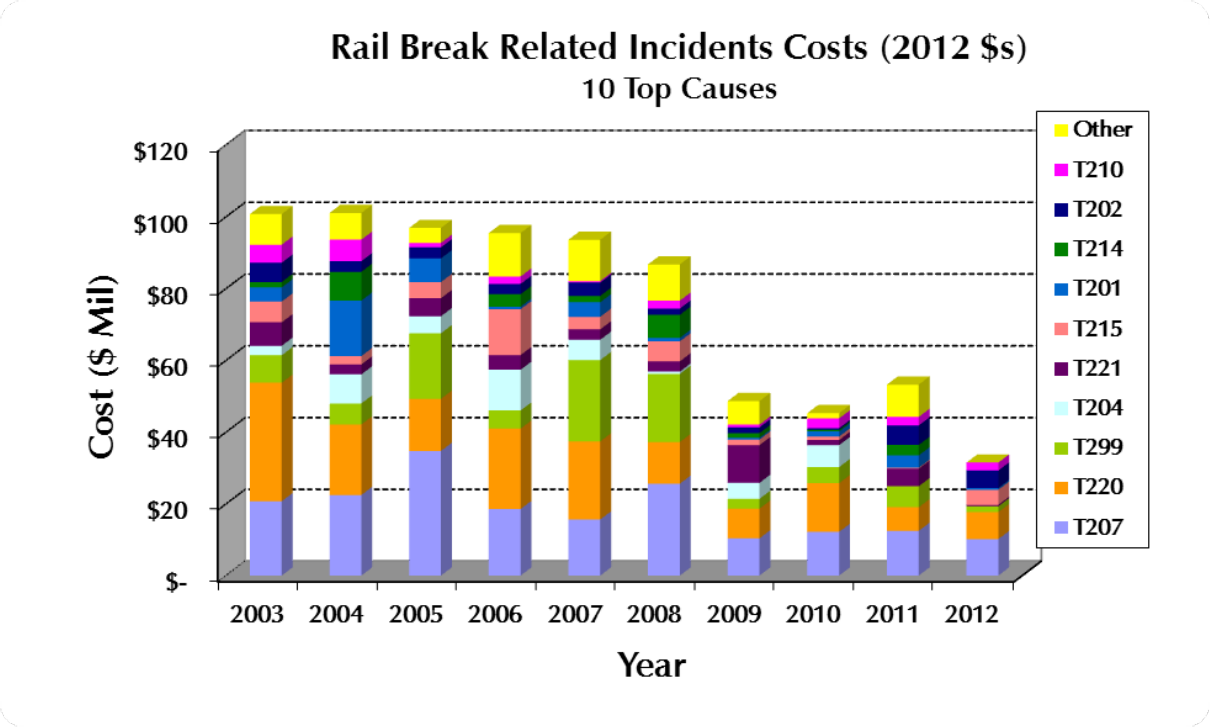


Figure 32. Track Related Derailment Costs in Current Dollars—Top 10 Causes

6. Impact of Increased Number of Detectors on Derailments

To investigate and evaluate the impact of the increase in the number of WILD, THD, TPD system installations on the number of derailments data for 2003 through 2012 were analyzed. The history of the derailment frequencies for track and equipment causes and the growth of detector systems are discussed next.

6.1 Impact of HBD, THD, and TPD Installations on Car/Truck Component Cause Related Derailments

To understand how the frequency of the mechanical equipment related derailments has been affected by the number of installed THD and TPD systems are plotted in Figure 33. Although the HBD installation history is not shown, there are as noted previously, ~6,000 HBD systems installed in the North American rail network and they are used to detect bearing with an elevated temperature. To avoid hot bearings related derailments, the train crew is warned to inspect trains when such bearings are detected.

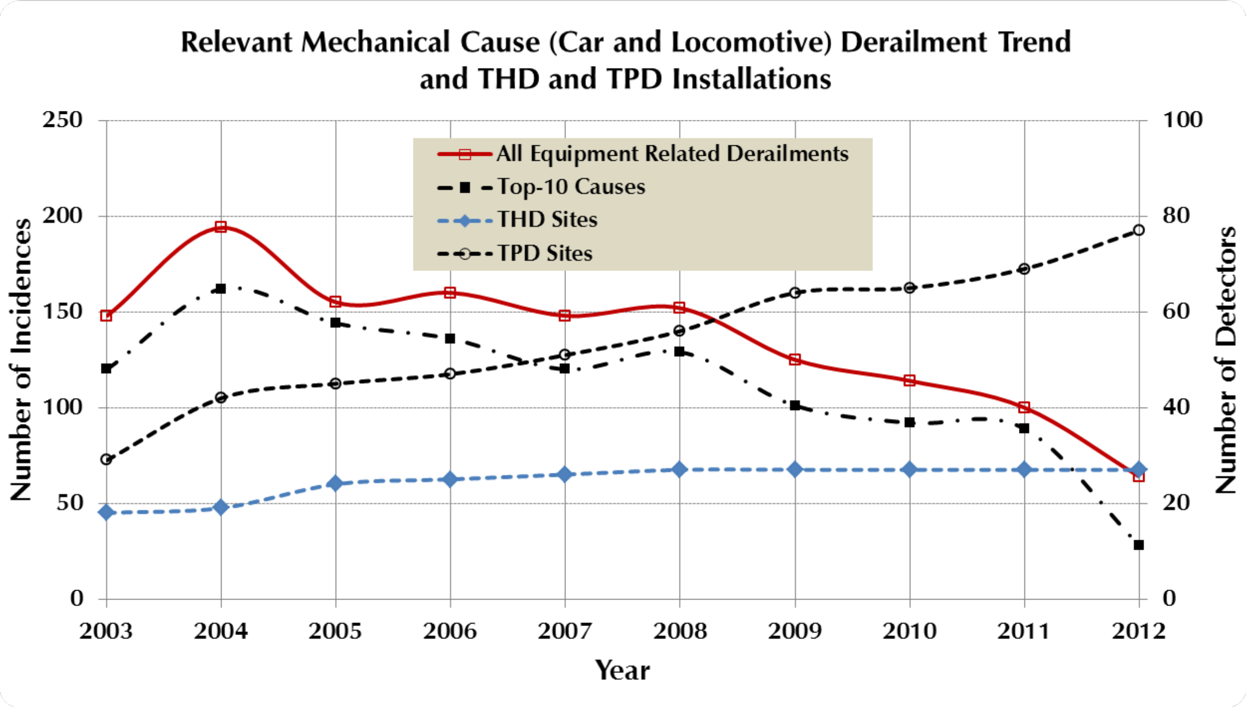


Figure 33. Impact of THD and TPD Installations on Car/Truck Component Cause Related Derailments

Figure 33 shows all relevant mechanical freight car truck/components related causes combined, and also the top 10 causes for each year from 2003–2012.

Figure 33 shows that, overall, there has been a decline in the number derailments that can be attributed to freight car truck/components. The number of derailments has declined significantly, from a high of 194 in 2004 to 64 in 2012. The top 10 causes related to freight car/components exhibit a similar reduction—from a high of 162 in 2004 to 28 in 2012. One of the high incidence causes—Hot Bearing (E53C)—has seen the largest reduction from a high of 42 incidences in

2003 down to 9 in 2012. One other cause that sees a sharp reduction is Stiff Truck Bolster (E46C), from a high of 22 in 2003 down to 1 in 2012. Although the number of TPDs in the network is small, it has made a significant contribution in identifying poorly steering trucks and thus flagging the affected cars for early truck repair/maintenance.

Although the number of derailments related to Truck Hunting (E4TC) have been small, early detection of truck hunting has contributed to timely truck repair/maintenance. Truck hunting behavior forces railroads to lower train speeds to prevent empty cars from hunting in a mixed train. The THDs have thus helped railroads in keeping more trains running at scheduled speeds. Furthermore, trucks shopped for truck hunting also get inspected for other suspension related issues and are returned to service with improved dynamic behavior.

It is clear that as the numbers of installations of TPD, THD, and HBD have grown, they have significantly helped in reducing the number of derailments related to freight car/components.

6.2 Impact of WILD Installations of Track Cause Related Derailments

In Section 5, the trend for derailments that are attributed to vertical wheel loads were discussed. To investigate how the incidences of these derailments have been affected by the number of installed WILD system growth, the number of derailments and the WILD sites are plotted in Figure 34. The figure includes all relevant track causes (e.g., Rail, Joint Bar, and Rail Anchoring) combined and also the top 10 causes for the period 2003–2012.

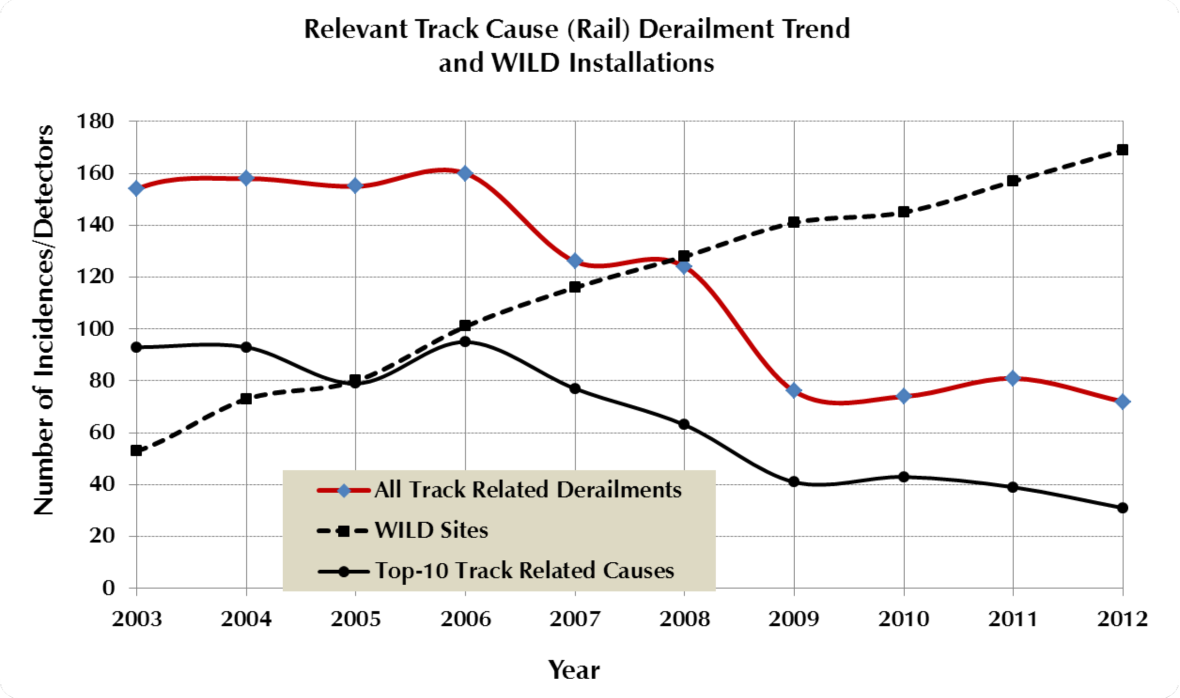


Figure 34. Impact of WILD Installations on Track Cause Related Derailments

It clear that as the number of WILD systems has grown from 53 in 2003 to 169 in 2012, the number of track cause code derailments has reduced from 154 in 2003 to 72 in 2012; a reduction of 53 percent. The trend for the top 10 causes is similar and shows a reduction in derailment from 93 to 31; a reduction of 66 percent. This suggests that the WILD systems have made a major contribution to the reduction in track-cause related derailments that are largely governed by high impact vertical wheel loads.

The rail causes that are low-cycle fatigue driven experienced the largest reduction, because the high impact loads (AAR Condemnable and Final Alert) experienced a dramatic reduction. For example, Transverse/Compound Fissure (T220) experienced the largest reduction from a high of 40 derailments in 2003 down to 20 in 2012. Similarly, Broken Base of Rail (T202) caused derailments reduced from a high of 18 in 2003 down to 6 in 2012. On the other hand, Detail Fracture Shelling/Head Check (T207) caused derailments remained relatively the same. It only reduced from a high of 24 in 2003 down to 17 in 2012.

It should also be noted that T220 and T207 related incidents reduced not only due to the reduction in the number of high impact wheels (because of WILD systems), but also due to the frequency and effectiveness of rail flaw detection programs. To determine how the rail-flaw detection system implementations have changed over the analyzed period, further analyses would be needed.

7. Conclusion

The work for this research was performed to understand the impact of wayside detection system installations on monitoring poor equipment performance and consequently the improvement in railroad operational safety; namely the reduction in the number of derailments.

The WILD, THD, and TPD data were queried from AAR's InteRRIS® system for 2004–2012 for a representative sample of 133,000 cars in the North American fleet of ~1,300,000 cars, i.e., ~10 percent of the fleet. These data included counts of high impact wheel loads, truck hunting and high lateral truck forces.

Installation history data was obtained from AAR to correlate the queried vehicle performance data to the growth in detector system installations.

Further, to investigate the impact of wayside detection systems, derailment data from FRA's derailment database was downloaded for the causes that were likely to be impacted by the parameters measured by the various detector systems.

- The trend analysis of the high impact wheel loads, truck hunting and high lateral truck forces shows that the detectors have had a significant impact on reducing the number of equipment and vehicle components with conditions that, if not detected and repaired or removed from service in time, can lead to unsafe operations including derailments.
- A trend analysis of the detector installations growth and number of relevant derailment cause codes shows a strong correlation.
- The increase in the number of HBD, THD, and TPD installations shows a definite impact in reducing the number of derailments related to overheated bearings and poorly steering trucks. Effective detection of these defects has led the railroads and equipment owners to monitor their fleet and schedule maintenance and repair to correct these issues.
- The analysis also identified areas where advancement in detection technology can lead to further improvements in equipment performance and railroad operational safety. For example, the broken rim failures are one the costliest derailments and have still not been effectively addressed by the industry. Although there has been some progress made in this area to showcase the available technology, a wider implementation should lead to a major impact on derailment reduction.
- The four mechanical causes—Journal (roller bearing) Overheating (E53C), Truck Bolster Stiff (E64C), Side Bearing Clearance Insufficient (E40C), and Broken Rim (E61C)—leading to the highest number of derailments show a 69, 65, 50 , and 6.3 percent reduction in derailments over the period of 2003–2012. Overall, derailments due to these four causes have reduced from 67 in 2003 down to 19 in 2012, a 71.5 percent reduction.
- Whereas the Broken Rim (E61C) related derailments remain almost unchanged, recent deployment of ultrasonic wheel crack detection system on one of the major railroads appears to be quite promising.
- Further reduction in the number of hot bearing related derailments is under scrutiny via AAR's ATSI and there is a focus on developing a bearing temperature trending criterion for industry-wide acceptance.

- The WILD systems show a major reduction in the number of high impact wheels. In fact, these systems seem to have largely reached their effectiveness in reducing the "AAR Condemnable" and "Alarm Level" in service.
- The effect of WILD systems on rail failure related derailments has been very significant. In some cases, the rail failure derailment causes which would be driven by high impact load cycles have been reduced by as much as 50 percent.
- The four highest track related causes of derailments—Transverse/Compound Fissure (T220), Detail Fracture-Shelling/Head Check (T207), Broken Base of Rail (T202), and Vertical Split Head (T221)—have reduced 57.5, 48, 75, and 53 percent, respectively, over the period of 2003–2012. Overall, derailments due to these four causes have reduced from 98 in 2003 down to 48 in 2012, a 51 percent reduction.

The wayside detectors had a significant impact on reduction in derailment costs.

The four mechanical causes with the highest cumulative derailment incidents experienced a decrease in the costs of associated derailments from \$21.42M to \$1.97M in 2012 dollars; a 90 percent reduction over the period 2004–2012. However, this was due to a dramatic reduction in incidents of broken rims from 21 in 2011 to only 6 in 2012.

The four highest derailment incidents due to track related causes saw the associated costs go down by 52 percent reduction over the period 2003–2012. Not all this cost reduction can necessarily be attributed to the detectors alone, but a reduction in high impact loads does lead to increased life and reduced failures of rail components.

In summary, the work reported herein suggests that the wayside detection systems have performed as expected in improving the railroad fleet performance and operational safety level.

8. References

Dedmon, S. L., et al. (June 2007). “Accelerated Shelling–A Winter-Time Problem,” Wheel Shelling/Failure Study Group. Topeka, KS.

Office of Railroad Safety. (2011). FRA Guide for Preparing Accident/Incident Reports. Report No. RRS-22. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.

Transportation Technology Center, Inc. (October 2007). “Initial Performance Limits: Three Hunting Detector Type.” Report No. TD-07-034. Pueblo, CO

Appendix A – Brief Description of Various Wayside Detector Systems

Wheel Impact Load Detector

A Wheel Impact Load Detector (WILD) system is designed to identify wheels with tread defects such as slid flats, out-of-rounds, built-up treads and shells that result in high impact loads. Such loads cause damage to truck and car components as well as the track structure. High vertical impact loads promote track defect growth and rail breakage.

There are two types of WILD systems—strain gauge based and vertical acceleration based—deployed in the North American rail network. Both systems have been approved by the AAR.

Truck Hunting Detector

Truck Hunting Detectors (THD) are designed to identify freight vehicles experiencing lateral instability at relatively higher speeds (> 40 mph), when operating empty or lightly loaded. Two types of THD systems—one based on rail strain gauges that measure lateral wheel loads on tangent track and the other based on laser measurements of angle of attack and lateral position of an axle—have been deployed on the rail network. Both systems have algorithms built in that convert raw measurements to hunting index values that provide a measure of the hunting activity in the trucks. The strain-gauge based THDs are often co-located with the WILD systems. The AAR has approved both systems and verified their indices against the AAR's hunting criteria quantified by carbody lateral root-mean-square (RMS) accelerations.

Truck Performance Detectors

A Truck Performance Detector (TPD assesses the performance of a rail car during curve negotiation as affected by suspension systems. The lateral forces on the rails are measured as the rail car moves over TPD sensors placed at each major segment of a track containing curves of four to six degrees of curvature.

Truck Alignment Detectors

Another system uses laser measurements of wheelset position and angle of attack on a tangent track segment to deduce trucks' steering behavior. This system—called Truck Alignment Detector (TAD)—is not yet part of the EHMS' InteRRIS® database.

Wheel Profile Measurement System

These systems are based on laser scanning of the passing wheelsets. The wheel profile is illuminated by a laser beam and a picture is captured by a high-speed camera. The data is processed to obtain an image of the wheel profile which then can be digitally compared against a benchmark profile for that wheel to determine wheel wear, flange height and flange and rim thicknesses. As of August 2013, there were only about 12 wheel profile measurement systems (WPMS) installed in the rail network and as of 2012 they had not been integrated into EHMS.

Hot Box and Dragging Equipment Detectors

According to the AAR,[10] more than 6,000 HBDs and 1,000 Dragging Equipment Detectors (DED) are installed in the North American rail network. The HBD system is an infra-red thermal

---

[10] AAR. Nationwide Wayside Detector System.

detection system to monitor temperature of bearings as wheelsets pass over the detector. The HBDs are not integrated into the EHMS-InteRRIS® yet and individual railroads and car owners utilize the data from these sites to monitor bearings on their fleet using proprietary trending and threshold limiting analysis. Through the AAR's Advanced Technology Safety Initiative (ATSI), there are plans to develop common industry-wide criteria to be practiced by all car owners.

Wheel Temperature Detector

Wheel temperature detectors (WTD) use sensors that employ infrared technology to scan the outer surface of the railcar wheel and typically record an average or a peak temperature for each wheel passing the detector. The hot and cold detection purpose is to indicate that a brake is applying when it should not or is not applying when it should, respectively. The detector output is aligned with an Automated Equipment Identification (AEI) system so that temperatures can be matched to a specific car and wheel location to ensure a targeted inspection and to facilitate proper documentation and subsequent remediation or repair.

The WTD systems use the same technology as hot bearing detection which is a mature technology that has been used in the rail industry for several decades.

Automatic Wheel Crack Detector

The automatic wheel crack detection (AWCD) systems require the trains to roll past a wheel crack detector at a slow speed with the wheel flange riding on the rail, thus allowing the wheel tread to be submerged in a water trough to provide water as couplant for ultrasonic detection As of 2013, only one facility has been put into service by one Class I railroad.

An association between the detectors' function(s) and FRA's regulations governing the freight equipment conditions monitored or detected by these systems are listed in the Table A-1.

Table A-1. Detector Technology and Associated CFR sections

Detector Technology (Symptoms Attributing To Trigger Detection or Measured Parameters)	**Associated 49 CFR Section**
Wheel Impact Load Detector (WILD) (Slid flat, tread built-up and shelling)	§ 215.103 (f-1&2)
Hot Box Detector (HBD) (Roller defects, loose cone, etc.)	§ 215.107
Acoustic Bearing Detector (ABD) (Roller defects, loose cone, etc.)	§ 215.115 (b-ii)
Truck Performance Detector (TPD) (Worn friction wedges and wear plates, broken/missing suspension springs, hollow worn wheels, dry center bowls, tight side bearings, mismatched side frames)	§ 215.117 § 215.119
Truck Alignment Detector (TAD) (Worn truck suspension, mismatched side frames, hollow worn wheels)	§ 215.119
Truck Hunting Detector (THD) (Worn truck suspension and wheels)	§ 215.119 § 215.221
Wheel Temperature Detector (WTD) (Air hose uncoupled or burst, broken brake pipe or connections, obstructed brake pipe, other brake components damaged, worn, broken, or disconnected, brake valve malfunction, rigging down or dragging, E/L malfunction)	§ 232.103 § 232.207
Wheel Profile Measurement System (WPMS) (Flange height and thickness, wheel diameter, wheel hollow, rim thickness, back-to-back gauge)	§ 215.103 (a)(b)(c)
Automated Wheel Crack Detector (AWCD) (Internal wheel rim defects)	§ 215.103(d)

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
ABD	Acoustic Bearing Detectors
ATSI	Advanced Technology Safety Initiative
AAR	Association of American Railroads
AEI	Automatic Equipment Identification
AWCD	Automatic Wheel Crack Detector
DED	Dragging Equipment Detector
EHMS	Equipment Health Monitoring System
FRA	Federal Railroad Administration
HBD	Hot Box Detector
HI	Hunting Index
InteRRIS®	Integrated Railway Remote Information Service
L/V	Lateral to Vertical Wheel Load Ratio
LAHRLV	Leading Axle High Rail L/V Ratio
SA	Sharma & Associates
TTCI	Transportation Technology Center, Inc.
TAD	Truck Alignment Detector
TGSF	Truck Gauge Spreading Force
THD	Truck Hunting Detector
TPD	Truck Performance Detector
WILD	Wheel Impact Load Detector
WPMS	Wheel Profile Measurement System
WTD	Wheel Temperature Detector