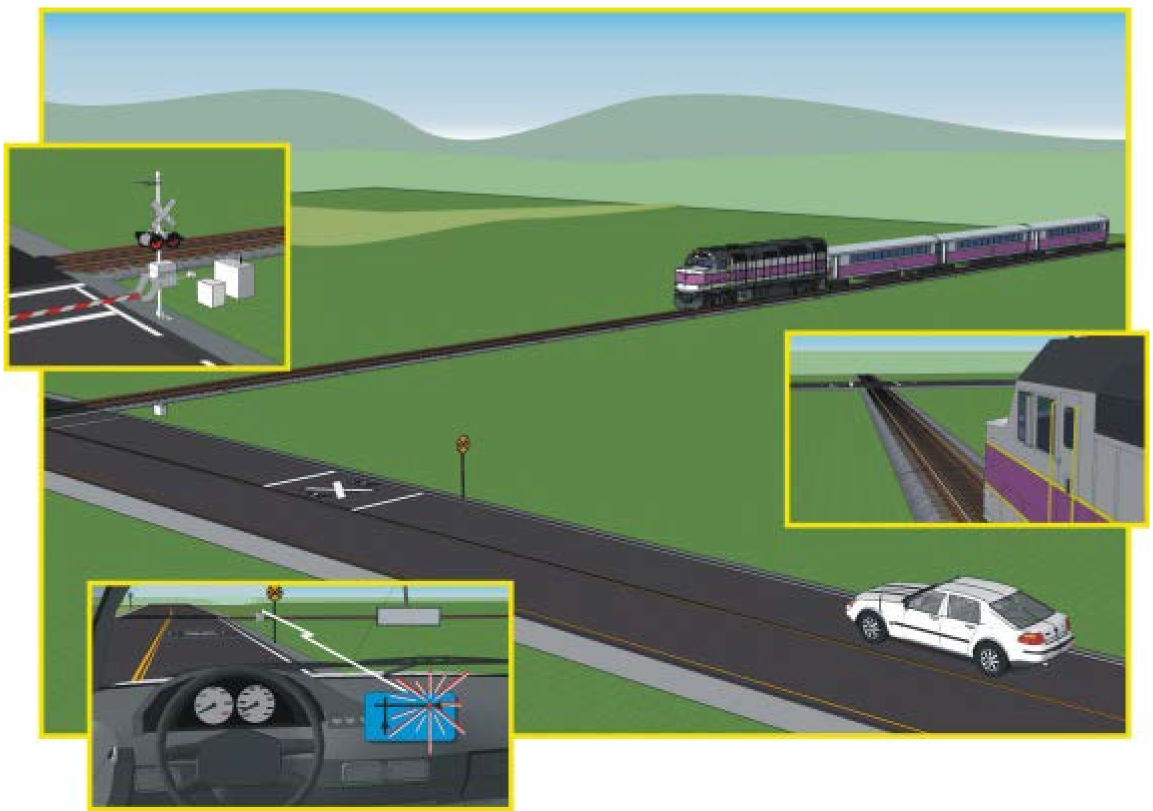
U.S. Department of
Transportation

**Federal Railroad
Administration**

Highway-Rail Intersection Crash Taxonomy for Connected Vehicle Safety Research – Ten Year Trend



DOT/FRA/ORD-19/25

Final Report
July 2019

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE July 2019		3. REPORT TYPE AND DATES COVERED Technical Report
4. TITLE AND SUBTITLE Highway-Rail Intersection Crash Taxonomy for Connected Vehicle Safety Research: 2008-2017 – Ten Year Trend			5. FUNDING NUMBERS RR18D2/QC780 RR18D2/RC780
6. AUTHOR(S) Adrian Hellman and Paul Poirier			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology John A. Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142			8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FRA-19-04
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-19/25
11. SUPPLEMENTARY NOTES COR: Jared Withers			
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the FRA website.			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) The Federal Railroad Administration (FRA) accident data from the 2008–2017 study period showed that annual combined highway-rail intersection (HRI) and rail infrastructure accident costs were between \$20 million and \$40 million dollars. An alternative method developed by the National Highway Cooperative Research Program (NCHRP) provides for the economic losses associated with medical and legal costs, lost productivity, and travel delay. The results from using this alternative method showed that these costs are between \$1.6 and \$1.9 billion annually.			
14. SUBJECT TERMS Highway-rail intersection, HRI, highway-rail grade crossing, grade crossing, taxonomy, connected vehicle, vehicle-to-infrastructure, vehicle-to-vehicle			15. NUMBER OF PAGES 45 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

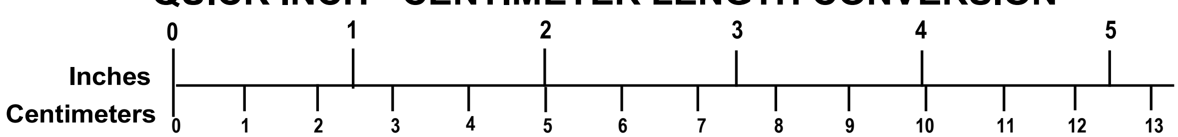
VOLUME (APPROXIMATE)

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)

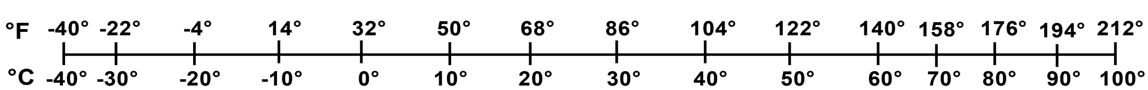
TEMPERATURE (EXACT)

[(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

Acknowledgements

The U.S. Department of Transportation (US DOT) Federal Railroad Administration (FRA) Office of Research, Development and Technology sponsored the work leading to this report. The author would specifically like to thank Jared Withers, Program Manager, Train Control and Communications Division, FRA, for his guidance during the project and in developing this report.

The authors would also like to thank Leonard Allen, Chief, Systems Safety and Engineering Division, US DOT John A. Volpe National Transportation Systems Center (Volpe Center) and Tashi Ngamdung of the Volpe Center for their support.

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Executive Summary

This report characterizes the frequency, severity, and costs of highway-rail intersection (HRI) crashes and estimates the potential reductions in these values resulting from the implementation of Connected Vehicle HRI safety applications.

In the 2008–2017 dataset used for this study, the Federal Railroad Administration (FRA) accident records registered 19,639 incidents, 1,909 fatalities, and 8,768 injuries; 80 percent of the incidents and 90 percent of all fatalities involved a train striking a motor vehicle. Most significantly, the probability of a fatality was twice as high for the "train striking motor vehicle" scenario rather than the "motor vehicle striking train" scenario. While commercial vehicles caused only 20–25 percent of all HRI incidents, they were responsible for 45–55 percent of the annual motor vehicle damage costs. On a per accident basis, commercial vehicle damage costs exceeded those of light vehicles by three to four times.

FRA accident data from the 2008–2017 study period showed that the average annual combined costs to society, were estimated at $1.7 billion (Federal Railroad Administration, 2011).

1. Introduction and Objectives

The purpose of this report is to serve as an update to an analysis of highway-rail intersection (HRI) incident and casualty data that was published by the Federal Railroad Administration (FRA) in 2015. The original report, Highway-Rail Intersection Crash Taxonomy for Connected Vehicle Safety Research (the "2015 report") characterized the frequency, severity, and costs of highway-rail intersection (HRI) collisions, and the estimated potential reductions in these metrics resulting from the implementation of Connected Vehicle HRI safety applications.

Connected Vehicle safety applications are designed to increase situational awareness and reduce or eliminate crashes through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmission. It has been estimated that these technologies may prevent up to 81 percent of crashes involving unimpaired drivers, preventing tens of thousands of automobile and truck crashes every year (Najm, Koopmann, Smith, & Brewer, 2010).

FRA data from the 2008–2012 study period showed that annual combined rail infrastructure and equipment costs due to HRI accidents were between $20 million and $35 million. An alternative method developed by the United States Department of Transportation's (US DOT) National Highway Traffic Safety Administration (NHTSA) provided for the economic losses associated with medical and legal costs, lost productivity, and travel delay. Using this alternative method, the annual costs to society were estimated at $650 million.

Since the publication of the 2015 report, there has been considerable progress in the characterization of the specific economic costs associated with HRI accidents, most notably by Brod, Weisbrod, Williges, Moses, Gillen & Martland in 2013. Although the results of this research were published prior to the 2015 report, the results of the 2015 report had already been finalized and the report was undergoing review by FRA.

There has also been significant progress in the Connected Vehicle safety technology domain. V2I HRI safety technology is being developed under the guidance of the Intelligent Transportation-Joint Projects Office (ITS-JPO) and the FRA Office of Research, Development and Technology. In April 2017, FRA demonstrated the operational functionality of a proof-of-concept V2I HRI safety application. In 2018, FRA initiated development of a prototype version of the safety application that will be tested in a controlled field setting and, possibly in a field operational test.

V2V technology is being tested in multiple field deployments, including the Ann Arbor, MI, Safety Pilot Model Deployment (SPMD) as well as pilots in New York City, Tampa, and Wyoming that incorporate V2V and V2I safety technology. While the latter three pilots are still under development, the results of the Michigan SPMD have been extensively documented.

1.1 Background

To define the magnitude of the problem, consider the following information from calendar year 2017, which as of this writing is the most recent year that FRA has published a complete safety dataset:[1]

- 209,005 non-pedestrian HRIs were in service
- 129,682 were public and 79,324 were private
- The public HRIs consisted of 70,369 equipped with active warning devices and 57,828 equipped with passive warning devices
- 1,945 HRI incidents involving motor vehicles and trains occurred at all HRIs (public and private)
- These incidents involved 192 fatalities and 784 injuries
- HRIs equipped with active warning devices accounted for 1,148 (59%) of the incidents, 110 (57%) of the fatalities, and 449 (57%) of injuries
- The majority of incidents, 1,663, (86%) occurred at public HRIs
- Likewise, most fatalities and injuries, 162 (84%) and 691 (88%) respectively, occurred at public HRIs
- Public HRIs equipped with active warning devices accounted for 1,131 (58%) of the incidents, 110 (57%) of the fatalities, and 451 (58%) of the injuries

1.2 Overall Approach

The FRA Office of Safety Analysis provides and maintains an online database system that is accessible to the public.

- Railroad Accident/Incident Reporting System (RAIRS)
- Highway-Rail Grade Crossing Accident (HRGCX) database
- Grade Crossing Inventory System (GCIS)

All relevant literature was reviewed to understand the frameworks used in analyzing crash scenarios and acquire the skillset needed for: 1) identification of potentially preventable HRI accidents using V2X technologies, 2) quantification of the economic and human costs of these accidents, and 3) estimation of the benefit that V2X safety applications may offer.

The most comprehensive research found on this topic was performed by the Volpe National Transportation Systems Center (Volpe Center) in support of NHTSA. Since the mid-1990s, the Volpe Center has been analyzing crash data from the NHTSA National Automotive Sampling System (NASS) General Estimates System (GES) database and one result of this research initiative was the creation of the crash scenario taxonomy and cost model, which is now considered the industry standard. Other relevant research has been performed by General Motors

[1] FRA public and private HRI accident data current through September 6, 2018. HRI GCIS files were downloaded from safetydata.fra.dot.gov on September 24, 2018.

Corporation and the Crash Avoidance Metrics Partnership - Vehicle Safety Communications Consortium (CAMP-VSCC). The information gathered from these research efforts and others constitutes a foundation for the analysis presented in this report. A more detailed description of these sources may be found in the 2015 report.

1.3 Organization of the Report

- Section 2 describes the methodology employed in this research.
- Sections 3 and 4 provide the results of the FRA crash and cost data analyses.
- Section 5 presents the conclusions.

2. Methodology

FRA defines three groups of reportable railroad accidents/incidents (Federal Railroad Administration, 2011). They are:

- Group I: Highway-Rail Grade Crossing – these accidents are required to be reported to FRA regardless of the incurred accident costs or the number of injuries or deaths. If the cost incurred to railroad infrastructure resulting from an accident exceeds the reporting threshold for rail equipment in Group II, then the accident is required to be reported as a Group II accident as well.
- Group II: Rail Equipment - These include labor expenses as well as any costs necessary to repair or replace in kind damaged on-track equipment, signals, track, track structures, or roadbed that meet the monetary reporting threshold specified by FRA. The costs associated with the clearing of an accident are not included.
- Group III: Death, Injury and Occupational Illness – Any new case of death, injury, or occupational illness that meets the general reporting criteria and monetary threshold as specified by FRA. Group III reporting forms are monthly summaries of railroad accident/incident activity that are documented at a low level of specificity and were not employed in any of the analyses in this report.

The accident/incident data for each of these groups, first collected in 1975, is maintained by FRA in a distinct database that is accessible to the general public. From here on, Groups I and II will be referred to as the Highway-Rail Grade Crossing Accident (HRGCX) Database and the Rail Equipment Accident/Incident Reporting System (RAIRS) Database. While HRI accidents are reported in both the HRGCX and RAIRS databases, only the HRI accidents that exceed a monetary reporting threshold are included in the RAIRS database. The monetary thresholds for the years spanning this study, 2008–2017, are shown below in Table 1.

Table 1. RAIRS Database Reporting Thresholds

Calendar Year	Reporting Threshold
2008	\$8,500
2009	\$8,900
2010	\$9,200
2011	\$9,400
2012	\$9,500
2013	\$9,900
2014	\$10,500
2015	\$10,500
2016	\$10,500
2017	\$10,700

While there is overlap among the information captured by both databases, the key differences between the two databases, for this analysis, is how monetary damages are reported. Since only highway vehicle accident damages are reported in the HRGCX, and only train consist and railroad infrastructure damages[2] are captured by RAIRS, both databases need to be accessed in order to characterize the costs associated with an HRI accident. The fundamental parameters that were employed in this study are shown in Table 2, below.

FRA notes that the completeness and accuracy of these databases is dependent upon the data collection and reporting processes of the nation's railroads as well as State and local highway agencies. While FRA conducts routine audits of these procedures, it does not have sufficient resources to perform comprehensive reviews of each railroad's reporting procedures.

Table 2. HRCX and RAIRS Databases Parameters of Interest

HRGCX Database Parameters		
Type of motor vehicle involved in HRI accident	Auto Bus Truck	Motorcycle Van Other Motor Vehicle
Type of warning device installed at HRI	Gated Non-gated (flashing lights, wig wags, audible devices, etc.)	Cross bucks Stop signs
Action of highway user at time of impact	Went around the gates Stopped and then proceeded Drove through the gate	Did not stop Stopped on crossing Suicide/attempted
Total killed and injured	All fatalities and injuries resulting from the impact, including highway users, railroad employees, and rail passengers	
Total highway vehicle occupants	Vehicle occupants at the time of impact	
Total highway vehicle damages	Vehicle repair costs as estimated by first responders	
RAIRS Database Parameters		
Railroad infrastructure damages	Damages to track, signals, roadbed, track structures	
Railroad equipment damages	Reportable damages sustained by the equipment consist	

Comprehensive Accident Costs

The FRA accident databases are very accurate sources for costs incurred from physical damage and statistics for HRI injuries and fatalities. However, FRA does not track HRI incident-related injury and travel delay costs. Additionally, FRA does not rate injury severity or cost.

The highway vehicle and railroad property damage costs described above are known as direct accident costs and more often than not, represent only a small fraction of the total losses resulting from an HRI accident. An alternative metric employed by NHTSA, the comprehensive accident cost, includes the overall societal losses attributed to a highway accident. The main input to this calculation is the Value of a Statistical Life (VSL) that is annually published by US DOT.

Brod et al., (2013), developed a tool to model HRI accident cost that is weighted for the fatalities and injuries associated with a highway vehicle collision with a train as well as inclusion of

[2] Includes damages to track, signals, roadbed, track structures and other railroad infrastructure.

railroad specific variables such as delay, rerouting, and supply chain costs. The tool, and the underlying model, were published in National Cooperative Highway Research Program (NCHRP) Report 755 ('NCHRP Report 755'), *Comprehensive Costs of Highway-Rail Grade Crossing Crashes*.[3] The crash elements and the attendant costs employed by the NCHRP tool, as calculated in the report, are shown in Table 3, below.

In 2011 dollars, the total comprehensive cost per HRI accident was $8.6 million. At $8 million per accident, casualty costs accounts for 93 percent of the total. Casualty costs includes direct costs such as emergency services, medical care, and rehabilitation as well as intangible damages due to lost work productivity, pain and suffering, and quality of life. Many of these losses, though incurred near the time of the accident, are intended to cover a lifetime of losses due to death or incapacitation. By contrast, only $83,400 could be attributed to the combined highway vehicle, railroad equipment, and railroad infrastructure damages.

As seen in Table 3 below, the secondary effect accident costs are specific to the railroad industry. The tool employs an estimate of 1.12 fatalities and 0.46 injuries per fatal crash and 1.4 injuries per injury crash. In a departure from the NHTSA model, the NHCRP 755 tool employs three injury levels that are derived from the NHTSA Maximum Abbreviated Injury Scale (MAIS); severe, moderate, and light, that are 11.4, 18.5, and 70.1 percent of all injuries, respectively.

[3] National Cooperative Highway Research Program, Comprehensive Costs of Highway-Rail Grade Crossing Crashes, Report 755, *Transportation Research Board of the National Academies*.

Table 3. NCHRP Tool Comprehensive HRI Accident Costs

		Fatal Crash Cost	Injury Crash Cost	PDO Crash Cost	Total Cost
Primary Effect Crash Cost Components					
Casualty cost		$7,673,246	$412,772	NA	$8,086,018
Highway vehicle damage		$8,483	$11,707	$7,598	$27,788
Railroad equipment damage		$24,328	$17,527	$8,045	$49,900
Railroad infrastructure damage		$2,448	$2,332	$923	$5,703
Total Primary Effect Crash Costs		$7,708,505	$444,338	$16,566	$8,169,409
Secondary Effect Crash Cost Components					
Delay cost		$147,395	$49,351	$49,351	$246,098
Rerouting cost		$2,815	$1,564	$938	$5,318
Supply Chain Cost, Transportation - Delay		$39,934	$24,606	$8,858	$73,399
Supply Chain Cost, Transportation - Diversion		$54,168	$30,093	$18,056	$102,317
Supply Chain Cost, Logistics - Loss		$1,541	$949	$342	$2,832
Supply Chain Cost, Logistics - Reliability		$7,663	$5,768	$2,077	$15,508
Total Secondary Effect Crash Costs		$253,517	$112,332	$79,622	$445,471
Total cost per Crash		**$7,962,021**	**$556,670**	**$96,188**	**$8,614,880**

3. Results of Crash Data Analysis

Despite increases in traffic and rail volume, several prior studies and analyses confirm that the number of incidents and fatalities occurring at HRIs in the United States declined over the past two decades. While factors such as improved vehicle safety and medical response have played very important roles in reducing HRI incidents, Mok and Savage (2005) attributed approximately 20 percent of the reduction to the installation of gates and/or flashing lights.

During the 2008–2017 study period for this research, there were an average of 228,982 HRIs in the United States. Of this total, approximately 141,000 HRIs were public and 88,375 HRIs were private. The FRA GCIS file structure categorizes HRI warning devices and this analysis classifies them in terms of five levels of protection, from highest to lowest:

- Gates
- Active devices (other than gates)
  - flashing light signals
  - wig-wags
  - highway traffic signals
  - bells
- Passive
  - crossbucks
  - stop signs
- Other
  - watchman/flagman
  - flagged by crew
- None

Only public HRI inventory data was complete enough to be analyzed, since private HRI inventory records are frequently incomplete. The 10-year trend for the public HRI inventory, shown in Table 4, reflects an average annual decrease of 1.1 percent. These numbers vary significantly from those found in the 2015 report. In January 2015, FRA published a final rulemaking, *National Highway-Rail Crossing Inventory Reporting Requirements,*[4] which codified what had previously been a voluntary submission system. The new rule, which went into effect in March 2015, resulted in the submission of previously unreported HRIs, re-opened HRIs, changes to HRI status from private to public (and vice versa) and changes to warning device makeup.[5]

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[4] Federal Railroad Administration. 2015. *National Highway-Rail Crossing Inventory Reporting Requirements*. Federal Register, 49 CFR Part 234, *80*(3).

[5] 49 CFR Part 234 - Grade Crossing Safety, §§ 234.401–234.415 (2015). Subpart F–Highway-Rail and Pathway Crossing Inventory Reporting

This process increased the accuracy and size of the FRA GCIS, but resulted in an addition of 10,000 HRIs to what had been the accepted inventory size under the previous system of voluntary submission. While the new inventory reporting system will ultimately result in a more accurate HRI database, the numbers in Table 4 represent the most current composition of the GCIS at the time it was accessed.

Table 4. Public Grade Crossing Totals, 2008–2017[6]

Year	Total
2008	147,207
2009	145,333
2010	142,692
2011	141,643
2012	140,971
2013	140,591
2014	140,027
2015	139,764
2016	136,232
2017	131,594

3.1 Historical Accident Trends

Figure 1 shows incident, injury, and casualty trends for public HRIs from 1997–2017 as published in FRA's annual railroad safety statistics reports. The incident values and the ancillary injury and fatality data in this figure include all reported occurrences at the HRIs, including those involving pedestrians. From 1997–2017, there is an almost linear decrease in the number of incidents. After 2009, the incident data behaves in a similar manner to the injury and fatality data. This broadest measure of public HRI safety shows a marked decrease of 50.4, 44.3, and 39 percent in incidents, injuries, and fatalities, respectively, despite increased rail traffic.

[6] Federal Railroad Administration. (2018, November 30). *Highway-Rail Crossing Inventory Data*. Office of Safety Analysis.

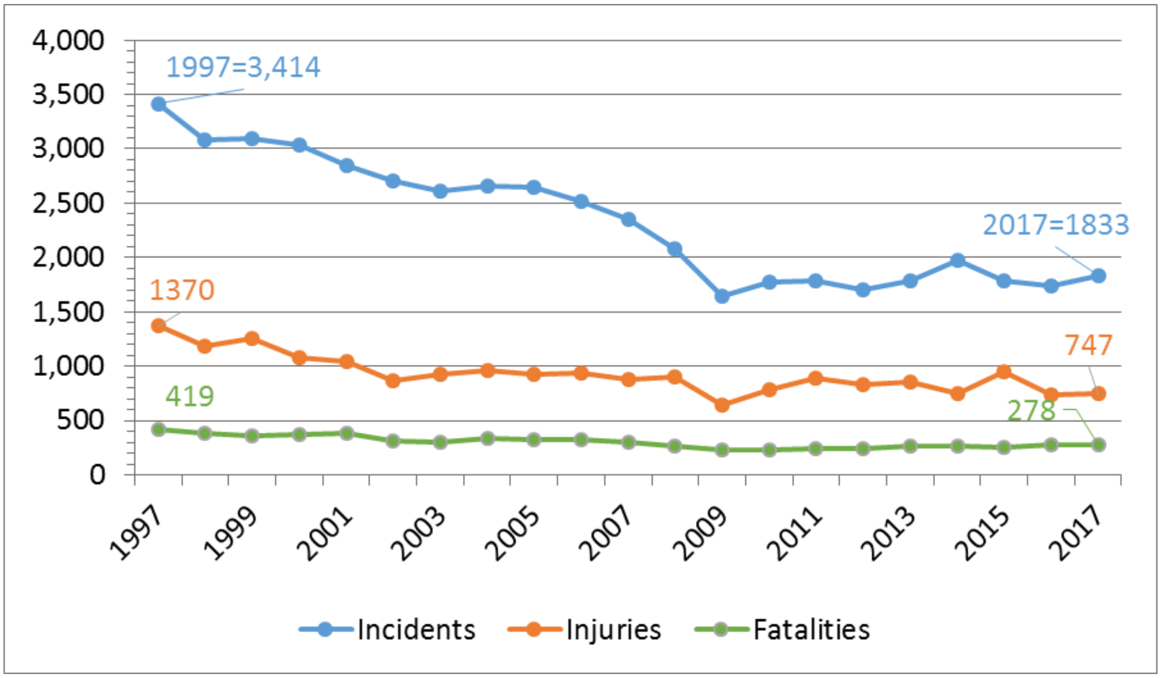

Figure 1. Public HRI Incident and Casualty Statistics from 1997–2017, including pedestrians

These values, regardless of their quality, are a measure of relative HRI risk. Absolute risk is a better metric since it includes yearly variations in highway vehicle and train traffic (exposure), the HRI GCIS, and the composition of active and passive HRIs. Absolute risk is expressed as a function of train miles traveled (TMT), but does not incorporate a measure of highway vehicle traffic. The Traffic Moment (TM) concept used in this report encapsulates both of these parameters as part of the risk calculation. As used in the report, TM is a convenient tool to normalize HRI casualty data. In a given year, the TM for a single HRI is the product of the HRI annual average daily traffic (AADT) and the number of daily trains using the HRI. In this report, all analyses used the total annual TM for all public HRIs in the FRA GCIS, which is expressed by the following equation (Ngamdung, 2009):

$$TM = \left(\frac{TotalAADTofXingType}{NumberofXingType}\right) \times \left(\frac{TotalTrainofXingType}{NumberofXingType}\right) \tag{1}$$

TotalAADTofXingType = the total AADT for all public HRIs in the FRA GCIS
TotalTrainofXingType = the total number of trains for all public HRIs in the FRA GCIS
NumberofXingType = the total annual number of public HRIs in the FRA GCIS

Figure 2 shows the incident and casualty data normalized for TM from 2008–2017. The figure suggests that the TM normalization process serves to “smooth” out the annual fluctuations in train and highway traffic volumes and HRI GCIS properties.

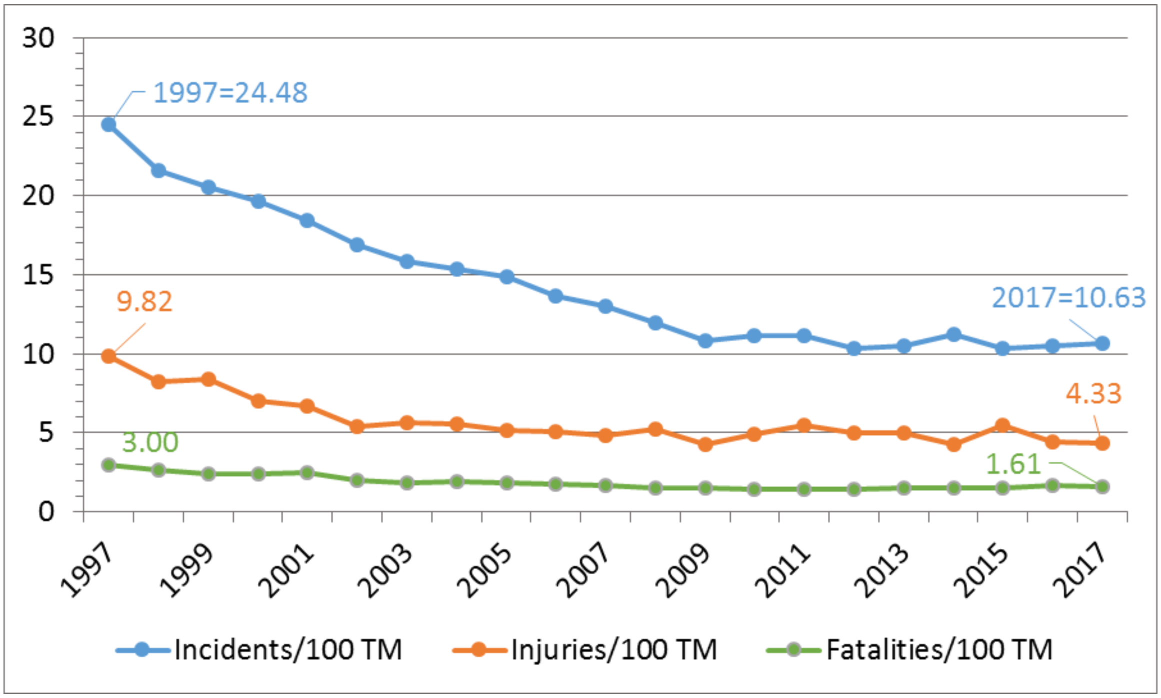

Figure 2. Normalized Public HRI Incident and Casualty Statistics from 2008–2017, Including Pedestrians

3.2 Data Analysis (2008–2017)

The focus of this report is on a 10-year set of data that spans from calendar year 2008–2017. Figure 3, which was prepared with this data, shows the annual number of HRI incidents, injuries, and fatalities from 2008 through 2017 at all HRIs, public and private. Although there is a general decrease in incidents for this period, the number of injuries and fatalities (excluding those involving pedestrian and other non-motor vehicle users) remains relatively stable. The 10-year totals for these categories are 19,639 incidents, 8,768 injuries, and 1,909 fatalities.

The data shows a significant decline from 2008–2009 in the frequency of incidents, injuries, and casualties (20.71%, 24.73%, and 16.74% respectively). Similarly, the number of TMT decreased by 13.7 percent between 2008 and 2009. After the decline, the yearly totals remain relatively constant and, in the case of injuries, actually show an increase above the 2008 values.

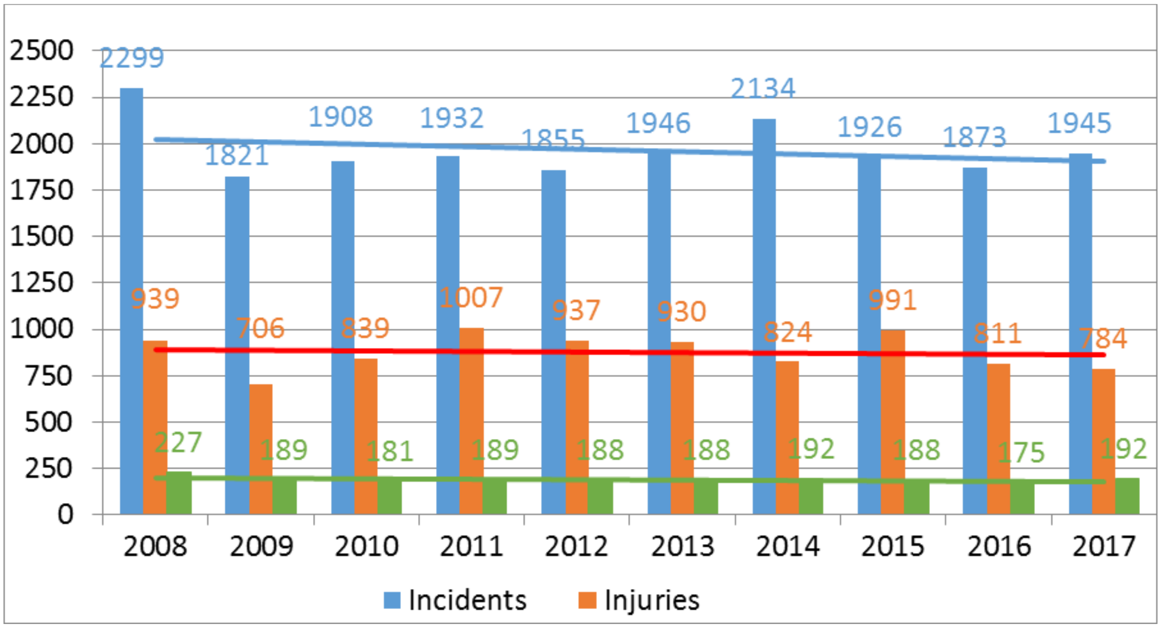

Figure 3. Public and Private HRI Incident and Casualty Statistics from 2008–2017, Excluding Pedestrians

A plausible explanation for this decrease is that the recession of 2008–2009 and the accompanying reduction in economic activity caused a significant decline in rail freight traffic, which is borne out by the 15.9 percent reduction of rail freight TMT and the 1 percent increase in passenger train TMT. The majority of HRIs are located on freight lines, which reinforces the theory that a significant percentage of the decrease in HRI incidents is a result of economic conditions.

Figure 4 shows the trends for public HRI incidents, injuries, and fatalities normalized with respect to 100 TM for the 2008–2017 accident dataset. The data shows a significant decrease between 2008 and 2009, followed by a gradual decrease from 2009-2017, as shown by the moving average lines in the chart. These values are contingent on accurate HRI AADT data.

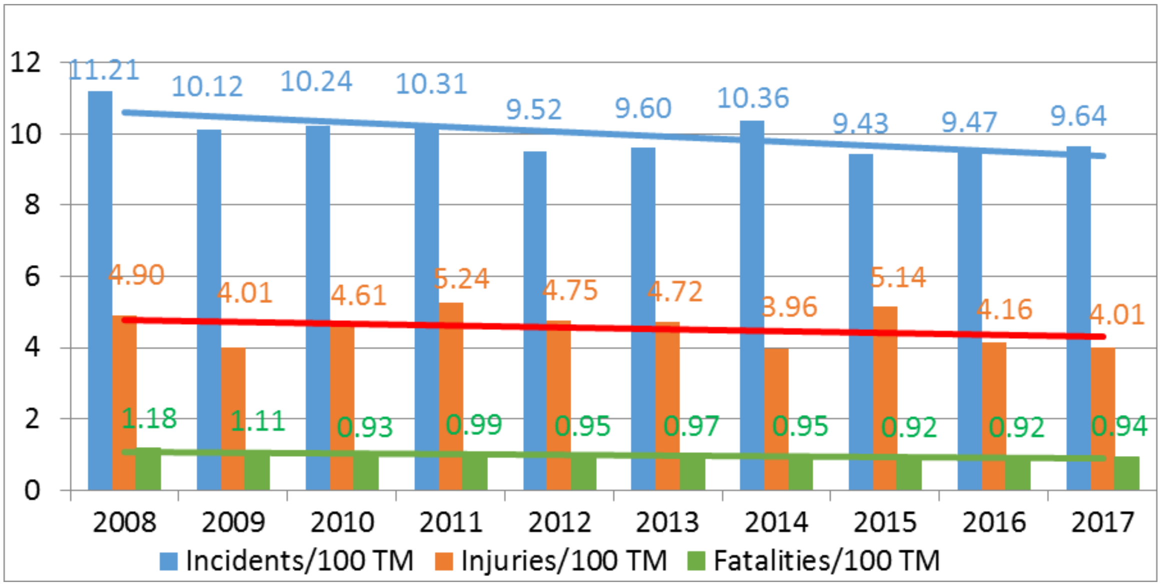

Figure 4. Normalized Public HRI Incident and Casualty Rates from 2008–2017, Excluding Pedestrians

Since accurate AADT data is not available for private HRIs, it is not possible to calculate TM for private HRIs. An alternative method is needed to incorporate private HRI incident, injury, and fatality data into the normalization process. One possible approach to normalizing both public and private HRI data is depicting it in terms of the annual TMT. Although TMT is not explicitly used in the TM equation, it is a proxy measure for the *TotalTrains* variable. Figure 5 displays public and private HRI incidents and casualties normalized with respect to 100 million TMT for the 2008–2017 dataset. However, instead of confirming the trends observed in Figure 2–Figure 4, the TMT data show a minimal leveling off of HRI incidents and no changes in casualties.

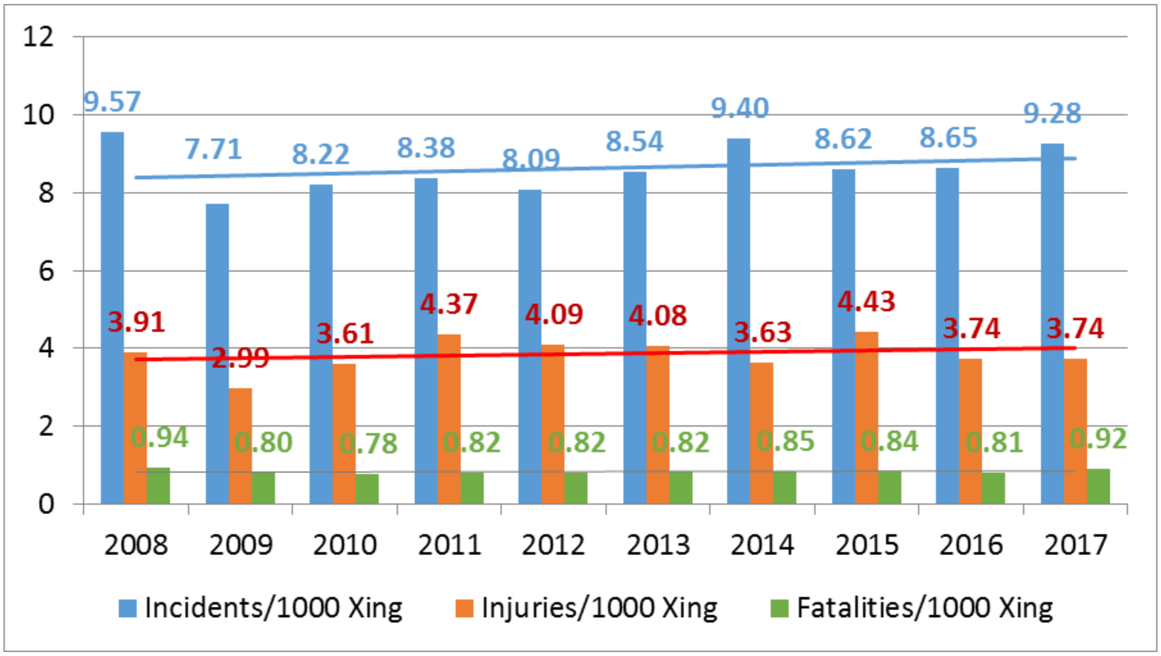

Figure 5. Public and Private HRI Incident and Casualty Rates per 100 million TMT, from 2008–2017, Excluding Pedestrians

Another approach to normalizing private and public HRI data is to express incident and casualty rates as a function of the total HRIs in the FRA GCIS. The HRI total is represented in the TM equation by the NumberofXings variable. The incident and casualty rates per 1,000 HRIs for the 2008–2017 dataset is shown in Figure 6. This trend line data shows an in increase in all three parameters, with the steepest increase in incidents from 2008–2017.

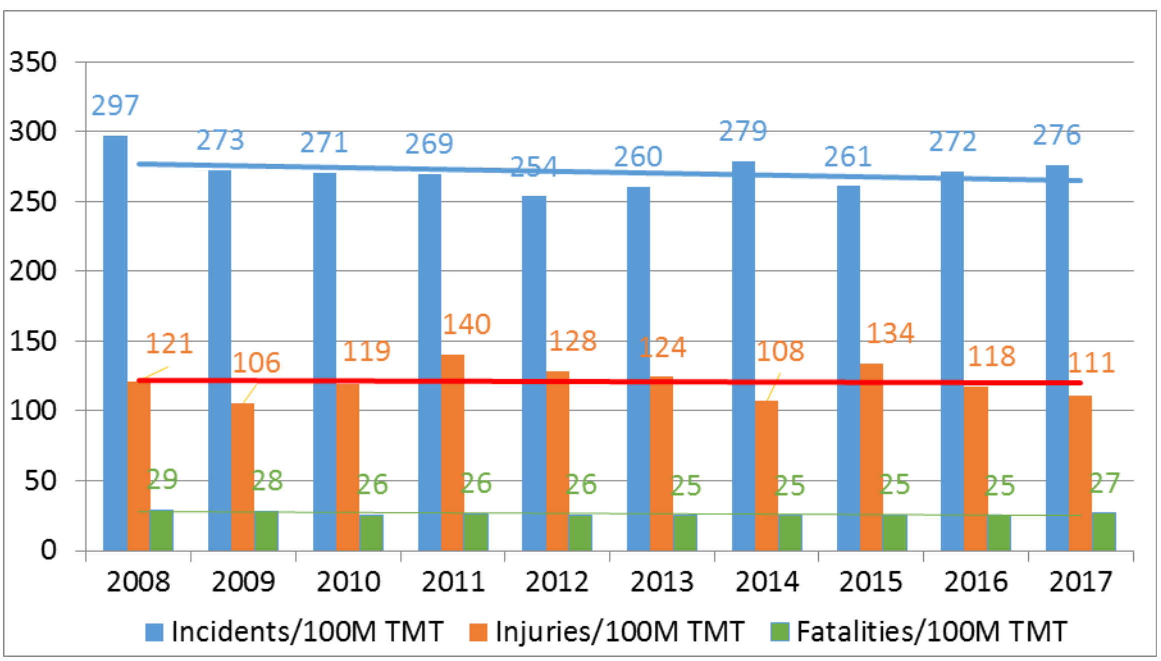

Figure 6. Public and Private HRI Incident and Casualty Rates per 1,000 HRIs, from 2008–2017, Excluding Pedestrians

All HRI incidents fit in one of two categories: either a train is struck by a highway user (Type I) or a train strikes a highway user (Type II). Figure 7 (see below) displays the incidents, injuries and fatalities for both scenarios. It is worth noting that the 2008–2017 dataset includes injuries and fatalities for HRI users, railroad employees, and railroad passengers. Although HRI users account for an average of 98.9 percent of all fatalities, they account for only an average of 76.9 percent of all injuries.

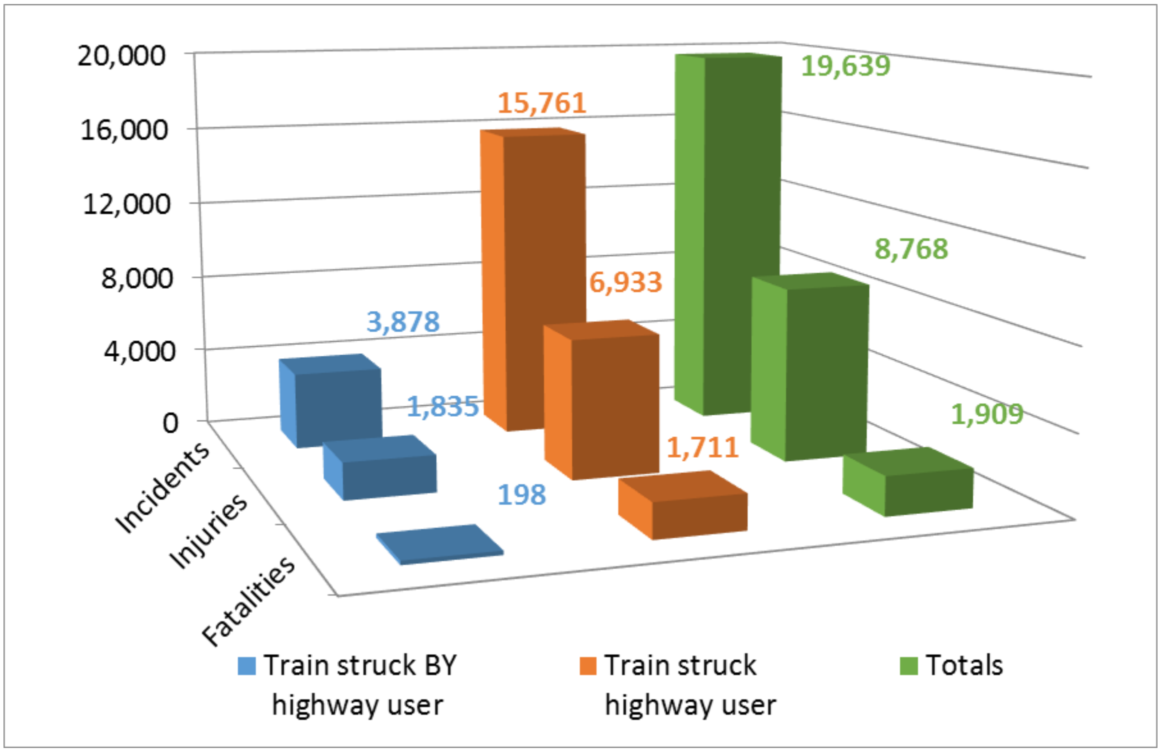

Figure 7. HRI Incident and Casualty Statistics from 2008–2017 for all HRIs, Excluding Pedestrians

However, any reduction in highway user injuries and fatalities, as a result of Connected Vehicle technology, will produce an accompanying reduction in railroad employee and passenger casualties. Therefore, the entire HRI injury and fatality dataset was employed in these calculations. As shown in Table 5, 80 percent of all incidents and 90 percent of all fatalities were Type II. However, given the occurrence of either incident type, a Type II incident was 80 percent more likely to result in a fatality than a Type I incident. There are multiple reasons for this disparity, including collision dynamics, the distribution of light and commercial vehicles, and the number and location of passengers in highway vehicles.

Table 5. Distribution of Type I and Type II HRI Incidents and Casualties from 2008–2017 for all HRIs, Excluding Pedestrians

	Incidents (%)	Injuries (%)	Fatalities (%)	Casualties (%)	Pr(Fatality)
Train struck *by* highway user (Type I)	3,878 (19.75%)	1,835 (20.93%)	198 (10.37%)	2,033 (19.04%)	9.74%
Train struck highway user (Type II)	15,761 (80.25%)	6,933 (79.07%)	1,711 (89.63%)	8,644 (80.96%)	19.79%
Totals	**19,639**	**8,768**	**1,909**	**10,677**	-

3.3 Highway User Demographics

Figure 8 through Figure 14 (see below) present 2008–2017 HRI incident and casualty data in terms of light, commercial, and motor vehicle types. Light vehicles include autos, pick-up trucks, and vans. Commercial vehicles consist of trucks, truck-trailers, buses, and school buses. Other motor vehicles include motorcycles. Figure 8 through Figure 10 shows the unprocessed HRI incident and casualty statistics, and Figure 11 through Figure 13 shows the statistics normalized with respect to 100 million TMT.

For both metrics, there is a significant decrease in incidents involving light vehicles between 2008 and 2017. The unprocessed incident data exhibited a decrease of 19 percent, and the normalized data shows a decline of 11 percent. The light vehicle category also exhibited a decrease of 21 percent in fatalities for the unprocessed data and 24 percent for the normalized set. However, light vehicle injury statistics, after experiencing a marked decrease from 2008–2009, were relatively flat between 2009 and 2017, for both metrics.

Commercial vehicle incident and casualty data trends diverged significantly from that of light vehicles. There was essentially no change in the absolute number of incidents or the normalized incident rate. Injuries increased by 24.9 percent and 30.3 percent, respectively, for both the unprocessed and normalized data, through 2012. After 2012, the absolute number of injuries decreased by 51 percent and the normalized number of injuries decreased by 49 percent. For the overall 2008–2017 dataset, fatalities were the exception, with increases of 17 percent and 28 percent for the unprocessed and normalized data.

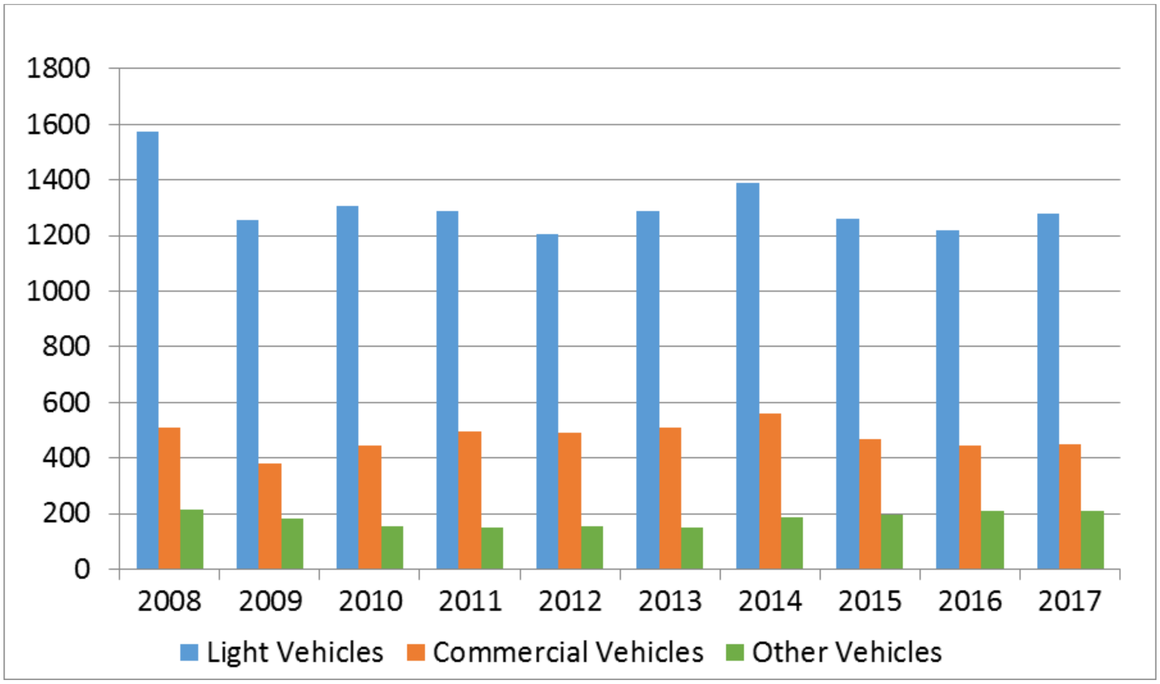

Figure 8. Public and Private HRI Incident Statistics by Motor Vehicle Type from 2008–2017, Excluding Pedestrians

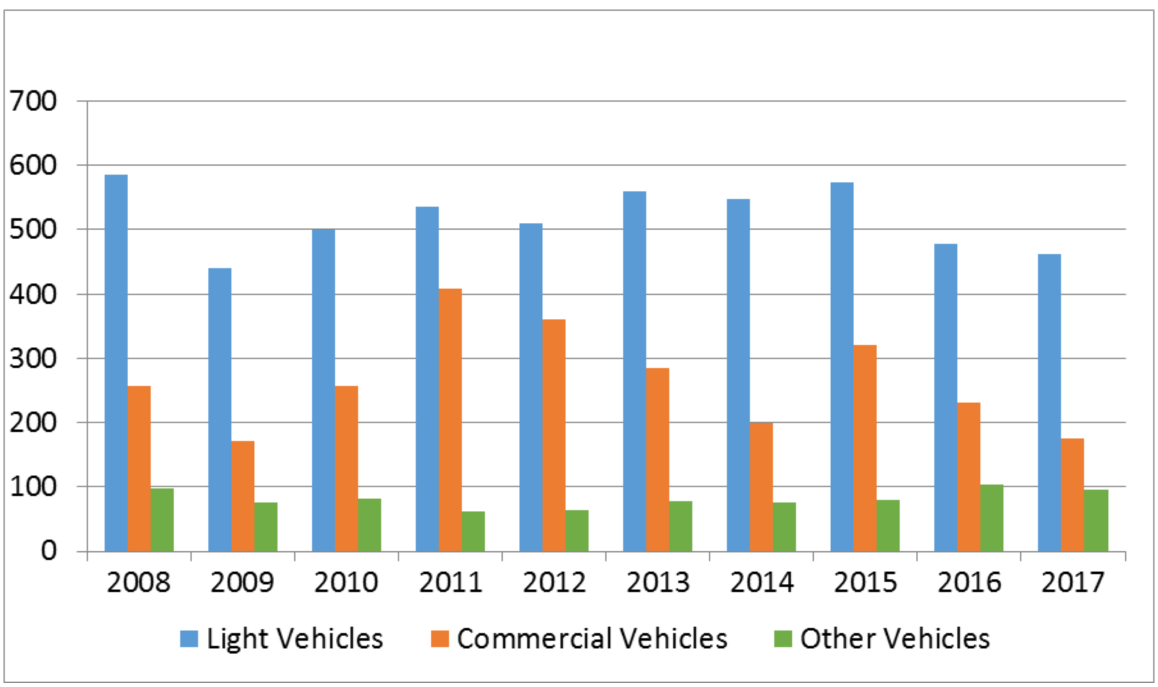

Figure 9. Public and Private HRI Injury Statistics by Motor Vehicle Type from 2008–2017, Excluding Pedestrians

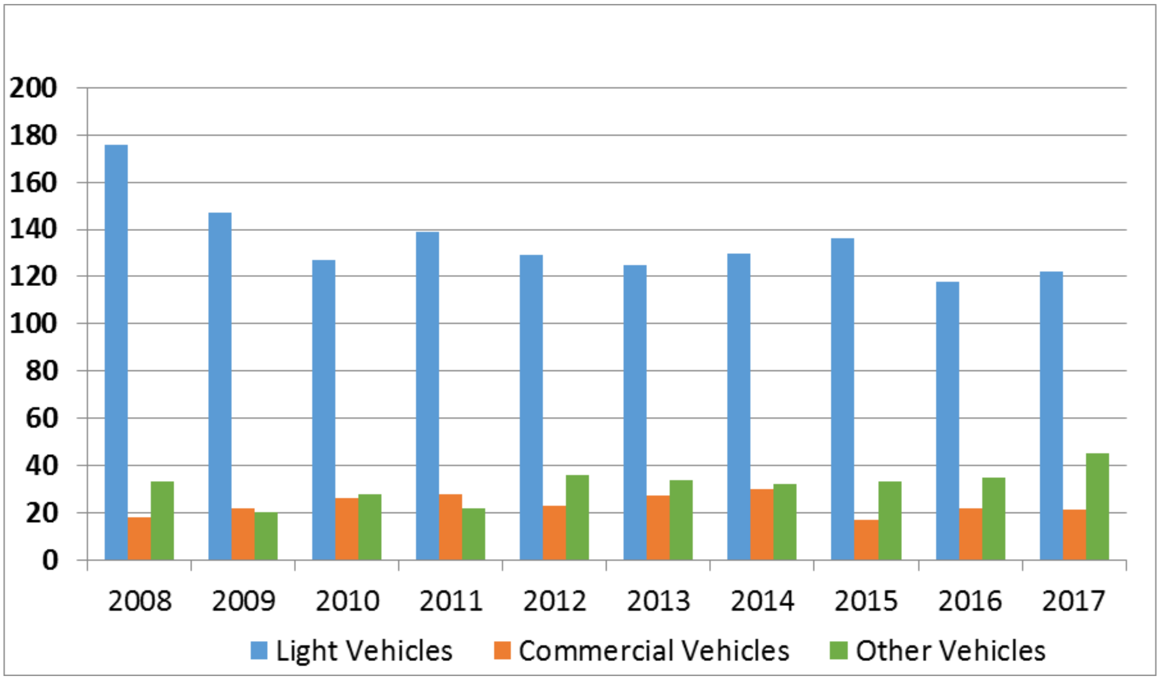

Figure 10. Public and Private HRI Fatality Statistics by Motor Vehicle Type from 2008–2017, Excluding Pedestrians

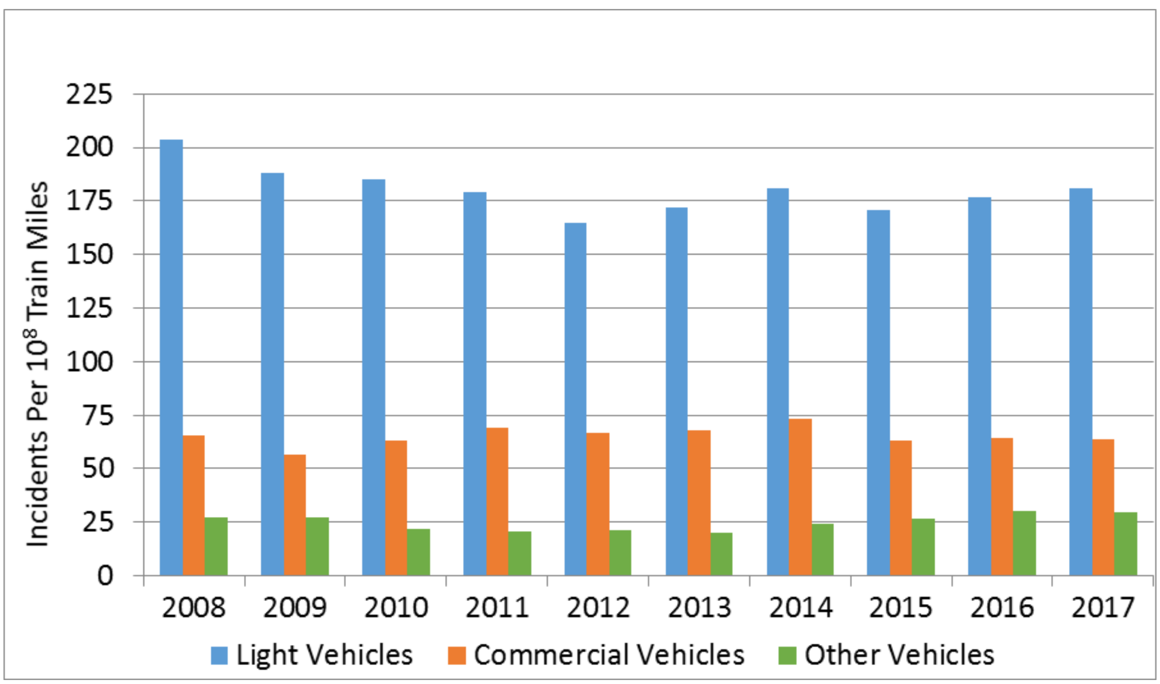

Figure 11. Public and Private HRI Incident Rates per 100 Million TMT by Motor Vehicle Type, from 2008–2017, Excluding Pedestrians

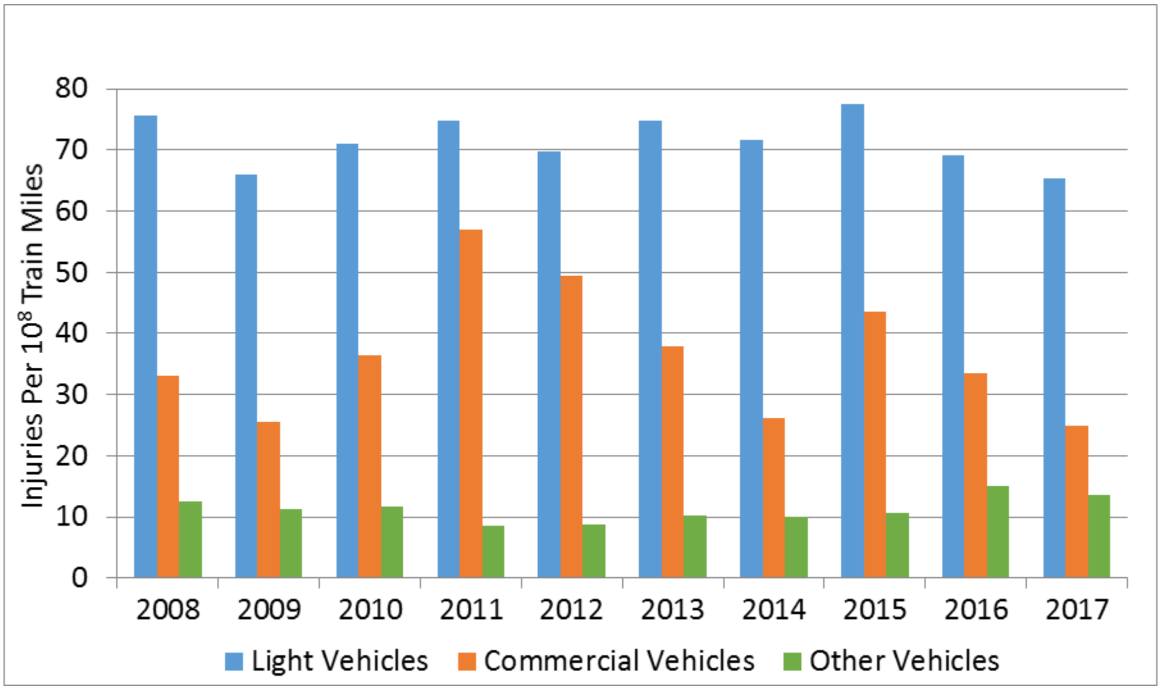

Figure 12. Public and Private HRI Injury Rates per 100 Million TMT by Motor Vehicle Type, from 2008–2017, Excluding Pedestrians

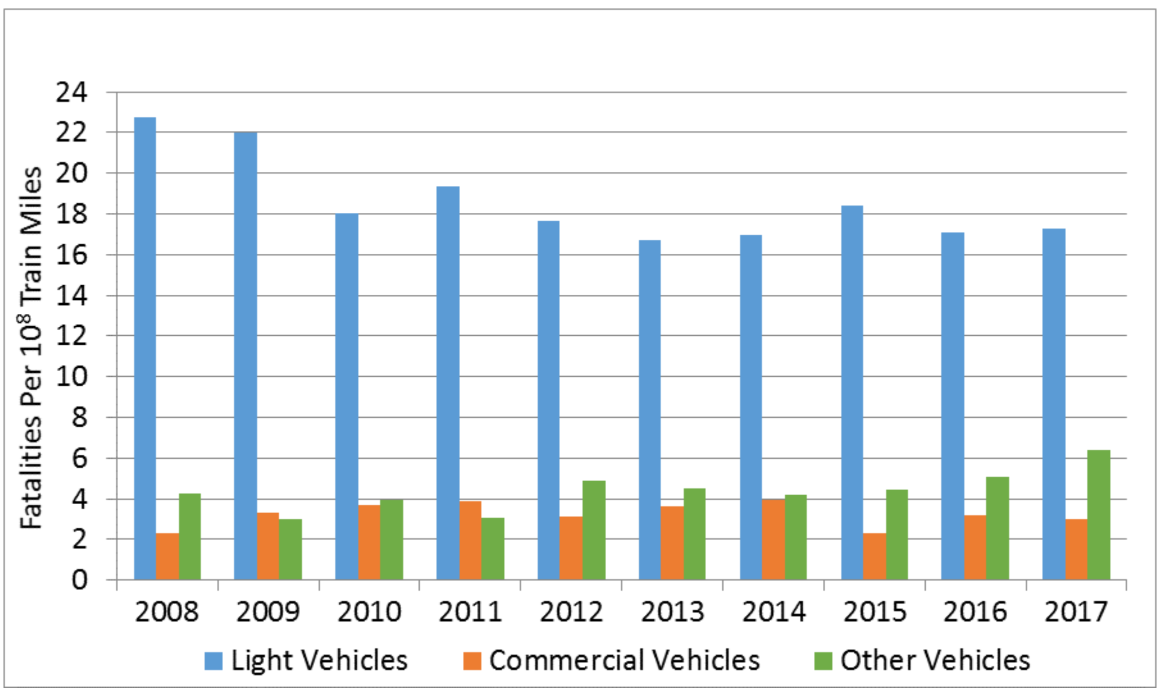

Figure 13. Public and Private HRI Fatality Rates per 100 Million TMT by Motor Vehicle Type, from 2008–2017, Excluding Pedestrians

3.4 Crash Mechanisms

Table 6 displays the distribution of HRI incidents as a function of the warning device type and the action taken by the motorist immediately prior to an incident. The number of incidents at active HRIs and passive HRIs was 10,946 (56%) and 7,888 (40%), respectively. HRIs equipped with gates exhibited the highest motor vehicle and rail traffic and 7,972 (41%) incidents were reported at those locations.

Table 6. Distribution of HRI Incidents as a Function of Motorist Action and Warning Device, 2008–2017

Warning Device	**Motorist Action**					
	Went Around/Thru Gates	Stopped and Proceeded	Did not Stop	Stopped on HRI	Other*	Totals
Gates	2,383	121	159	2,608	2,701	7,972
Active (FLS, WW, HTS, Bells)	0	311	1,980	606	77	2,974
Passive (CB, SS)	1	810	5,089	1,788	200	7,888
Other (Watchman, Crew)	0	22	97	36	7	162
Unknown	0	66	366	178	33	643
Totals	**2,384**	**1,330**	**7,691**	**5,216**	**3,018**	19,639

*Other = other, went around/through temporary barricade, suicide/attempted suicide.

Figure 14 illustrates the distribution of motorist action regardless of warning device. Motorists who failed to stop at the HRI were the largest demographic 7,691 (39%), while motorists who stopped on the HRI followed 5,216 (27%). Motorists driving around gates were responsible for 2,384 (12%) HRI incidents, while 1,330 (7%) stopped at an HRI and then proceeded to drive through.

Any highway traffic signal that is within 200 feet of HRIs and is equipped with active warning devices must be interconnected with HRI train detection circuitry. When a train is detected by the HRI, the HRI controller will transmit a preemption message to the highway traffic signal controller. This will result in the highway traffic signal cycling to green so that motor vehicles that may be queued up over the crossing may safely clear.

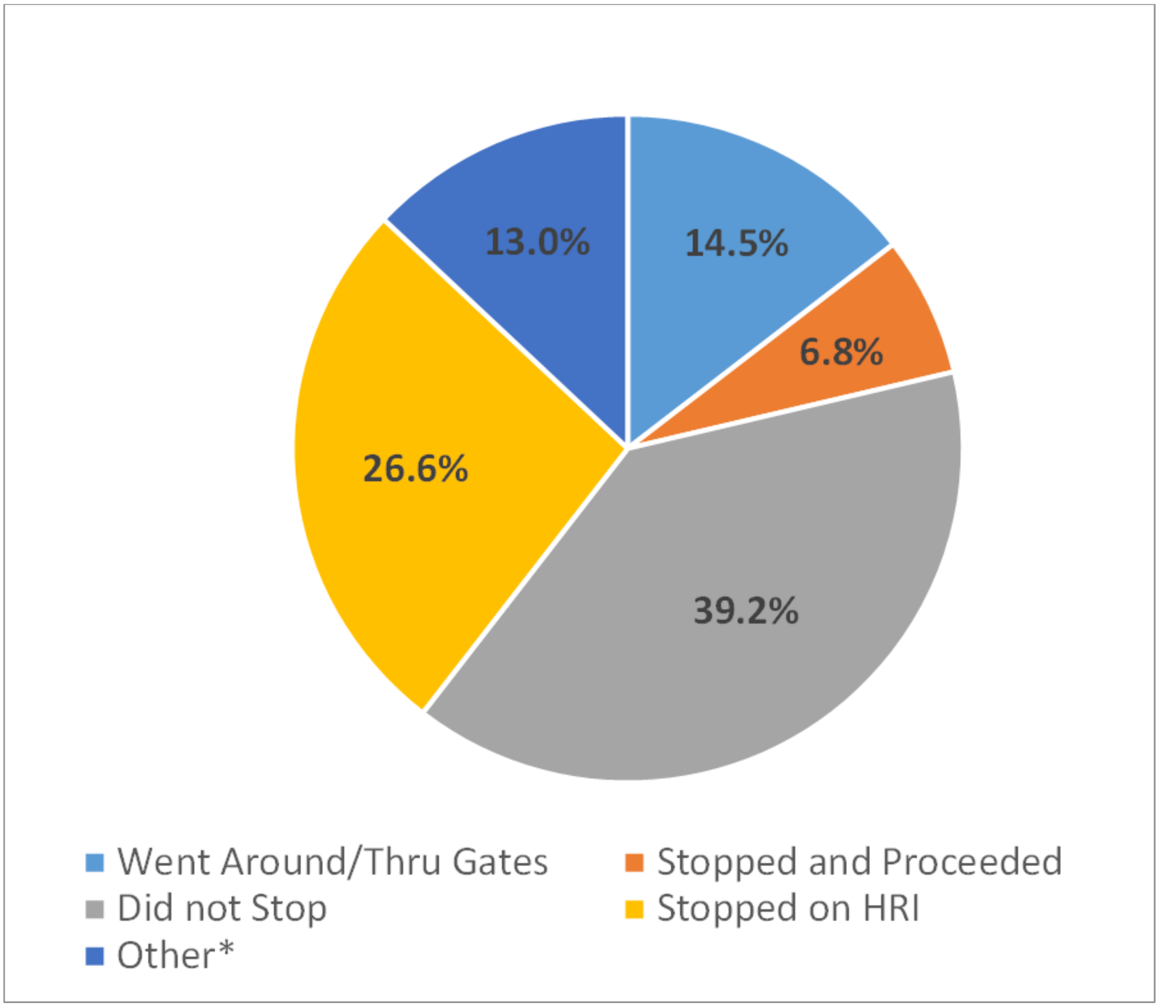

Figure 14. Distribution of HRI Incidents as a Function of Motorist Action, 2008–2017

Around 4,650 (2.2%) of all HRIs are interconnected with highway traffic signals, and an even smaller number of these, approximately 3,576 (1.7%), are equipped with gates. As depicted in Table 7, the majority of HRI incidents, 12,977 (66%), occurred at locations with no traffic signal interconnection. The 2,164 incidents that occurred at HRIs with a highway traffic signal interconnection represent 11 percent of all HRI incidents. This is a relatively large frequency compared to the total number of interconnected HRIs, which indicates that many HRI crashes occur at locations with the highest amounts of rail and highway traffic. As further confirmation, 1,714 of the accidents occurred at HRIs equipped with gates.

Table 7. Distribution of HRI Incidents as a Function of Motorist Action and Highway Traffic Signal Interconnection, 2008–2017

Highway Traffic Signal Interconnection?	Motorist Action					
	Went Around/Thru Gates	Stopped and Proceeded	Did not Stop	Stopped on Crossing	Other*	Grand Total
Yes	483	78	274	822	507	2164
No	1,762	892	5,546	3,440	1,337	12,977
Unknown	122	41	277	173	105	718
(blank)	488	319	1,594	781	598	3,780
Grand Total	**2,855**	**1,330**	**7,691**	**5,216**	**2,547**	**19,639**

*Other = other, went around/thru temporary barricade, suicide/attempted suicide.

4. Accident Costs

4.1 Motor Vehicle Damage Cost Analysis Based on FRA Accident Data

The FRA Railroad Accident and Incident Reporting System (RAIRS) is the source of the cost data in Table 8. The table shows the distribution of HRI incidents, casualties, and vehicle damage costs as a function of the total number of fatalities per incident for the 2008–2017 dataset. Vehicle monetary damages represent repair costs as estimated by first responders. However, as these estimates are prepared at accident scenes, they are highly subjective and not supported by insurance claims or actual repair bills (Brod et al., 2013).

The majority of the 19,639 HRI incidents recorded, 18,008 (92%), did not involve any fatalities. The zero fatality accidents accounted for 7,802 (89%) of injuries and $130,886,749 (89%) of the vehicle damages incurred. The average vehicle damage costs equaled $7,322 (on a per accident basis).

Table 8. Distribution of HRI Incidents, Injuries, Fatalities and Motor Vehicle Damage Costs as a Function of Total Fatalities per Incident, 2008–2017

Total Fatalities per Incident	Incidents	Injuries	Fatalities	Vehicle Damage
0	18,008	7,802	0	$130,886,749
1	1,427	601	1,427	$13,510,792
2	156	108	312	$1,200,847
3	31	42	93	$563,000
4	10	70	40	$564,500
5	5	4	25	$39,500
6	2	141	12	$109,600
Totals	**19,639**	**8,768**	**1,909**	**$146,874,988**

Figure 15 shows motor vehicle damage costs resulting from train crashes at HRIs for the years 2008–2017. These costs are categorized in terms of light, commercial, and other types of motor vehicles. For every year, commercial vehicle damage costs equal or exceed the costs incurred by the other categories. The same data, normalized for cost, is shown as a function of vehicle damage per incident in Figure 17. Unlike Figure 16, the normalized cost associated with light vehicle HRI incidents is no longer approximately equivalent to the commercial vehicle damage costs. The data shows that normalized commercial vehicle damage cost is greater than normalized light vehicle damage cost by a factor of 3 to 4.

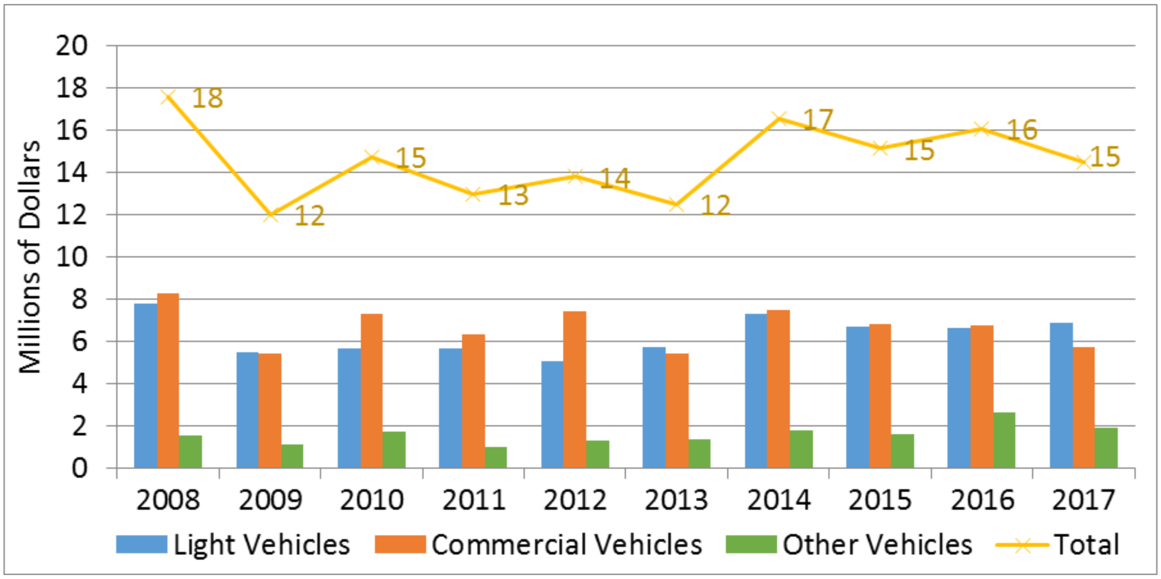

Figure 15. Annual Motor Vehicle HRI Incident Damage Costs for Light, Commercial and Other Motor Vehicles, from 2008–2017

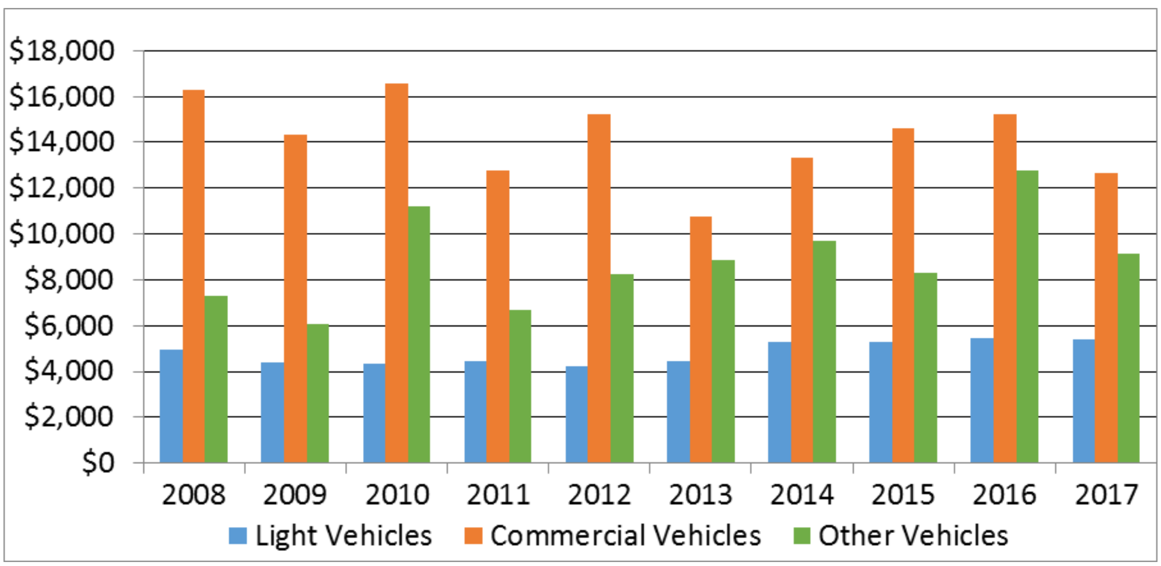

Figure 16. Annual Motor Vehicle HRI Incident Damage Costs for Light, Commercial and Other Motor Vehicles, from 2008–2017, Normalized Per Incident

4.2 Railroad Infrastructure Costs Based on FRA RAIRS Data

The data in Figure 17 was obtained from the FRA RAIRS. The histograms in Figure 19 illustrate annual damage to railroad equipment and track assets. Damage to railroad equipment is strictly limited to the train consist involved in the accident. Track asset damages include damages to the track itself, signals, roadbed, track structures, and so on.

During the years that were studied, damages to railroad equipment greatly exceeded those incurred to track infrastructure. There is a gradual reduction in damage-related costs between

2008 and 2010, followed by a large increase in 2011. The data for 2012 shows a slight reduction in damage-related costs from the previous year.

Since most HRI accidents involve a collision between a light vehicle and a train, damage-related costs involving railroad infrastructure fall within a tight range. Therefore, rare high-consequence accidents with significant damages can significantly distort the total for a particular year. For example, when an Amtrak train was struck by a semitrailer in Reno, NV, in June 2011, the accident resulted in $8,554,000 and $214,682 of equipment and track damages, respectively. In contrast, there were only three accidents in 2008 and one in 2009 in which the total damage exceeded $1 million. In 2010, one accident occurred with total damages of $3.3 million, while none of the remaining accidents was greater than $650,000.

The data in Figure 18 depicts the motor vehicle and rail infrastructure damage costs incurred annually from 2008–2017 and includes a combined total for each year. From 2008–2010, motor vehicle and rail infrastructure damages are roughly equal. In 2011 and 2012, infrastructure damages significantly outweigh those incurred by motor vehicles, which reflects the impact of outlier accidents. Although a 10-year sample size is far too small to speculate if infrastructure damages will become the primary driver, total annual accident costs are bounded between $20 million and $40 million.

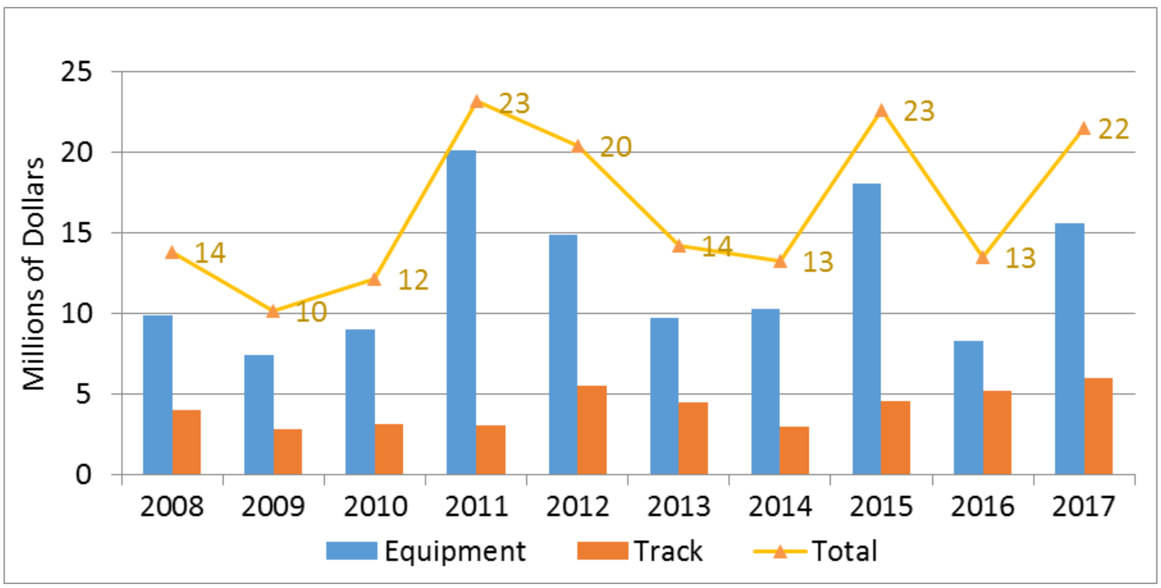

Figure 17. Annual Rail Infrastructure Damage Costs resulting from HRI Incidents, from 2008–2017

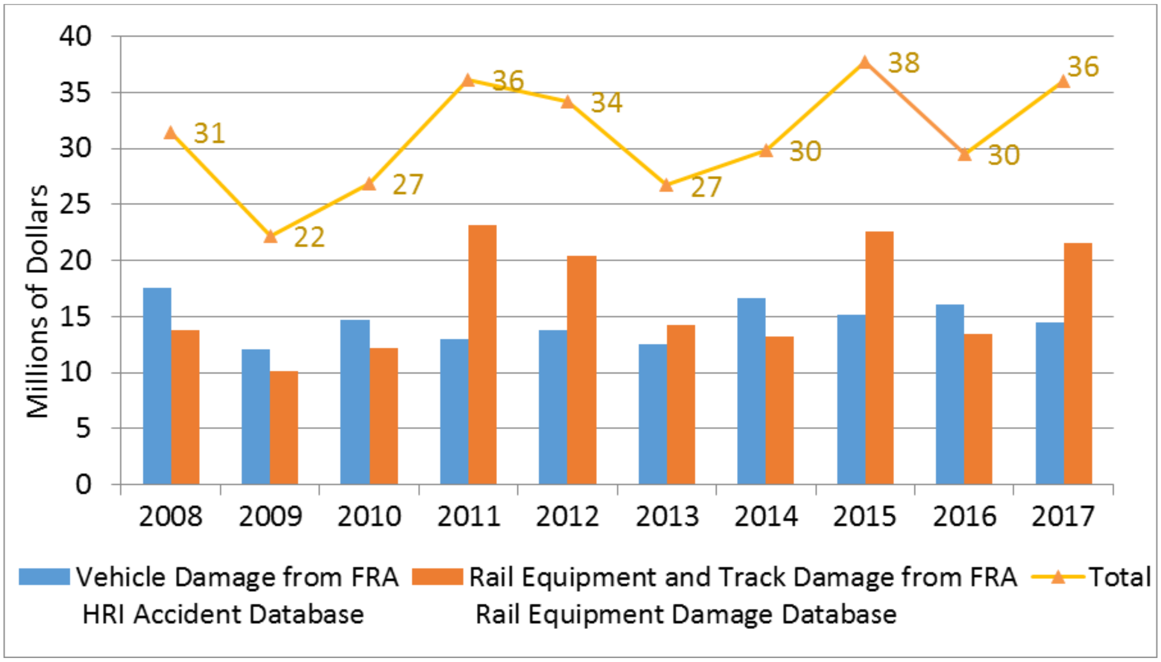

Figure 18. Combined Annual Highway and Rail Infrastructure Damage Costs Resulting from HRI Incidents, from 2008–2017

4.3 Accident Cost Related to Vehicle Violations

The primary y-axis in Figure 19 displays the light and commercial vehicle damage costs, in millions of dollars, as a function of the highway user actions or violations that precipitated the incidents. The secondary y-axis is a plot of light and commercial vehicle incident counts. Most of the light commercial vehicle accident-related costs and incidents were associated with the "Did not Stop" violation type. Of the approximately $147 million in motor vehicle accidents costs incurred between 2008 and 2017 (Table 10), the action "Did not Stop" accounted for approximately $63 million or 43 percent of the total. The damages from the combined actions "Did not Stop" and "Stopped on Crossing" totaled $103 million, equivalent to 71 percent of the entirety.

On a per incident basis, the significance of commercial vehicle incidents is more apparent. The average incident cost for commercial vehicles involved in "Went Around/Thru Gates" violations was $13,100 compared to an average of $4,500 for light vehicles. Likewise, the average incident cost for commercial vehicles linked to "Did not Stop" violations was $13,900 and the average cost for light vehicles was $4,400. This is consistent with the data in Figure 16, which shows that commercial vehicle incidents are, on average, 3–4 times more costly than light vehicle incidents.

Figure 20 is similar to Figure 19, but it displays incident cost and incident totals in terms of the warning system at the HRI (active or passive). The vehicle damage costs at both active and passive warning device sites that were assigned to the "Did not Stop" violation type totaled $60 million or roughly 41 percent of the $146 million in motor vehicle damage costs, and damage costs at passive warning device-equipped HRIs for this violation type equaled $45 million or almost $8,900 per incident. The "Stopped on Crossing" violation type showed the highest number of active HRI incidents as well as damage costs of $13 million or approximately $7,800 per incident.

Taken together, Figure 19 and Figure 20 imply that the most common cause of crashes with trains (and the costliest) is motor vehicles who fail to stop at HRIs. The majority of these crashes occurred at passive HRIs, which seems to validate the effectiveness of active HRI technology.

There are many reasons that drivers do not stop at HRIs when trains are approaching, including driver distraction, lighting, and weather conditions. However, commercial vehicle users appear to be disproportionally involved.

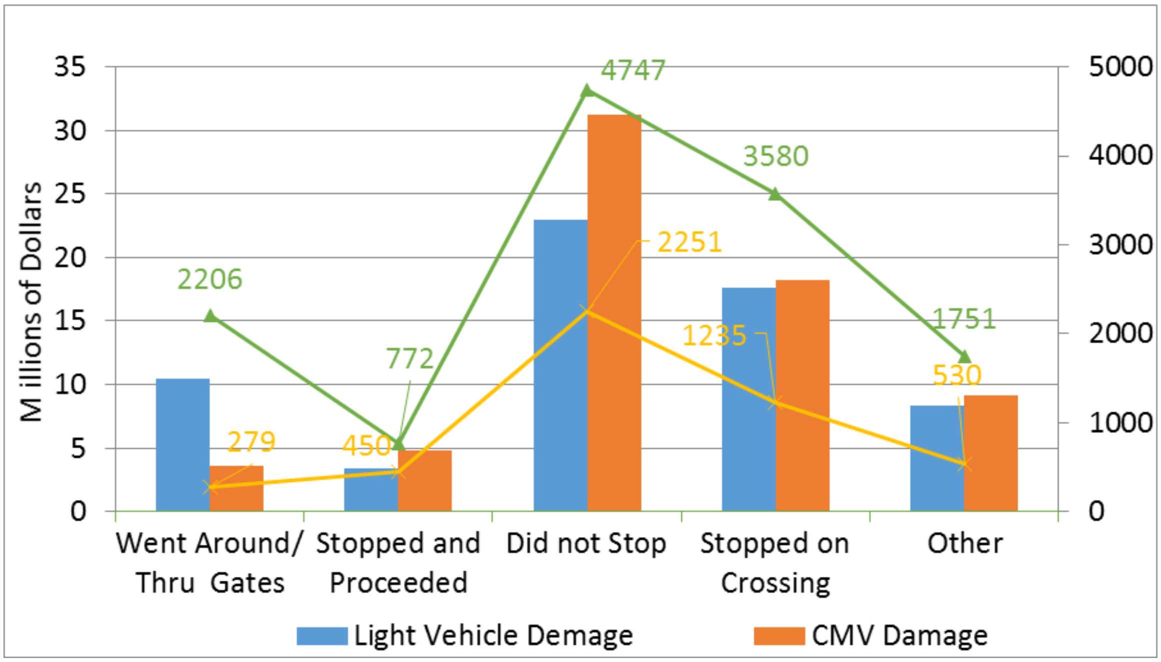

Figure 19. HRI Incident Cost, in Millions of Dollars, by Crash Mechanism for Light and Commercial Vehicles and the Number of Incidents at All Crossing Type as a Function of Vehicle Type, from 2008–2017

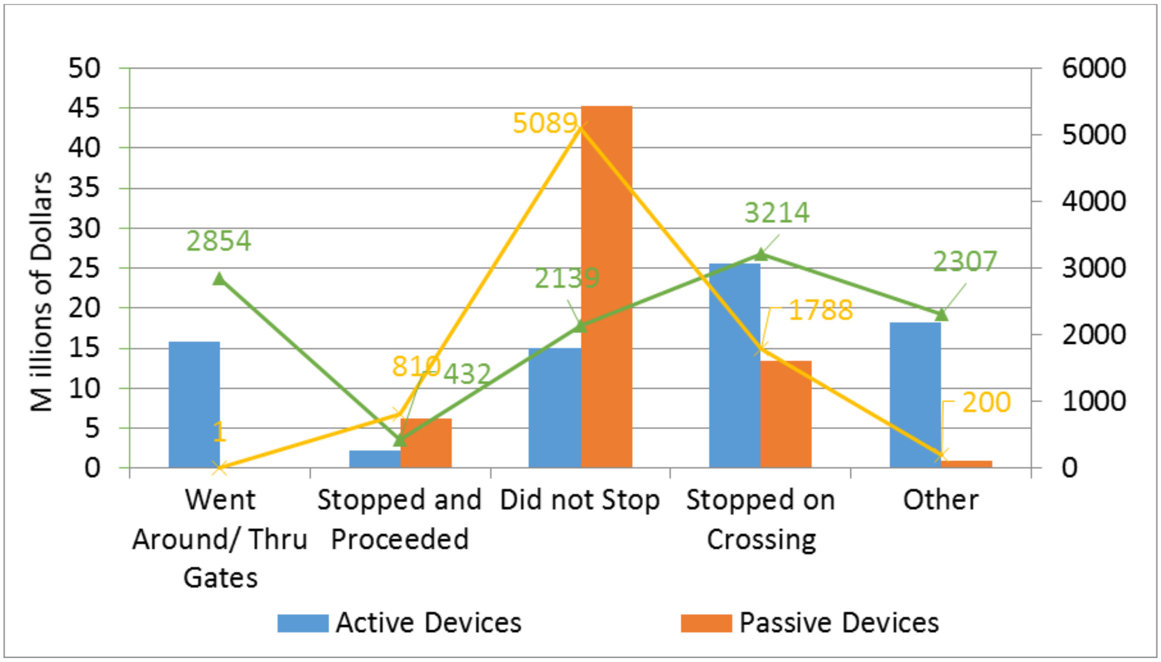

Figure 20. HRI Incident Cost by Crash Mechanism for Active and Passive Warning Devices and the Number of Incidents as a Function of Warning Device from 2008–2017

4.4 Comprehensive Accident Costs Using NCHRP Tool

Table 9 shows the results of processing FRA HRI accident and casualty data with the NCHRP tool. The values in column five of Table 9 are calculated based on the 2011 VSL of $6.2 million, with the 10-year average damage costs of $1.7 billion per year. Despite the gradual decline in fatalities during the study period, there is no discernible change in damage costs (Table 9). Weighting of the injuries and fatalities in the MAIS cost matrix is partially responsible for this lack of change in damage costs. The values in Table 9 provide a contrast with the damage costs maintained in the FRA HRGCX and RAIRS databases. As illustrated in Figure 21, the economic costs calculated using the NCHRP tool are roughly 50–70 times the combined motor vehicle damage and rail infrastructure damage costs.

Table 9. FRA HRI Incident and Casualty Estimated Average Damage Costs

Year	Fatal Crashes	Injury Crashes	Property Damage Only Accidents	Cost*
2008	177	621	1,501	$1,899,348,795
2009	153	459	1,209	$1,589,992,679
2010	160	530	1,218	$1,686,116,125
2011	163	565	1,204	$1,728,139,019
2012	164	551	1,140	$1,722,151,600
2013	165	591	1,190	$1,757,189,857
2014	169	572	1,393	$1,797,987,433
2015	163	553	1,210	$1,722,036,103
2016	147	518	1,208	$1,574,967,921
2017	170	511	1,264	$1,759,584,262
10 Year Average	**163**	**547**	**1,254**	**$1,723,751,379**

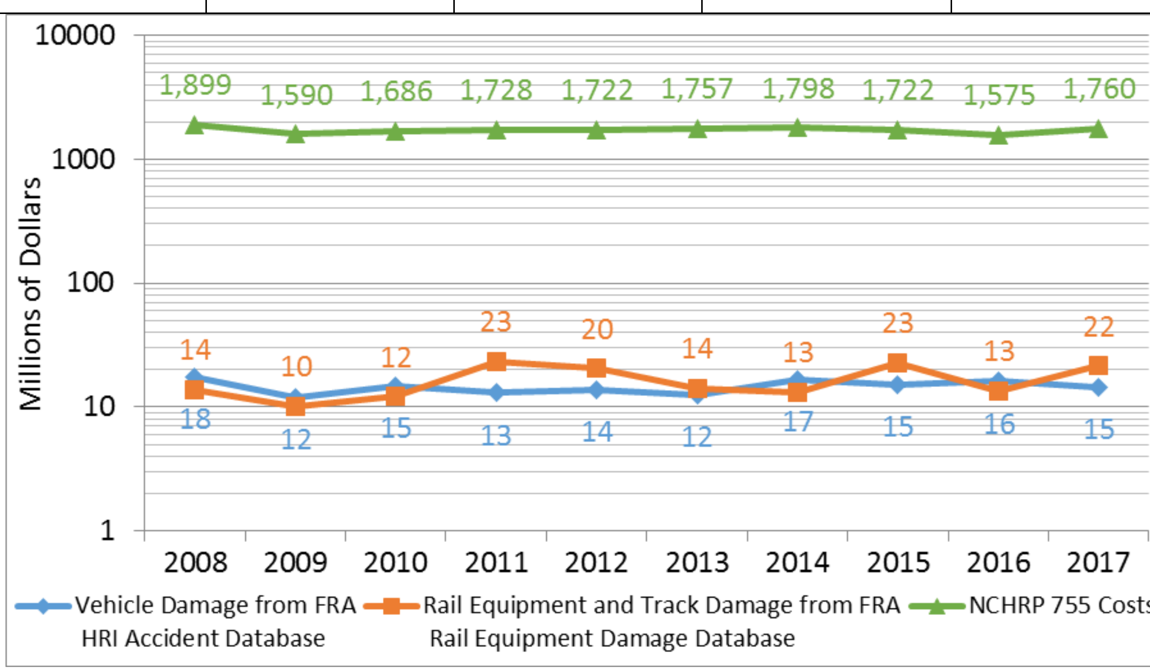

Figure 21. Comparison of Motor Vehicle, Rail Infrastructure, and NCHRP Report 755 Costs, from 2008–2017

4.5 Potential Accidents Prevented by Connected Vehicle Technology

Connected Vehicle technology has the potential to prevent many categories of HRI accidents. Two categories that cannot be prevented are intentional collisions (suicides) and collisions resulting from impaired drivers. After filtering accident report narratives for these two types, the original dataset of 19,639 HRI accidents was reduced to 19,352, or a decrease of 287 accidents. While a combined total of 287 accidents for suicides and impaired drivers appears relatively small, these numbers reflect the difficulty experienced by first responders to provide an objective depiction of an accident while the crash scene is still active. Since an HRI accident report is required to be completion during the month in which the accident occurred, coroner and toxicology reports may not be available at the time of submission. There is a 5-year timeframe following the accident in which the accident report can be amended, but this is limited to changes in injuries and fatalities, grade crossing identification number, and the rail equipment. Therefore, the reliability of the suicide and impaired driver totals is an estimate at best.

This dataset was adjusted for real world considerations. Specifically, a safety envelope encompassing train and highway vehicle speeds of less than or equal to 60 mph was employed to define the set of all potentially Connected Vehicle preventable accidents. This was based on the assumption, that contrary to highway accidents, only the driver of a highway vehicle will be able to take evasive action to avoid an HRI accident. Under this paradigm, of the 19,352 accidents involving unimpaired highway vehicle drivers during the 2008–2017 study period, a maximum of 16,885 (87%) were potentially preventable by Connected Vehicle technology. This equated to a comprehensive accident cost of $13,178,058,576. Table 10, shows a tabulation of the severity and comprehensive cost of these accidents for active and passive HRIs. The number of and the severity of accidents account for approximately one-half of the totals for the 2008–2017 study. However, the active HRI cost per accident of $733,306 is 15 percent less than the passive HRI cost per accident. There are numerous possible explanations for this discrepancy, including highway and train speeds at active HRIs, train consist makeup, the frequent presence of gates and warning device perception among highway drivers.

Table 10. Potential HRI Accidents Prevented by Connected Vehicle Technology at Active and Passive HRIs from 2008–2017, Unimpaired Drivers. Train and Highway Vehicle Speeds $\leq$ 60 mph[7]

	Accidents	Fatalities	Injuries	Comprehensive Accident Cost	Cost per Accident
Active HRIs	8,982	676	3512	$6,586,552,784	$733,306
Passive HRIs	7,157	669	3043	$6,192,946,422	$865,299

[7] This 60–60 mph envelope coincided with the nominal line-of-sight distance of a wireless communication link between a radio-equipped highway vehicle and a radio-equipped train broadcasting in an unlicensed band. This distance is considered to be 300 meters.

Other	746	35	202	$398,559,370	$534,262
Total	16,885	1,380	6,757	$13,178,058,576	$780,459

Table 11 shows the number and severity of accidents attributable to heavy vehicle and light vehicle HRI accidents. The data show that heavy vehicle HRI accidents and incidents accounted for approximately 25 percent of the totals for each category. However, fatalities and comprehensive accident cost for heavy vehicles contributed to 15 and 18 percent of the respective category totals. In contrast, the light vehicle accident and severity parameters were consistent at around two-thirds of the category totals. These results reflect two potential areas of improvement for the NCHRP tool. First, the tool does not differentiate between property/infrastructure damages costs for heavy and light vehicles. Second, the tool does not distinguish between the severity of injuries for heavy and light vehicle HRI accidents.

Despite the limitations posed by the NCHRP tool, the results show that property and infrastructure damage costs are severely outweighed by the societal costs associated with an HRI accident.

Table 11. Potential HRI Accidents Prevented Metrics by Connected Vehicle Technology, for Heavy and Light Vehicles from 2008–2017, Unimpaired Drivers. Train and Highway Vehicle Speeds < 60 mph.

	Accidents	Fatalities	Injuries	Comprehensive Accident Cost
Heavy Vehicles	4,318	206	1,851	$2,382,228,852
Light Vehicles	11,081	947	4,260	$8,809,198,458
Other Vehicles	1,486	227	646	$1,986,631,267
Total	16,885	1,380	6,757	$13,178,058,576

5. Conclusions

The number of HRI incidents declined between 2008 and 2012 by approximately 20 percent, but aside from the years 2008–2009, there was no comparative decrease in injuries and fatalities.

This is reflected in the overall trend from 1997–2017, which shows a leveling of injuries and fatalities after 2009.

Of the 19,639 incidents and 1,909 fatalities in the 2008–2017 dataset, 80 percent of all incidents and 90 percent of all fatalities involved a train striking a motor vehicle. Most significantly, the probability of a fatality is twice as high when a train strikes a motor vehicle than when the reverse occurs.

More than one-half of all incidents occurred at HRIs with active warning devices and 41 percent occurred at HRIs with gates. Moreover, 12 percent of incidents at HRIs, equipped with gates, involved motor vehicles that drove around them. Since most motor vehicle traffic is concentrated at active HRIs, especially those equipped with gates, it is not surprising that more than 50 percent of incidents occurred at active HRIs. However, the number of gate-equipped HRIs, especially those interconnected with highway traffic signals, presents an opportunity for targeting new incident prevention technologies, especially V2I.

While commercial vehicles are involved in only 20–25 percent of all HRI incidents, they are responsible for 45–55 percent of the annual motor vehicle damage costs. On a per accident basis, commercial vehicle damage costs exceed those of light vehicles by three to four times.

The economic cost to railroad infrastructure may vary from year-to-year since a relatively small number of incidents are responsible for a significant amount of the damage. Damage to railroad equipment far outweighs damage to track assets resulting for such events. During the 2008–2017 study period, annual combined HRI and rail infrastructure accident costs were between $20 million and $40 million.

Using the NCHRP tool to calculate economic losses associated with medical and legal costs, lost productivity, and travel delay, the total cost to society average $1.7 billion during the 2008–2017 study period. The NCHRP tool was also used to estimate the number of accidents potentially preventable by Connected Vehicle technology. A further analysis was performed to remove intentional HRI accidents (suicides) and accidents resulting from impaired driving. After filtering the dataset to consider only realistic accident-closing speed envelopes, 16,885 (87%) of HRI accidents were found to be potentially preventable by Connected Vehicle technology.

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Abbreviations and Acronyms

ABBREVIATIONS	EXPLANATION
AADT	Annual Average Daily Traffic
FARS	Fatality Analysis Reporting System
FRA	Federal Railroad Administration
HRGCX	Highway-Rail Grade Crossing Accident
HRI	Highway-Rail Intersection
ITS-JPO	Intelligent Transportation-Join Projects Office
Volpe Center	John A. Volpe National Transportation Systems Center
MAIS	Maximum Abbreviated Injury Scale
NHTSA	National Highway Traffic Safety Administration
RAIRS	Railroad Accident and Incident Reporting System
SPMD	Safety Pilot Model Deployment
TM	Traffic Moment
TMT	Train Miles Travelled
US DOT	United States Department of Transportation
VSL	Value of a Statistical Life
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle