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Review of Highway-Rail Grade Crossing Incidents, 1986 – 2015: Trends and Potential Safety Gaps

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13. ABSTRACT

Every year in the U.S., hundreds of individuals lose their lives at highway-rail grade crossings and even more are injured or otherwise involved in an incident at a crossing. Today's crossing incident rates, however, are significantly lower than they were years ago. This report collected and analyzed 30 years of incidents at public, at-grade, highway-rail crossings as well as the inventory of crossings during that time. Between 1986 and 2015, the number of open, public, at-grade crossings in the country has decreased by over 60,000, and the proportion of these crossings which use active warning devices rose from 34 percent to 55 percent. These changes in the crossing inventory, at least in part, helped to achieve large improvements in safety, including a reduction in the number of incidents at crossings with a casualty by over 60 percent. However, despite these safety improvements, fatal incidents involving pedestrians at crossings are increasing. In fact, the linear models developed in this paper predict that given historic trends, by 2019 pedestrians will overtake vehicles as the road user with the most fatalities. These findings suggest that it may be worth investigating why pedestrians have not benefited from the general safety advancements achieved at crossings.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0			1			2			3		4		5
Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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

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Executive Summary

The purpose of this research effort is to better understand how crossing incidents have changed over the past 30 years, with a focus on changes to the crossing inventory, the incidents that occurred, and the interaction between the two. Researchers at the Volpe National Transportation Systems Center (Volpe) collected and analyzed 30 years of incidents at public, at-grade, highway-rail crossings as well as the inventory of crossings during that time.

While safety overall has dramatically improved over the past 30 years, the one area which has not seen the same improvement is pedestrian safety at crossings. Based on trends since 1986, fatal pedestrian incidents at crossings are predicted to outnumber fatal vehicular incidents at crossings by as early as 2019, highlighting the importance of considering this vulnerable road-user group.

Overall, incidents resulting in fatalities, injuries, and other non-casualty incidents have decreased substantially since the mid-1980s. There are many reasons for this, including advancements in technology, regulatory changes, and availability of Federal and State funding for crossing safety improvements. The goal of this report was not to identify the myriad factors that prompted these changes, but instead to catalog the changes that did occur. The changes investigated were largely along two fronts: changes to the crossings themselves and changes in the types of incidents that occurred at these crossings. A change in the crossing inventory, such as a reduction in the total number of crossings or a shift to more crossings with active protections, may help explain how some of the incident reductions were achieved. Changes in the incidents help uncover what results were achieved and where these safety reductions were most clearly realized.

As one may expect, since 1986 the number of open, public, at-grade, highway-rail crossings has decreased substantially, from over 193,000 in 1986 to just over 130,000 in 2015. In addition to the reduction in the number of open crossings, the proportion of those open crossing protected with active warning devices increased from 34 percent in 1986 to 54 percent in 2015. Therefore, not only was there a reduction in the exposure of road users to crossings, but the crossing to which they were exposed were more protective. During this time when the number of crossings decreased by over 60,000, the number of active crossings with gates increased by over 22,000. These changes alone likely explain part of the reduction in the number of incidents at crossings in the U.S.

Between 1986 and 2015, incidents of all severity types at crossings (resulting in fatality, injury, or other reportable damage) were reduced by over 60 percent. In 1986, the U.S. had 492 incidents that resulted in a fatality, 1,674 incidents that resulted in an injury, and another 4,347 non-casualty incidents at crossings. Almost 30 years later, in 2015, the U.S. had 207 incidents that resulted in a fatality, 564 incidents that resulted in an injury, and another 1,250 non-casualty incidents at crossings. These reductions, however, were not uniformly distributed around the U.S. Some states, such as Ohio, saw reductions in fatal crossing incidents of over 1.6 per year, while others, like California, saw a net increase in fatal crossing incidents. Additionally, not all road users saw the same benefit from the safety changes that were made. While fatal vehicular incidents at crossings were reduced by roughly 10 per year since 1986, pedestrian incidents actually *increased* by 0.7 fatal incidents per year during the same time. Models that accounted for changes in annual average daily traffic were fit to both vehicular and pedestrian fatal incidents at crossings, and it predicted that, given historic trends, pedestrians will comprise the majority of crossing fatalities by 2019.

Lastly, multilevel modeling was used to better understand which changes in the crossing inventory yielded the biggest impacts on crossing incidents. These models showed that the best predictor of reductions in incidents that resulted in injuries or fatalities was not adding gates to crossings, but the removal of passive crossings (be that through the addition of active protective features or the closure of the crossing). Adding gates or bells/lights to a crossing seemed to only appear to improve safety; however, the true impact was the removal of a passive crossing and not necessarily the addition of a gated crossing. This same result was found for injury and fatal incidents involving vehicles; reducing the proportion of passive crossings was the best predictor of improved safety. In contrast, reductions in pedestrian incidents (injury and fatality) were best explained by increases in the proportion of non-gated, active crossings. While this is an interesting preliminary finding, more investigation is required to understand the causal mechanisms behind this statistical relationship and how it can be best applied to improve safety.

Between 1986 and 2015, the U.S. rail system saw impressive improvements in safety. A substantial number of crossings were closed and less protected crossings were upgraded with more protective warning devices. While these changes occurred, there was also a large reduction in incidents. The one group that seemed immune to the overall safety improvement was pedestrians at crossings, and more specifically, train-pedestrian collisions that resulted in a fatality. It may be worth further investigating why these road users are not seeing the benefits that other road users have seen.

1. Introduction

Every year, in the U.S., hundreds of individuals lose their lives at highway-rail grade crossings. Even more are injured or otherwise involved in an incident at a crossing. While crossing fatalities have been reduced by well over 50 percent over the past 30 years, they still result in substantial loss of life and injury. Figure 1 shows crossing incidents that resulted in a fatality (left), injury (middle), or other non-casualty incidents (right) since 1986.

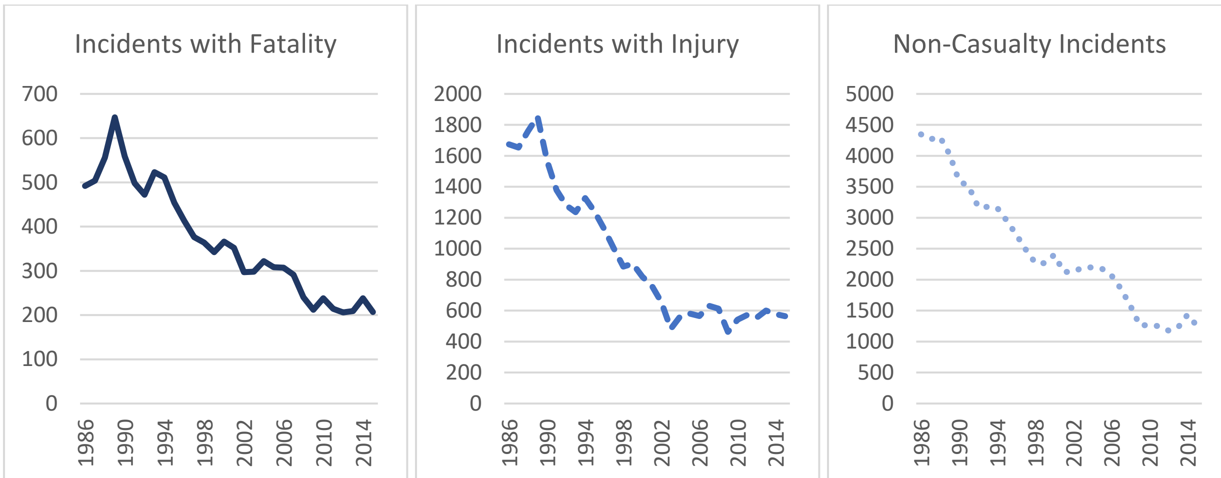

Figure 1. Crossing Incidents that Resulted in Fatalities (left), Injuries (middle), and Other Non-Casualties (right), 1986 – 2015

The overall trend of these graphs shows an overwhelming improvement in safety. Crossing incidents that resulted in at least one fatality were 68 percent lower in 2015 (207 fatal incidents) than the study period peak of 647 fatal incidents in 1989. Similarly, incidents that resulted in an injury were 70 percent lower in 2015 (564 injury incidents) than their study period peak of 1,853 injury-causing incidents in 1989, and non-casualty incidents were down 71 percent over the same timeframe, from 4,301 in 1988 to 1,250 in 2015.

There are many reasons why such a drastic decrease was achieved. Other researchers (e.g., Mok and Savage, 2005; Horton et al, 2009) have identified a wide range of factors which helped contribute to these effects. Those contributing factors include: reduced drunk driving; improved emergency response; improved crossing safety technology; an increase in the installation of gates and/or flashing lights; increased educational outreach (e.g., Operation Lifesaver); locomotive conspicuity (e.g., reflectorization); commercial driver safety improvements; improved reliability of motor vehicles; improved sightline clearance, crossing closures, and grade separation; traffic signal preemption; grade crossing maintenance rules; and the Federal Highway Administration (FHWA) Section 130 funding program. Each of these contributing factors is likely to have improved a slightly different aspect of crossing safety.

While the specific cause of these safety improvements is important to understand, researchers at the Volpe National Transportation Systems Center (Volpe) focused on the outcomes of this collection of safety efforts and not the impacts of any particular effort. Specifically, Volpe researchers aimed better understand how rail incidents at crossings have changed over the past 30 years. While reductions in incidents that result in fatalities, injuries, or other reportable damage are clear, the details of these reductions are less clear without further investigation. For example, were these reductions in fatal crossing incidents similar for all road users, or were they different for vehicles compared to pedestrians? Or did an increase in the number of gated crossings in the U.S. drive a subsequent increase in the number of incidents that occur at gated crossings (as might be expected from exposure alone)? Understanding how these incidents have changed over time may help to determine if there are crossing types or road users who have been more resistant to the overall safety improvements seen nationwide.

1.1 Background

Highway-rail grade crossings are inherently complex, requiring the cooperation of two different modes of transportation, involving multiple government jurisdictions and multiple rail operators. Local and State agencies are tasked with controlling and maintaining the roadway, while private railroads are tasked with controlling and maintaining the railroad tracks. This complication has been known for some time, and there have been several programs aimed at protecting both the railroad's right-of-way and the highway's users. Crossing safety moved to the forefront of the public concerns in the mid 1960s, when the rate of fatalities relative to rail traffic hit its peak in 1966 – at 1.95 highway-user fatalities per million train miles compared to 1.13 in 1950 (Mok and Savage, 2005). After years of debate, the Federal-Aid Rail-Highway crossing program joined the Federal Highway Act of 1973; this program is now commonly referred to as the Section 130 Program.

Over the past 40 years, the Section 130 Program has assisted State highway authorities and municipalities in purchasing and maintaining upgrades (e.g., gates, bells, lights) at some of the most dangerous crossings across the country. Nationwide, this program has been deemed a huge success (Mok and Savage, 2005; Sööt, Metaxatos, and Sen, 2004; McCollister and Pflaum, 2006), with a reduction in incidents of over 70 percent from 1986 to 2015. Between this and other funding programs and other technological advancements and regulatory improvements, much has been done to improve safety at crossings, and it appears that the expected declines in incidents has followed. However, it remains somewhat unclear if these declines in incidents are uniform (e.g., by severity of the incident outcome, by type of road user, by state). Additionally, the impact on incident rate of these initiatives has slowed in recent years and may be reaching its limit; new improvements will need to be developed to continue to reduce incidents.

1.2 Objectives

The objective of this report is to provide a better understanding of how grade crossing incidents have changed over the past 30 years. While researchers understood that the number of crossing incidents have decreased greatly, it remained unclear if the characteristics of the incidents that occurred in the early 2010s were similar to those from the late 1980s. Other reports have focused on the cause of the reductions in incidents; this report will focus more closely on how these incidents, and the crossing inventory, have evolved.

1.3 Overall Approach

Data from 1986 through 2015 was obtained from the Federal Railroad Administration (FRA) Office of Safety Analysis website (www.safetydata.fra.dot.gov). The data includes both crossing inventory data as well as data collected after a crossing incident. The data was summarized, graphed, and analyzed to provide a general understanding of how these incidents have evolved over time. Details and limitations about each dataset are discussed in more detail in the corresponding sections of the report.

1.4 Scope

This work focuses solely on incidents that occurred at public, at-grade, highway-rail grade crossings and does not consider other incidents (e.g., trespassing) that may have occurred elsewhere on a right-of-way. The data in this report also excludes incidents officially determined to have been the result of an act of suicide. Only the years between 1986 and 2015 are considered for this analysis. This represents a 30-year span, ending with the last complete year of reliable data available when this report was written.

1.5 Organization of the Report

This report is organized into four main sections, each with several subsections.

2. Crossing Inventory – A description of the crossings which were open each year during the study timeframe.
3. Crossing Incident History – A description of the types of incidents that were occurring at these crossings.
4. Analysis of Crossing Incident History and Crossing Inventory – A statistical analysis of the relationship between the crossing inventory and incident history
5. Conclusion and Discussion – A discussion of what can be learned from these findings.

2. Crossing Inventory

The FRA Highway-Rail Crossing Inventory database indicates that in 2015, there were 128,024 open, public, at-grade highway-rail grade crossings in the U.S. Each crossing does not necessarily share the same risk of a potential incident due to a variety of factors, including traffic (both vehicular and train), train speed, and warning devices present. This variety of crossing types makes it important to understand the inventory of public crossings through which road users may travel. Each year this inventory changes, some years more so than others, thus understanding how the inventory has changed through time may help better reveal the safety improvements the rail industry has achieved.

2.1 Method

To understand how crossing incidents have changed in the past 30 years it was critical to understand how the inventory of crossings have changed during that same timespan. Detailed records of these crossings are kept by FRA on its Office of Safety Analysis website (safetydata.fra.dot.gov/). For each state, the website provides both a current crossing file and a crossing history file. Together, these files provide a detailed record of every crossing that has existed in each state – or at a minimum, every crossing reported to FRA.

For this effort, only a subset of all crossings were considered for analysis – specifically, crossings that were public, involved a roadway/highway (i.e., not pedestrian-only pathways), and at-grade (i.e., the rail tracks and roadway intersect one another physically – neither the roadway or rail system are elevated above the other). The crossings considered for the following analyses were likely to be the focus of public safety improvement efforts. Safety research and public funding are likely to be focused on public crossings and, more specifically, on public crossings which are at the highest safety risk. Grade-separated crossings, while they may still pose safety risks, are far safer than at-grade crossings. As such, a focus on only public, highway-rail, at-grade crossings provides the best understanding of how these crossings have evolved over the past 30 years.

Historic data for highway-rail crossings in the U.S. is available through FRA; however, they are stored in huge, State-level files that track every change that has ever been recorded for each crossing. Additionally, while incredibly detailed, these historic files relied on voluntary carrier input prior to 2015. Therefore, the overall quality and precision of the data prior to 2015 is not well understood. For additional limitations or data concerns, please see the more complete discussion in the Limitations section.

For this effort, a Python script was developed which took the current inventory and isolated the crossings that met the research team's criteria that the crossing was: public (TypeXing = 3 in the FRA database), at-grade (PosXing = 1), and a highway-rail crossing (XPurpose = 1). With this subset, the researchers identified all crossings listed as open in 2015, and then worked backwards by year to identify prior crossing closures or re-openings to generate a complete list of open crossings by year from 1986 through 2015. This set of crossings was then categorized, based on the type of warning device present at the crossing, into one of three categories using their "WdCode" in the FRA database:

- Passive (WdCode = 1, 2, 3, or 4): This includes all crossings without an active warning device that signals an approaching train. Passive crossings may be marked with a passive warning device, including signs/signals, other signs or signals (the definition of which is left to carrier interpretation), crossbucks, or stop signs. The specific definition of signs/signals is not provided, but was taken to mean any sign or other item that informs drivers of the crossing, but is not intended change in appearance or sound as a train approaches.

- Bells/Lights (WdCode = 5, 6, or 7): This includes all active warning devices without gates, including special active warning devices such as highway signals, wigwags, bells, and flashing lights.
- Gates (WdCode = 8 or 9): This includes any active crossing with gates, either two quadrant gates or full barrier four-quadrant gates.

This method provided researchers with an estimate of the number of crossing which were passive vs. active, and then beyond that, how many of those active crossing had gates.

2.2 Crossing Warning Type

Most public crossings in the U.S. have some sort of safety enhancement. Some are as simple as a crossbuck sign, telling drivers and pedestrians that they are about to cross over a train track, while others have gates, flashing lights, and bells activated by an approaching train. At the broadest level, the biggest distinction between crossing safety enhancements is whether the crossing is *passive* or *active*. Passive crossings use only passive warning devices, which indicate to the roadway user that the location is a highway-rail crossing, but do not provide any indication whether a train is approaching. Examples of passive crossings include crossbucks (an x-shaped sign that means yield to the train), yield signs, stop signs, and/or pavement markings. Active crossings, in addition to passive warning devices, also have bells, lights, and gates (or just bells and lights) which are activated by an approaching train. Figure 2 shows that while the total number of open, public, at-grade crossings in the U.S. has decreased (from 193,357 in 1986 down to 130,091 in 2015), this has been driven by a reduction in the number of passive crossings; both the number and the proportion of active crossings has increased. Active crossings went from accounting for just over one-third of all crossings in 1986 to more than half of all crossings in 2015.

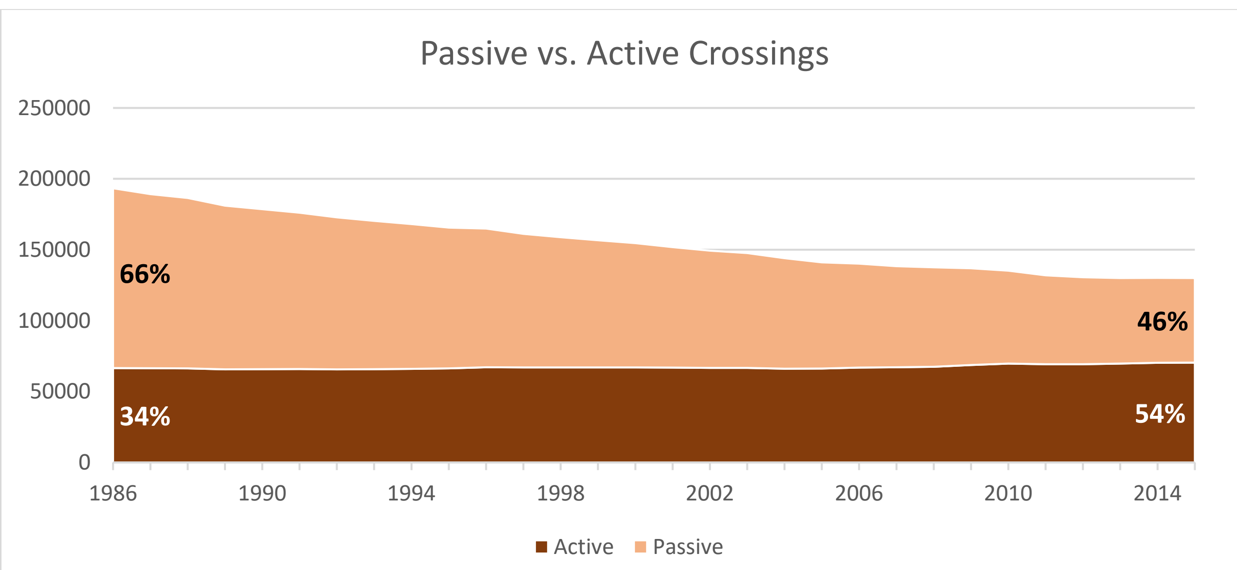

Figure 2. Crossing Inventory for Public, At-Grade Highway-Rail Crossings, Active vs. Passive, 1986 – 2015

2.2.1 Passive Crossings

Over the past 30 years, both the overall number and the proportion of passive crossings have declined in the U.S. With over 126,000 passive crossings in this analysis in 1986, passive crossings comprised the vast majority of crossings in the U.S. (66 percent). That overall number of passive crossings was reduced to just under 60,000 in 2015, a reduction of 53 percent, as seen in Figure 3.

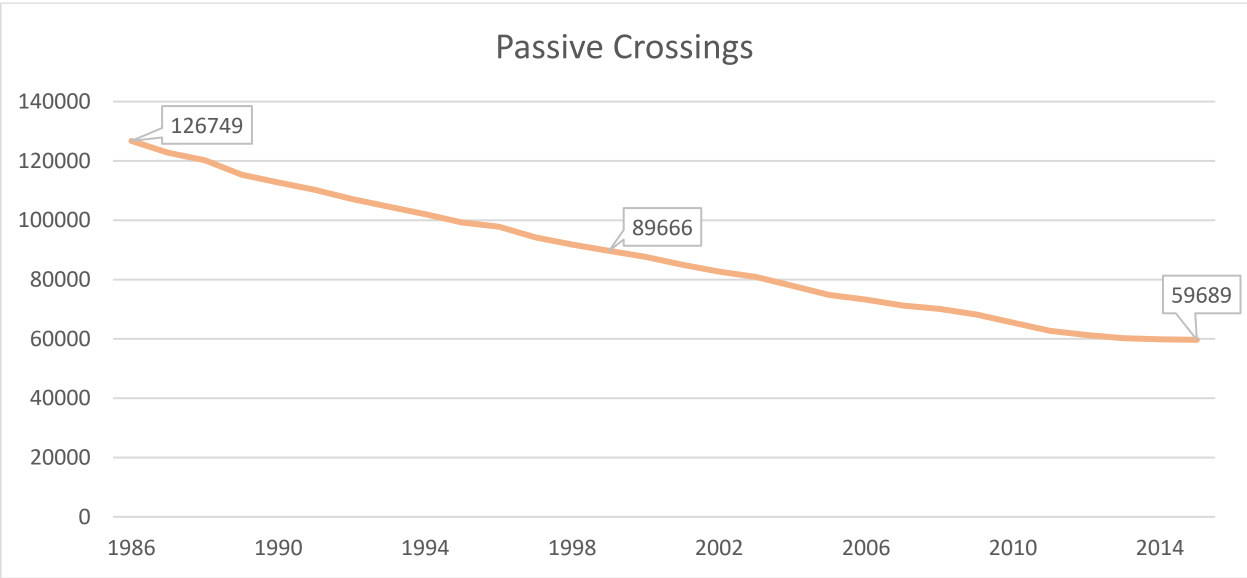

Figure 3. Passive Crossing Decline, 1986 – 2015

This decline in passive crossings may have been the result of many factors: passive crossing closures, upgrading a passive crossing to an active crossing (with gates or without gates), grade separating a passive crossing, or converting a passive public crossing to private.

2.2.2 Active Crossings

While the number and proportion of passive crossings has decreased over the 30-year timeframe being investigated, active crossings saw an increase, as displayed in Figure 4. While the increase in active crossings was relatively small compared with the decrease seen in passive crossings, this increase occurred during a time when the overall number of open, public, at-grade crossings in the U.S. decreased by over 60,000.

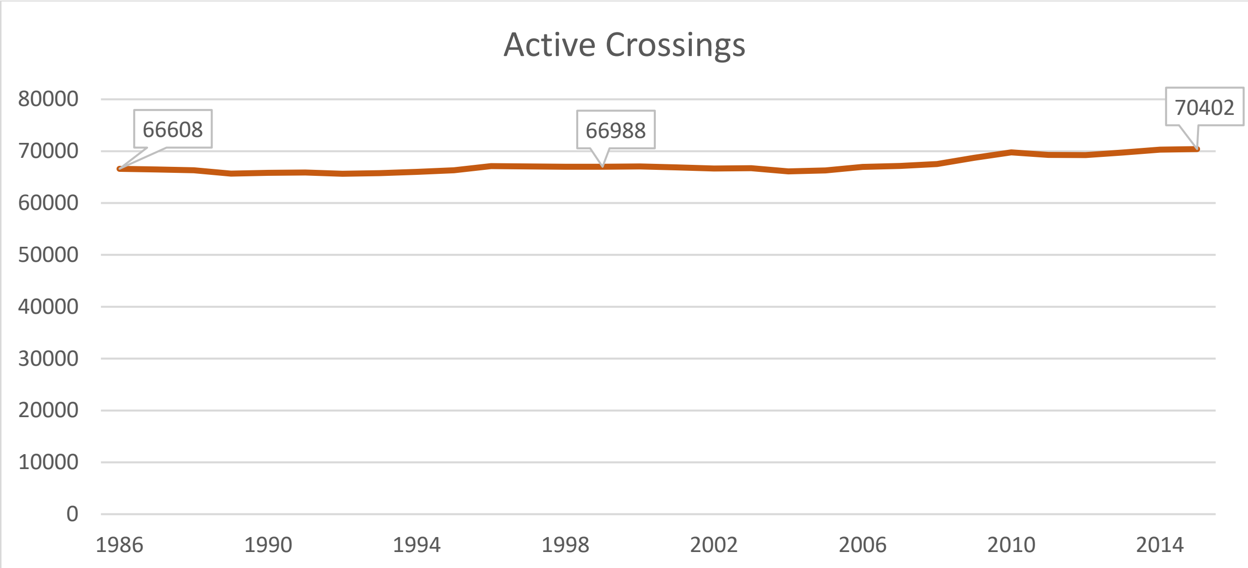

Figure 4. Active Crossing Increase, 1986 – 2015

The number of active crossings surpassed the number of passive crossings in 2009 and has continued to grow as passive crossings decreased. Figure 5 shows this crossover in 2009.

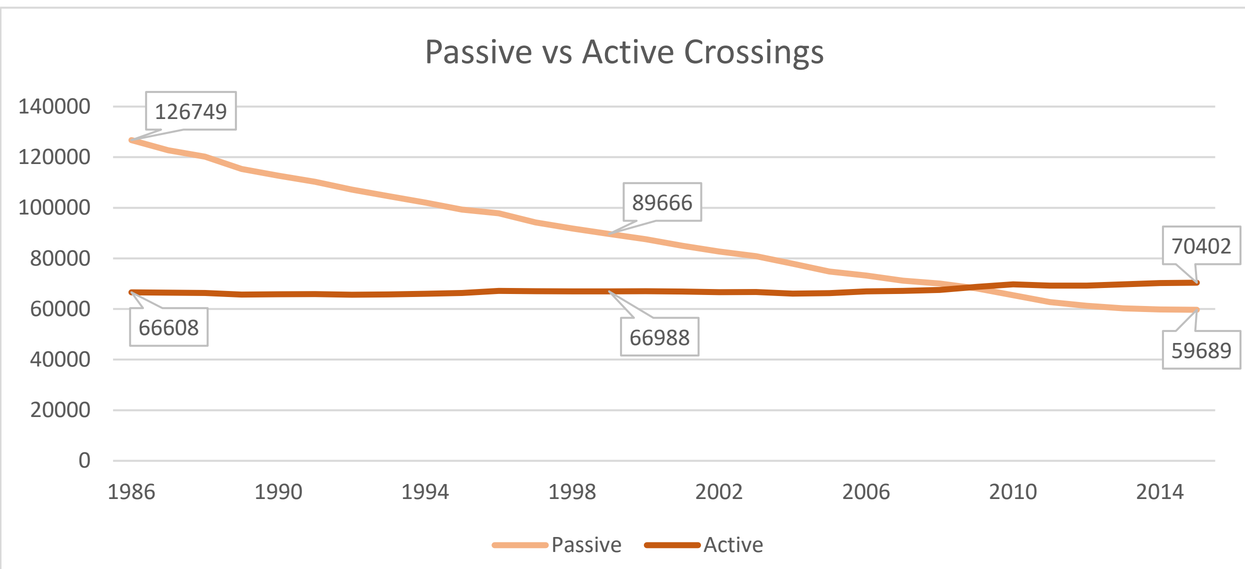

Figure 5. Passive vs. Active Crossings, 1986 – 2015

While the increase in active crossings was not large, it has been fairly consistent. These changes in the inventory of active crossings over time are described separately below for crossings with bells/lights and crossings with gates. This distinction is important, as the addition of gates provides the road users with not only an active alert that a train is approaching but also presents a physical barrier on the roadway (and sometimes on adjacent sidewalks) that restricts access to the right-of-way.

2.2.2.1 Bells/Lights

Despite the small but consistent increasing trend across all types of active crossings, non-gated active crossings saw a steady decrease over the past 30 years. In this case, crossings referred to as bells/lights crossings may have had a wide range of active warning enhancements, but none of these crossings had protective gates. These crossings may have had either bells, lights or both in combination. Additionally, this term is used in this paper to refer to all other active warning protections that are non-gated, such as flagged crossings or those with alternative active warning protections. Figure 6 shows how bells/lights crossings have changed since 1986.

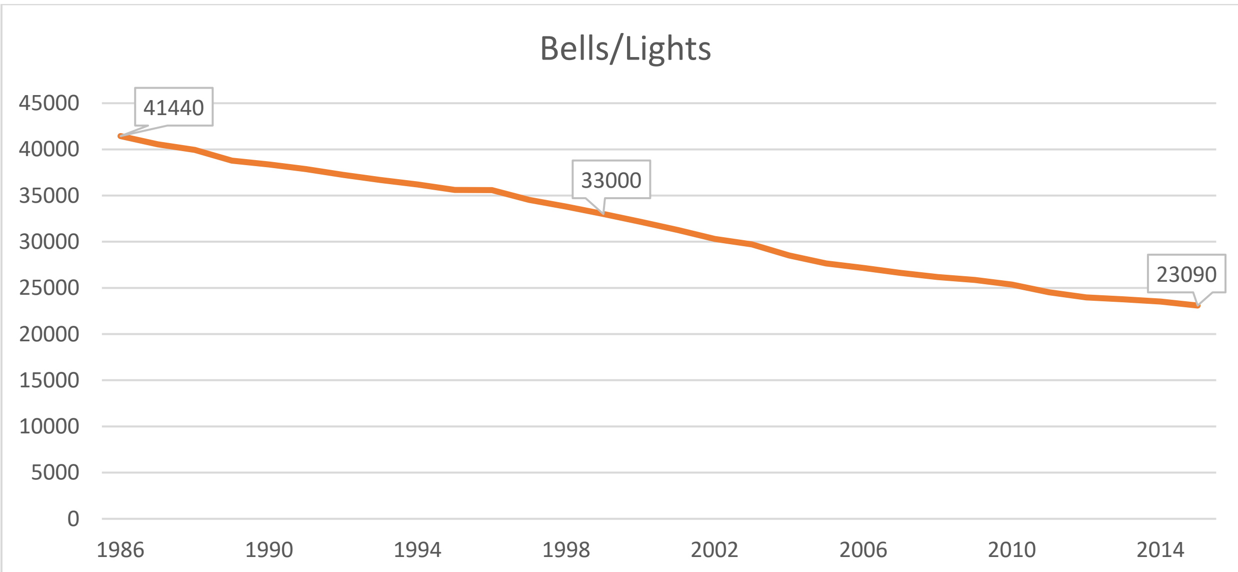

Figure 6. Active Crossings with Bells/Lights, but no Gates; 1986 – 2015

In 1986, active crossings without gates accounted for 21 percent of all crossings in the U.S. (41,440 crossings). After a steady decline, these crossings accounted for 18 percent of all crossings in the U.S. in 2015 (23,090 crossings).

2.2.2.2 Gates

Gated crossings are the one crossing type category that saw a steady increase in both number and proportion during the timeframe of this study, as shown in Figure 7.

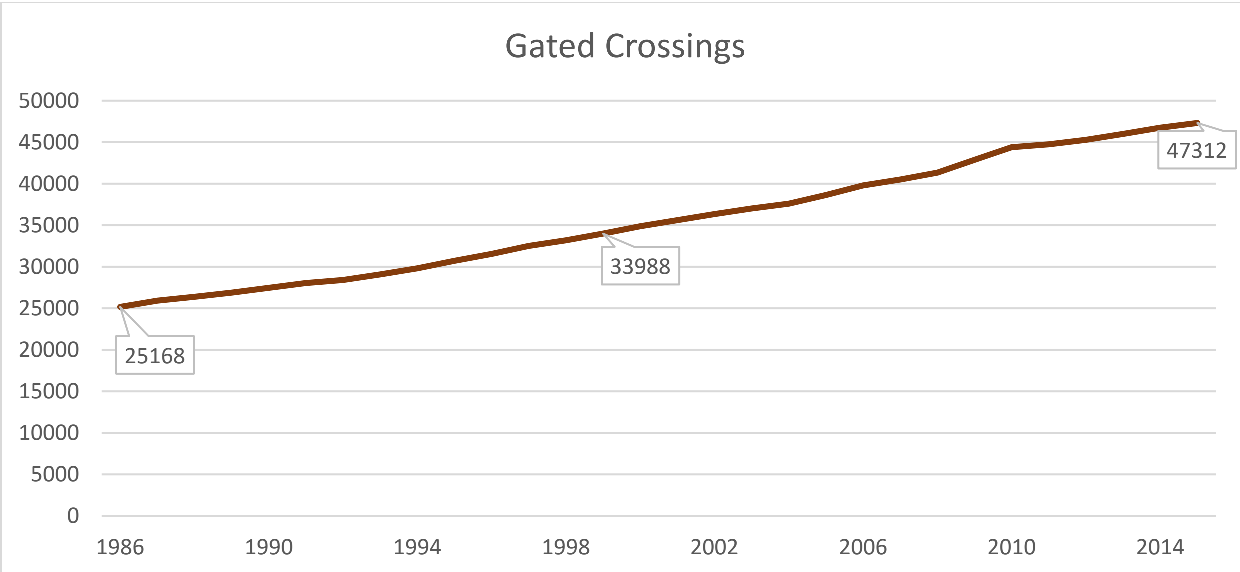

Figure 7. Active Crossings with Gates, 1986 – 2015

The total number of crossings with gates nearly doubled from 1986 – 2015, from 25,168 crossings up to 47,312. Due to the decline in the overall number of crossings during that time, the proportion of crossings in the country with gates nearly tripled, from 13 percent in 1986 to 36 percent in 2015.

2.3 State Differences

The changes in the crossing inventory shown above represent national numbers. While these trends represent the sum of the changes found across all of the states, the pattern of change in crossing inventory varied dramatically across states. Figure 8 shows the proportion of open, public, at-grade crossings with gates in each state in 1986 and 2015 (chart on the left). The states in this graph are in order of the amount of change from 1986 to 2015, with the states at the top showing the biggest change. Every state in the country had a higher percentage of crossings with gates in 2015 (filled orange circles) than in 1986 (open orange circles). In some states the change was quite large, such as North Carolina, which went from 17 percent gated to 58 percent gated. Other states show less change over the same 30-year period, such as South Dakota, which increased its gated crossing proportion from 1 percent in 1986 to 4 percent in 2015.

Every crossing in this analysis had a higher proportion of passive crossings in 1986 (open orange circles) than in 2015 (filled orange circles), with one exception (chart on the right). This graph is also organized by the amount of change from 1986 to 2015, with the states at the top showing the biggest change. Some states show large changes, such as Texas, whose passive crossing proportion dropped from 68 percent in 1986 to 36 percent in 2015. Other states showed a less dramatic shift, like Massachusetts, which dropped from 22 percent passive in 1986 to 17 percent in 2015; or New Hampshire, the only state to move in the opposite direction, which increased from 45 percent passive in 1986 to 47 percent passive in 2015.

Figure 8. Proportion of Crossings with Gates (left) and that are Passive (right), 1986 – 2015

A shift in the proportion of crossings with upgraded safety measures is only a part of the story. An increase in proportion does not account for the overall reduction in the number of crossings that are open in the U.S., shown in Figure 9. Points plotted to the left of the dotted line at zero represent reductions in the overall number of open, public crossings, while points to the right represent an overall increase. States in Figure 9 are organized alphabetically.

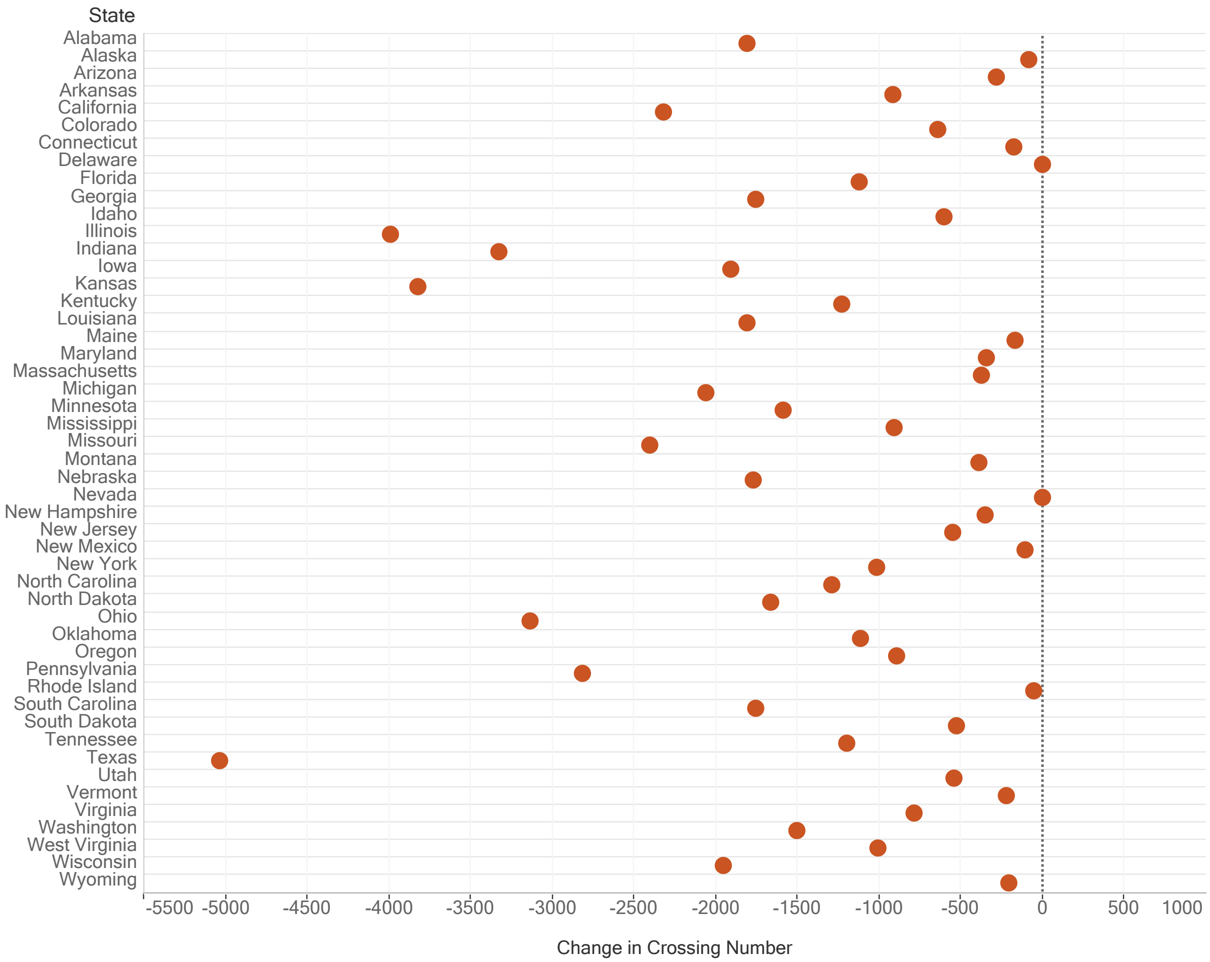

Figure 9. Change in the Number of Open, Public, At-Grade, Highway-Rail Crossings, 1986 – 2015

Only two states, Delaware and Nevada, had a net increase in the number of crossings during the study timeframe (each of which added eight crossings over 30 years). Every other state saw a net reduction in the number of open crossings – and some states, like New Hampshire, reduced their crossings by huge proportions (more than half of crossings were eliminated, grade separated, or made private), even though the overall number seems small as compared with other states.

2.4 Incidents by Crossing Type

These changes in the inventory of crossings, both nationally and within states, are expected to yield safety benefits. By closing crossings or by making passive crossings active (or adding gates), it is presumed that the number of incident will be reduced as well. Conversely, another expectation may be that as the proportion of crossings with gates increases, so will the number of incidents that occur at gated crossings (based purely on exposure and opportunity). That is, while gated crossings are more protective, and thus the number of incidents expected at a gated crossing per vehicle that traverses it would be lower, converting a passive crossing to a gated crossing doesn't eliminate the risk, it merely reduces the risk. Therefore, as the proportion of crossings which are gated increases, so should the number of incidents at gated crossings.

In Figure 10, the number of incidents at each crossing type (per year) are divided by the total number of crossings of that type (per year). For example, in 1986 there were 3,177 incidents at passive crossings, and there were 126,749 open, public, at-grade, passive crossings in the U.S. Therefore the lightest colored line (Passive) in 1986 shows 0.025. If the number of incidents per crossing increases, it indicates that this crossing type is becoming more risky. As this number decreases, it indicates that this crossing type is, on average, becoming safer.

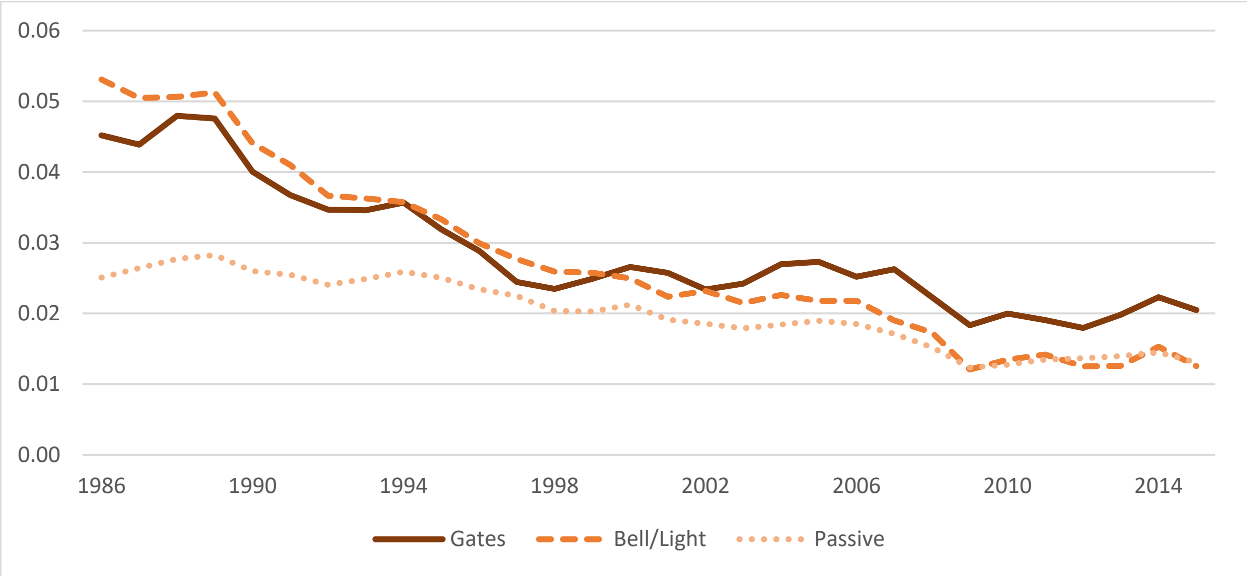

Figure 10. Incidents per Crossing by Crossing Type, 1986 – 2015

The number of incidents per crossing is going down for all crossing types, which indicates improvements in safety for each crossing type. These improvements for passive and bells/lights crossings are beyond what would be expected by closing crossings alone – if safety improvements were entirely due to closing crossings, the lines would be flat as incidents per crossing remained constant. The improvements for gated crossings indicate that despite an increase in the number of gated crossings, the number of incidents at gated crossings is not rising at that same rate (and as will be seen in the following section – these number are actually trending down despite the increase in gated crossings). Surprisingly, it appears that after 2002, gated crossings have the highest rate of incidents per crossing, despite in theory being the most protective form of active crossing. In part, this is likely the result of a confounding factor – the most dangerous crossings will probably be the first crossings targeted for safety improvements, such as the addition of a gate. However, it still suggests that there is room for further safety improvements, even at gated crossings; some road users may not be sufficiently protected by gated crossings, or some types of incidents may not be prevented by gated crossings.

3. Crossing Incident History

The goal of any safety enhancement at a crossing is to prevent incidents from occurring. Making a crossing safer by adding gate enhancements or upgrading the technology of existing enhancements reduces the risk that incidents will occur at that crossing. The worst outcome from a crossing incident is the loss of life; therefore, reducing the number of fatal incidents is the top priority. However, incidents that result in injury and even incidents that don't result in any casualties (but are still reportable) are still important to consider. Throughout this section, analyses will often focus on *fatal incidents*, *incidents with casualties* (which includes both fatalities and injuries), and *all incidents* (which includes fatalities, injuries, and other reportable incidents).

3.1 Method

Throughout this paper the unit of measurement used for analysis is *incidents*, not fatalities (or injuries). Each incident is counted a single time and is classified into a category based on the most severe casualty resulting from the incident. If a single incident resulted in multiple casualties, it would be recorded as a single incident. If an incident resulted in both an injury *and* a fatality, it is only recorded once as an incident with a fatality and not a second time as an incident with an injury. This method of reporting was chosen to provide the clearest picture of the safety improvements achieved at the crossings. While a reduction in the number of lives affected is the ultimate goal, this is largely accomplished through attempts to reduce the number of road users who expose themselves to danger at a crossing, independent of additional passengers in the vehicle. The number of fatalities resulting from an incident, beyond the first, is primarily a function of the number of individuals in the vehicle involved, not necessarily a function of the crossing itself.

3.2 Overview

In the past 30 years incidents have greatly declined. Incidents that resulted in fatalities, injuries, and other non-casualty losses are each far lower today than they were 30 years ago. Figure 11 shows these rates at a national level.

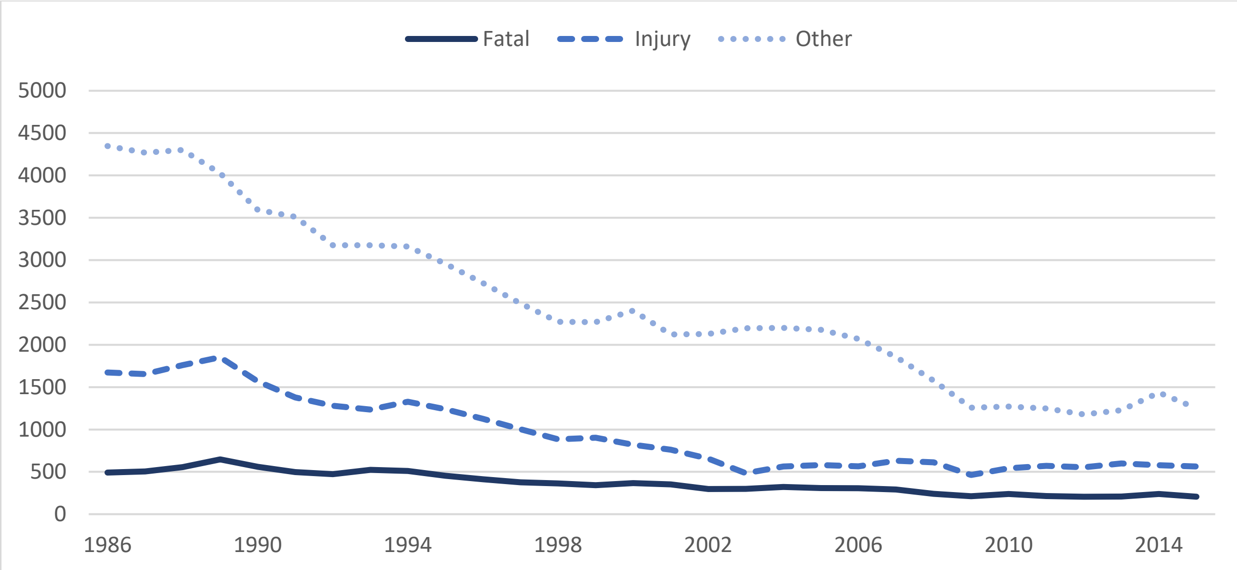

Figure 11. Incidents by Severity of Outcome, 1986 – 2015

All types of incidents declined by over 60 percent, when comparing the first five years (1986 – 1990) to the last five years (2011 – 2015), during the past 30 years. Fatal incidents declined by 61 percent, incidents that resulted in injury declined by 66 percent, and other incidents dropped by 69 percent. Dramatic improvements in safety have been achieved across all types of incidents.

These trends are even more pronounced given that both vehicle and train traffic has increased significantly during this timeframe. Aside from a short period of decline/stagnation from roughly 2006 – 2009, both train miles[1] and annual average daily traffic (AADT)[2] have been steadily rising. Increases in both train miles traveled and daily vehicle traffic would increase the opportunity for grade crossing incidents to occur. Therefore, while even a steady number of incidents during a period of traffic growth may be seen as an improvement in safety, the rail industry has gone well beyond that and seen a substantial decline in incidents. Figure 12 displays the number of incidents per million total train miles in the U.S.

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[1] Data for train miles are the sum of Class I freight train miles and intercity/Amtrak train miles from the Bureau of Transportation Statistics: www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_35.html (last accessed April 12, 2017).

[2] AADT is calculated as the total vehicles miles traveled (not including travel on interstate highways, which do not have highway rail crossings) / (the total miles of highway infrastructure (not including interstate highways) * 365). All data obtained from the FHWA website: www.fhwa.dot.gov/policyinformation/statistics/2015/ (last accessed April 12, 2017).

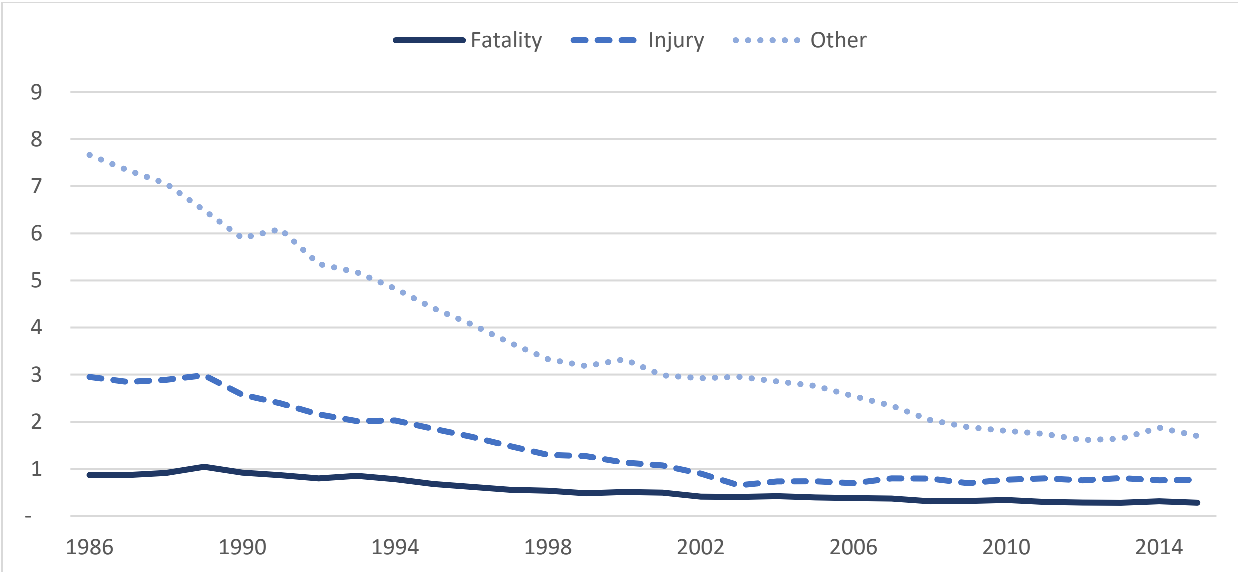

Figure 12. Incidents per Million Total Train Miles by Incident Type, 1986 – 2014

The declines in incidents per train miles show a very similar pattern to the decline in incidents overall. Beyond the similar pattern, the overall drop was even greater – from over 11 incidents per million train miles down to roughly 2.5, a drop of over 77 percent. A similar pattern is seen in Figure 13 when the number of incidents is divided by AADT in the U.S. for each year of this analysis.

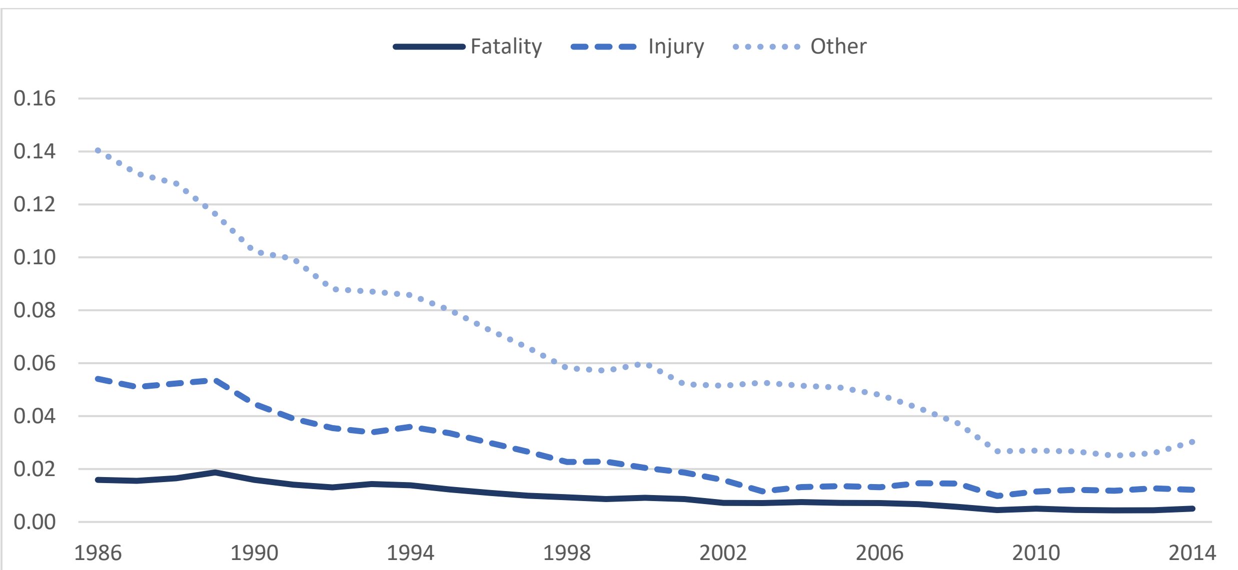

Figure 13. Incidents per Annual Average Daily Traffic (AADT) by Incident Type, 1986 – 2014

The AADT-corrected figure looks similar to the train traffic-adjusted figure and the raw number of incidents figure. This indicates that the reduction in rate of incidents is not an artifact of the selection of an exposure metric; the reductions in incidents is the most salient factor, not the choice between vehicular or train traffic as a measure of exposure. In other words, despite increases in both train and motor vehicle traffic, incidents of every type of severity were reduced.

3.3 Overview by State

The national trends seen above show dramatic overall improvements in safety. However, the degree to which safety has improved varies substantially across states. While nearly all states experienced some safety improvement, in some states these effects were more pronounced than others. One way to visualize the change within a state is to look at the slope of a line fitting the annual number of incidents per year. For this, researchers looked at incidents which resulted in a fatality, as the variability of this data allowed for more clear comparisons. As an example of how the slope is determined, see Figure 14, which shows fatal incident data for Ohio, the state with the largest reduction in fatal incidents since 1986.

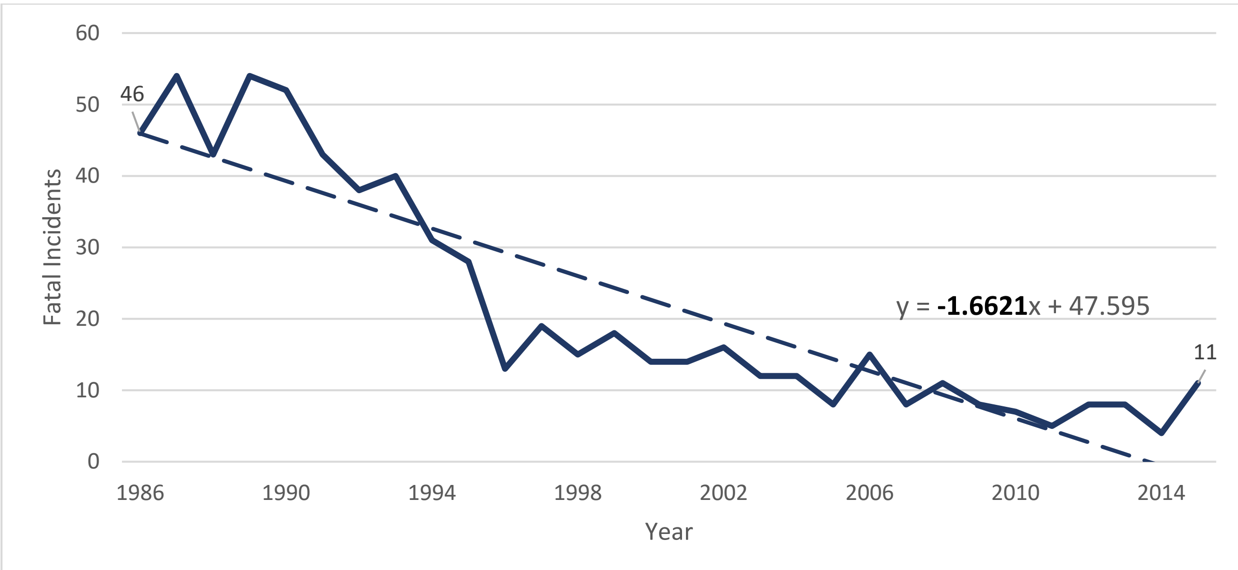

Figure 14. Fatal Incidents in Ohio with Linear Trend Line, 1986 – 2015

The trend line fit to this data shows the best linear approximation of how yearly fatalities have changed from 1986 – 2015. The equation displayed on the graph describes that line. In bold is the slope, in this case -1.6621. That slope represents the average change in fatal incidents per year. Therefore, from 1986 to 2015, Ohio saw an average of 1.6621 fewer fatal incidents each year than the year prior. The reduction in fatal incidents in Ohio saved approximately 1.7 lives each year over the 30-year timespan, for a total of nearly 50 lives saved since 1986.

While it may have been possible to achieve better fit by creating a unique curvilinear model for each state's data, the research team chose to apply the same simple linear model to each state. Though a linear model may not perfectly capture the nuances of how safety improved (or worsened) each year over the study timeframe, it provides a single metric which, when applied consistently to each state, can describe the approximate change in safety experienced at crossings within that state during this timeframe in a way that can be meaningfully compared across states.

Additionally, note that the data presented is raw data and has not been normalized in any way. While states clearly differ greatly in average annual daily traffic, pedestrian traffic, train traffic, and the number of crossings, the team felt it may be most informative to present the unmodified data. The slope values presented for each state compare that state to itself in prior years and not to any other state. Therefore, the data should not be read as a certain state being more or less safe than another, but rather that some states experienced greater changes in fatal incidents/year relative to that state's own starting point in 1986. However, since these data have not been normalized, this analysis does not account for population fluctuations, or changes in train, vehicle, or pedestrian traffic that may have been disproportionately experienced by certain states.

Figure 15 shows the slope of the trend line for fatal incidents for 48 states (Hawaii, DC, and Rhode Island are omitted due to insufficient data). The more negative the slope, the greater the decrease in fatal incidents over the study timespan.

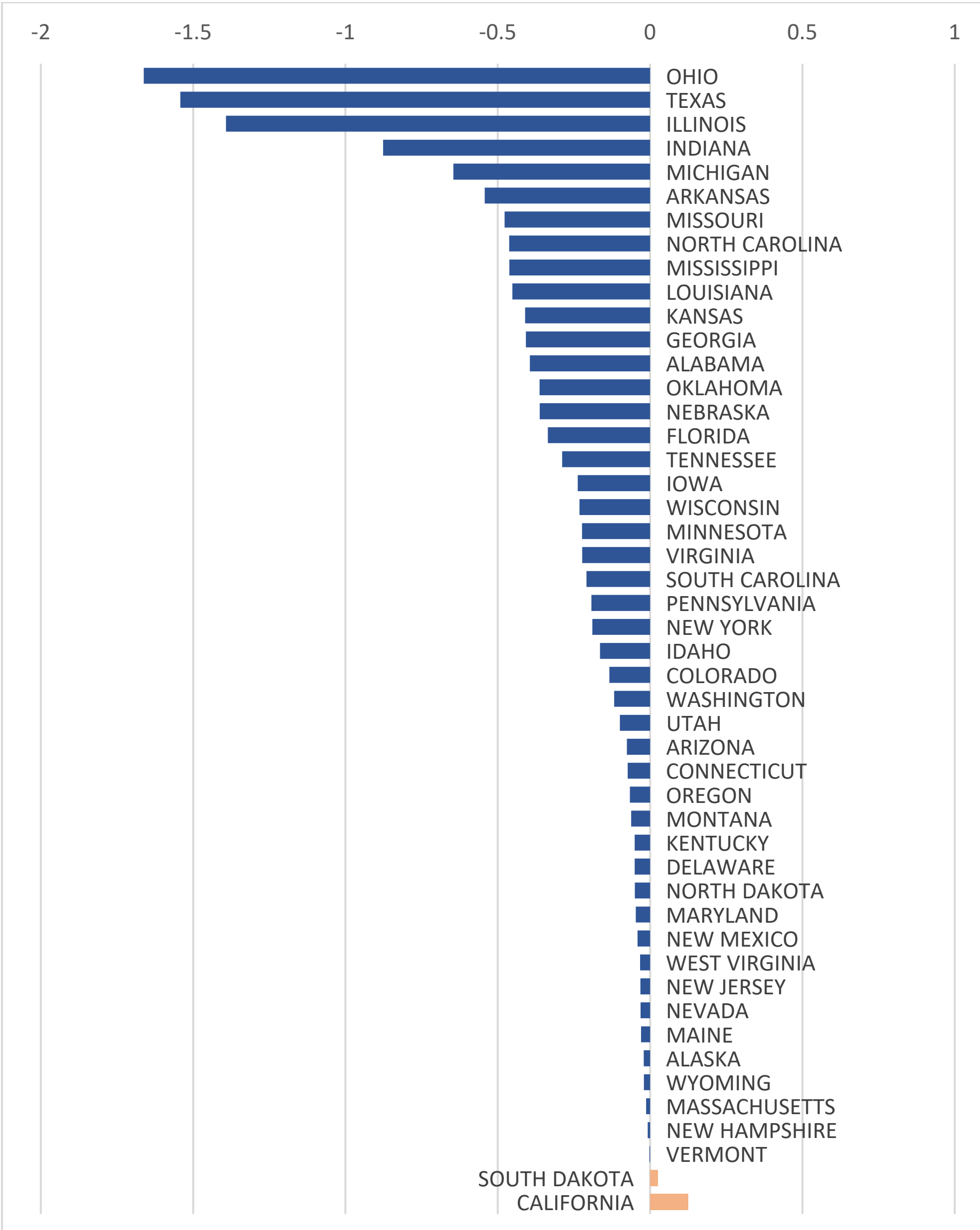

Figure 15. Change in Fatal Incidents per Year (slope of trend line), by State

The overall trend over time varied greatly across states. Some of this may be driven by differences in population or train traffic; these factors were not taking into account when calculating this slope. Only two states showed an overall increase in fatal incidents over the past

30 years: South Dakota and California. The largest reductions in fatal incidents were achieved by Ohio, Texas, and Illinois.

When normalized for AADT, a somewhat similar story emerges. In Figure 16, the states on the vertical axis are in the same order as above in Figure 15. Again, the values represent the slope of a linear trend, though this time the numbers of fatal incidents are divided by the AADT of that state in each year.

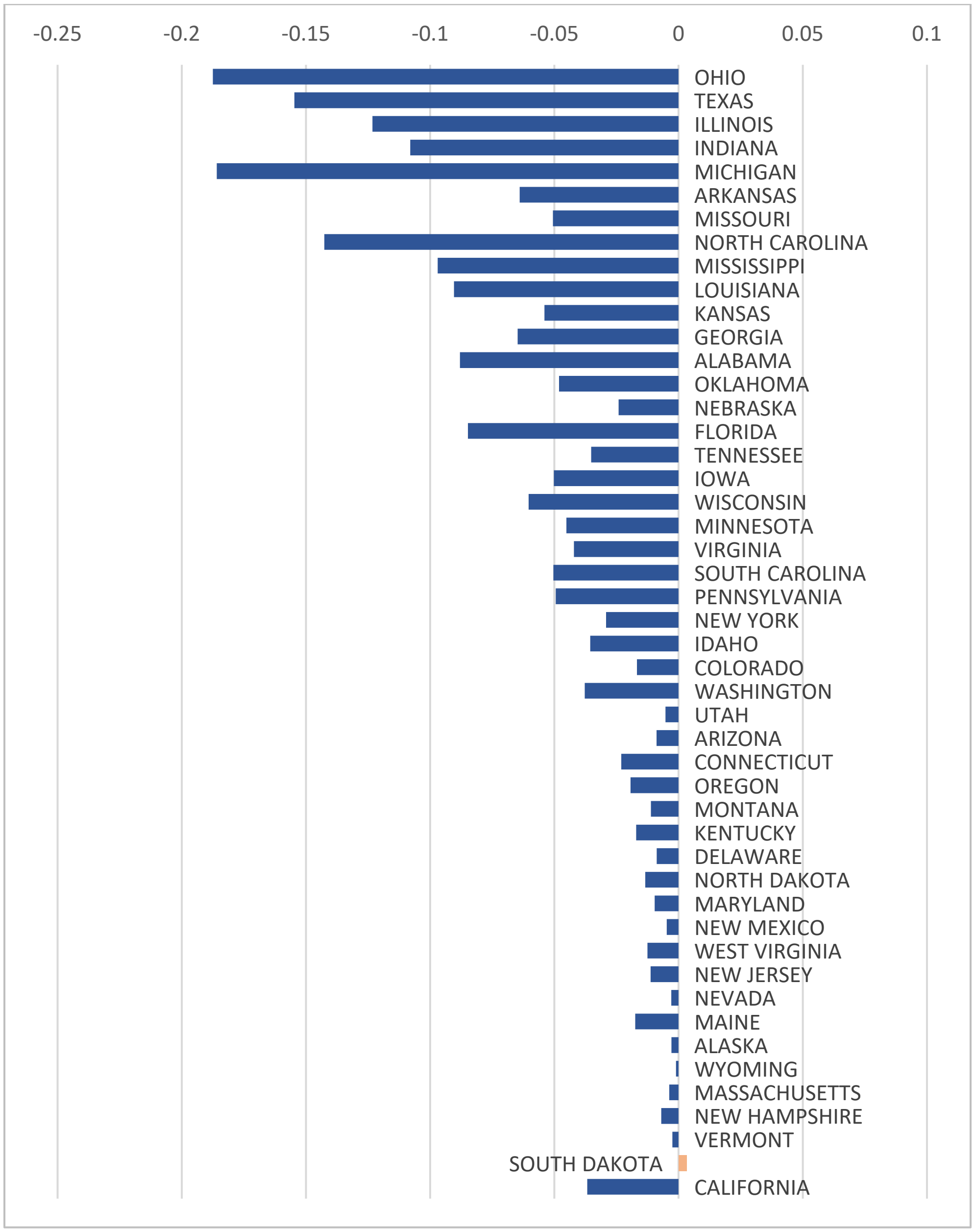

Figure 16. Change in Fatal Incidents/AADT per Year (slope of trend line), by State

A similar trend emerges when correcting for AADT. Ohio is still the state with the largest change, even after accounting for AADT. Michigan and North Carolina both rise up higher than when looking at fatal incidents alone. Also of note, California shows a reduction in fatal incidents per AADT. This is likely due to the relatively higher rate of population growth in California over the past 30 years, compared to other states.

3.4 Incident Outcome

While the total number of incidents has decreased over time, the relative distribution of the severity of these incidents has remained approximately constant. Over the 30-year span of this analysis, the number of incidents classified as "other" (non-casualty causing, but reportable incidents) have been reduced by slightly more than incidents which resulted in an injury or fatality. In 1986, fatalities occurred in approximately 8 percent of all incidents, and injuries occurred in approximately 26 percent of all incidents. In 2015, both fatal and injury incidents were up by 2 percent to 10 percent and 28 percent, respectively, while other incidents fell to 62 percent (see Figure 17).

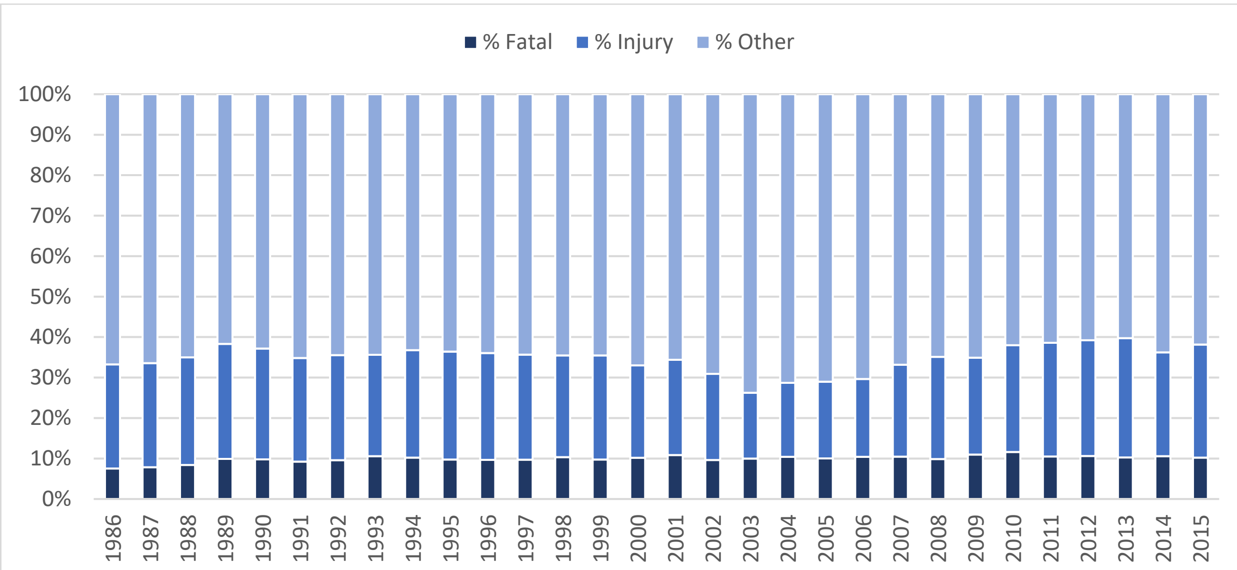

Figure 17. Proportion of All Incidents by Severity, 1986 – 2015

3.5 Road User Type

Vehicles are not the only types of road users involved in grade crossing incidents; these numbers also include pedestrians struck by trains at crossings. Vehicles and pedestrians do not interact with grade crossings in the same way, and grade crossing safety measures may have different impacts on each type of road user. The following section analyzes the difference in the number of incidents for vehicles (and types of vehicles) and pedestrians.

3.5.1 Vehicle

When thinking about incidents that happen at highway-rail grade crossings, passenger motor vehicles are likely the first thing that comes to mind. This is for good reason; vehicular incidents have been the number one cause of accidents at highway-rail crossings since data has been recorded by FRA. However, since 1986, vehicular incidents of all types have dropped dramatically (see Figure 18).

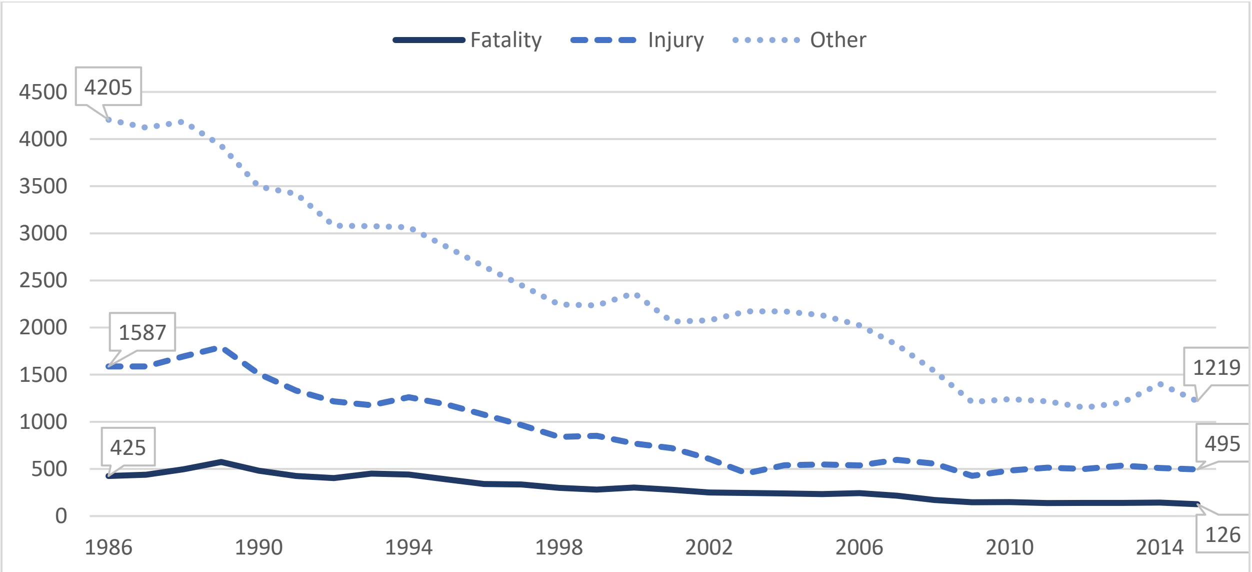

Figure 18. Vehicular Incidents at Crossings by Outcome, 1986 – 2015

Of course, there are many different types of vehicles. Personal vehicles, like cars, pick-up trucks, vans, or motorcycles, have always comprised the majority of all crossing incidents. In 1986, personal automobiles (including motorcycles) accounted for 65 percent of all incidents at crossings, while in 2015 automobiles and motorcycles accounted for 45 percent of all incidents at crossings. Figure 19 shows the decline in the raw number of incidents involving personal automobiles. Note that prior to 1997, there was no distinction for pick-up trucks, vans, or other motor vehicles. It is unclear if these incidents would have been captured in the "Auto" field or with one of the other heavy truck fields. Also, note that the van and motorcycle categories make up a very small proportion of the incidents at crossings, and are thus difficult to see at this scale.

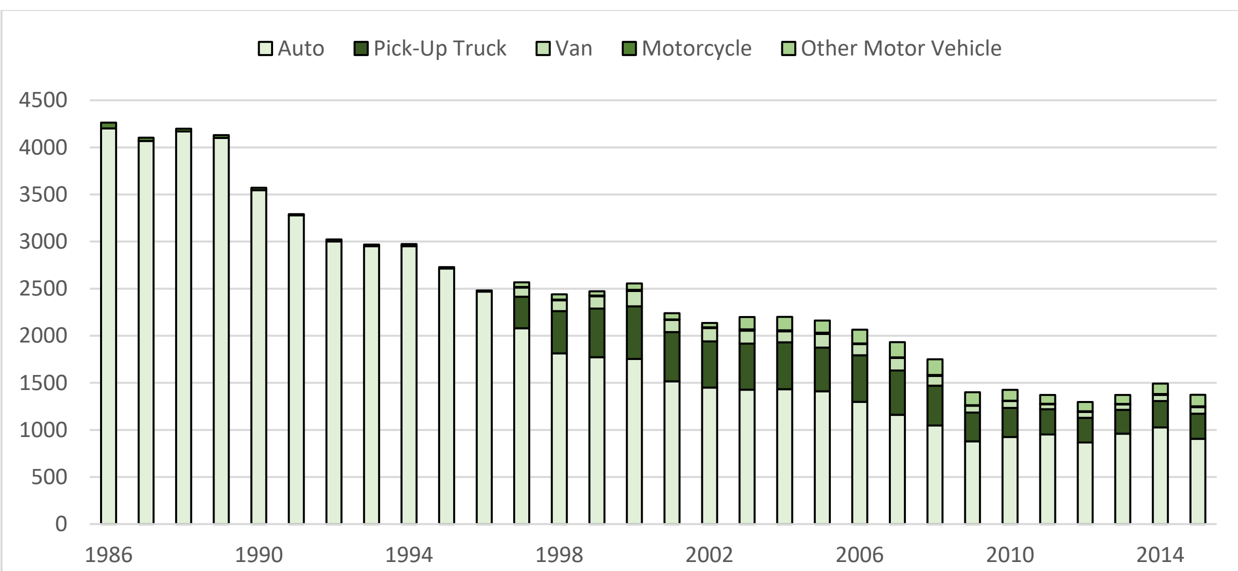

Figure 19. All Crossing Incidents by Type for Personal Vehicles

These are not the only vehicles involved in incidents at crossings. Commercial and other heavy trucks and buses are also at risk for crossing incidents, and in many cases the ramifications of these events may be even greater (e.g., a large number of passengers). Figure 20 shows the same trends for commercial/heavy trucks and buses (note that the vertical scale is smaller than for the automobile graph above, indicating fewer overall incidents each year). Also, note that the number of incidents involving busses and school busses is incredibly small and thus difficult to see at this scale.

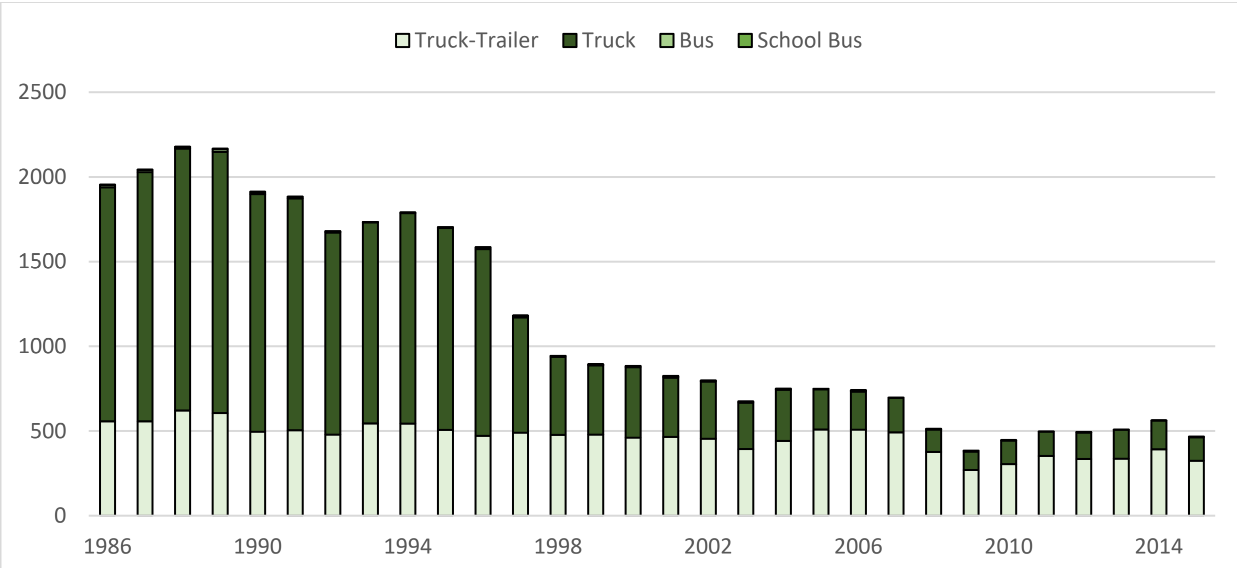

Figure 20. All Crossing Incidents by Type for Heavy/Commercial Vehicles

Just as with personal vehicles, there is a large downward trend in the number of incidents which involve larger trucks and buses. Worth noting is that the drastic decline in "Truck" incidents in 1997/1998 may be, at least in part, due to the addition of the "pick-up truck" category, which are displayed in Figure 19. The majority of the incidents that occur at crossings are captured by the two graphs above; however, they do not account for pedestrian incidents at crossings, which are discussed further below.

3.5.2 Pedestrian

Historically, pedestrian incidents have accounted for a minority of incidents at crossings (only 1 percent of all incidents in 1986 and 6 percent of all incidents in 2015). However, despite the relatively small number of pedestrian incidents, they account for a disproportionately large number of fatal incidents. This is likely due to protective features of vehicles and advancements in safety enhancements inside vehicles – a person inside a vehicle is more likely to survive a train strike than a person who is directly struck. Looking at just fatal pedestrian incidents at crossings (see Figure 21) shows a steady increase in incidents over the study timeframe. The results of a simple linear regression indicate that pedestrian fatalities are significantly increasing over time, with a linear trend for change over time explaining 36 percent of the variance in yearly national total number of pedestrian fatalities ($F(1,28)=15.982$, $p<0.001$, $R^2=0.363$), and pedestrian fatalities increasing at a rate of 0.73 per year.

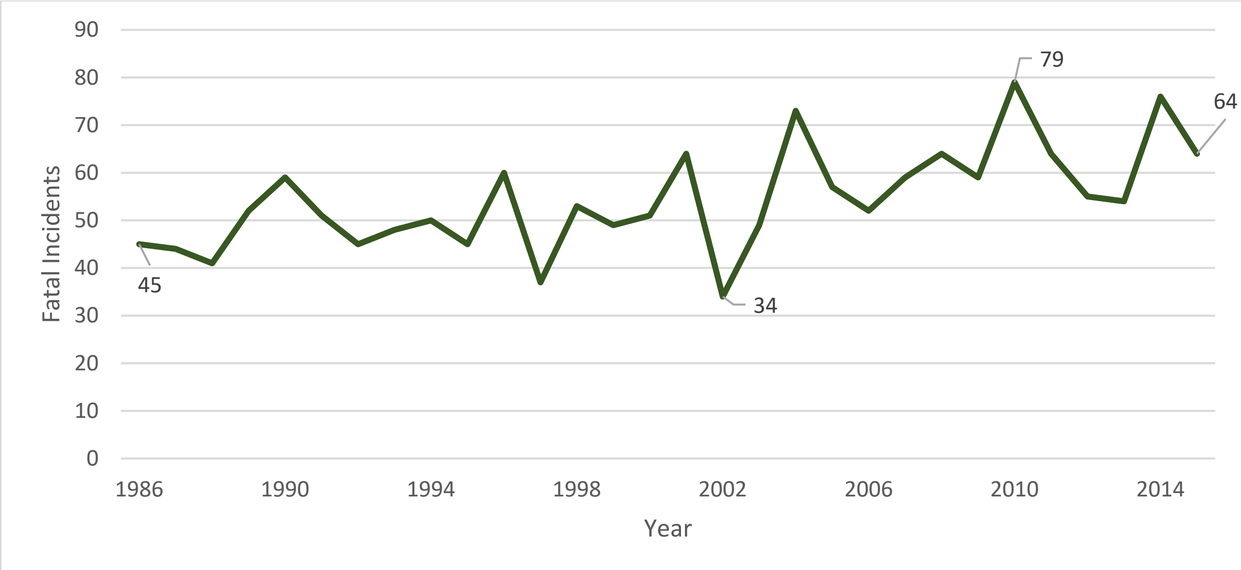

Figure 21. Fatal Pedestrian Incidents, 1986 – 2015

This increase in fatal pedestrian incidents is even more pronounced when it is plotted next to the decreases in fatalities for other road users (see Figure 22). This figure excludes the FRA category "Other" road users, for whom there was insufficient detail to classify by type. Fatal incidents involving personal vehicles decreased from over 300 per year to just over 100 per year, and fatal incidents involving commercial vehicles decreased from a high of over 150 per year to approximately 20 per year. During that same timeframe, fatal pedestrian incidents increased from under 50 per year to often reaching totals above 60 or 70 per year (a peak of 79 in 2010).

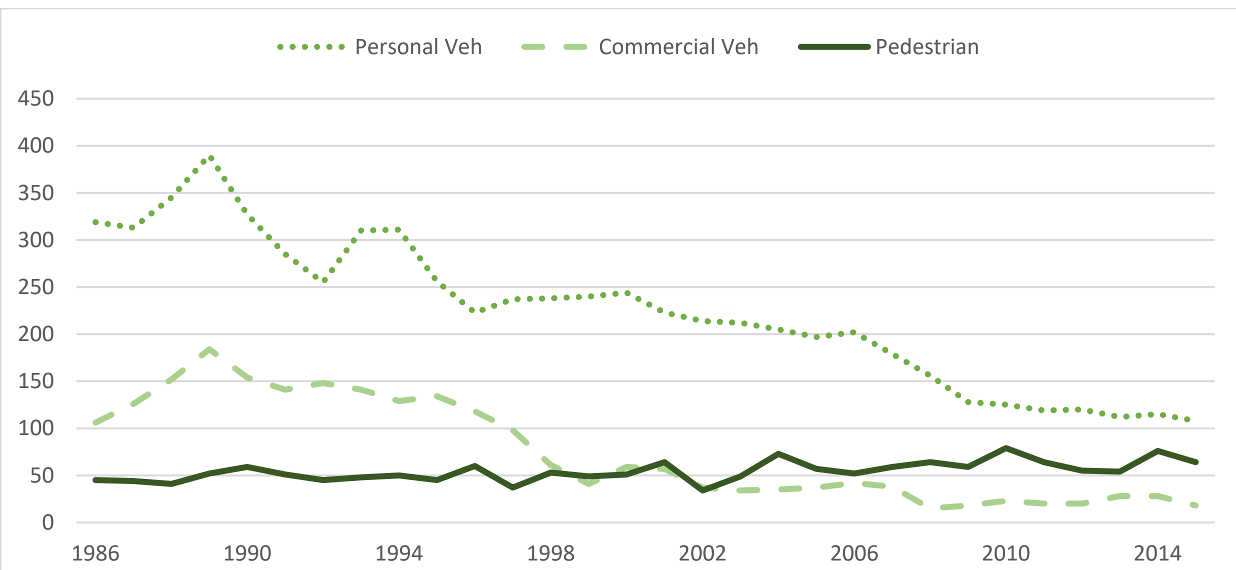

Figure 22. Fatal Incidents by Road User Type, 1986 – 2015

This increase in fatal pedestrian incidents is quite surprising. The safety improvements in nearly every aspect of highway-rail crossings are clear, with the exception of pedestrians at crossings, which not only hasn't seen the same benefit, but has actually trended toward higher numbers.

The next sub-section will look at historic trends to predict what future years will look like in terms of fatal incidents by road user type.

3.5.2.1 Pedestrian Predictions

Multiple regression analysis was used to project national annual totals for vehicle and pedestrian fatal incidents in future years. In order to account for changes in traffic rates, the models estimated yearly fatalities per AADT rather than just total numbers of fatalities (see Section 3.2 *Overview* for more about AADT calculations). Sample size for this analysis was 29 (there were 30 years of data, but AADT predictions were only available up to 2014). Change over time in both vehicle and pedestrian fatalities was best fit by a quadratic curvilinear model. Regression results are presented in Table 1 and Table 2. The model presented in Table 1 explained 95 percent of the variance in vehicle fatalities per AADT over time.

Table 1. Model for National Fatal Vehicle Incidents per AADT

	B	SE	β	*t*	Sig.
Intercept	0.016	0.000		31.90	0.000
Year (Linear)	-0.001	0.000	-1.40	-8.47	0.000
Year (Quadratic)	7.60E-06	0.000	0.45	2.72	0.012

R^2=0.95

The results in Table 1 indicate that the quadratic model used to predict the number of fatal incidents that involved a vehicle was quite good. The majority of the variation over time in the number of fatal vehicle incidents was explained by the fit line described above. This means that this model should be a good candidate to accurately predict the number of incidents of this type in future years.

Table 2. Model for National Fatal Pedestrian Incidents per AADT

	B	SE	β	*t*	Sig.
Intercept	0.001	0.000		13.21	0.000
Year (Linear)	-1.96E-05	0.000	-0.81	-1.08	0.289
Year (Quadratic)	6.63E-07	0.000	0.79	1.06	0.298

R^2=0.04

The results in Table 2 indicate that the quadratic model was a poor fit for the fatal incidents involving a pedestrian. While the number of pedestrian fatalities is increasing over time, as shown in Figure 21, the rate of pedestrian fatalities per AADT is not changing significantly over time. A linear model of change over time without the quadratic term was also tested and was also non-significant. Therefore, from 1986 to 2014, pedestrian fatalities appear to have been occurring at a consistent rate of 0.00135 per AADT per year. While a consistent rate may not seem undesirable, note that this lags behind fatal vehicular incidents per AADT, which have trended significantly toward fewer incidents over the same timeframe.

This model was intentionally designed to take into account changes over time in AADT. Therefore, to generate projected fatal incident totals for future years, it was also necessary to create projected values for AADT. An additional linear model was created for AADT. This model, summarized in Table 3, explained 97 percent of the variance in AADT over time. Figure 23 shows the predictions of this model in comparison to the historical data, as well as the projected AADT values based on this fit equation.

Table 3. Model for National AADT

	B	SE	β	*t*	Sig.
Intercept	32213.96	287.63		112.00	.000
Year (Linear)	564.77	17.64	0.99	32.03	.000

R^2=0.97

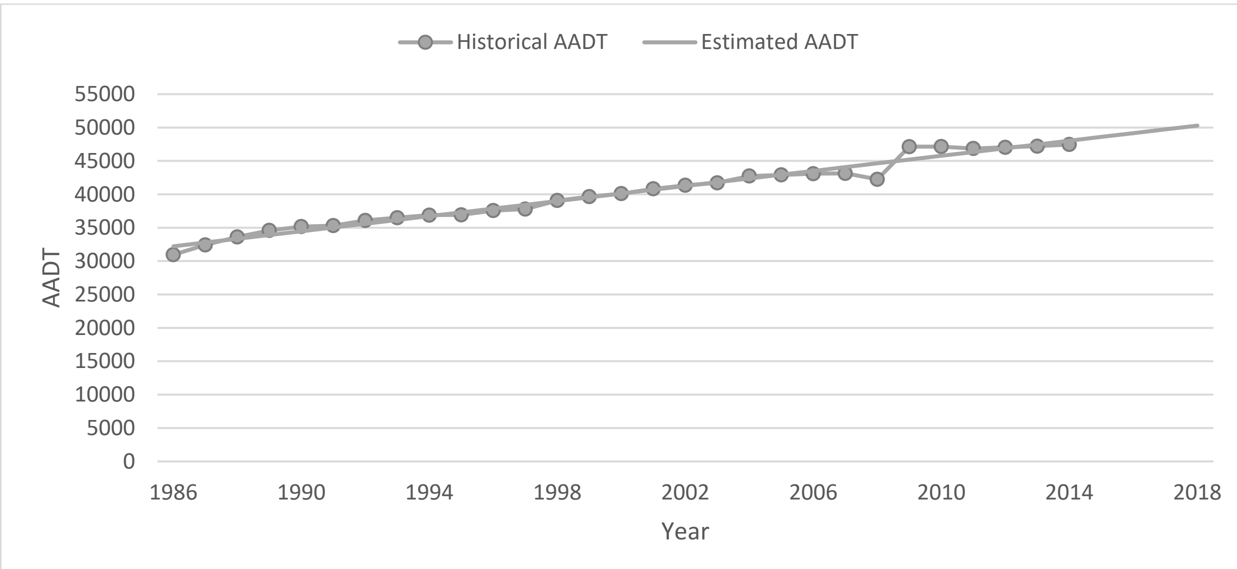

Figure 23. National Total Annual Average Daily Traffic, Automobile, Non-Interstate

The AADT followed a very linear trend, increasing steadily over the past 30 years. This model assumes that this trend will follow in the coming years.

Projected fatal incidents for vehicle and pedestrian users were calculated using the values in Table 1 and Table 2 and AADT projections, as shown in Figure 23. These fatal incident projections are summarized in Figure 24. Given the current trajectory of each of these types of incidents, fatal incidents involving pedestrians may become more common than fatal incidents involving vehicles within the next several years. These projections highlight the importance of considering all road user types when developing mitigation strategies.

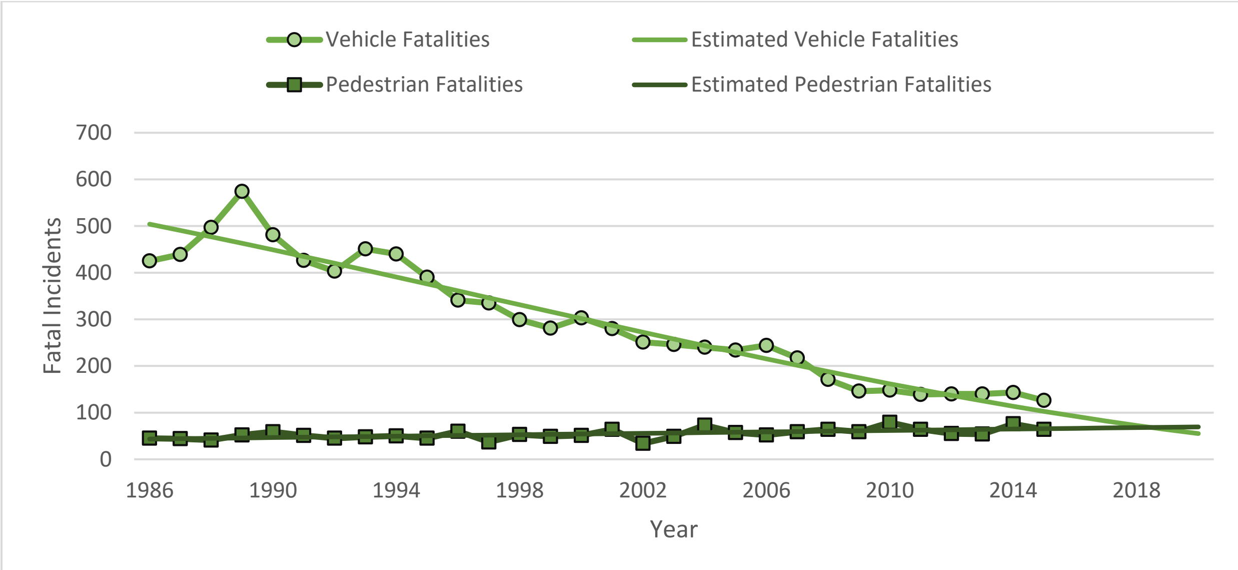

Figure 24. Historical and Projected Grade Crossing Fatalities by Road User Type

3.6 State Differences

These trends are not the same across all states. In fact, the trend in pedestrian incidents is largely concentrated in a few key states. California, Illinois, and Florida alone account for 40 percent of all fatal pedestrian incidents at crossings in the U.S. over the past 30 years. In each of these states, there has been at least one year since 2010 in which pedestrians accounted for the most fatal incidents, as compared with vehicles. The state with the clearest upward trend in pedestrian fatal incidents over the study timeframe was California, whose fatal incidents are plotted below in Figure 25.

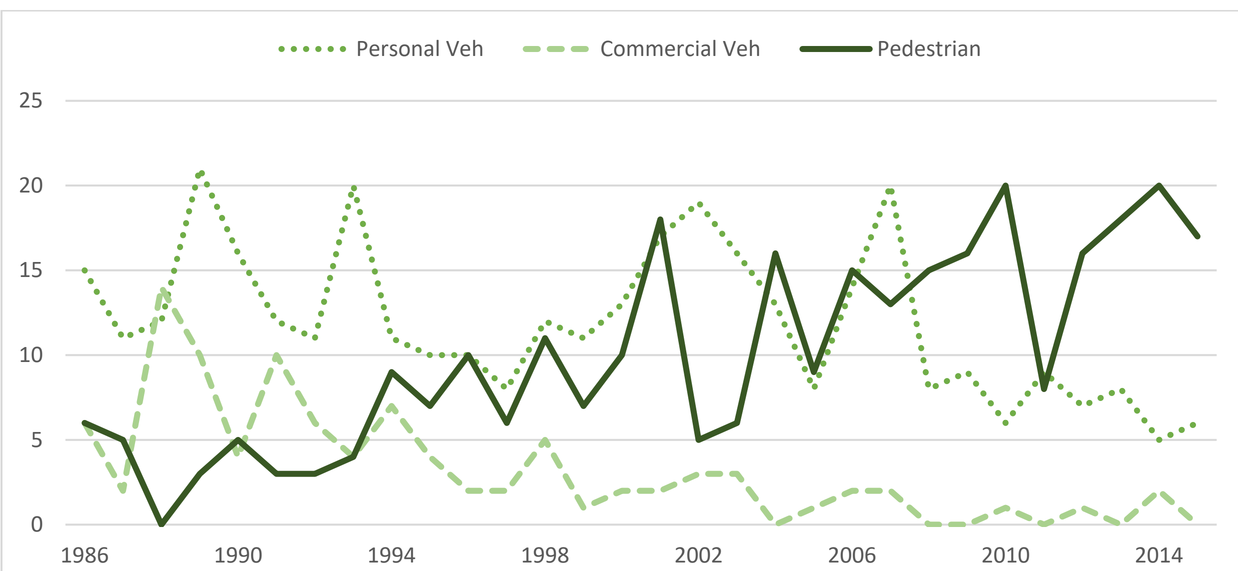

Figure 25. Fatal Crossing Incidents in California, 1986 – 2015

California has largely eradicated fatal incidents involving commercial/heavy trucks and busses at crossings. Fatal incidents involving motor vehicles are also on the decline. The four lowest years, in terms of fatal vehicle incidents, all occurred between 2010 and 2015. Fatal crossing incidents involving pedestrians, on the other hand, have been increasing across the study timeframe. In 7 of the past 8 years, pedestrian fatalities have outnumbered all vehicle related fatalities at crossings in California.

Despite the fact that most pedestrian crossing fatalities appear to be concentrated in a small number of states, this limited geographic trend is still noticeable at a national scale. This indicates that pedestrian casualties are an issue that is worth consideration – perhaps focusing first on these few states where pedestrian incidents are most problematic. The knowledge gained from efforts in these states can then be used to ensure that other states can combat such issues proactively. The next portion of this report will further explore all types of incidents (including pedestrian and vehicle casualties) using more sophisticated statistical methodologies that investigate the relationship between the evolution of the crossing inventory and the incidents themselves.

4. Analysis of Crossing Incident History and Crossing Inventory

A remaining question is if the changes in crossing type may explain why some incident types declined and others increased. As discussed in 2.2., Crossing Warning Type, and 2.3, State Differences, crossing types vary strongly both across states and within a given state over time. As discussed in 3.3, Overview by State, trajectories in incident rates also vary across state. Therefore, the number of crossing incidents in a given state occurring in a given year may be a function of the state's crossing inventory for that year, it may be a function of the otherwise unexplained factors causing the observed decrease in incidents over time, or it may be a function of other unidentified state or national level variables. Due to the nested nature of the data, the research team developed a hierarchical linear model (HLM) to look at the effects of changing the crossing make-up on the number of incidents of each type.

4.1 Method

Raw data took the form of reports for each incident and details on the characteristics of each crossing in the crossing inventory. This data was aggregated up to the level of years within states. Data for Hawaii, Rhode Island, and the District of Columbia was excluded from the analysis; these states had too little crossing data to model. The time span covered by the data ran from 1986 to 2014; AADT was not available for 2015. Final sample size was 1,392 yearly incident totals by state, nested in 48 states.

The outcome variable was number of incidents. Raw counts of incidents could not be modeled; researchers conducted two transformations on this data to prepare it for modeling. First, incident counts were divided by AADT as a correction factor for differing state sizes. Second, since incidents per year is a count variable, it is heavily positively skewed. Therefore, the team used a natural logarithmic transformation to normalize the data. Following this statistical transformation, the outcome variable followed an approximately normal distribution. Each of these transformation leaves the data intact, but provides an opportunity to use more advanced statistical techniques to more closely look at these trends.

The first thing the team modeled was the trend in incidents over time. Looking at the trends in the data over time, injuries, fatalities, and vehicular casualties appear to be steadily decreasing over time, while pedestrian casualties appear to be following a flat trend. Furthermore, while casualties are generally decreasing over time, the rate of reduction in casualties appears to be slowing over time, so there may also be a curvilinear trend. A curvilinear trend of this sort would indicate that the dramatic declines achieved over the past 30 years may be slowing down. When carrying out HLM where temporal trends are present in the data, Raudenbush and Bryk (2002) recommended modelling these changes over time first before fitting any other predictors to the model.

This study's modeling approach used random intercepts in order to allow for variance between states. Researchers also allowed for random slopes for time, allowing the slope of linear trend over time to vary between states; while incidents are generally decreasing over time, a glance at Figure 15 shows that it is reasonable to assume that incidents are not decreasing at the same rate across all states. Allowing slopes to randomly vary allowed the team to capture this otherwise unexplained variance in rate of change across states.

Apart from the linear trend for time, other slopes were fixed. Researchers had no a priori hypotheses that the effects of crossings would vary between states; if passive crossings are associated with a greater number of incidents, there was no reason to assume that the strength of this association should not be equally strong across states. Keeping these fixed allowed the team to create the most parsimonious model by keeping the number of parameters estimated in the model to the minimum required.

As discussed in 2.1, Method, crossing types were divided into passive, gated, and bell and light crossings. Rather than using the number of crossings, these covariates were also converted to be more directly comparable across states of different sizes. For each type of crossing, the team used the percent of crossing inventory by state by year equipped with the crossing type. Converting crossing inventory to percentages of each type resulted in an issue while analyzing the data. These percentages of these three types of crossings always add up to 100 percent; therefore, all three cannot be included as predictors in the same regression model. One will always be a linear combination of the other two variables. Therefore, it was necessary to add them each individually as predictors first and then see whether model fit was further improved by adding a second type of crossing to the model.

4.2 Results

Results for the final models for incident resulting in injury, incidents resulting in fatality, incidents resulting in vehicle user casualties (injuries plus fatalities), and incidents resulting in pedestrian casualties are summarized in Table 4.

Across all incident types there was a significant negative linear effect for change over time and (with the exception of fatal incidents) a significant positive quadratic effect. In most cases, this indicates that the number of incidents is decreasing, but has leveled off over time. (For pedestrian incidents, the interpretation is slightly different; number of incidents is relatively flat, but is increasing over time. See Figure 29 for details.)

Across most incident types, the percent of passive crossings was the only portion of the crossing inventory that remained a significant predictor of the number of incidents, after controlling for other crossing types. For pedestrian incidents, the percent of bells and lights crossings was the only portion of the crossing inventory that remained a significant predictor of the number of incidents, after controlling for other crossing types.

Table 4. Summary of Final Models for All Incident Types

	Injuries	Fatalities	Vehicle User Casualties	Pedestrian Casualties
Change Over Time				
Years (Linear Slope)	-0.10***	-0.029***	-0.092***	-0.032***
Years (Quadratic Slope)	0.0020***		0.0015***	0.0012***
Effect of Crossing Type				
% Passive	Positive***	Positive***	Positive***	
% Gated				
% Bells & Lights				Negative***

* p<0.05

** p<0.01

*** p<0.001

4.2.1 Injuries

Table 5 shows the results of the analysis of incidents resulting in injury. The model values are in terms of log incidents per AADT.

Model 1 presents the unconditional model, which partitions the variance into within state and across states portions, without yet adding any predictors. Intraclass correlation (ICC) was calculated based on the random effects in Table 5. (ICC is the Between State Variance (1.48) / (Between + Within State Variance (0.47 + 1.48)) = 0.76.) ICC indicates the proportion of the total variance in the outcome variable that is between groups, in this case states, rather than within groups. Based on this ICC, 76 percent of variance in injury incident per AADT was between states, and the remaining 24 percent was within states over time. Meaning, 76 percent of the variability in the numbers is driven by differences between states (e.g., Texas having more injuries than Vermont, regardless of year). However, 24 percent of the variability is independent of state differences and is indicative of a change over time.

The trend in incidents resulting in injury across years was fit by both linear and quadratic terms (Model 2). Percent passive crossings and percent gated crossings were both significant predictors alone, such that injuries decreased as percent passive decreased, and as percent gated increased (Models 3 and 4, respectively). Percent of bell and light crossings was not a significant predictor of number of incidents resulting in injury (Model 5). When both passive and gated crossings were added to the same model, gated crossings were no longer a significant predictor of injuries (Model 6); it appears that the reduction in passive crossings has the greatest impact on reduction in injuries, and the significant effect of gated crossings alone occurs indirectly due to the resulting reduction in number of passive crossings. Model 3 seems to be the best-fitting model of incidents resulting in injuries; this model explained 14 percent of the variance between states and 64 percent of the variance within state over time (based on percent reduction in variance from the unconditional model).

Table 5. Results from Multilevel Analysis of Incidents Resulting in Injury

Fixed Effects	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-4.00***	-2.96***	-4.46***	-2.73***	-2.88***	-4.19***
Years (Linear)		-0.11***	-0.10***	-0.10***	-0.11***	-0.10***
Years (Quadratic)		0.0019***	0.0020***	0.0020***	0.0018***	0.0020***
% Passive			2.42***			2.07**
% Gated				-1.79***		-0.43
% Bells & Lights					-0.32	
Random Effects						
Within State Variance	0.47	0.16	0.17	0.16	0.16	0.16
Between State Variance	1.48	1.90	1.27	1.79	1.81	1.32
Linear Slope Variance		0.00033	0.00029	0.00027	0.00033	0.00028

* p<0.05
** p<0.01
*** p<0.001

Coefficients presented in Table 5 are unstandardized and only indicate significance and direction of effects. They are not scaled in such a way as to allow for easy estimation of the number of incidents resulting in injury. Therefore, Figure 26 shows the resulting model estimates translated into actual estimated counts of incidents resulting in injury. This figure is based on several assumptions. First, the model was converted to injuries per AADT to allow for comparison across states; this uses the estimated national yearly AADT to get national injury totals. Second, the inventory of passive crossings varies both across states and across time; low, medium, and high percent passive crossings were selected based on the 25th, 50th, and 75th percentiles for percent of passive crossing inventories across states and years. They correspond to states where 43 percent, 55 percent, and 67 percent of the crossings use passive protections, respectively. While the figure presents model predictions based on these sample values for percent passive crossings as if they were fixed over time, crossing inventory has in fact changed over time; this is likely one factor driving the observed reduction in the number of incidents over time.

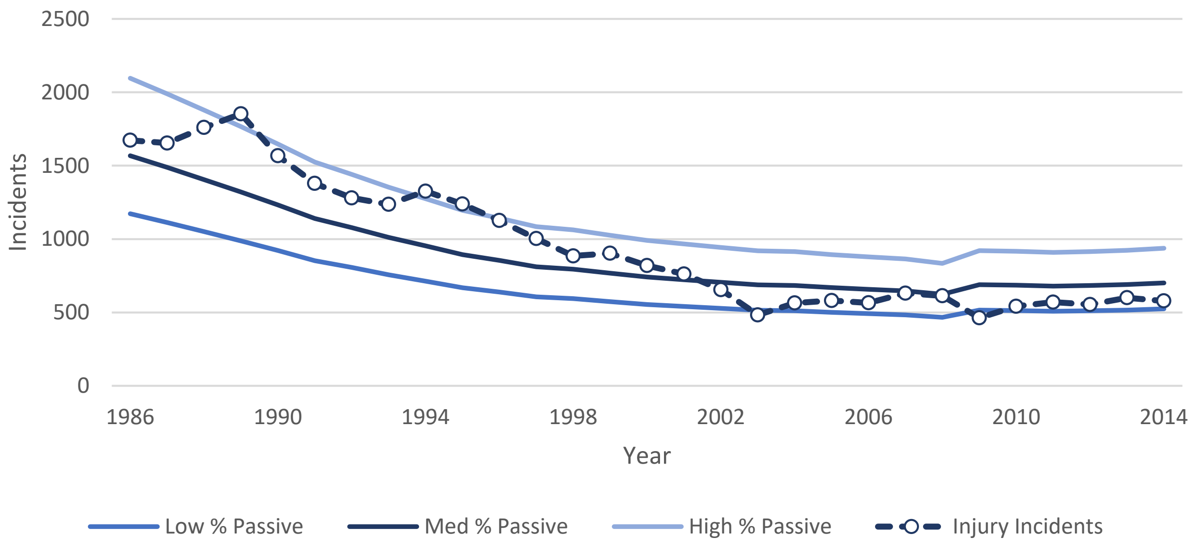

Figure 26. Estimated National Total Number of Incidents Resulting in Injury, by Year

In summary, the results from this model indicate that the best predictor of a reduction in injury-causing incidents was a reduction in the proportion of crossings which used passive warning devices. In other words, states that reduced the road users' exposure to passive crossings were associated with a reduction in incidents that resulted in injury. This proportion reduction in passive crossings is independent of any changes in the total number of passive crossings. Reducing exposure to passive crossings may have been accomplished by reducing the number of passive crossings or by increasing the number active crossings, thus reducing the proportion of crossings which were passive. Adding gates may be one method to help reduce injury-causing incidents; however, the percent of gated crossings no longer predicted injury-causing incidents after controlling for the percent of passive crossings. Thus, gating crossings only appears to improve safety if doing so reduces the relative number of passive crossings.

4.2.2 Fatalities

Table 6 shows the results of the analysis of incidents resulting in fatality. The model values are in terms of log incidents per AADT.

The unconditional model (Model 1) was created as a baseline and to compute ICC (ICC=0.72). Based on the ICC, 72 percent of variance in fatal incident per AADT was between states, and the remaining 28 percent was within state over time. The trend in fatal incidents across years was fit by a linear term (Model 2); the quadratic term was not a significant predictor. Percent passive crossings, percent gated crossings, and percent bells and lights crossings were all significant predictors alone, such that fatal incidents decreased as percent passive decreased, as percent gated increased, and as percent bells and lights increased (Models 3, 4, and 5, respectively). When both passive and gated crossings were added to the same model, gated crossings were no longer a significant predictor of fatal incidents (Model 6); similarly, when both passive and bells and lights crossings were added to the same model, bells and lights crossings were no longer a significant predictor of fatal incidents (Model 7). It appears that the reduction in passive crossings has the greatest impact on reduction in fatal incidents, and the significant effect of gated crossings and bells and lights crossings alone occurs indirectly due to the resulting reduction in number of passive crossings. Model 3 seems to be the best-fitting model of incidents resulting in fatalities; this model explained 29 percent of the variance between states and 53 percent of the variance within state over time (based on percent reduction in variance from the unconditional model).

Table 6. Results from Multilevel Analysis of Incidents Resulting in Fatality

Fixed Effects	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Intercept	-4.81***	-4.13***	-6.35***	-3.93***	-3.48***	-7.01***	-5.85***
Years (Linear)		-0.052***	-0.029***	-0.039***	-0.055***	-0.033***	-.033***
% Passive			3.54***			4.37***	3.22***
% Gated				-1.73**		1.16	
% Bells & Lights					-2.55***		-1.16
Random Effects							
Within State Variance	0.45	0.21	0.21	0.21	0.21	0.21	0.21
Between State Variance	1.13	1.47	0.80	1.42	0.98	0.71	0.71
Linear Slope Variance		0.00039	0.00029	0.00032	0.00045	0.00031	0.00031

* p<0.05
** p<0.01
*** p<0.001

Coefficients presented in Table 6 are unstandardized and only indicate significance and direction of effects. They are not scaled in such a way as to allow for easy estimation of the number of fatal incidents. Therefore, Figure 27 shows the resulting model estimates translated into actual estimated counts of fatal incidents. This figure is based on estimated national yearly AADT. Low, medium, and high percent passive crossings were selected based on the 25th, 50th, and 75th percentiles for percent of passive crossing inventories across states and years. They correspond to states where 43 percent, 55 percent, and 67 percent of the crossings use passive protections, respectively.

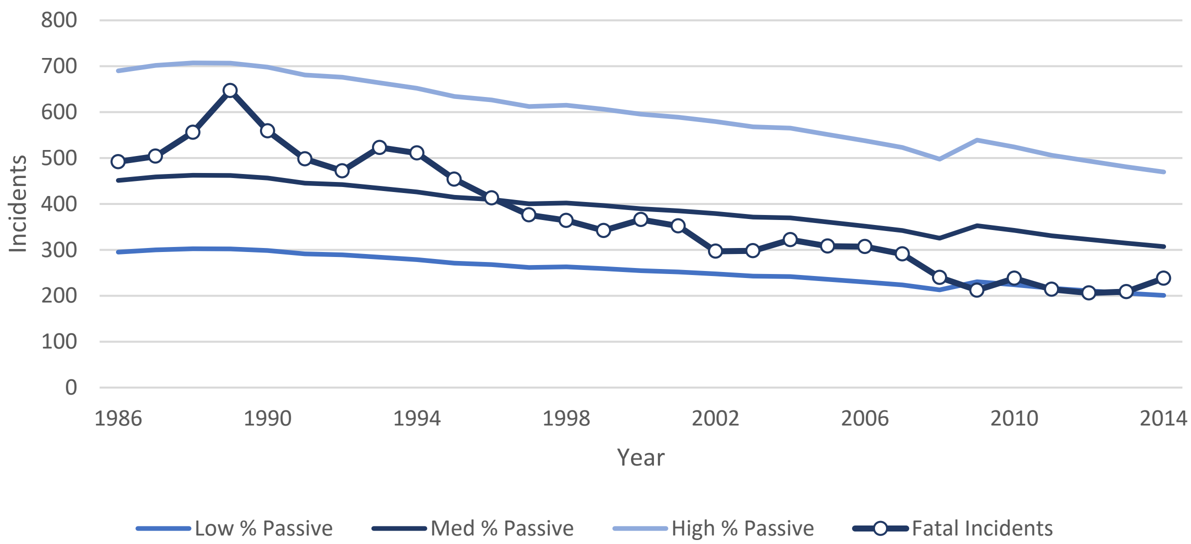

Figure 27. Estimated National Total Number of Fatal Incidents, by Year

In summary, the results from this model indicate that the best predictor of a reduction in fatal incidents was a reduction in the proportion of crossings which used passive warning devices. In other words, states that reduced the road users' exposure to passive crossings were associated with a reduction in incidents that resulted in fatality. This proportion reduction in passive crossings is independent of any changes in the total number of passive crossings. Reducing exposure to passive crossings may have been accomplished by reducing the number of passive crossings or by increasing the number active crossings, thus reducing the proportion of crossings which were passive. Adding gates or adding bells and lights may both be effective method to help reduce fatal incidents; however, neither of these types of active crossings predicted injury-causing incidents after controlling for the percent of passive crossings. Thus, gating crossings or adding bells and lights only appears to improve safety if doing so reduces the relative number of passive crossings.

4.2.3 Vehicle Occupant Casualties

Table 7 shows the results of the analysis of incidents resulting in vehicle occupant casualties. The model values are in terms of log incidents per AADT.

The unconditional model (Model 1) was created as a baseline and to compute ICC (ICC=0.78). Based on the ICC, 78 percent of variance in vehicle incident per AADT was between states, and the remaining 22 percent was within state over time. The trend in vehicle incidents across years was fit by both linear and quadratic terms (Model 2). Percent passive crossings and percent gated crossings were both significant predictors alone, such that vehicle incidents decreased as percent passive decreased, and as percent gated increased (Models 3 and 4, respectively). Percent of bell and light crossings was not a significant predictor of number of vehicle incidents (Model 5). When both passive and gated crossings were added to the same model, gated crossings were no longer a significant predictor of vehicle incidents (Model 6); it appears that the reduction in passive crossings has the greatest impact on reduction in vehicle incidents, and the significant effect of gated crossings alone occurs indirectly due to the resulting reduction in number of passive crossings. Model 3 seems to be the best-fitting model of vehicle incidents; this model explained 18 percent of the variance between states and 70 percent of the variance within state over time (based on percent reduction in variance from the unconditional model).

Table 7. Results from Multilevel Analysis of Incidents Resulting in Vehicle Occupant Casualties

Fixed Effects	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-3.79***	-2.73***	-4.11***	-2.55***	-2.60***	-4.05***
Years (Linear)		-0.10***	-0.092***	-0.097***	-0.10***	-0.092***
Years (Quadratic)		0.0014***	0.0015***	0.0016***	0.0014***	0.0015***
% Passive			2.20***			2.13**
% Gated				-1.45**		-0.093
% Bells & Lights					-0.52	

Random Effects	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Within State Variance	0.47	0.14	0.14	0.14	0.14	0.14
Between State Variance	1.71	2.02	1.41	1.95	1.88	1.43
Linear Slope Variance		0.00030	0.00026	0.00025	0.00031	0.00026

* $p<0.05$

** $p<0.01$

*** $p<0.001$

Coefficients presented in Table 7 are unstandardized and only indicate significance and direction of effects. They are not scaled in such a way as to allow for easy estimation of the number of vehicle incidents. Therefore, Figure 28 shows the resulting model estimates translated into actual estimated counts of vehicle incidents. This figure is based on estimated national yearly AADT. Low, medium, and high percent passive crossings were selected based on the 25th, 50th, and 75th percentiles for percent of passive crossing inventories across states and years. They correspond to states where 43 percent, 55 percent, and 67 percent of the crossings use passive protections, respectively.

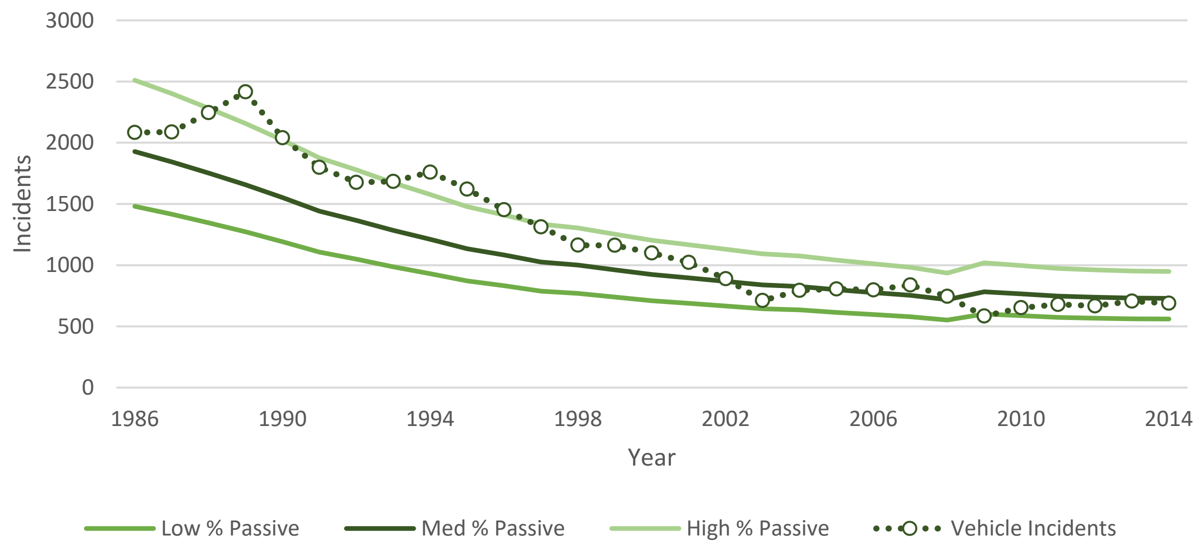

Figure 28. Estimated National Total Number of Vehicle Incidents, by Year

Unsurprisingly, the results for vehicle casualties are similar to the results described earlier for injury-causing incidents; injury-causing incidents involving vehicle users make up the majority of all injury-causing incidents and the majority of all vehicle related casualties. In summary, the results from this model indicate that the best predictor of a reduction in vehicle incidents was a reduction in the proportion of crossings which used passive warning devices. In other words, states that reduced the drivers' exposure to passive crossings were associated with a reduction in vehicle incidents that resulted in injury or fatality. This proportion reduction in passive crossings is independent of any changes in the total number of passive crossings. Reducing exposure to passive crossings may have been accomplished by reducing the number of passive crossings or by increasing the number active crossings, thus reducing the proportion of crossings which were passive. Adding gates may be one method to help reduce vehicle incidents; however, the percent of gated crossings no longer predicted vehicle incidents after controlling for the percent of passive crossings. Thus, gating crossings only appears to improve safety if doing so reduces the relative number of passive crossings.

4.2.4 Pedestrian Casualties

Table 8 shows the results of the analysis of crossing incidents resulting in pedestrian casualties. The model values are in terms of log incidents per AADT.

The unconditional model (Model 1) was created as a baseline and to compute ICC (ICC=0.61). Based on the ICC, 61 percent of variance in pedestrian incident per AADT was between states, and the remaining 39 percent was within state over time. The trend in pedestrian incidents across years was fit by both linear and quadratic terms (Model 2). Percent passive crossings and percent bells and lights crossings were both significant predictors alone, such that pedestrian incidents decreased as percent passive decreased, and as percent bells and lights increased (Models 3 and 5, respectively). Percent of gated crossings was not a significant predictor of number of pedestrian incidents (Model 4). When both passive and bells and lights crossings were added to the same model, passive crossings were no longer a significant predictor of pedestrian incidents (Model 6); it appears that an increase in bells and lights crossings has the greatest impact on reduction in pedestrian incidents, and the significant effect of passive crossings alone occurs indirectly due to the resulting shift to other types of crossing protection. Model 5 seems to be the best-fitting model of pedestrian incidents; this model explained 38 percent of the variance between states and 15 percent of the variance within state over time (based on percent reduction in variance from the unconditional model).

Table 8. Results from Multilevel Analysis of Incidents Resulting in Pedestrian Casualties

Fixed Effects	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-5.77***	-5.48***	-6.56***	-5.41***	-4.93***	-5.81***
Years (Linear)		-0.041***	-0.032***	-0.039***	-0.040***	-0.035***
Years (Quadratic)		0.0011***	0.0012***	0.0011***	0.00093**	0.0010***
% Passive			1.71***			1.06
% Gated				-0.59		
% Bells & Lights					-2.26***	-1.39*
Random Effects						
Within State Variance	0.27	0.23	0.23	0.23	0.23	0.23
Between State Variance	0.42	0.43	0.29	0.42	0.26	0.26
Linear Slope Variance		0.00032	0.00029	0.00031	0.00034	0.00030

* $p<0.05$
** $p<0.01$
*** $p<0.001$

Coefficients presented in Table 8 are unstandardized and only indicate significance and direction of effects. They are not scaled in such a way as to allow for easy estimation of the number of pedestrian incidents. Therefore, Figure 29 shows the resulting model estimates translated into actual estimated counts of pedestrian incidents. This figure is based on estimated national yearly AADT. Low, medium, and high percent bells and lights crossings were selected based on the 25th, 50th, and 75th percentiles for percent of bells and lights crossing inventories across states and years. They correspond to states where 14 percent, 20 percent, and 30 percent of the crossings use bells and lights, respectively.

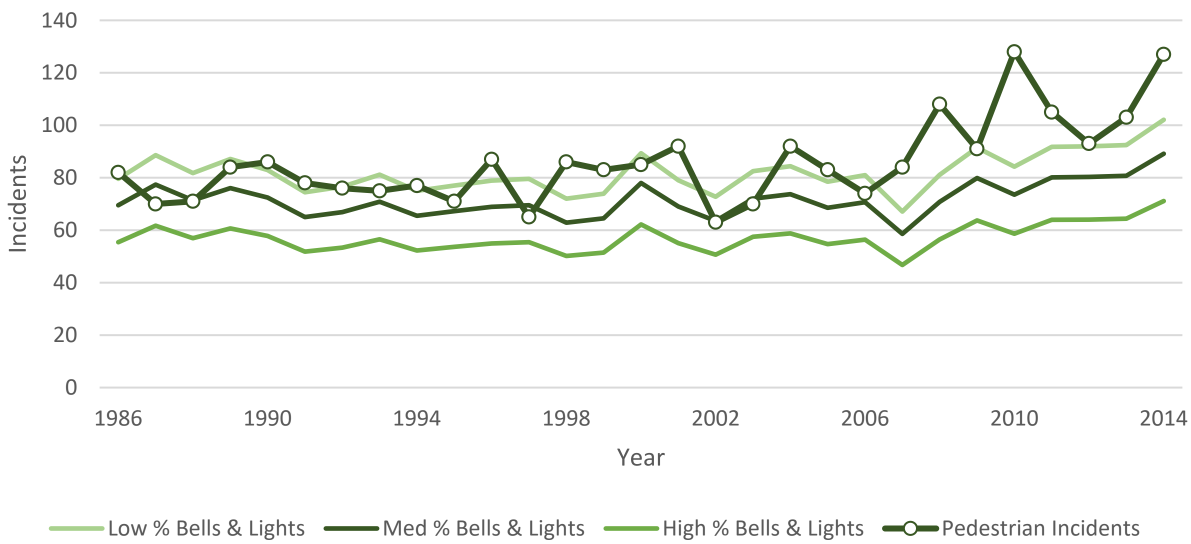

Figure 29. Estimated National Total Number of Pedestrian Incidents, by Year

In summary, the results from this model indicate that the best predictor of a reduction in pedestrian casualties was an increase in the proportion of crossings which were equipped with active warning devices. In other words, states that increased the proportion of crossings that had bells/lights (or other non-gated active protections) were likely to reduce pedestrian incidents more than others. This proportion increase in bells/lights crossings is independent of any changes in the total number of bells/lights crossings. Increasing exposure to bells/lights crossings may have been accomplished by reducing the number of passive crossings or by reducing the number gated crossings, thus increasing the proportion of crossings which were equipped with non-gated active protections. Also interesting in this model is that increasing the proportion of crossings which were gated failed to explain any reduction in pedestrian casualties. One of the first things people think about when considering how to improve grade crossing safety is to add gates to non-gated crossings, but this analysis tells us that this is not likely to have any effect on pedestrian incidents.

5. Conclusion and Discussion

This report helps explain how incidents at highway-rail grade crossings have changed over the past 30 years. Both the crossing inventory and the incidents that are occurring at those crossings have changed drastically during this time span. In almost every possible way, these changes have been for the better. Overall, incidents that resulted in fatalities, injuries, and other reportable damages are all at least 60 percent lower than in the 1980s. Additionally, the inventory of public crossings in the country has shifted toward fewer crossings total and more protected crossings. Specifically, the total number of open, public, at-grade highway-rail crossings went from 193,357 in 1986 down to 130,091 in 2015. As the number of crossings decreased, the total number of gated crossings increased, initially accounting for 34 percent of all crossing in the U.S. in 1986 and in 2015 accounting for over 54 percent. These shifts toward fewer overall and more protected crossings all help improve safety.

The one area which seems to have been resistant to these shifts toward a safer railroad system are incidents involving pedestrians at crossings. Incidents involving pedestrians most often result in fatality, unlike vehicular incidents in which a fatality is the least likely outcomes (behind non-casualty and injury incidents). These pedestrian fatal incidents have, on average, increased by 0.73 fatal incidents per year since 1986. The analyses conducted for this report indicate that given current trends in AADT, fatal pedestrian incidents will surpass fatal vehicular incidents at crossings within the next few years.

The hierarchical linear models that were conducted sought to understand if the changes in the crossing inventory in each state could be used as predictors of the changes in incidents per AADT. Two interesting findings emerged: First, for incidents that result in injury or fatality (and for vehicle injuries/fatalities) the best predictor of a drop in incidents was a reduction in the proportion of crossings which were passive. So, while it may seem that adding gates to crossings has the biggest effect on improving safety, it may actually be the removal of a passing crossing which was most effective. Second, for pedestrian casualties the biggest predictor of a drop in pedestrian incidents was increasing the proportion of crossings with bells/lights. Additionally, increasing the proportion of crossings with gates did not significantly predict a change in pedestrian casualties.

In summary, while crossing safety has improved to a large extent over the past 30 years, it seems that pedestrian safety has been suppressed. The strategies that are most effective at reducing vehicular incidents may not be effective at reducing pedestrian incidents. It may be valuable for rail carriers and the FRA to further explore these incidents in greater detail in order to determine what strategies are likely to be more effective at reducing pedestrian incidents. Given that pedestrian fatalities may overtake vehicular in the coming years, prioritizing this may be an important way to continue to see declines in fatal incidents at crossings.

6. Limitations

All of the data presented in this document were taken from the FRA Office of Safety Analysis website (http://safetydata.fra.dot.gov). This data is subject to change at any time, so the data downloaded on a later date may not perfectly match those from when this report was initially analyzed.

While the data captured in the Current Inventory and Crossing History files represent an accurate reflection of what was reported to the FRA by rail carriers, they may not perfectly represent the true inventory at a given time. The most significant reason for this uncertainty is that prior to January 6, 2015, it was not mandated by federal law that railroads provide updated information about the crossings through which they operate. In fact, in the Federal Register Notice which made this reporting a law, the authors claim that the "FRA estimates the Crossing Inventory contains up-to-date information for approximately 50 percent of the highway-rail crossings reported" (49 CFR Part 234).

While the accuracy of the historic information in the FRA database may be questionable, it is still the best estimate of the historic annual inventory of crossings in the U.S. The concerns over the accuracy of these records was part of the reason why the authors of this report selected to look at overall, long-term trends rather than specific year-to-year effects. For example, if the inventory of crossings changes drastically from one year to the next within a given state, it remains unclear if that change was due to an actual change in the inventory that year or if many old records were updated that year (e.g., perhaps by a new reporting officer of a rail carrier getting around to a needed update in that state). While the year-to-year trends may not reflect true inventory changes from that year, they likely *do* represent a more accurate representation of the crossing inventory at that time. Therefore, these updates through history are important and likely do represent at least an approximation of the change in the crossings over time.

The analyses conducted in this paper were done at the state or national level. It was outside the scope of the current analyses to take into account the unique characteristics of each crossing, or even of certain types of crossings, that may drive incident rates. For example, these analyses did not control for factors such as population density surrounding certain types of crossings or of the vehicle traffic through certain crossings. These types of factors may help to explain why, for example, gating crossings doesn't necessarily correlate with reductions in pedestrian fatalities. Pedestrian fatalities may occur more in densely populated areas where crossings already tend to be gated with more consistency. That does not mean that gating crossings is ineffective; rather, the practice of gating crossings isn't going to work on those populations simply because the crossings in question are already gated. A more comprehensive analysis that accounts for the specifics of the areas surrounding each crossing may provide a more compelling answer to these questions.

This report purposefully excludes incidents deemed to be suicides by a proper authority. The reason for excluding these incidents is that they were not collected prior to June 2011, thus making long-term trends impossible to gather and making the overall number of incidents inflate artificially in June 2011 (these incidents did occur prior to June 2011 – they were just not reported). Additionally, these incidents, which are important to understand, may require unique approaches to mitigating future incidents. Still, if suicide incidents at crossings were considered in this report, there would be an additional 45 fatal incidents at crossings per year. Of these suicide incidents, over 70 percent of them involved pedestrians, thus making the pedestrian issue highlighted in this report even more substantial.

This report is not intended to identify the specific causes behind trends in crossing incidents over items; it is intended to identify and describe these trends. There are a wide range of factors which likely contributed to these safety improvements, including things like the Section 130 funding program, increased enforcement for impaired driving, and improved crossing safety enhancements. While identifying the cause of the safety improvements at crossings is incredibly valuable, it was not the intent of this report.

Lastly, the historic inventory of crossing data is an incredibly rich – but also complex – dataset. Over time, the definitions of variables in this dataset have been modified and/or updated, and understanding how to account for these modifications is vital to painting the most accurate picture of the inventory as possible. As time passes, further modifications may be made to the understanding of how to interpret the inventory data. Given this, it will be important to remember that the conclusions drawn in this report reflect the understanding of the data as described above.

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Abbreviations and Acronyms

Abbreviation or Acronym	Name
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
AADT	Average Annual Daily Traffic
HLM	Hierarchical Linear Model
ICC	Intraclass Correlation