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Transportation

**Federal Railroad
Administration**

In-Depth Data Analysis of Grade Crossing Accidents Resulting in Injuries and Fatalities

Office of Research,
Development
and Technology
Washington, DC 20590

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Final Report
May 2017

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Grade crossing accidents represent a significant proportion of railroad-related fatalities and injuries. FRA is committed to improving public safety by decreasing the number of grade crossing accidents. In this project, the FRA grade crossing incident and crossing inventory databases were analyzed to identify the factors that contribute to highway-rail grade crossing accidents. Descriptive statistics, trend and frequency analyses, and correlational analysis of variables were calculated. Time series decomposition, driver demographic analysis, and analysis of temporal and environmental effects were also performed as part of this research.

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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)

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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)

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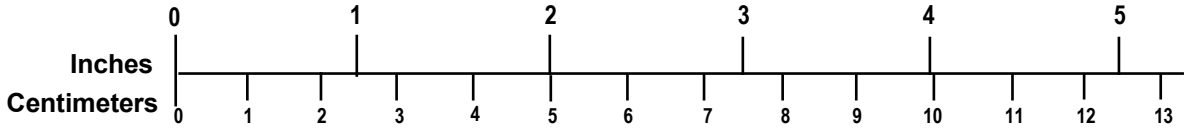

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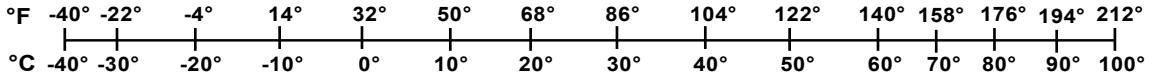

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Executive Summary

This project was aimed at better understanding the mechanisms that cause highway-rail grade crossing accidents. This project's research team queried the accident database of the Federal Railroad Administration (FRA) to gather data on potential factors associated with grade crossing accidents (e.g., driver demographics, motorist actions over crossings, and weather conditions) from 2005-2014.

A time series decomposition analysis was performed to transform monthly accident data into a product of its average value, its linear trend, its cyclical trend, its seasonal trend, and a random factor. This type of analysis helps to summarize a complex system by using a combination of simpler parts.

Additional data from the Federal Highway Administration, U.S. Census Bureau, Insurance Institute for Highway Safety, U.S. Department of Transportation, and the Association of American Railroads (AAR) were also used, where necessary, to support claims.

The results of the in-depth data analysis provided the following insights into grade crossing accidents:

1. Rail and highway traffic volumes have the largest influence on accidents.
2. Train speed has a significant effect on the injury and fatality rate of vehicle drivers.
3. Higher volume of main tracks and highway lanes lead to more accidents.
4. Having a highway intersection near a grade crossing nearly doubles the risk for accidents.
5. Having a crossing angle less than 30 degrees with respect to the tracks increases the accident risk by nearly 50 percent.
6. Active warning devices are more effective deterrents than passive warning devices.
7. Male drivers are involved in nearly 75 percent of all grade crossing accidents.
8. Even after normalizing by miles driven, males have a higher rate of accidents.
9. Fifteen-nine percent of drivers in grade crossing accidents are 20-49 years old.
10. The rate of accidents per capita is negatively correlated with the affluence of an area.
11. The months with the highest accident rates are December, January, and February.
12. Fifty-two percent of accidents occur in the 9-hour window between 9am and 6pm.
13. Weekend days, especially Sundays, have notably fewer accidents than weekdays.
14. Weekends have a larger accident percentage occur from 12 am-6am relative to weekdays.
15. The average age of drivers in accidents decreases late at night and in the early mornings.
16. Female drivers are involved in relatively more accidents after 5pm and also on Sundays.
17. Night driving is associated with more grade crossing accidents per traffic volume.
18. Driving into a rising or setting sun is associated with higher accident numbers.

1. Introduction

Highway-rail grade crossing accidents are costly as well as a significant cause of physical harm to motorists. From 2010 to 2014, an average of nearly 2,100 accidents per year have taken place at such crossings in the United States, and most of them involved collisions between a train and a motor vehicle. Over the same period of time, more than 250 people were killed in those collisions each year. The Federal Railroad Administration (FRA) maintains a database of these incidents in order to better understand the factors that contribute to them. This database can be queried by various characteristics, such as vehicle type and train speed, so that a "snapshot" of each accident can be documented and analyzed.

In addition, FRA keeps an inventory database of all 211,631 (as of October 2015) highway-rail grade crossings that are in operation in the United States. Characteristics of each crossing, such as warning device type and daily train and vehicle traffic, are documented and can be used to gauge exposure to various crossing conditions.

When the team used the two databases together, they were able to examine both the degree of risk each type of crossing poses, as well as the amount of risk exposure related to each type of U.S. crossing.

Past FRA research examined motorist behavior by installing video cameras in automobiles and analyzing the drivers' actions [1]. This research adopted a data-driven approach. Specifically, this research used the FRA's accident database and crossing inventory database to calculate trends and correlations associated with highway-rail grade crossing accidents between 2005-2014.

2. Objectives and Scope

This research used FRA's accident database and crossing inventory database, data on Class I railroad operations, and data from the U.S. Census Bureau on regional populations to provide insight into probable causes of highway-rail grade crossing incidents. Information from the U.S. Department of Transportation concerning the amount of national traffic volume was also used. This research was limited to the years 2005-2014. In addition, 2015 data were used to corroborate proposed trends.

One objective was to determine why so many grade crossing collisions continue to occur, even at crossings with active warning devices (i.e., flashing lights and gates). Once the descriptive statistics were calculated, further analyses were conducted to determine the root causes of the incidents.

The team performed correlation analysis in order to understand which variables contributed to accident risk. Similarly, correlations between the variables themselves were calculated in anticipation of creating a predictive model in the near future.

3. Methodology

The first step for this research was to download the grade crossing incident database [2] and the crossing inventory database [3] from FRA's website.

The research team analyzed accident data from 2005-2014 because it was the most recent decade's worth of data available when the project began. Once the accident data from 2015 was released, it was incorporated into a trend analysis.

Since the project scope was limited to at-grade, in-service, highway-rail crossings, a filter was used to exclude crossings that are not at-grade, closed, or abandoned from the crossing inventory database.

After the database was filtered, the team developed tables and charts that contained relevant statistics. For example, the team created a table showing the number of accidents at each hour of the day to determine what time of day grade crossing accidents are most likely to happen.

By making similar graphics based on several different parameters from the accident database, the team was able to obtain a comprehensive picture of highway-rail grade crossing accidents. They were also able to develop additional research questions to explore in the analyses.

4. Results

The study's results regarding grade crossing accidents are broken down into six sections: descriptive statistics, traffic effects, driver demographics, temporal and environmental effects, grade crossing characteristics, and useful information for constructing a predictive model.

The tables and charts in this section are generated from queries of the grade crossing accident database and the grade crossing inventory database. Note that some entries in the databases contain blanks where there was no reported data; this could help to explain why the total accident count might be inconsistent between two tables. The team used the U.S. Census Bureau's population estimates [4] to calculate the number of accidents per capita. Vehicle Miles Traveled (VMT) data were obtained from the Federal Highway Administration's Traffic Volume Trends report [5]. The numbers of miles driven by gender in 2008 were taken from the Insurance Institute for Highway Safety's Fatality Facts [6].

4.1 Descriptive Statistics

This section presents descriptive statistics about grade crossing accidents.

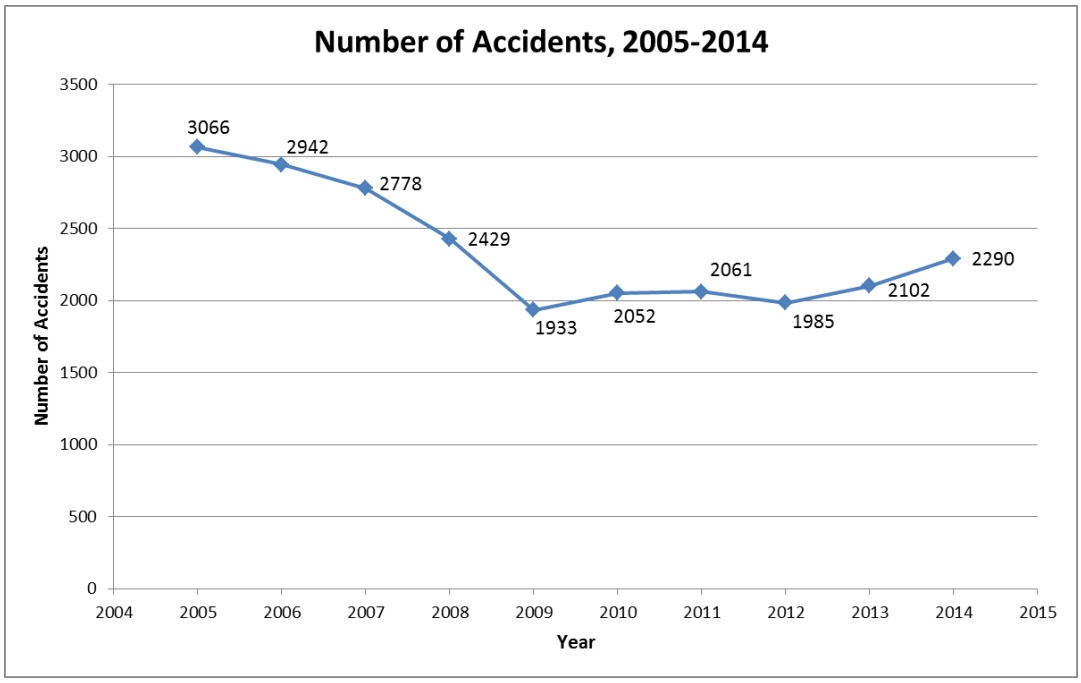

Figure 1. Number of annual grade crossing accidents, 2005-2014

Grade crossing accidents have decreased significantly since 2005 as a result of FRA's safety efforts. In 2009, the number of grade crossing accidents reached an all-time low. The jump in accidents in recent years is likely due to higher traffic volumes; during the recession (from approximately 2008 to 2012), rail and traffic volumes were down and the U.S. economy remained stagnant.

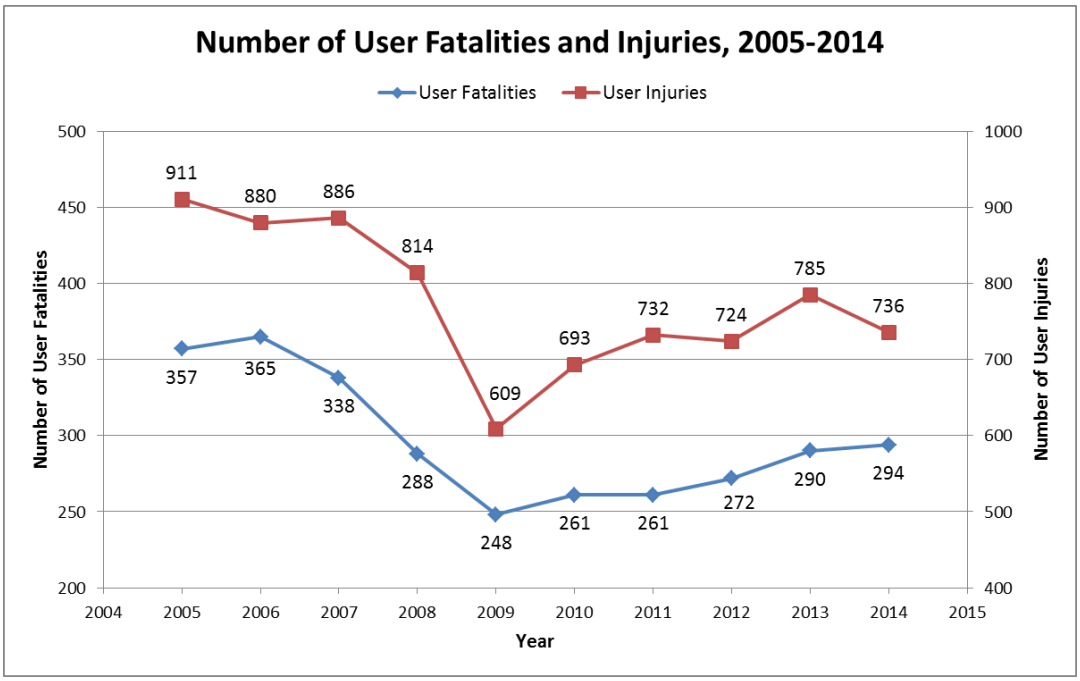

Figure 2. Number of user fatalities and injuries, 2005-2014

The number of user fatalities and injuries follows roughly the same trends as the total number of accidents. The term "user" is in the language used by the FRA accident database and refers to a user of a highway-rail grade crossing, which can be a driver, passenger, or pedestrian. Table 1 below shows the breakdown of these accidents by motor vehicle type.

Table 1. Vehicle type, 2005-2014

		Year											
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014		
Vehicle Type	Auto	1411	1298	1160	1046	879	925	960	876	972	1038	10565	45%
	Truck	237	225	203	132	109	140	144	155	171	172	1688	7%
	Truck-trailer	509	508	492	376	269	304	352	333	336	392	3871	16%
	Pick-up truck	463	494	472	423	306	308	270	265	254	279	3534	15%
	Van	144	120	131	105	72	73	54	64	58	66	887	4%
	Bus	3	6	2	4	5	4	2	3	2	1	32	0%
	School bus	1	2	1	1	1	0	0	1	0	0	7	0%
	Motorcycle	15	7	8	10	5	4	5	6	6	8	74	0%
	Other motor vehicle	129	146	161	166	138	111	93	100	95	109	1248	5%
	Pedestrian	115	102	110	130	112	144	132	133	158	163	1299	5%
	Other	39	34	38	36	37	39	49	49	50	62	433	2%
		3066	2942	2778	2429	1933	2052	2061	1985	2102	2290	23638	100%

Nearly half of grade crossing accidents involve basic automobiles. Truck-trailers are the second most common vehicles involved, with 16 percent of accidents. Pick-up trucks account for 15 percent of accidents.

Table 2 breaks down the accidents by public or private crossing.

Table 2. Percent of grade crossing accidents, public vs. private crossings, 2005-2014

	Year										
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Private Crossing	13.8%	14.4%	15.3%	14.3%	15.0%	13.7%	13.3%	14.5%	15.3%	14.1%	14.4%
Public Crossing	86.2%	85.6%	84.7%	85.7%	85.0%	86.3%	86.7%	85.5%	84.7%	85.9%	85.6%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

A large percentage of grade crossing accidents occur at public crossings, as opposed to private, often rural, crossings. Public crossings generally have higher vehicle traffic and the majority of them have active warning devices such as gates and flashing lights.

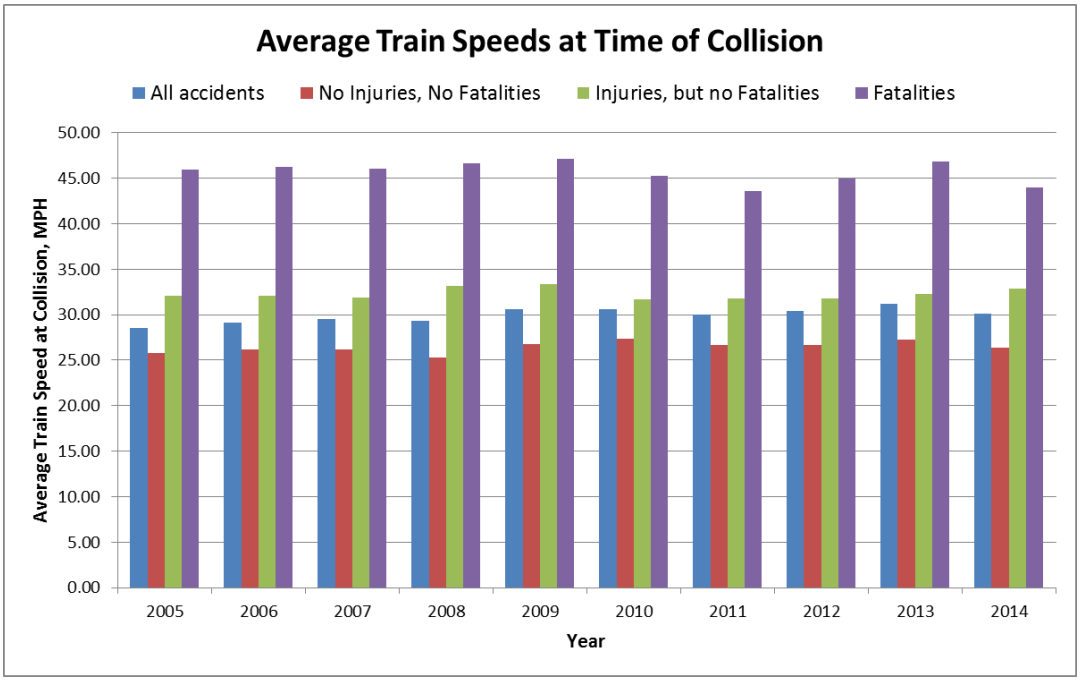

Figure 3. Average train speed at collisions and outcomes

Figure 3 above shows train speeds at the time of grade crossing collisions. It illustrates how train speed had a strong effect on whether the vehicle occupants were injured or killed. The average train speed in fatal accidents was 15-20 mph higher than in non-fatal accidents. Collision speeds have remained mostly consistent from year to year.

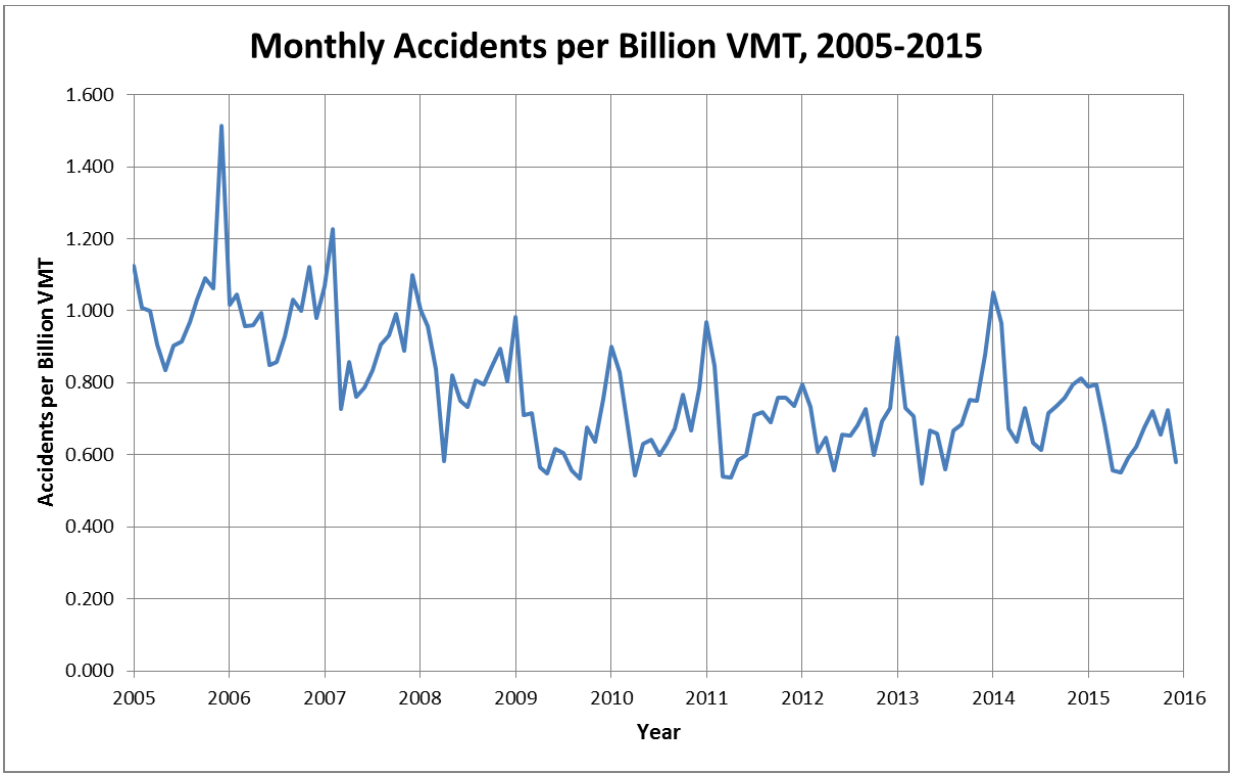

Figure 4. Monthly accidents per billion VMT, 2005-2015

Figure 4 shows monthly grade crossing accidents per billion VMT from 2005-2015. Data from 2015 was included to determine if actions taken by FRA in 2014 and early 2015 led to a decrease in 2015's accident numbers. 2059 accidents occurred in 2015, down from 2290 in 2014. Therefore, FRA's efforts seem to have been effective.

Time series decomposition analysis allows one to better understand trends in time-based data, such as the data presented above. The benefit of time series decomposition is that a complex data set can be broken into simpler components, which can be studied and understood more clearly. In essence, time series decomposition analysis is a statistical process that attempts to separate the following elements of time-based data:

- Linear trends that show long term changes, such as the drop in accident rates.
- Cyclic trends that capture medium term changes such as business cycles, economic downturns, etc.
- Seasonal trends that capture month-to-month changes in activity that are annually cyclic.
- Randomness, accounts for changes that cannot be attributed to the above three elements.

Figure 5 shows how the baseline time series data is broken into these separate elements, and how combining those data elements will result in regeneration of the original data.

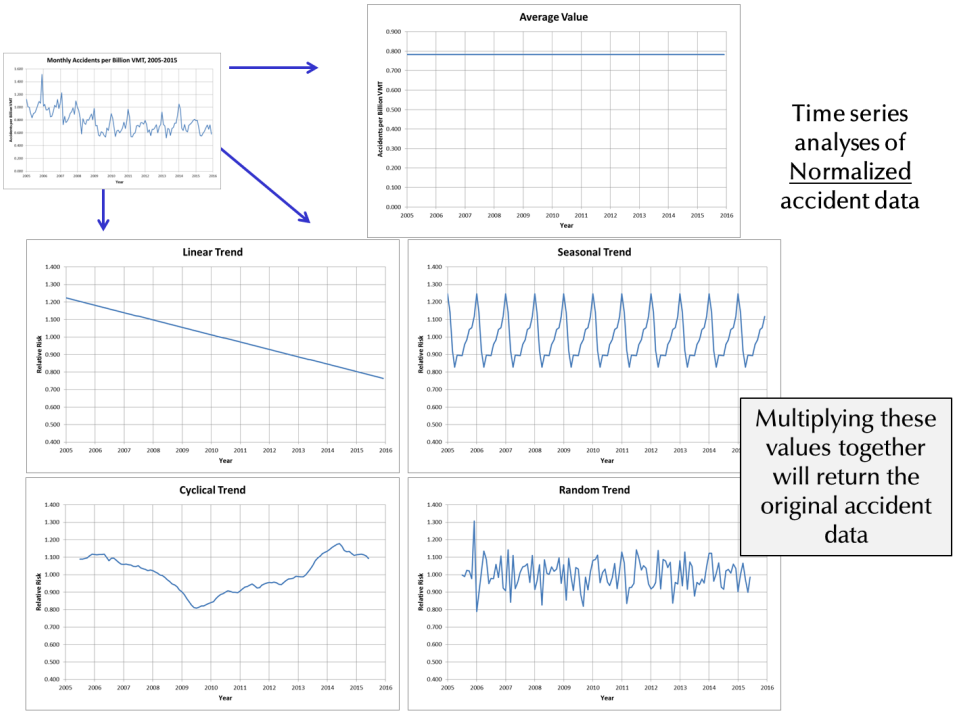

Figure 5. Graphic overview of time series decomposition

The following five charts are part of a time series decomposition analysis of . Multiplying Figure 6 through Figure 10 together will reproduce Figure 4. The term "relative risk" on the vertical axis of the graphs refers to a relative risk level of that specific month compared to the average of the months from 2005 through 2015. By multiplying the relative risk levels together, the original value can be reconstructed.

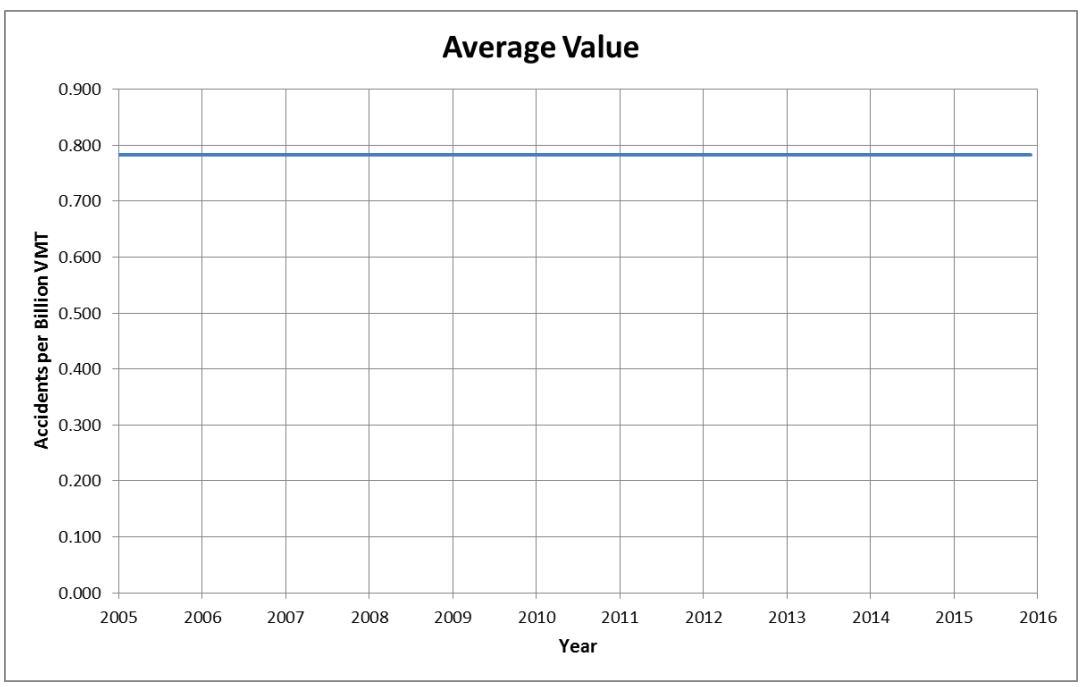

Figure 6. Time series decomposition, average value

In Figure 6, the average monthly value of accidents per billion VMT from January 2005 through December 2015 is shown.

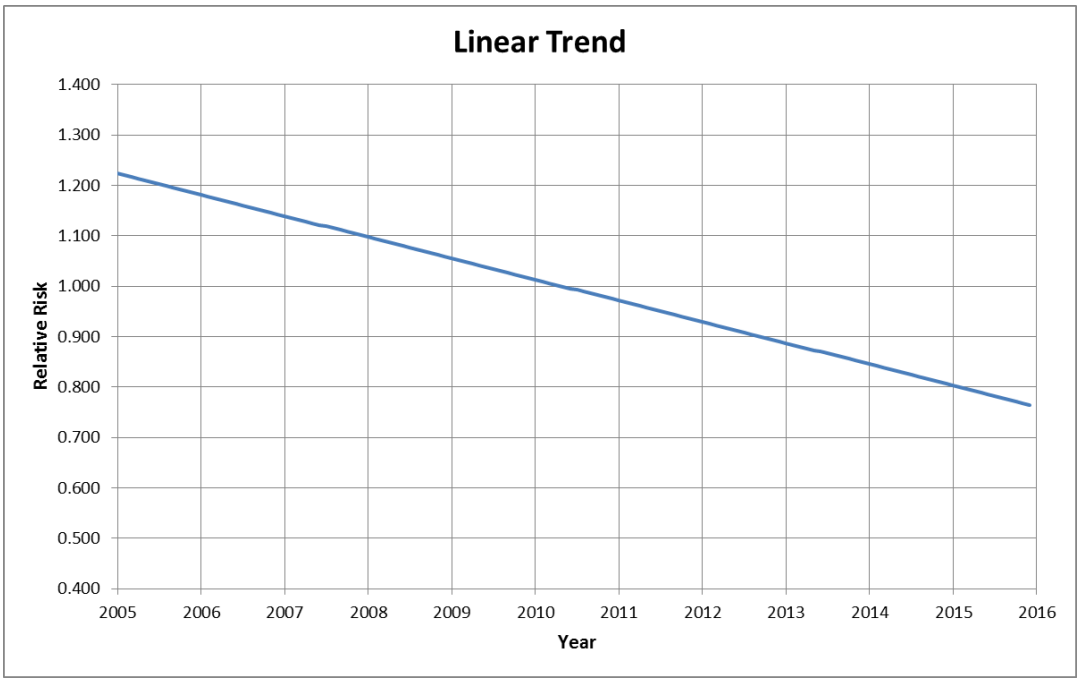

Figure 7. Time series decomposition, linear trend

The linear trend in Figure 7 is the least squares regression line for the 12-month moving average of accidents per billion VMT; it highlights long term changes in the data set. From 2005 through 2015, accidents per vehicle mile traveled generally decreased.

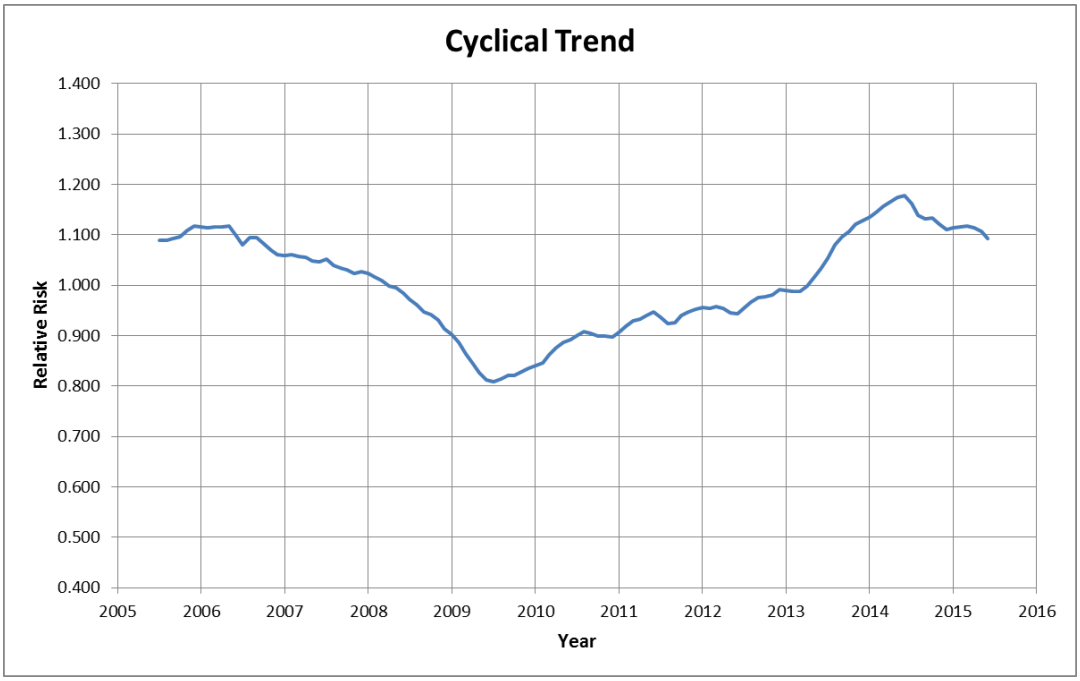

Figure 8. Time series decomposition, cyclical trend

The cyclical trend is shown in Figure 8; it highlights medium range economic effects, which are not repeated on any regular basis. For example, the recession of 2008-2010 resulted in less freight movement and relatively fewer accidents at grade crossings.

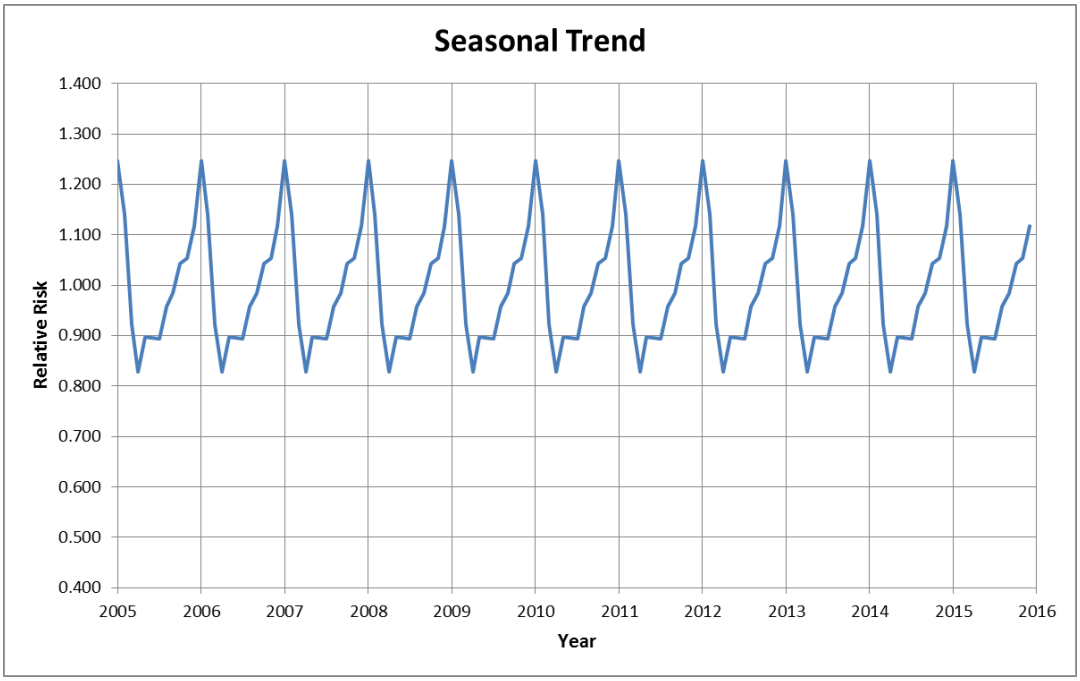

Figure 9. Time series decomposition, seasonal trend

In Figure 9, the seasonal trend shows monthly fluctuations which repeat from year to year. These could be due to weather, holidays, and other similar causes.

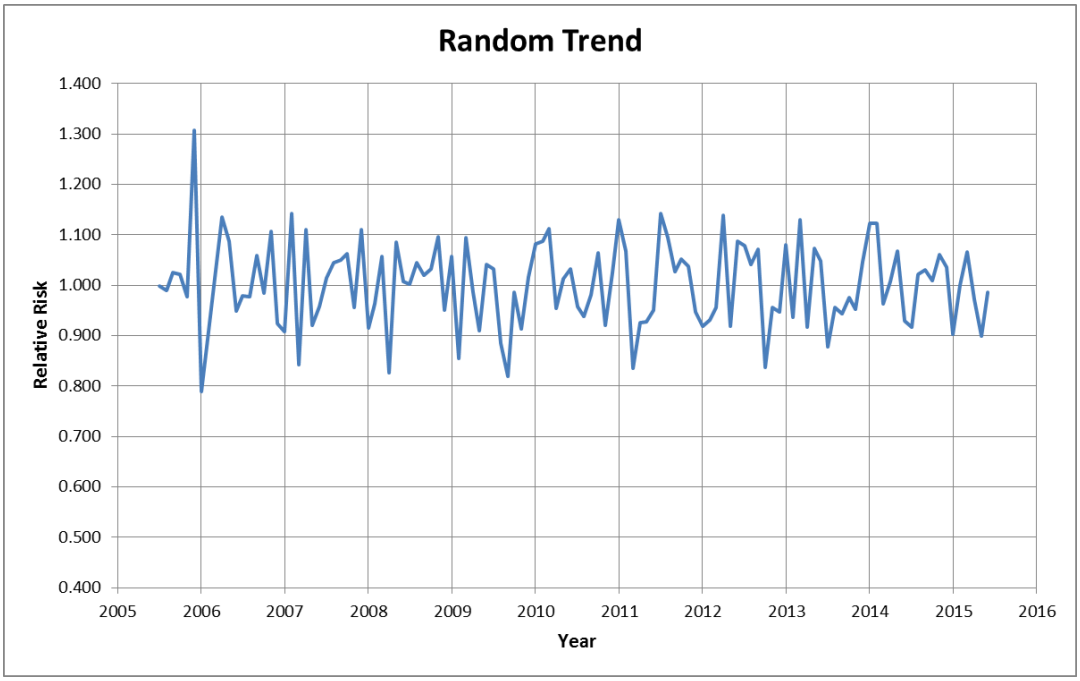

Figure 10. Time series decomposition, random trend

The random trend, Figure 10, highlights effects which cannot be explained by any of the other factors. A value around 1.000 indicates the data is explained well by the previous factors.

Figure 11 shows all grade crossing accidents from 2005 to 2014 which had sufficient latitude and longitude data to plot on a U.S. map (22,080 out of 23,638 total accidents).

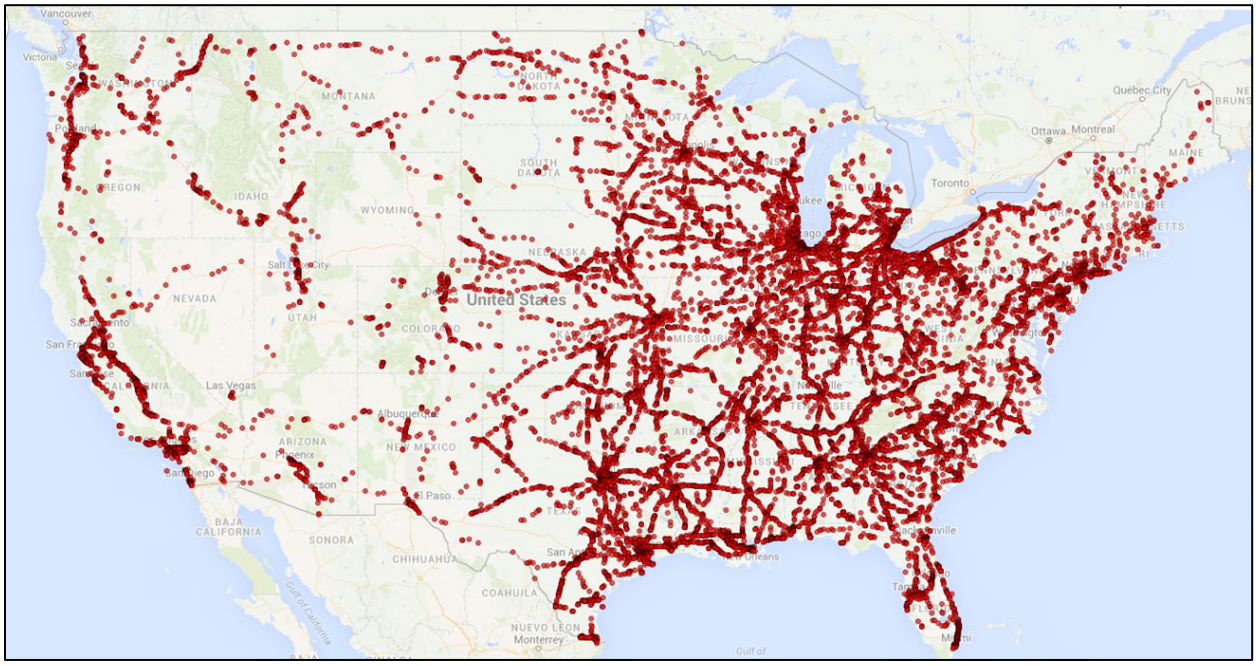

Figure 11. Grade crossing accident map, 2005-2014

4.2 Traffic Effects

The two factors most highly correlated with grade crossing accidents were rail and highway traffic volumes. Increases and decreases in the month-to-month traffic volumes significantly affect the number of grade crossing collisions. Figure 12 and Figure 13 show the monthly rail volumes and the highway traffic volumes.

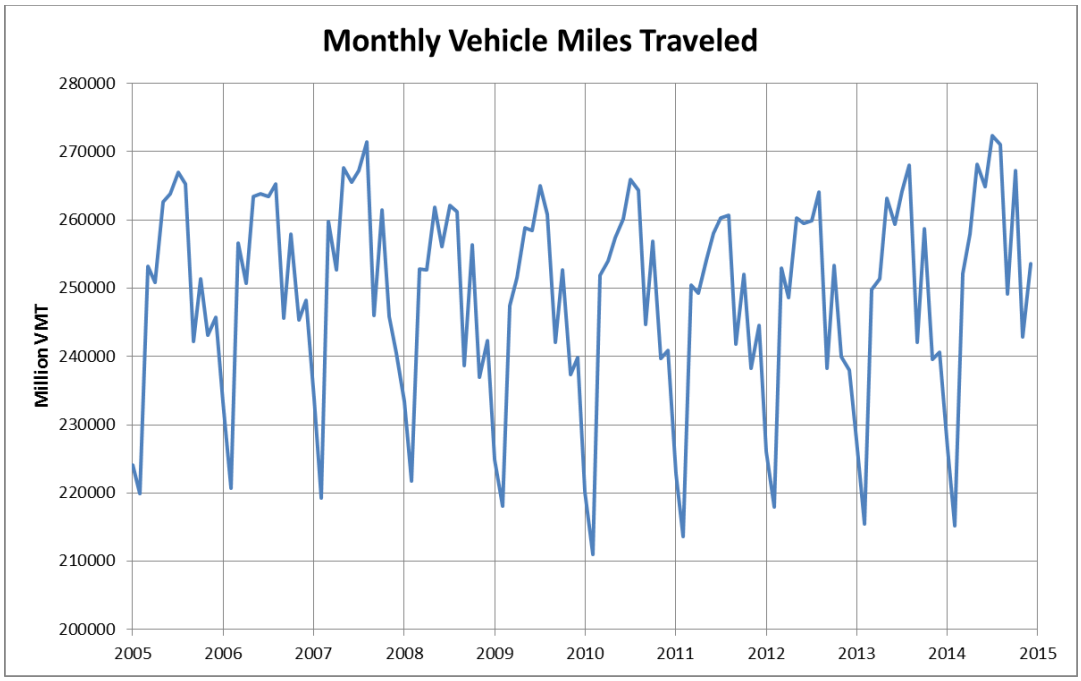

Figure 12. Monthly vehicle miles traveled, 2005-2014

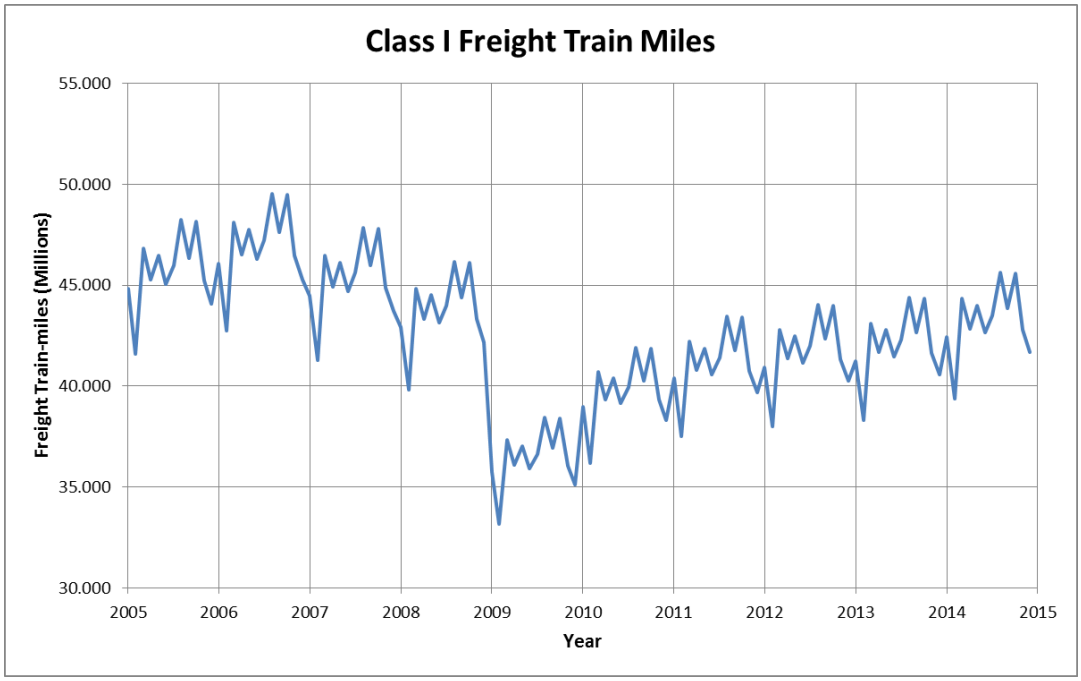

Figure 13. Monthly Class 1 freight train miles, 2005-2014

Highway traffic, shown in Figure 12 as monthly vehicle miles traveled, is highly seasonal. Traffic is relatively less in the colder months from December through February, and then increases in the warmer summer months.

Time series decomposition of monthly rail carloads [7] was performed to obtain the seasonal trend of carloads, similar to how Figure 9 shows the seasonal trend of grade crossing accidents. Afterwards, the team applied that trend to the AAR's data on yearly freight train miles [8] to

obtain the monthly freight train miles. These are only estimates since actual monthly data is not available. Rail traffic is generally more consistent than highway traffic, although August was the busiest month and February was the least busy.

The team used traffic volumes to normalize the accident data and obtain the number of accidents on a per mileage basis. For example, the State of Virginia had 42 accidents in 2014 while California had 128. However, the population of California drove over four times as many miles as Virginians did in 2014, so Californians' rate of accidents per mile driven was actually lower than the Virginians.

Rail traffic, specifically U.S. Class 1 freight train miles, was especially strongly correlated with accident numbers. In Figure 14 freight train miles are plotted against the cyclical trend of accidents obtained from time series decomposition. The cyclical trend accounts for medium-term changes in the economic environment, after monthly and linear effects were excluded.

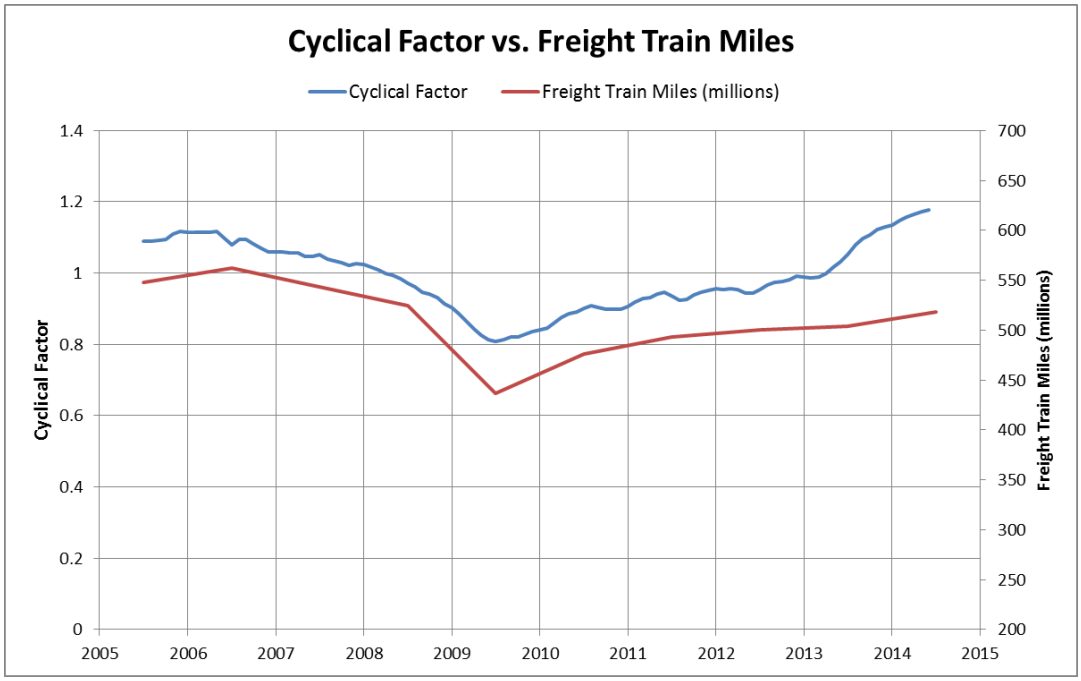

Figure 14. Cyclical trend vs. freight train miles, 2005-2014

The trend of the cyclical factor closely mirrors the shape of yearly freight train miles, indicating that freight train miles strongly influence grade crossing accident numbers.

Figure 15 shows that highway traffic, in the form of fatal auto crashes, is also strongly correlated with grade crossing accidents.

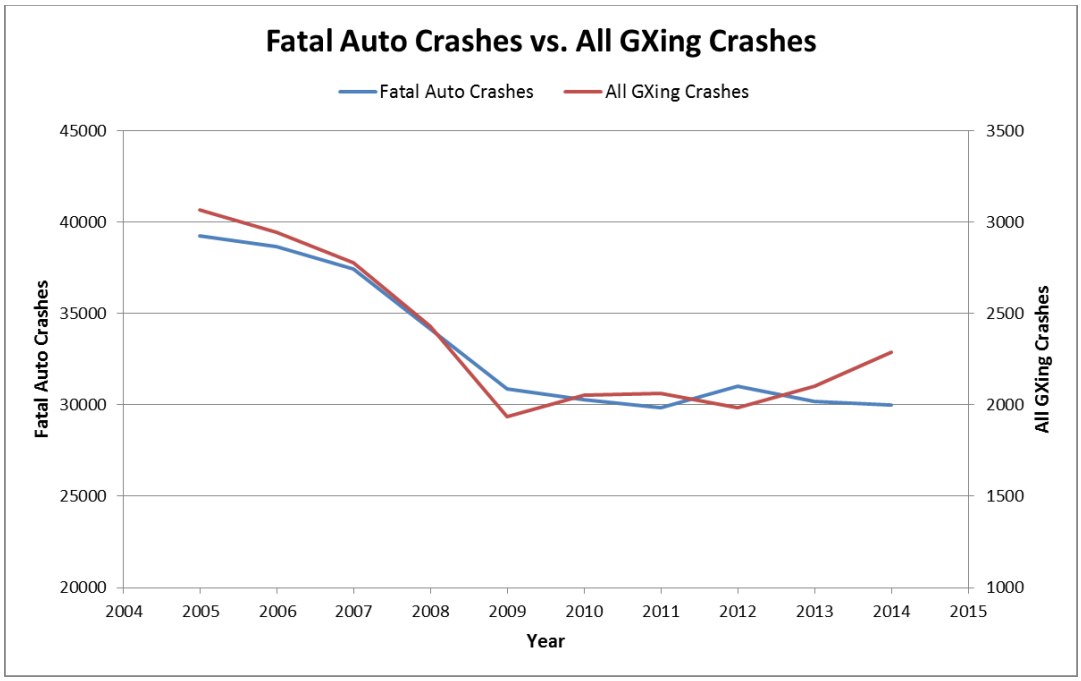

Figure 15. Fatal auto crashes vs. grade crossing accidents, 2005-2014

The number of fatal auto crashes [9] followed the frequency of grade crossing accidents; when highway traffic decreases, grade crossing accidents also tend to decrease.

Each crossing listed in FRA's grade crossing inventory database contains the number of total trains that pass the crossing each day, as well as the Average Annual Daily Traffic (AADT). AADT is the number of vehicles that go over the crossing on a daily basis.

Crossings were grouped by the number of accidents which occurred at each location between 2005 and 2014. After they were grouped, the average number of trains per day and the average number of vehicles per day for each crossing group were plotted.

Figure 16 and Figure 17 show that as traffic (i.e., trains or AADT) increases, the accident frequency per crossing also increases. Note that the last point in Figure 16 is due to small sample size (29 crossings with 6 accidents).

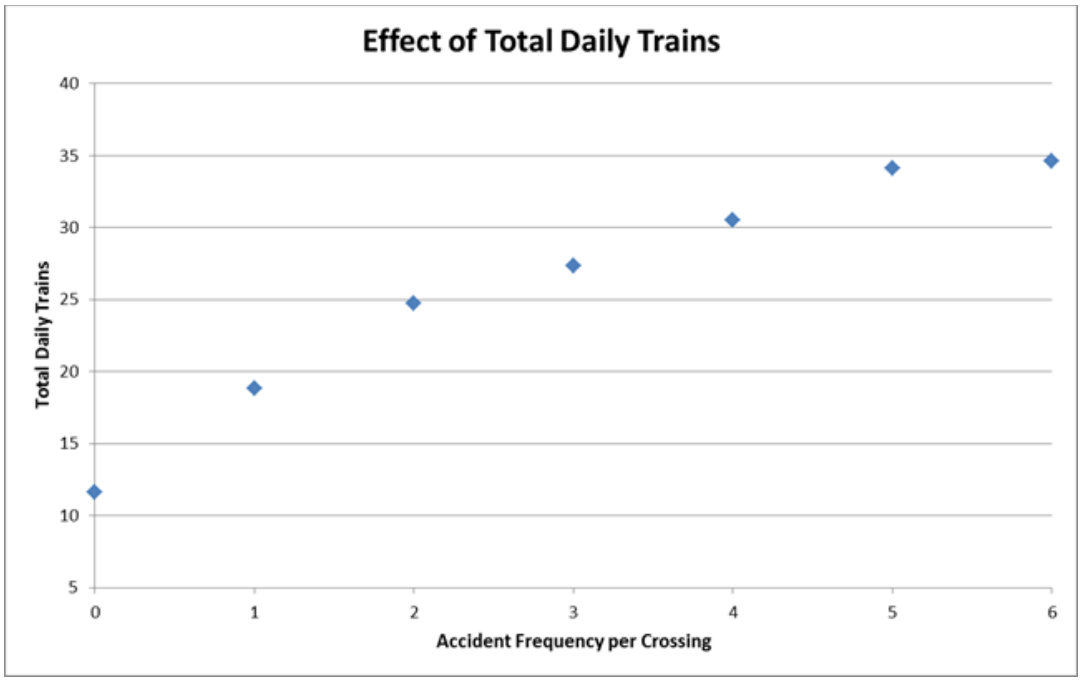

Figure 16. Effect of total daily trains on accident frequency

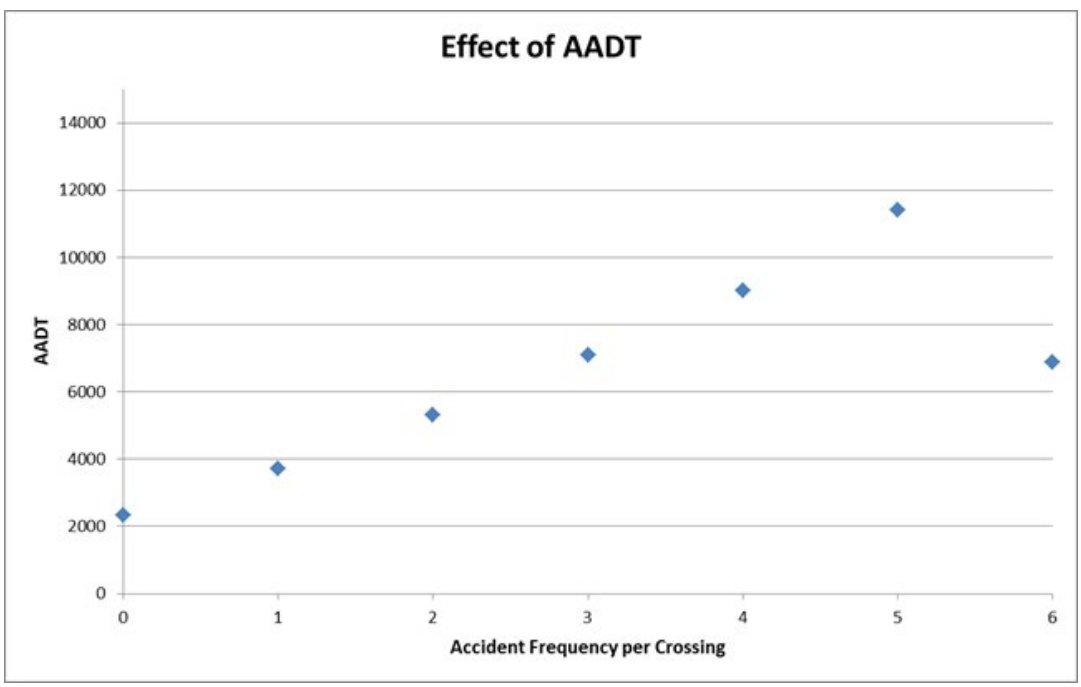

Figure 17. Effect of AADT on accident frequency

4.3 Driver Demographics

The accident database has information about the age and gender of the vehicle drivers involved in collisions. It also contains information about the number of non-driver occupants in the vehicle at the time of the collision.

Table 3. Number of grade crossing accidents by age group, 2005-2014

		Year										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Driver's Age	0-9	1	0	1	1	2	0	1	1	0	0	7
	10-19	215	184	172	150	104	129	130	122	114	129	1449
	20-29	558	525	507	449	317	333	341	344	350	383	4107
	30-39	539	498	473	416	304	331	330	308	332	342	3873
	40-49	463	509	446	380	335	319	336	317	347	348	3800
	50-59	331	342	367	328	261	314	320	335	354	374	3326
	60-69	183	180	179	143	145	158	144	173	189	228	1722
	70-79	120	129	98	100	79	92	89	93	90	96	986
	80-89	73	47	69	51	51	54	50	42	51	52	540
	90-99	5	6	6	8	5	14	11	7	7	15	84
	Unknown	578	522	460	403	330	308	309	243	268	323	3744
		3066	2942	2778	2429	1933	2052	2061	1985	2102	2290	23638

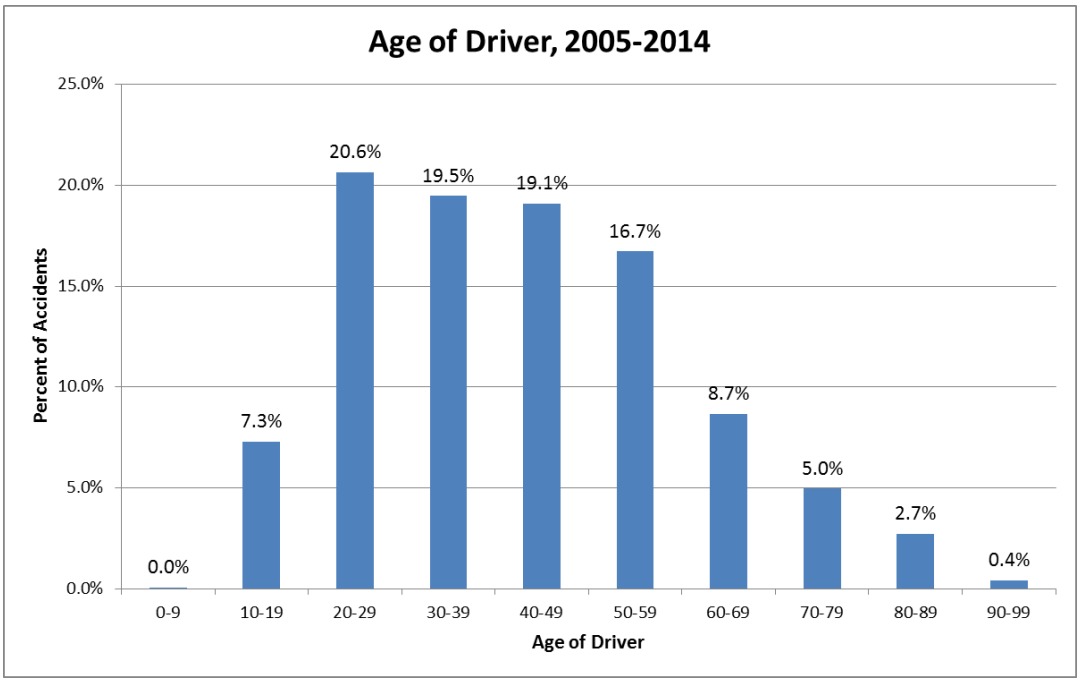

Figure 18. Percent of accidents by age group, 2005-2014

Figure 18 shows that 59 percent of grade crossing accidents involve drivers who are 20 to 49 years of age. Individuals between ages 20 and 49 also do the majority of the driving. According to the 1990 Nationwide Personal Transportation Survey, this age group accounts for over 73 percent of all miles traveled. After normalizing grade crossing accidents by miles traveled, relative age risk was calculated. Table 4 shows that very young and very old drivers are the most unsafe.

Table 4. Relative risk by driver age, 2005-2014

Driver Age	Relative Age Risk
0-19	0.6090
20-49	0.2873
50-69	0.4946
70+	1.0000

Table 5. Gender of drivers, 2005-2014

	Accidents
Male	16908
Female	5526
Unknown	1204
	23638

Table 6. Percent of grade crossing accidents by gender, 2005-2014

	Year										
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Male	73%	73%	72%	72%	70%	70%	70%	71%	71%	71%	72%
Female	22%	21%	23%	23%	24%	24%	23%	24%	25%	25%	23%
Unknown	5%	5%	5%	5%	6%	6%	7%	5%	4%	4%	5%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

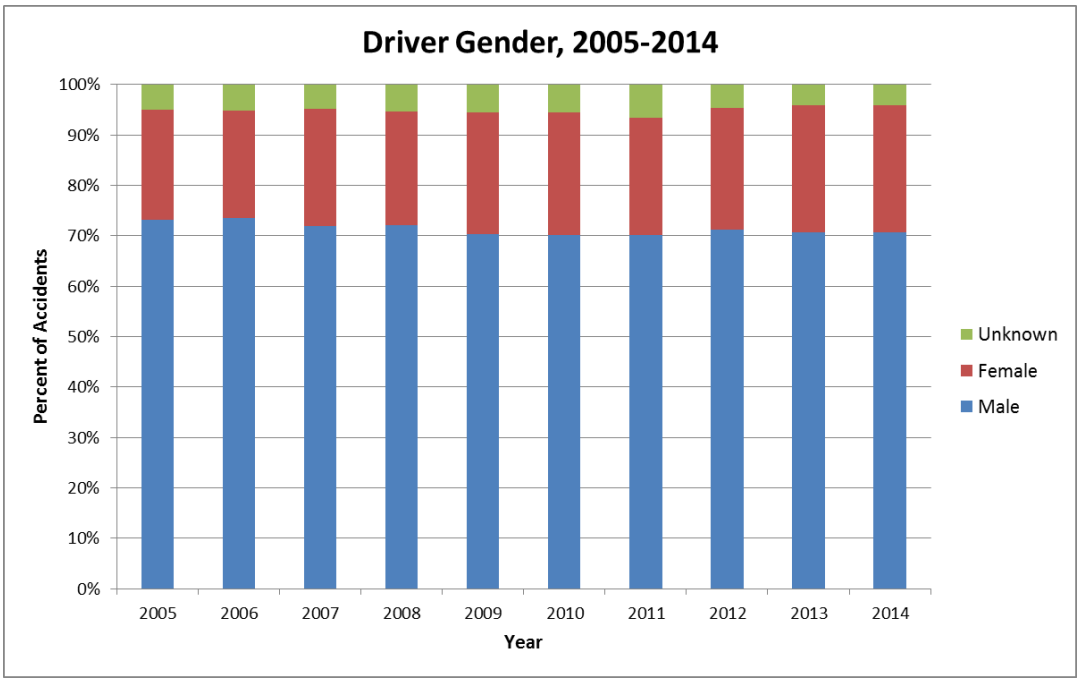

Figure 19. Grade crossing accidents by driver gender, 2005-2014

Table 6 and Figure 19 show that over 70 percent of grade crossing accidents involve male drivers. The team collected data to determine whether male driving behavior is responsible for this imbalance, or male drivers have more accidents because they drive more miles than females.

Table 7. Accidents and miles traveled by age and gender, 2008

		Male			Female			Total	
Age		Miles Traveled	Accidents		Miles Traveled	Accidents		Miles Traveled	Accidents
16-19		47,101,113,156	95		40,725,999,996	39		87,827,113,152	134
20-29		144,498,696,245	324		131,455,554,074	124		275,954,250,319	448
30-59		885,054,888,347	876		559,809,444,138	246		1,444,864,332,485	1122
60-69		158,220,245,972	112		102,579,182,791	30		260,799,428,763	142
≥70		80,488,354,469	107		41,430,048,664	52		121,918,403,133	159
Total		1,317,040,742,517	1514		878,100,269,096	491		2,195,141,011,613	2005

Table 8. Accidents by age and gender, normalized by miles traveled, 2008

Accidents Per Billion Miles Traveled, 2008					
Age	**Male**		**Female**		**Overall**
16-19	**2.0169**		0.9576		1.5257
20-29	**2.2422**		0.9433		1.6235
30-59	**0.9898**		0.4394		0.7765
60-69	**0.7079**		0.2925		0.5445
≥70	**1.3294**		1.2551		1.3042
All Ages	**1.1495**		0.5592		0.9134

Even after accounting for the difference in miles driven, males were at much higher risk than females, as shown in Table 8.

The research team also examined the relationship between a county's median income and the area's grade crossing accidents. Data for population estimates, median income (Figure 20) and percent poverty (Figure 21) by U.S. county were obtained from the U.S. Census Bureau's Small Area Income and Poverty Estimates [10].

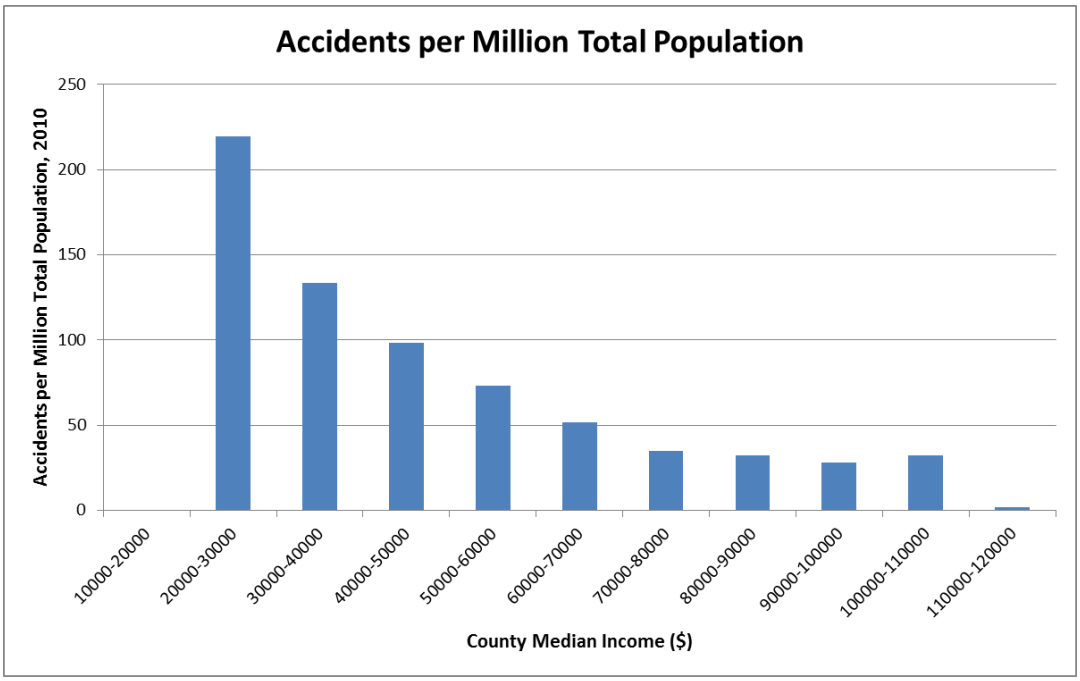

Figure 20. Accidents per million people by county median income

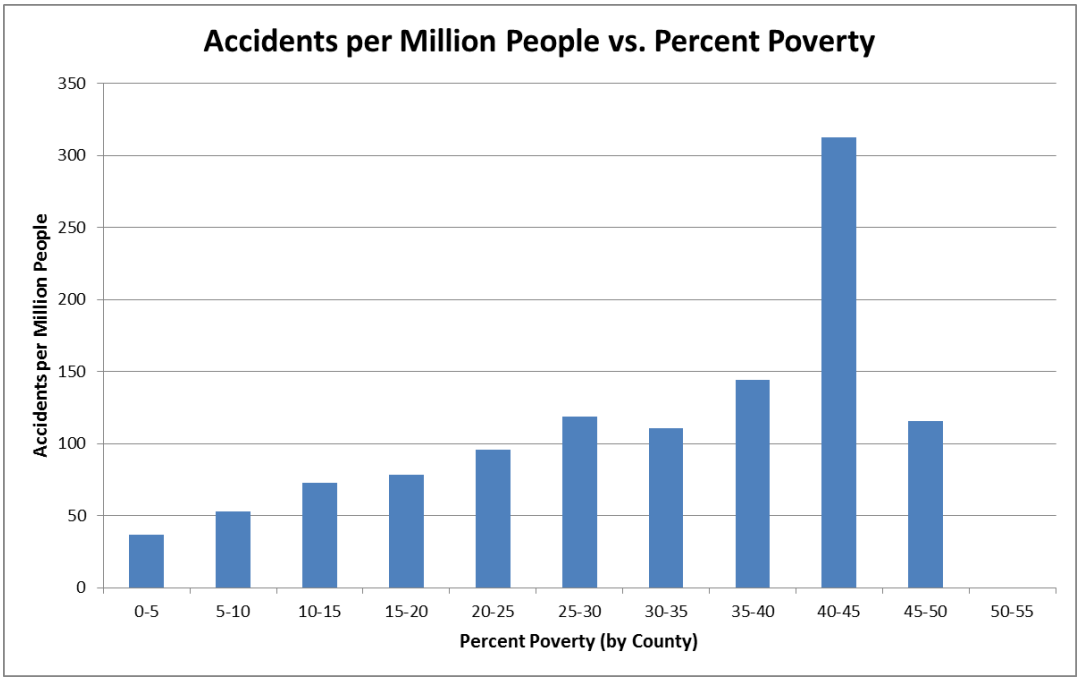

Figure 21. Accidents per million people by county percent poverty

Both metrics indicate that less wealthy counties have a higher rate of grade crossing accidents per capita (the low rate in the 45-50 percent poverty chart is due to small sample size).

Further research revealed that wealthier counties have fewer grade crossings, and that their subsequent rate of accidents per crossing was actually higher than less wealthy counties, as seen in Figure 22.

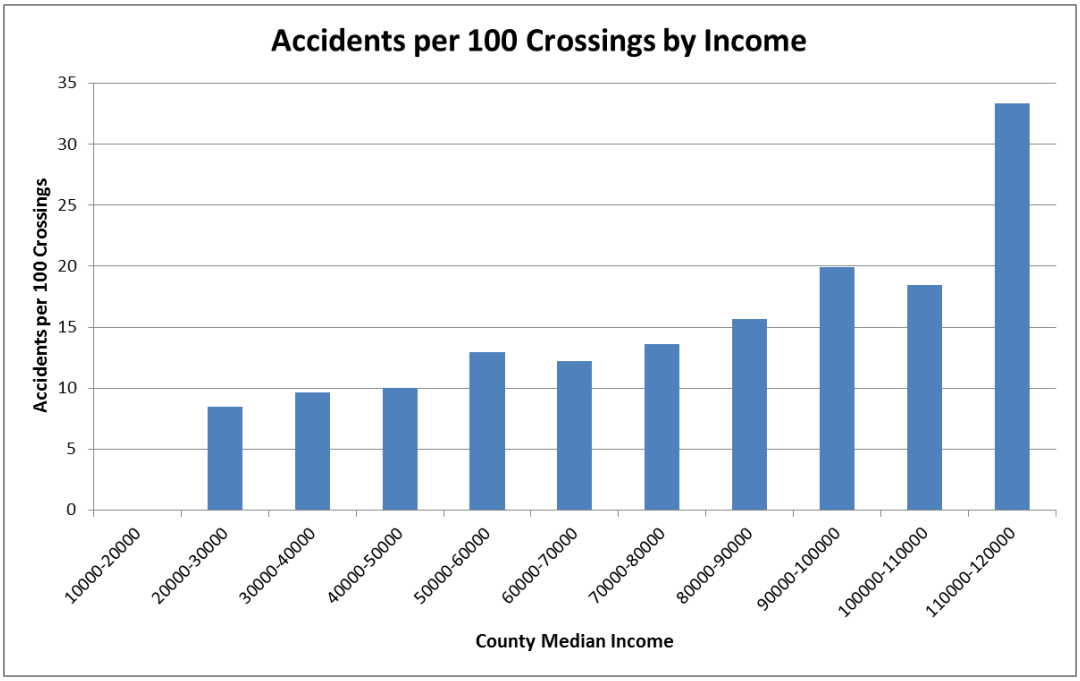

Figure 22. Accidents per 100 crossings by income

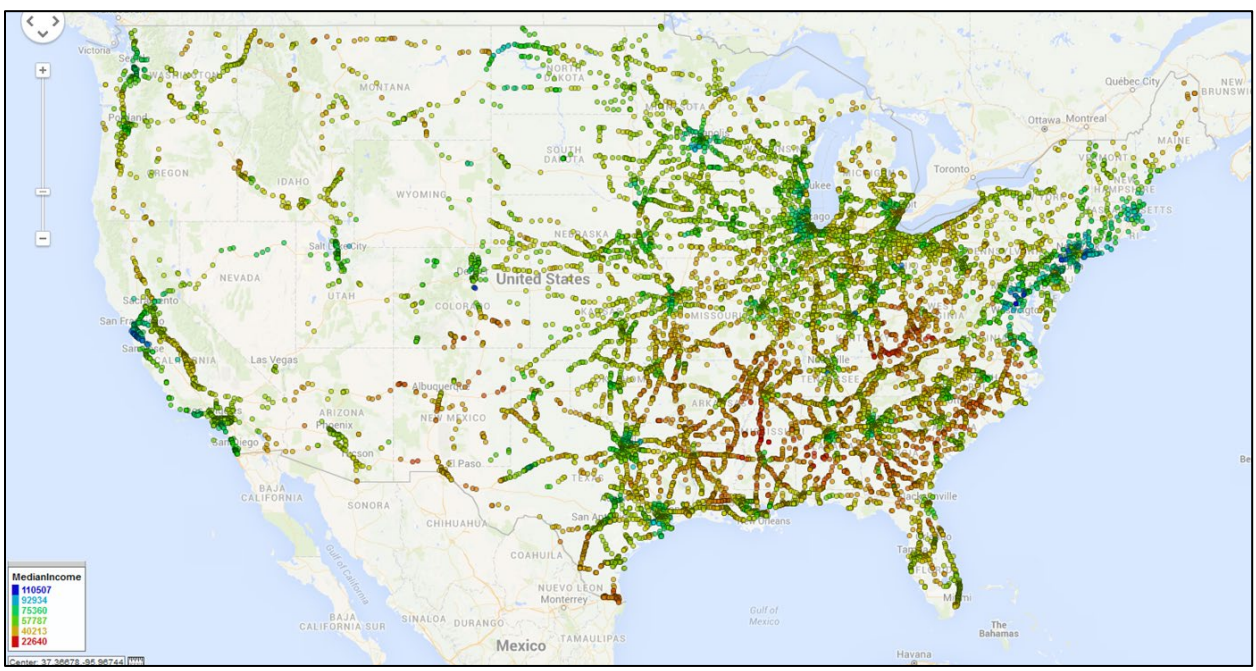

Figure 23. Accidents plotted as a function of county median income

Each dot in Figure 23 illustrates an accident, with blue dots representing wealthy counties, and red dots representing counties with low median income.

4.4 Temporal and Environmental Effects

This section describes time-of-day, day of the week, and environmental effects (e.g., weather and sun patterns) associated with grade crossing accidents.

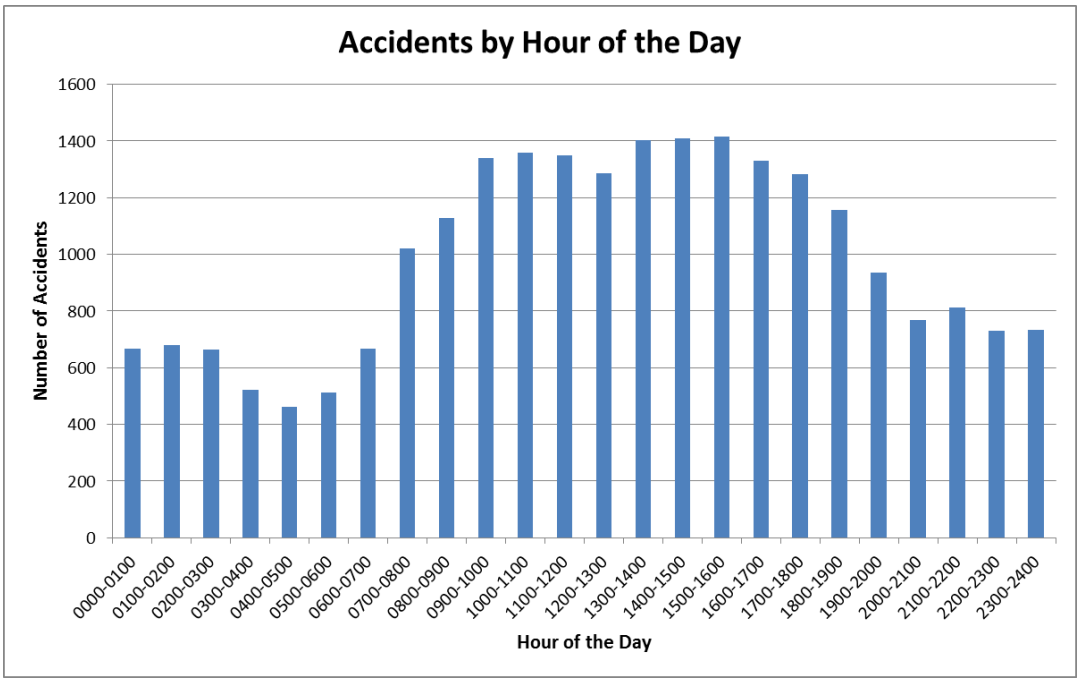

Figure 24. Number of grade crossing accidents by hour of the day, 2005-2014

As shown in Figure 24, grade crossing accidents occur most frequently in the middle of the day, from 9am to 6pm. The same data are shown in 2-hour increments in Figure 25. It is probable that this accident trend mimics the volume of vehicle traffic throughout the day; however, traffic count data by the hour is not available to confirm this.

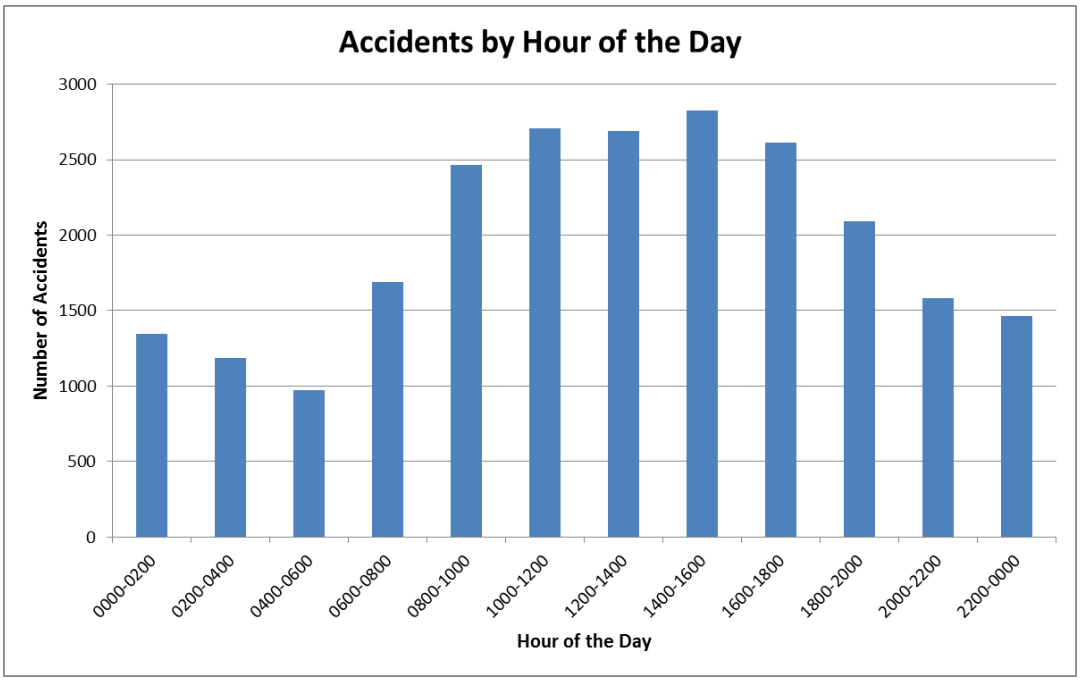

Figure 25. Number of grade crossing accidents by 2-hour blocks, 2005-2014

Figure 26 shows the association between day of the week and the number of grade crossing accidents.

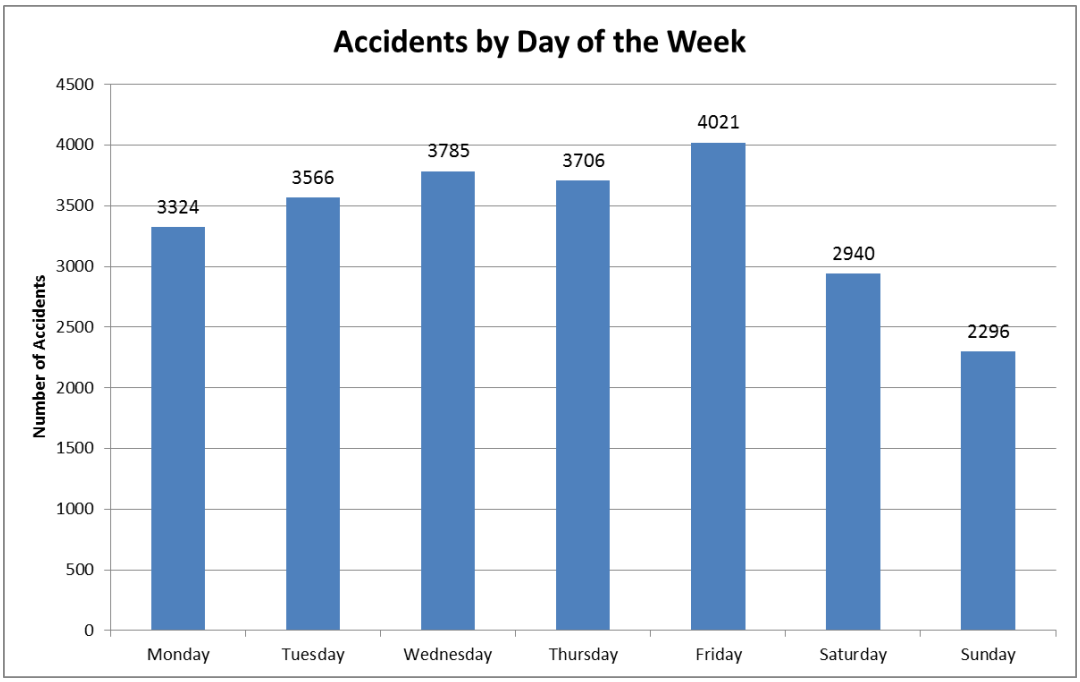

Figure 26. Number of grade crossing accidents by day of the week, 2005-2014

These figures are further broken down and the trends examined in the table and figures below.

Table 9. Accidents by hour of the day and day of the week

			Number of Accidents							
Hour	From	To	All Days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0000-0100	12AM	1AM	667	60	91	81	102	101	116	116
0100-0200	1AM	2AM	679	63	82	85	80	96	142	131
0200-0300	2AM	3AM	665	51	61	79	78	95	152	149
0300-0400	3AM	4AM	522	30	37	53	74	72	140	116
0400-0500	4AM	5AM	463	55	49	58	54	72	85	90
0500-0600	5AM	6AM	511	54	77	82	73	77	82	66
0600-0700	6AM	7AM	666	93	102	129	117	110	65	50
0700-0800	7AM	8AM	1022	170	176	172	183	180	84	57
0800-0900	8AM	9AM	1129	185	182	214	194	218	82	54
0900-1000	9AM	10AM	1339	218	227	207	199	235	168	85
1000-1100	10AM	11AM	1360	219	202	219	208	244	164	104
1100-1200	11AM	12PM	1350	201	217	230	255	208	144	95
1200-1300	12PM	1PM	1287	192	221	228	190	213	131	112
1300-1400	1PM	2PM	1402	207	218	232	226	238	156	125
1400-1500	2PM	3PM	1410	211	224	242	238	240	144	111
1500-1600	3PM	4PM	1415	224	217	239	232	236	148	119
1600-1700	4PM	5PM	1329	186	228	237	212	239	127	100
1700-1800	5PM	6PM	1283	210	207	207	220	216	118	105
1800-1900	6PM	7PM	1158	182	158	187	178	199	137	117
1900-2000	7PM	8PM	935	125	151	155	145	155	121	83
2000-2100	8PM	9PM	769	113	105	119	102	135	104	91
2100-2200	9PM	10PM	812	112	128	98	124	138	129	83
2200-2300	10PM	11PM	730	76	116	113	106	147	98	74
2300-2400	11PM	12AM	735	87	90	119	116	157	103	63
			23638	3324	3566	3785	3706	4021	2940	2296

As shown in Table 9, Saturday and especially Sunday have fewer accidents than weekdays. This is probably due to reduced traffic.

Figure 27 and Figure 28 show that grade crossing accidents are linked to the time of day. Weekend nights (i.e., 5pm Friday night through 5pm Sunday night) are associated with more late night accidents than weekdays. Between 1am and 3am, there are three times as many grade crossing accidents on weekend nights as compared to the same times on weekday nights. Most weekday grade crossing accidents (69 percent) occur between 7am and 7pm.

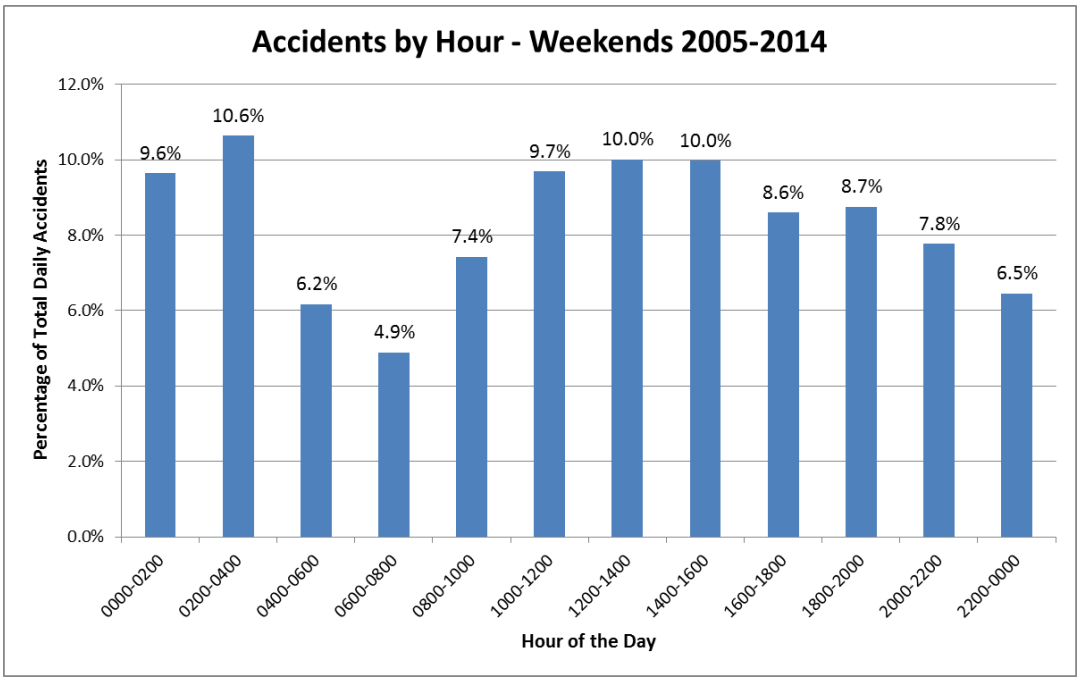

Figure 27. Accidents by 2-hour blocks, weekends 2005-2014

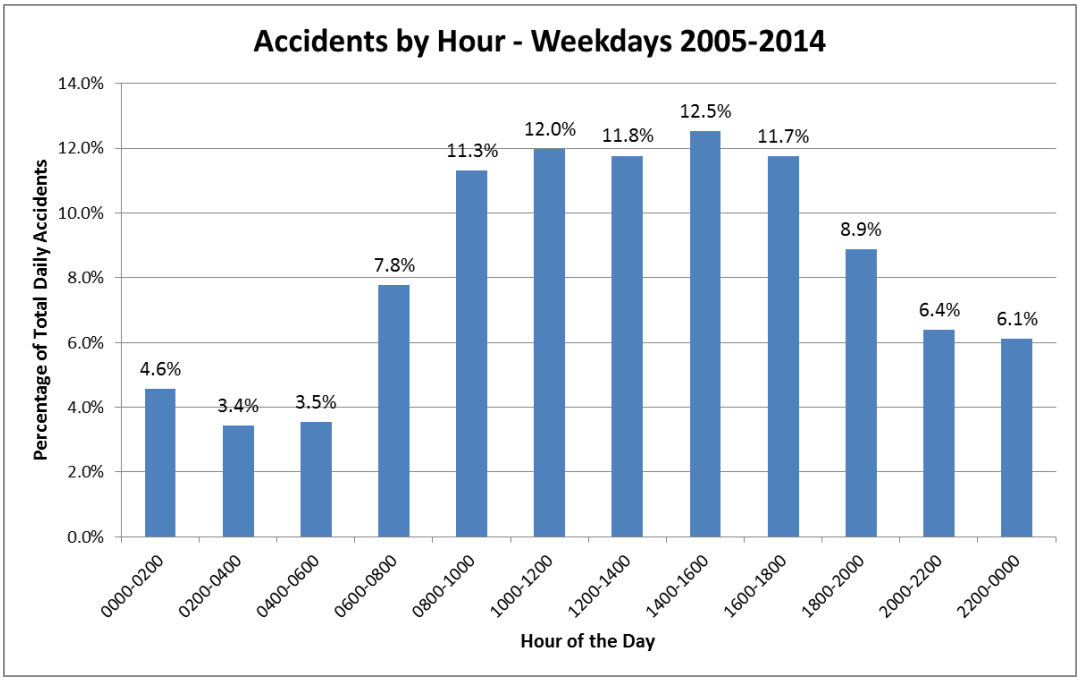

Figure 28. Accidents by 2-hour blocks, weekdays 2005-2014

In Table 10, red cells indicate young drivers while green cells indicate older drivers. The table shows that the average age of drivers involved in late night accidents on Friday and Saturday nights is 7 to 8 years younger than the overall average of all drivers involved in grade crossing accidents. Overall, the average age of drivers involved in grade crossing accidents is 42.24; while on Friday and Saturday nights the average age is 35.37.

Table 10. Age distribution of accidents by day and hour

			All Days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Hour	From	To	Avg. Age	Avg. Age	Avg. Age	Avg. Age	Avg. Age	Avg. Age	Avg. Age	Avg. Age
0000-0100	12AM	1AM	35.77	32.26	39.92	32.40	38.43	35.74	35.24	34.95
0100-0200	1AM	2AM	35.17	37.65	35.74	39.35	35.23	34.57	33.34	33.52
0200-0300	2AM	3AM	33.64	35.55	35.96	37.38	31.38	32.71	33.72	31.85
0300-0400	3AM	4AM	33.03	36.95	33.21	37.34	35.52	34.51	31.01	29.44
0400-0500	4AM	5AM	36.36	43.02	40.42	35.84	38.00	40.76	31.86	30.55
0500-0600	5AM	6AM	39.49	37.81	40.49	39.29	39.20	44.83	38.33	34.93
0600-0700	6AM	7AM	41.43	42.88	43.85	41.52	41.43	39.55	42.22	35.90
0700-0800	7AM	8AM	41.73	43.73	39.72	39.50	41.02	45.02	41.93	40.29
0800-0900	8AM	9AM	44.60	44.15	44.52	43.98	44.22	45.04	48.16	43.33
0900-1000	9AM	10AM	46.49	48.00	45.65	46.43	46.99	45.52	45.59	48.69
1000-1100	10AM	11AM	46.40	45.14	47.53	47.84	47.75	45.46	45.77	44.19
1100-1200	11AM	12PM	45.45	45.00	45.81	47.50	45.67	45.30	42.49	44.40
1200-1300	12PM	1PM	45.74	46.97	45.80	45.82	48.56	44.40	44.25	42.52
1300-1400	1PM	2PM	45.74	46.20	46.83	46.42	46.67	45.58	43.97	42.61
1400-1500	2PM	3PM	45.00	49.08	45.38	46.14	45.48	41.70	43.63	42.76
1500-1600	3PM	4PM	42.86	41.41	42.02	44.50	44.23	40.85	44.05	43.35
1600-1700	4PM	5PM	42.36	43.38	44.58	42.77	39.40	42.58	40.28	43.07
1700-1800	5PM	6PM	41.77	41.22	41.56	42.22	41.35	42.44	42.91	40.51
1800-1900	6PM	7PM	42.23	41.85	43.77	42.86	42.12	43.12	39.24	41.86
1900-2000	7PM	8PM	41.22	42.06	41.24	41.57	40.12	40.93	41.78	40.99
2000-2100	8PM	9PM	41.00	41.32	41.51	41.66	39.71	38.36	44.80	40.43
2100-2200	9PM	10PM	39.25	40.12	38.70	41.55	39.34	38.30	38.66	38.55
2200-2300	10PM	11PM	38.54	38.02	42.03	35.64	41.17	38.29	36.61	37.36
2300-2400	11PM	12AM	36.69	37.54	35.49	40.01	38.17	34.45	35.96	34.86

Table 11 shows that the gender of drivers in accidents was also different at various times of the day. During the later hours of the day (after 4pm) and also during nearly all hours on Sundays, female drivers were involved in a larger number of grade crossing accidents. In this table, red cells signify relatively more female drivers; blue cells indicate relatively more male drivers.

Table 11. Gender distribution of accidents by day and hour

			Male Driver Percentages							
Hour	From	To	All Days	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0000-0100	12AM	1AM	76.0%	76.4%	76.7%	80.3%	74.7%	66.7%	77.8%	79.2%
0100-0200	1AM	2AM	76.2%	79.6%	75.7%	87.7%	70.4%	75.0%	78.7%	69.4%
0200-0300	2AM	3AM	73.8%	81.3%	72.7%	77.9%	75.0%	74.4%	65.2%	76.8%
0300-0400	3AM	4AM	79.1%	88.0%	70.6%	76.0%	73.1%	73.4%	83.5%	83.8%
0400-0500	4AM	5AM	76.1%	75.5%	76.2%	75.9%	81.3%	75.8%	75.9%	74.0%
0500-0600	5AM	6AM	78.1%	82.0%	74.0%	79.2%	81.8%	74.0%	79.7%	77.2%
0600-0700	6AM	7AM	78.5%	78.2%	82.8%	80.6%	70.8%	77.2%	83.1%	80.0%
0700-0800	7AM	8AM	73.7%	76.2%	80.1%	71.4%	71.2%	71.5%	81.7%	55.6%
0800-0900	8AM	9AM	76.5%	72.9%	75.8%	82.1%	78.8%	76.2%	65.8%	78.0%
0900-1000	9AM	10AM	79.6%	82.0%	76.3%	83.1%	82.1%	79.9%	75.5%	74.7%
1000-1100	10AM	11AM	77.6%	80.8%	75.0%	80.4%	75.9%	80.3%	75.3%	70.3%
1100-1200	11AM	12PM	79.2%	81.1%	82.5%	79.8%	81.2%	79.8%	70.7%	72.5%
1200-1300	12PM	1PM	76.6%	80.7%	79.8%	74.0%	77.0%	78.8%	70.9%	69.8%
1300-1400	1PM	2PM	77.3%	79.0%	76.9%	77.6%	81.7%	77.3%	77.1%	67.2%
1400-1500	2PM	3PM	74.5%	77.1%	75.3%	78.5%	71.1%	68.2%	76.9%	76.4%
1500-1600	3PM	4PM	76.5%	79.9%	75.5%	76.0%	75.0%	78.9%	75.5%	71.9%
1600-1700	4PM	5PM	74.3%	70.9%	71.8%	74.6%	77.3%	76.4%	78.0%	69.4%
1700-1800	5PM	6PM	72.3%	69.8%	70.1%	71.1%	78.5%	68.0%	80.9%	70.6%
1800-1900	6PM	7PM	70.7%	72.4%	75.7%	72.5%	72.2%	64.0%	71.4%	67.0%
1900-2000	7PM	8PM	73.6%	71.1%	80.4%	69.4%	71.0%	81.0%	65.2%	76.3%
2000-2100	8PM	9PM	71.2%	74.0%	69.7%	71.3%	69.8%	74.8%	74.2%	62.8%
2100-2200	9PM	10PM	69.1%	72.8%	66.4%	69.6%	66.4%	72.7%	71.1%	62.8%
2200-2300	10PM	11PM	73.2%	70.8%	78.2%	75.0%	68.4%	74.6%	69.0%	74.2%
2300-2400	11PM	12AM	72.9%	78.3%	65.4%	75.9%	71.3%	66.4%	80.0%	77.2%

Selected environmental factors associated with grade crossing accidents are shown in Table 12 and Table 13. Most accidents occur during the day and when the weather is clear with good visibility; this is likely because the majority of driving occurs under these conditions. However, a fairly high number of accidents occurred while driving when dark.

Table 12. Number of accidents by visibility, 2005-2014

		Year											
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014		
Visibility	Dawn	79	72	59	68	59	68	106	125	163	181	980	4.1%
	Day	1910	1846	1736	1510	1183	1243	1227	1157	1155	1232	14199	60.1%
	Dusk	94	74	82	65	58	69	115	114	176	222	1069	4.5%
	Dark	983	950	901	786	633	672	613	589	608	655	7390	31.3%
		3066	2942	2778	2429	1933	2052	2061	1985	2102	2290	23638	100.0%

Table 13. Number of accidents by type of weather, 2005-2014

		Year											
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014		
Weather	Clear	2165	2089	1932	1699	1343	1384	1409	1436	1447	1526	16430	69.5%
	Cloudy	581	550	554	450	371	419	420	373	417	471	4606	19.5%
	Rain	187	201	176	153	134	131	135	122	144	163	1546	6.5%
	Fog	45	46	44	36	25	40	21	21	30	32	340	1.4%
	Sleet	11	14	4	10	4	2	4	3	2	11	65	0.3%
	Snow	77	42	68	81	56	76	72	30	62	87	651	2.8%
		3066	2942	2778	2429	1933	2052	2061	1985	2102	2290	23638	100.0%

As shown in Figure 29, FRA splits the country into eight regions. The northern region was defined as regions 1, 2, 4, 6, and 8. The southern region contains regions 3, 5, and 7.

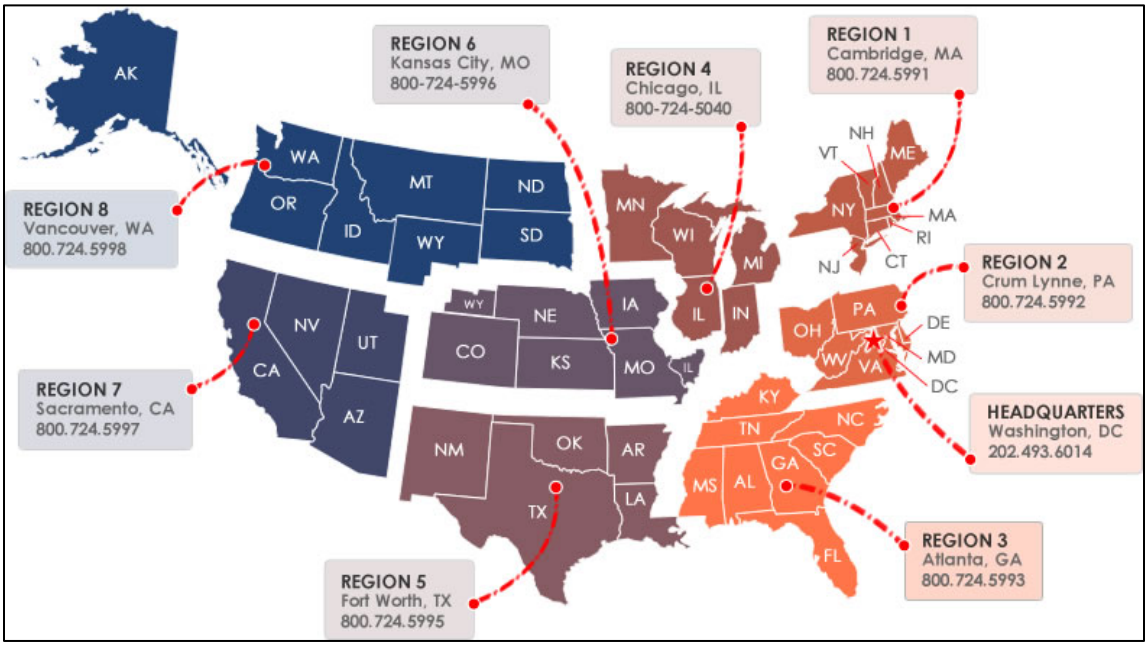

Figure 29. FRA designated regions

Figure 30 shows that a higher percentage of accidents occur from 4pm to 8pm in December as compared to 4pm to 8pm in June. This time of day corresponds to hours when it is generally dark outside in December but still light outside in June. Thus, driving in darkness is most likely responsible for this difference in accident percentages. Analyzing accident percentages in the southern region rules out the possibility of weather causing this discrepancy.

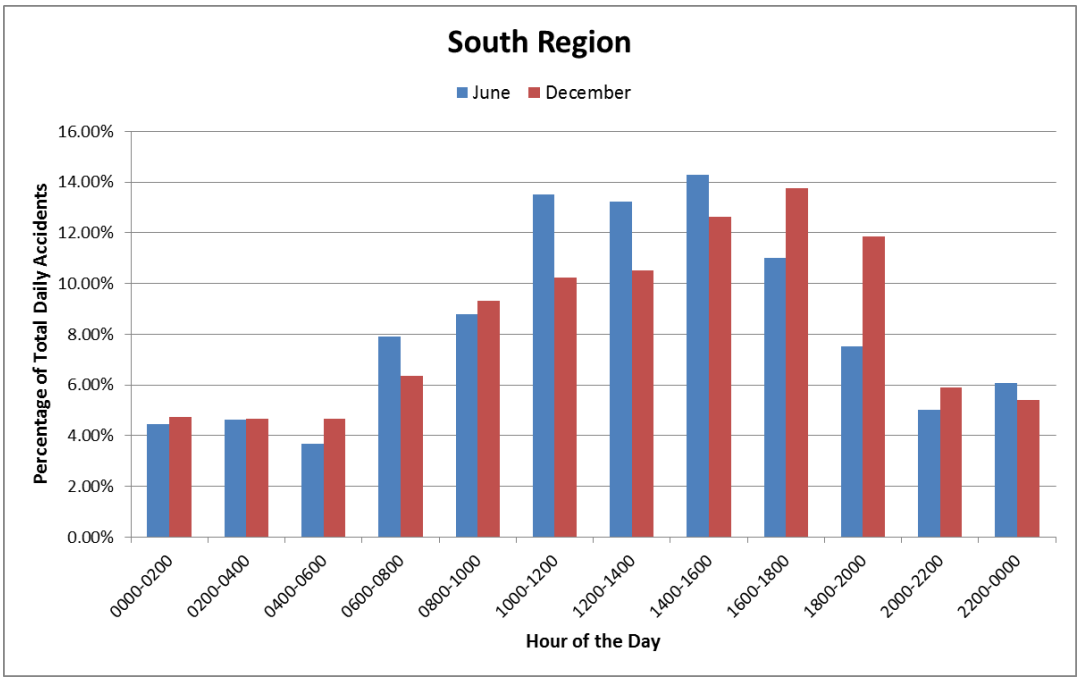

Figure 30. Accidents in the South Region – June vs. December

Another environmental factor analyzed was the effect of daylight saving time (DST) on grade crossing accidents (Figure 31). Because it was determined that darkness hours contribute to accidents, it was suspected that DST might be correlated with accident frequency.

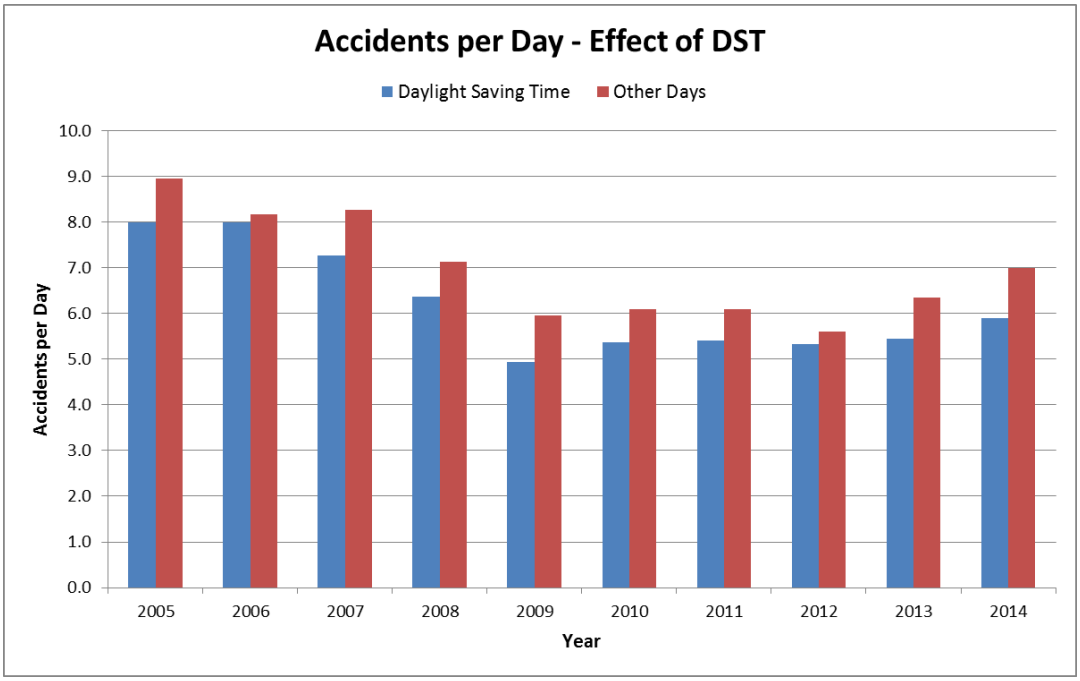

Figure 31. Accidents by day, effect of DST, 2005-2014

Almost one additional accident per day occurred on non-DST-days, as compared to DST-days. On a yearly basis, this equals over 300 more accidents per year.

The number of accidents per month normalized by vehicle miles corroborated the effect of driving in darkness.

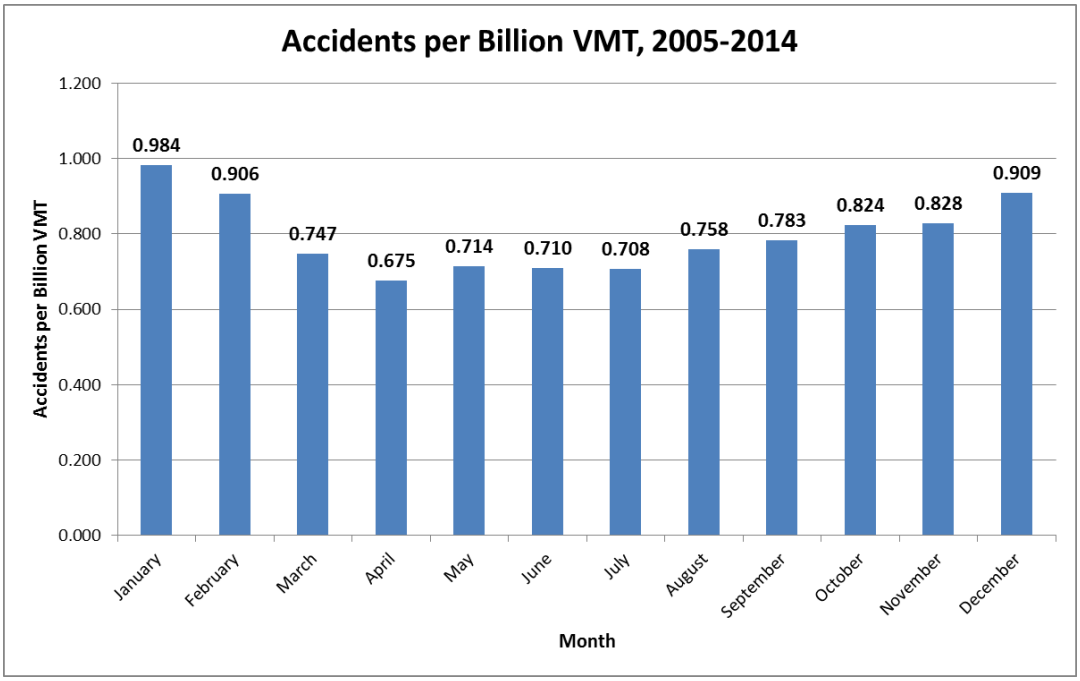

Figure 32. Accidents per billion VMT by month, 2005-2014

As shown in Figure 32, the months with the most hours of darkness have the highest rate of grade crossing accidents per vehicle mile traveled. To check whether this result is due to darkness or from weather patterns, the team analyzed the accident data for the Northern Region separately from the Southern Region, as shown in Figure 33 and Figure 34, respectively.

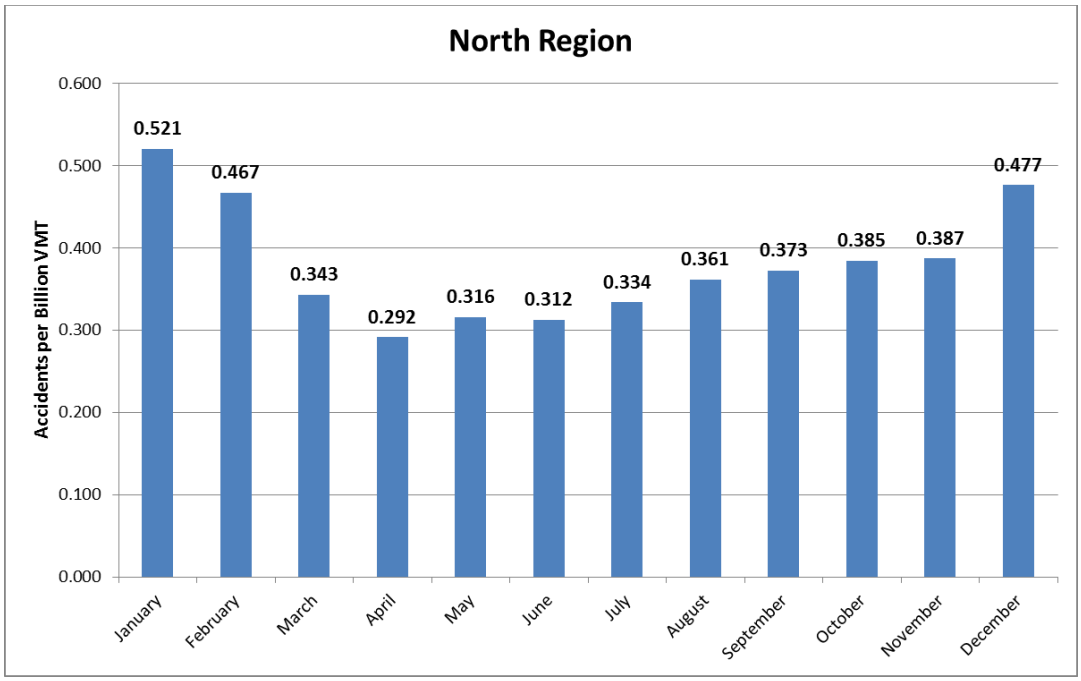

Figure 33. Accidents per billion VMT, Northern Region 2005-2014

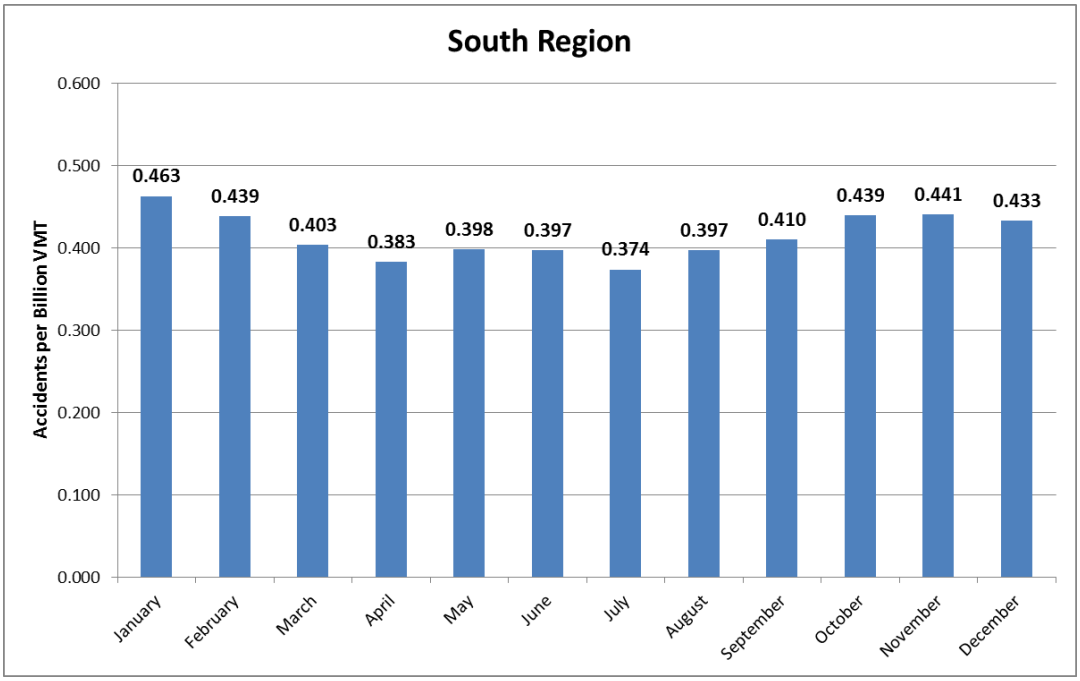

Figure 34. Accidents per billion VMT, Southern Region 2005-2014

The Northern Region is affected by weather patterns to some extent; accident rates for the winter months are much higher than other months. In the Southern Region, the months with more darkness are still the most dangerous, but the effect is much smaller because the weather does not get as severe as it does in the north.

One last environmental effect considered was the effect of sunrise and sunset on motorists. It is logical that having the sun in the drivers' eyes could affect motorists' ability to distinguish

warning devices and to make appropriate decisions at grade crossings. For example, Figure 35 below is a Google street view image of grade crossing 025590V in Arizona. This crossing had eight accidents during the study period (2005-2014).

Figure 35. Google image of crossing 025590V

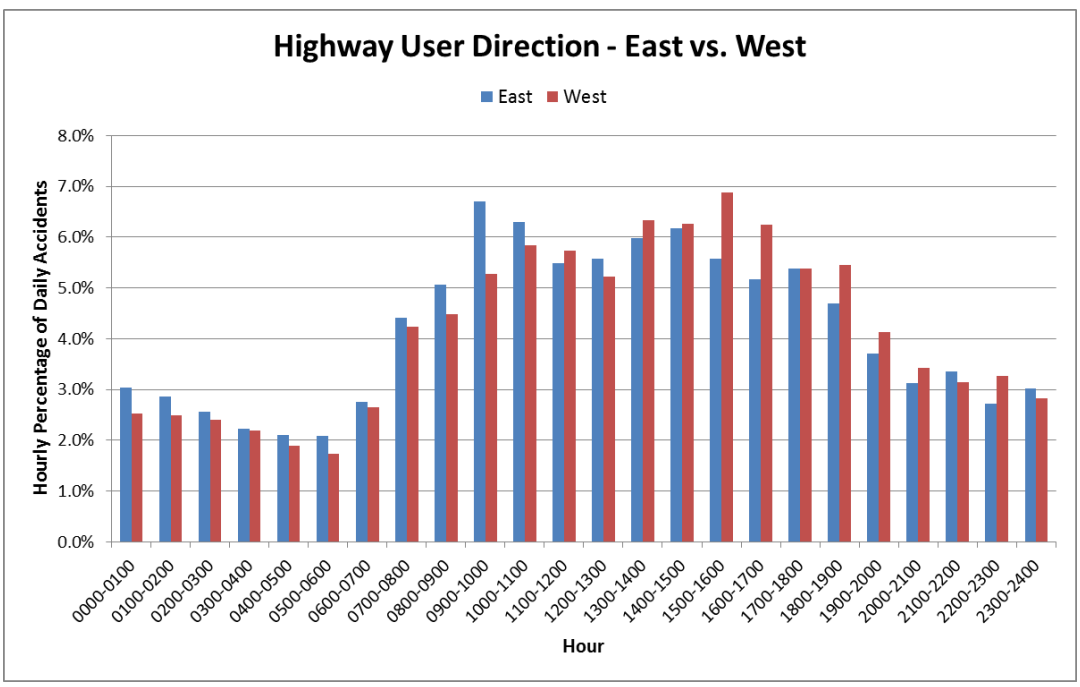

Figure 36. Effect of sun on morning and evening commute

Figure 36, which presents data from the FRA accident database, shows a higher percentage of morning (6am-11am) accidents when motorists are traveling in direction of the rising sun (east). During the afternoon/evening commute (3pm – 8pm), motorists who drive towards the setting

sun (west) also have a higher percentage of accidents. This effect may be small, but there is a clear shift between 11am and 3pm that indicates some mechanism is causing this change. Altering warning devices to limit sun-related interference could potentially reduce accident numbers.

4.5 Grade Crossing Characteristics

FRA's grade crossing inventory database contains over 100 descriptive fields for each crossing. When it is linked with the accident database, it is possible to determine which factors are associated with grade crossing accidents.

The warning system is an important characteristic of each crossing. This system can either be passive or active. Active systems or devices include flashing lights and gates, or anything that actively gets the attention of motorists. Passive devices include stop signs and crossbucks.

Passive devices are generally reserved for rural areas because fewer vehicles pass over them each day. Active devices are typically used at busy urban crossings. As a result, the team chose to analyze the number of accidents per crossing per train per vehicle.

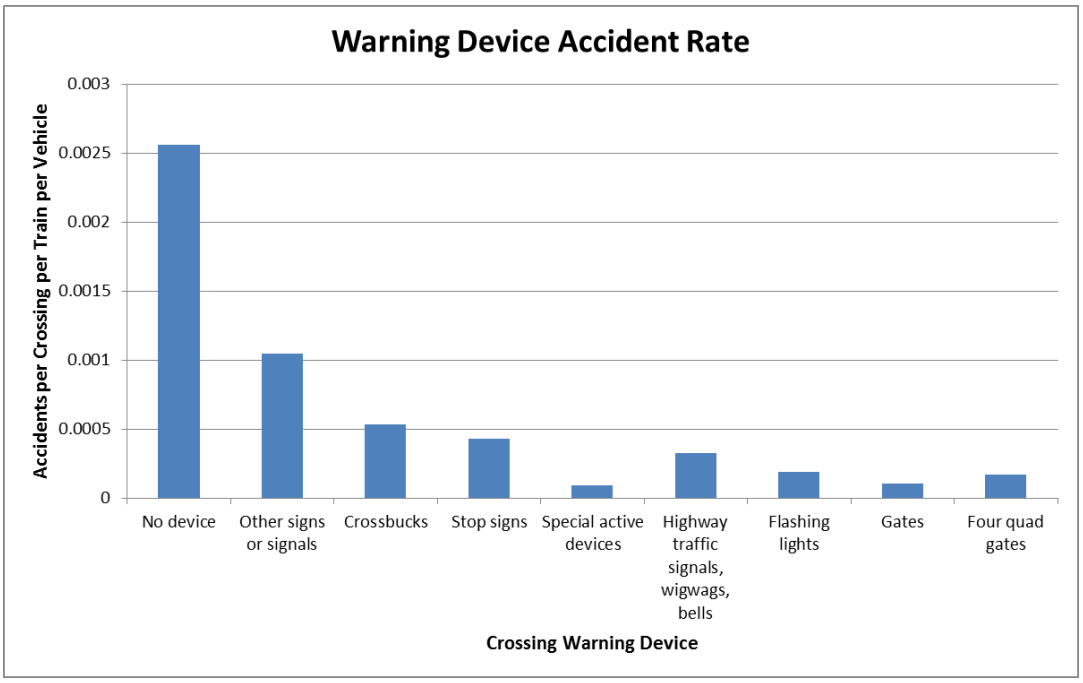

Figure 37. Warning device accident rates

Figure 37 shows that a crossing with no device at all is in the most dangerous situation. Active devices such as flashing lights and gates are safer than passive devices such as crossbucks and stop signs. This data was normalized such that the risk was analyzed per car and per train that go over a crossing. This way each crossing, whether in an urban or rural area, can be directly compared.

Another important crossing characteristic is whether a highway intersection is near the crossing.

Figure 38. Google maps image of crossing 879204S

Figure 38 contains a Google Maps image of crossing 879204S in Indiana, which had 15 accidents during the study period. In these situations, where a highway intersection is near a crossing, it becomes difficult for drivers to decide where to stop if the traffic signal turns red. Drivers may end up stopped on the railroad tracks at the crossing even when they know it is unsafe. This results in high numbers of accidents at these types of crossing geometries.

Table 14. Effect of nearby intersecting highway on accident rate

		Number of Grade Crossings	2005-2014 Accidents	Accidents per Crossing
Distance to Nearby Intersecting Highway	Less than 75ft	52842	9547	0.1807
	75 to 200ft	12477	1845	0.1479
	200 to 500ft	6899	924	0.1339
	N/A	72498	7868	0.1085
	Total	144716	20184	0.1395

As Table 14 shows, the closer a crossing is to a highway intersection, the higher its accident rate. Crossings with no intersection nearby (i.e., N/A) have the lowest accident rates.

Also with respect to crossing geometry, the angle at which the road and the rail tracks intersect is also important; however, its effect on grade crossing collisions is difficult to quantify.

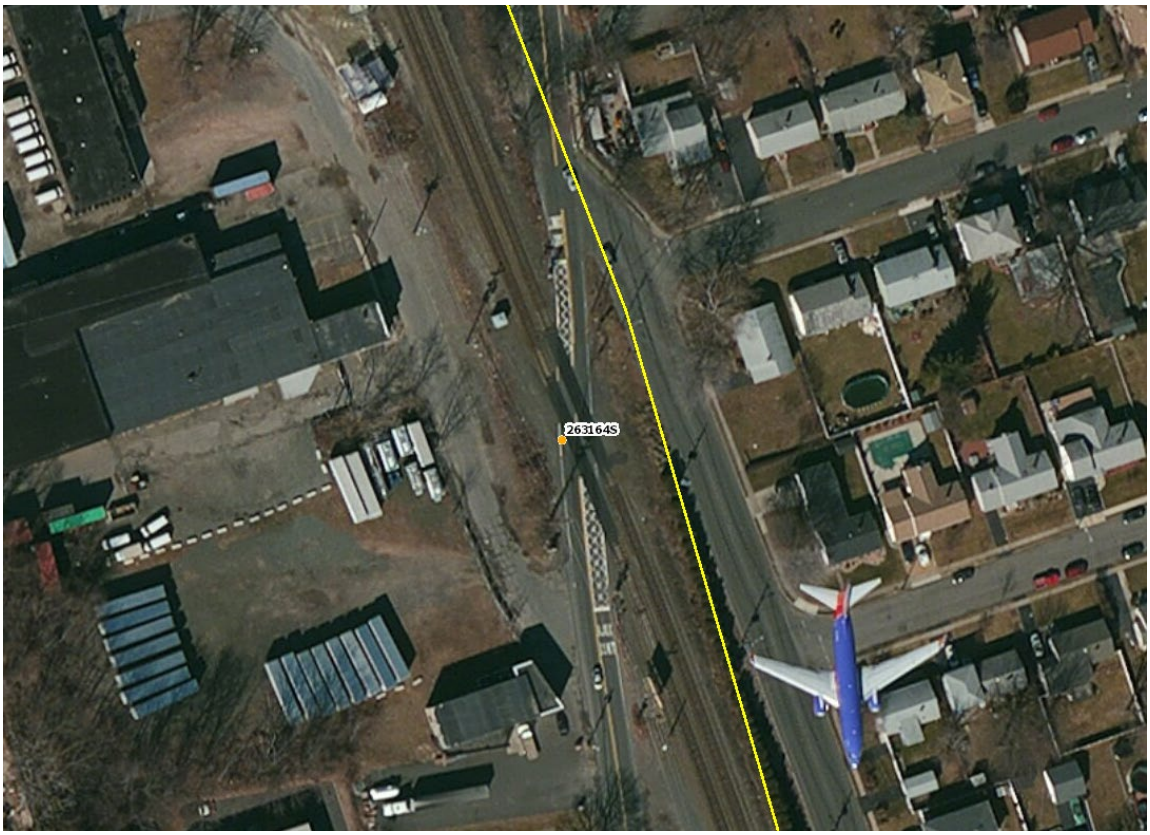

Figure 39. Google maps image of crossing 263164S

Figure 39 is an image of crossing 263164S, which is in New Jersey and had 13 accidents during the study period. The angle of the intersection is far from perpendicular, which increases the distance between the gates and the tracks. This increases the likelihood that vehicles will become trapped while a train comes through. The intersection angle also makes it nearly impossible for motorists to look down the tracks and visually identify an on-coming train.

The FRA data suggests that a crossing angle between 0-29 degrees is more dangerous than crossing angles that are greater than 29 degrees.

Table 15. Effect of crossing angle on accident rates

		Accidents per Crossing per Train per Vehicle
Smallest Crossing Angle	0-29	0.0004961
	30-59	0.0003204
	60-90	0.0003507
	Average	0.0003507

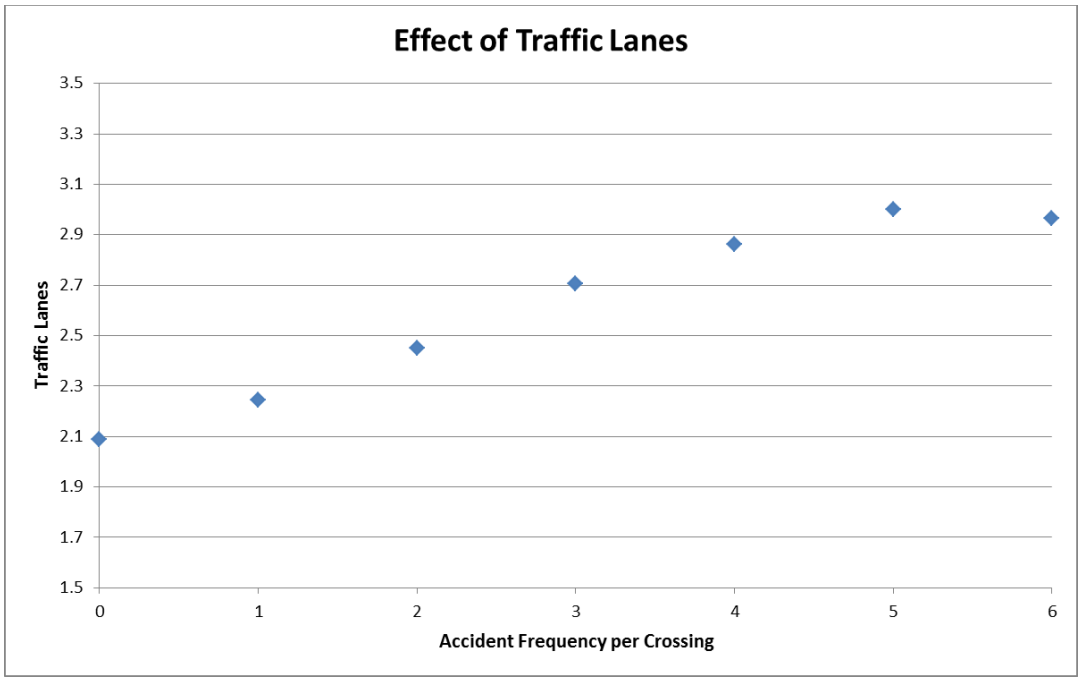

Figure 40. Effect of traffic lanes on accident frequency

The number of traffic lanes and main line tracks at a grade crossing also affects the potential for grade crossing accidents. Figure 40 and Table 16 highlight the relationship between the number of traffic lanes and accident frequency at a crossing. However, Figure 39 gathers crossings with different accident frequencies and averages the number of traffic lanes within these groups, while Table 16 gathers crossings with different numbers of traffic lanes and averages the accident frequencies. They both show that crossings with more traffic lanes experience more accidents. The traffic lane effect is correlated with AADT at a crossing because extra traffic lanes are usually only added when high AADT warrants their addition.

Table 16. Effect of traffic lanes on accident rate

Number of Traffic Lanes	Average Number of Accidents, 2005-2014
1	0.0863
2	0.1534
3	0.3109
4	0.3504
5	0.4876
6	0.6199
7	0.8857

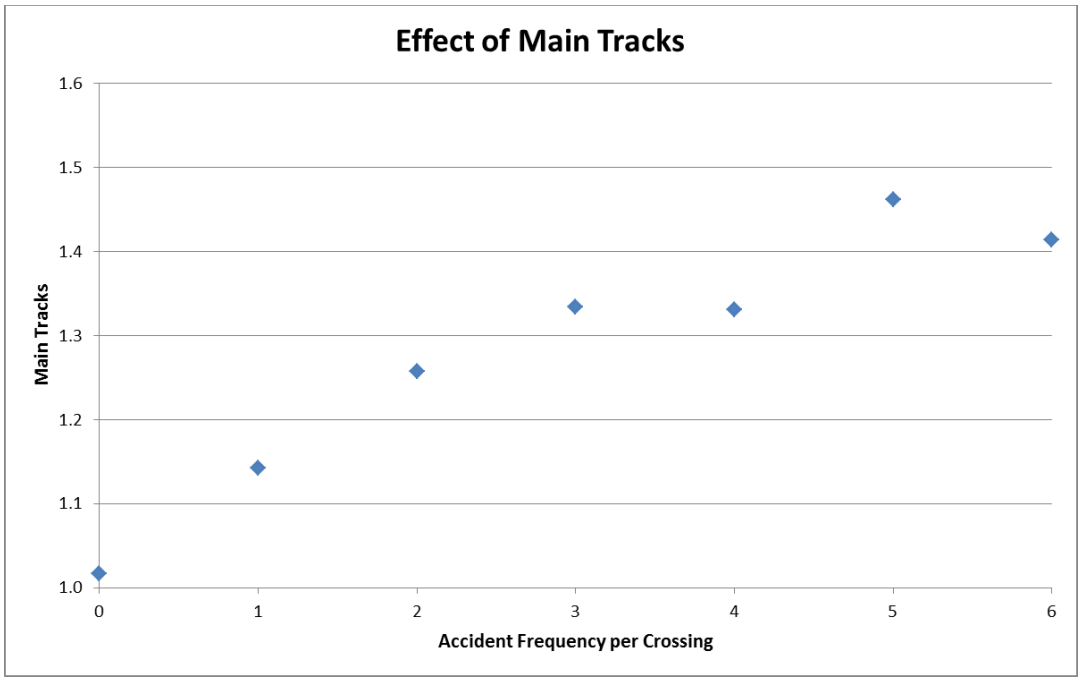

Figure 41. Effect of main tracks on accident frequency

In Figure 41 and Table 17, the number of main tracks at a crossing is linked to a similar effect; as the number of main tracks at a grade crossing increases, the accident frequency increases.

Table 17. Effect of main tracks on accident rate

Number of Main Tracks	Average Number of Accidents, 2005-2014
1	0.1460
2	0.3584
3	0.5752
4	0.5303
5	0.4167
6	1.6000

4.6 Useful Information for Constructing a Predictive Model

The first step in creating a predictive model for grade crossing accidents is choosing the variables that will be included. There is a balance that needs to be struck, because adding more variables can increase the model's predictive power, but may make the model too complex and too difficult to use. Variables that must be included in the model are:

- Total daily trains
- AADT
- Number of main tracks

- Number of traffic lanes
- Whether a highway intersection is near

In addition, the following variables should also be considered for inclusion but might need closer inspection:

- Maximum train timetable speed
- Day thru trains
- Night thru trains
- Is highway paved
- Posted highway speed
- Total switching trains

Driver age and gender should also be considered for inclusion in the model. However, since these factors differ for each accident and are not physical characteristics of a grade crossing, they need to be considered separately and in a different manner than the other variables.

The present research indicates that the inventory database must be filtered to create accurate data. Many crossings (mostly private crossings) have blank or impossible values for certain variables. For example, a crossing with an AADT or total train count of zero cannot be used in the model because there can be no collisions if there is no traffic. The crossings selected in the making of the model must have data available for each included variable.

The model should use a combination of the variables listed above and properly fit them to the observed data. Also, previous accident history should be incorporated to account for any intangible effects which the crossing characteristics cannot sufficiently capture. What seems like a safe crossing on paper could actually be a dangerous crossing out in the field, whether due to poor sight lines, poor road condition, or any other number of factors.

5. Conclusions

A number of factors may contribute to grade crossing accidents. For example, the volume of rail and highway traffic over a crossing is significantly related to accident frequency. Other factors, such as time of day or weather patterns, have a smaller but not negligible influence on accident frequency.

The rail industry's efforts to have a positive impact on driver behavior at grade crossings by using gates and flashing lights have been effective in reducing accident frequency. However, there are nearly a thousand accidents per year at crossings equipped with active gates; this would suggest drivers are often disobeying warning devices.

As a result, drivers who ignore crossing warnings, or distracted drivers, may have a greater likelihood of becoming victims in vehicle-train collisions. The risk of such incidents can be minimized but it would require drivers to make good critical decisions at grade crossings.

6. References

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Abbreviations and Acronyms

ACRONYMS	EXPLANATION
AAR	Association of American Railroads
AADT	Average Annual Daily Traffic
DST	Daylight Saving Time
FRA	Federal Railroad Administration
VMT	Vehicle Miles Traveled