Determining the Causes of the Improvement in Grade Crossing Safety in the United States since 1975

Ian Savage

Department of Economics and the Transportation Center
Northwestern University, Evanston, Illinois, USA

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Abstract

The number of collisions and fatalities at highway-rail intersections in the United States has declined significantly over the past thirty years, despite considerable increases in the volume of rail and highway traffic. This paper disaggregates the improvement into its constituent causes. Negative binomial regressions are conducted on a pooled data set for 49 states from 1975 to 2001. The analysis concludes that about two-fifths of the decrease is due to factors such as reduced drunk driving and improved emergency medical response that have improved safety on all parts of the highway network. The installation of gates and/or flashing lights accounts for about a fifth of the reduction. The development in the 1970s and early 1980s of the Operation Lifesaver public education campaign, and the installation of additional lights on locomotives in the mid 1990s, each led to about a seventh of the reduction. Finally, about a tenth is due to closure of crossings resulting from line abandonments or consolidation of little-used crossings. Further analysis, using data from 1996 to 2002, finds that increasing the amount of Operation Lifesaver activity in a state reduces the number of collisions with a point elasticity of -0.11, but the effect on the number of deaths cannot be concluded with statistical certainty.

Introduction

This paper is a summary of two peer-reviewed published papers that deal with disaggregating the improvement in highway-rail grade crossing safety in the United States since the mid-1970s into its constituent causes [3,4]. The objective of the papers was to assess the relative contribution of various public policy initiatives in the 1970s to the very noticeable decline in the number of incidents and deaths. In 1970, almost 1,500 highway users died in grade crossing collisions. By 2005, this number had declined to 350. The decline is even more remarkable given that the number of potential highway vehicle-train interactions has increased. Average annual daily traffic (AADT) on non-grade-separated highways has more than doubled, and the average number of trains on those parts of the network that were not abandoned has increased by 80%.

The policy initiatives of the early 1970s were a response to a public debate in the late 1960s. Highway traffic was increasing, the number of deaths at crossings had reversed its long-run decline, and the railroads did not have the financial resources to increase the proportion of crossings that were equipped with active warning devices. The *Federal Highway Act* of 1973 contained provisions, now known as the Section 130 program, that provided federal money to states to cover most of the cost of upgrading warning devices. The federal government also encouraged the closing of little-used crossings. Since 1975, 30% of crossings have been closed due to the crossing consolidation program or because the railroads abandoned lines following liberalization of economic regulations by the *Staggers Act* of 1980. In a later initiative, the government conducted research in the early 1990s to determine ways to improve the visibility of trains. The resulting federal rule, effective from 1998, required that the traditional single headlight had to be augmented by two additional lights lower down on the front of the locomotive. These are known as ditch or crossing lights, and provide added illumination of the sides of the track and, what is more important, the triangular pattern provides highway users with a greater perception of an approaching train's speed and distance from the crossing.

Engineering was only one aspect of the policy response. A perpetual issue has been highway users' poor perception of the dangers of grade crossings [2]. A public information campaign to educate drivers was established in Idaho in 1972 using the Operation Lifesaver (OL) brand name. Its introduction was claimed to have produced a 40% decline in crossing fatalities. The program then spread state by state across the nation (excepting Hawaii and the District of Columbia) by 1986.

It would be incorrect to attribute all of the apparent improvement to these initiatives. Over the same time period, safety has also improved on the highways in general. Laws raising the minimum drinking age and increasing the penalties for drunk-driving have been enacted. Societal attitudes on impaired driving have changed. Improvements in automobile technology and emergency medical response have allowed more people to survive crashes. The rate of fatal highway crashes at locations other than highway-rail crossings per mile of travel has been cut in half since 1975. Safety at highway-rail intersections has to be viewed in relation to the experience at highway-highway intersections and elsewhere on the highway network.

Analytical Technique

There is a huge literature on modeling the risk at individual crossings. Models have existed for more than sixty years. Austin and Carson [1] provide a historical review and a state-of-the-art model, using the negative binomial regression technique. The models in this paper also use the negative binomial, but they are at a much more macro level. Rather than looking at individual crossings, this analysis models the incident experience in a state in a given year. Therefore, the appropriate primary measure of exposure to incidents is the number of crossings, rather than the levels of highway and rail traffic that are used in models of risk at individual crossings (these latter two variables do appear in this regression, but as additional explanatory variables).

The primary analysis in this paper uses a panel data set for 49 states for the years between 1975 (when comprehensive data were first collected) and 2001. Hawaii and the District of Columbia are excluded. The reason for the choice of a panel data set is that the factors explaining the improvement in crossing safety are highly collinear when looking at a time series of data at the national level. The correlations are at least 0.6 and in many cases in excess of 0.9. The panel data introduces much more variability, and generally reduces correlations below 0.5, and in some cases considerably below 0.3.

The estimated equation can be usefully visualized as having the form:

$$\text{count of incidents} = e^{(\beta \ln(\text{number of crossings}) + \gamma \text{ other variables})} + \varepsilon \qquad (1)$$

The negative binomial regression is a more generalized version of the Poisson regression. It assumes that the mean, E(y), and variance, Var(y), of the count of incidents for a group of states/years with identical values of the explanatory variables have the following relationship:

$$\mathrm{Var}(y) = E(y) + \alpha E(y)^2 \qquad (2)$$

The statistical output reports the estimated value and standard error of α. If α is found to be insignificantly different from zero, the model simplifies to the Poisson assumption. The regressions estimated in this paper reject the null hypothesis that $\alpha = 0$. Moreover because the estimated values of α are positive, the data are referred to as overdispersed.

Data

Two separate regressions are conducted. The first regression has as its dependent variable the number of incidents in a state in a given year at public crossings involving a motor vehicle. Railroads are required to file a report on all collisions between trains and highway users regardless of severity. The analysis is restricted to public crossings as these are the crossings for which the most data are available. The analysis is also restricted to incidents involving motor vehicles because data are not available on the amount of pedestrian, equestrian and bicycle traffic. The second regression has the number of deaths that occur in these incidents as the dependent variable. The persons killed are mainly highway users, but there are fatal injuries sustained by train crew and passengers. Data for both of these items are available from the Federal Railroad Administration (FRA).

The variable representing the amount of exposure to incidents and deaths is the number of public crossings in a state. Information on the “inventory” of crossings is reported by the FRA. In the regression, the variable is expressed in logarithms. The effect is to imply that:

$$\text{Count of Incidents} = \text{Crossings}^{\beta} \times \text{other variables} \quad (3)$$

In the classic Poisson formulation, β is restricted to equal unity. Twice as many crossings should imply that there will, on average, be twice as many incidents. In the initial analysis, β will not be constrained in this way. The reason is that the crossings that have been closed will probably not be "typical" crossings. Lines that have been abandoned will typically be those with a lower-than-average number of trains, and crossings that are closed as part of the consolidation program generally have lower-than-average highway traffic. Because the number of expected conflicts at these crossings will be lower than average, crossing closure should have a less-than-proportional effect on incidents and deaths. This can be verified by conducting standard statistical tests on the estimated coefficient based on a null hypothesis that $\beta = 1$. Moreover, the form of the regression means that β can be interpreted as an elasticity. This useful feature has been carried over to the other continuous independent variables, which are also expressed in logarithms.

Explanatory variables include the amount of rail and highway traffic. Full details on the construction of these variables are given in the original paper [3]. The highway AADT was calculated for non-interstate highways (ie., these grade-separated highways are excluded) by dividing the number of annual non-interstate vehicle miles traveled in a state by the number of miles of non-interstate highways, and then divided by the number of days in the year.

Disaggregated data on train miles are not available by state. There is national data on the number of train miles and also the number of route miles. This can be used to calculate a time series of the national number of daily trains per route mile. A point estimate of the state-by-state distribution of train frequency can be obtained from the FRA's crossing inventory data. The most current inventory file for public at-grade crossings was downloaded from the FRA's web site, and the average number of daily trains were calculated for each state. A "state correction factor" was derived by comparing the state average to the national average. This factor varied from 1.72 in Nebraska (72% above the national average) to 0.21 in South Dakota (79% below the national average). This state correction factor was then applied to the national average number of daily trains in each year.

The next variable represents the proportion of crossings fitted with active warning devices (gates and/or flashing lights, highway signals, wig-wags, bells or flag persons). In regression models of risk at individual crossings, there is a problem that the installation of active warning devices is endogenous. The inherent risk at the crossing (due to the amount of road traffic, crossing alignment etc.) determines the priority given to the crossing when budget decisions are made for installation of devices. While active warning devices should reduce risk, the regression might misstate the magnitude of the effect because only higher risk crossings are provided with active warning devices. This is less of a problem in this analysis. The data represent the situation in a state in a given year. In an ideal world, Section 130 monies would be distributed to states in relation to the relative risks. In this case, there would be problems of endogeneity. Of course, political realities mean that funds have to be distributed with regard to "equity" and perhaps other considerations. Overall there is a low correlation, of -0.08, across states between the number of incidents per crossing and the proportion of crossings with active warning devices, suggesting that other factors may be at work. For example, among the states with high numbers of incidents per crossing, some (Florida, Indiana and Ohio) have a high proportion of active warning devices, while some southern states (Louisiana, Mississippi, Alabama and Arkansas) have a very low proportion. Therefore endogeneity is much less of an issue in this analysis than it is in Austin and Carson's [1] study of individual crossings.

The next variables represent highway safety performance on parts of the roadway away from grade crossings. Slightly different versions of this variable are used in the two equations. In the fatalities equation, the variable is the number of fatalities in all motor vehicle crashes, less those occurring at grade crossings, divided by annual vehicle miles traveled on all classes of road. The variable is expressed as a rate per 100 million vehicle miles traveled. In the incidents equation, the variable is the total number of fatal motor vehicle crashes, less those occurring at grade crossings, divided by annual vehicle miles traveled.

In the primary analysis, the effect of OL is represented by a dummy variable equal to one for years in which the program was operational in a state, and zero otherwise. Later in the paper, a follow-up analysis is reported on the relationship between the amount of activity by OL in a state and crossing risks. However, that analysis has to be confined to the years since 1996, because data on OL activity were not collected in a consistent way prior to this date.

The rule that required fitting of ditch lights to trains was issued at the end of August 1995, and took effect from December 31, 1997. Assuming that locomotives were fitted with these additional lights at a constant rate from September 1995 to December 1997, the average proportion of locomotives so fitted would be zero in 1994 and prior years, 0.05 in 1995, 0.33 in 1996, 0.78 in 1997 and 1 from 1998 onwards. It was not possible to determine whether the rate of installation varied by state.

A series of dummy variables for each state are used to represent regional differences that are not captured by the other explanatory variables. These include (but are not limited to) geographic and socioeconomic factors such as topography (which will affect sight lines at crossings), the degree of settlement at the time that the railroads were first built, and the degree of urbanization. Because a constant term is included in the regressions, it is necessary to exclude one dummy variable. That state then acts as the base against which others are compared. Georgia was selected to be the base state because it has a large number of crossings and is ranked in the middle with regard to incidents and deaths per crossing. Some might argue that state dummy variables should not be included in the regressions, as they might subtract from the power of the other variables in explaining the differences between states. While this may be true, inclusion of the variables is consistent with the purposes of this initial analysis, which is more concerned with analyzing change over time than trying to explain the differences between different parts of the country.

Regression Results

The regression results for the main variables are shown in Table 1. For the sake of space, the estimated coefficients for the state dummy variables are not shown here, but can be found in the original paper [3]. The pseudo R^2 is 0.30 for the incidents equation and 0.28 for the fatalities equation.

In both equations the coefficient on the exposure variable, the number of crossings, is significantly less than unity. This implies that the number of incidents and fatalities falls at a lower rate than the number of crossings. Closing 10% of crossings is estimated to reduce the number of incidents by 5.1% and the number of fatalities by 2.7%. The explanation is that the crossings that have been closed probably had lower than average risk either because the number of trains was few (in the case of crossings closed due to line abandonment) or because the amount of highway traffic was limited (in the case of crossing consolidation). Moreover, in the case of crossing consolidation, the risk does not totally disappear because the displaced highway traffic is usually still traversing the railroad at a neighboring crossing.

The effects of the variables that indicate the expected number of conflicts between trains and highway users are, for the most part, consistent with prior expectations. A 10% increase in the average number of trains per day leads to an almost proportional increase in the number of fatalities, and a 6.6% increase in the number of incidents. The effect of increases in highway traffic is somewhat smaller. An increase in highway AADT of 10% leads to a 4.4% increase in fatalities, but a very small increase of only 0.2% in the number of incidents. The latter effect is statistically indistinguishable from zero.

The results of this analysis are not necessarily inconsistent with the large body of existing literature which has found that highway traffic volume is a very strong predictor of the risk of incidents at individual crossings. All of that literature is at a very *micro* level and focused on differences in risk between individual crossings. It makes sense that heavily-used crossings will generate more incidents than lightly-used crossings. The current analysis is at a much more *macro* level and asks what is the effect of changes in highway traffic density on crossing safety in general, and should not be taken to imply that highway traffic volumes are not good predictors when making *micro* level comparisons of individual crossings.

An increase in the proportion of crossings with active warning devices by 10% leads to a 4.8% decrease in incidents and a 3.1% decline in fatalities. Both effects are highly statistically significant, particularly in the incidents regression.

A strong relationship is found with regard to safety elsewhere on the highways, meaning that the improvement in safety at grade crossings cannot be considered in isolation to public policy initiatives and changes in driver behavior on the roads in general. A 10% decrease in the rate of fatal crashes elsewhere on the highway is associated with an 8.5% decrease in the incidents at grade crossings. A 10% decrease in the fatality rate elsewhere on the highway is associated with a 5.8% decrease in fatalities at grade crossings. The fact that the coefficients of these variables are less than unity should not be taken as an indication that safety has not improved as fast at grade crossings than it has at other locations. In fact the reverse is true. While highway safety away from grade crossings has improved by about 55% between 1975 and 2001, the rate of incidents and fatalities at grade crossings per vehicle mile traveled has declined by more than 80%.

Implementation of OL in a state is found to result in a 15% decrease in the number of incidents and a 19% decrease in the number of fatalities. (One takes the exponential of an estimated dummy variable coefficient to find its effect in this type of regression.) This is smaller than the greater than 40% decrease claimed from its initial implementation in Idaho. However, that analysis simply compared incident rates before and after implementation and did not account for other factors that reduced risk.

The installation of ditch lights is found to have a particularly large effect. The equipping of the entire fleet is estimated to have reduced the number of incidents by 29% and the number of fatalities by an amazing 44%.

Decomposition of Changes in Incidents and Fatalities

From 1975 to 2001 the number of annual incidents involving motor vehicles fell by 8,276 from 10,971 to 2,695. The number of annual fatalities in these incidents fell by 471 from 786 to 315. What can the regressions tell us about the contribution of the various causes to this decline? As described in detail in the original paper, the regressions can be used to predict the effect of the changes from year to year in the explanatory variables. Consequently, one can predict the change that is expected to occur in the number of incidents and fatalities in, say, Illinois from 1975 to 1976. The decomposition was carried out for each of the annual changes from 1975 to 1976 through 2000 to 2001 for each of the states. This is a total of 1,274 cases for both equations. The cases were then summed together to produce a total for the nation over the 27-year period. The resulting decompositions are shown in Table 2. The sum of the error terms, which is to say the changes not explained by the regression, total a net increase of 294 incidents and 95 fatalities. The explanation is that the actual number of incidents and fatalities in 1975 were remarkably low, whereas in 2001 the actual and predicted numbers are much closer.

Interpretation of Results

A number of conclusions can be drawn from the analysis. The first is that improvements in crossing safety cannot be viewed in isolation to general changes in highway safety. Reductions in drunk-driving, advances in automotive technology such as braking, and improvements in the effectiveness of emergency medical response have as much effect at highway-rail intersections as they do at highway-highway intersections. The magnitude of this effect on crossing incidents and fatalities is about twice the size of that due of the installation of active warning devices. That said, some of the improved safety elsewhere on the highway is a result of actions similar to those in the Section 130 program such as signalization of intersections and improved geometry and signage. To some extent it is possible that some of the benefits of the Section 130 Program may be included in the estimated magnitude of this variable. Although the correlation between Section 130 expenditures (measured by the installation of active warning devices) and the death and fatal crash rates elsewhere on the highway is less than 0.5.

The second is that ditch lights would appear to be very successful. The triangle of locomotive lights has been really effective in allowing motorists to judge how far a train is from a crossing and the speed at which it is moving. Even though ditch lights were introduced at a time when the risks at crossings were already much reduced from the 1970s, the magnitude of the effect on incidents is similar in size to that of OL and the installation of active warning devices. In terms of fatalities, the magnitude is the same as the *combined* effect of OL and the installation of active warning devices. The size of the effect probably exceeds all expectations by the proponents of increased locomotive conspicuity.

A possible explanation is that there were a number of other, unquantifiable, risk reduction activities occurring about the same time. The impetus for these activities was a collision between a school bus and a commuter train at Fox River Grove, Illinois in October 1995 that led to the deaths of seven children. The activities included clearing of line side vegetation in some parts of the country which improved sight lines, industry funded prime-time public service announcements, and the gradual posting of signs at crossings giving a toll-free telephone number for reporting problems such as vehicles stalling on the tracks. The latter would become more useful later in the decade as cellular telephones became more ubiquitous.

Third, the implementation of OL has a remarkably large effect. In terms of the number of incidents averted, the effect is four-fifths of the size of that due to installation of active warning devices. In terms of fatalities, the effect is larger than that due to installation of active warning devices. This result is not too surprising. More than half of all fatalities occur at crossings with passive warning devices and, because the traffic volumes are much lower, the risks to the highway user are at least four times as great as at a crossing with active warning devices. There is considerable public misperception of the risks posed by grade crossings, the meaning of various warning signs, and the type of conduct required [2]. Consequently there are great potential benefits from public education.

One qualification needs to be made with respect to OL. The estimated equation is multiplicative in nature. The estimated coefficients predict that OL reduces the number of incidents by 15% and the number of fatalities by 19%. OL spread across the country during the late 1970s and early 1980s when the level of risk was much higher than it is today. We estimate that the initial implementation of OL prevented 1,455 annual incidents and 164 annual fatalities. The effect of ceasing these activities today would be much smaller, leading to 500 more collisions each year and 75 more deaths.

Finally, capital expenditures on installing active warning devices have led to annual reductions in the number of incidents and fatalities. Using these data, a cost-benefit analysis in the original paper [3] estimated that the present value of the safety improvements and the time saving benefits from not having to slow down to reconnoiter is $18.7 billion over the life of the equipment, compared with $9.0 billion in capital expenditures and annual maintenance. The benefit-cost ratio of the Section 130 program is approximately 2.1, or $1.10 of net benefits for every $1 expended. Not included in these figures are the benefits from reduced rail and highway disruption because of the smaller number of incidents.

Of course, Section 130 money has not been used exclusively on installation of active warning devices. It has been partly used to renovate existing crossings that already had active warning devices, consolidate crossings, close some crossings by providing bridges, renew passive warning devices and many other types of crossing improvements. Allowing for the fact that the capital costs may be overstated, and the possibility that some of the benefits have been captured by the variable representing safety improvements elsewhere on the highway, the estimated benefit-cost ratio should be regarded as the lower bound for the actual effectiveness of this program. In retrospect, the Section 130 program can be regarded as remarkably successful, and has led to real saving of life and serious injury at a relatively modest cost.

Further Analysis of the Effect of Operation Lifesaver

OL is a state-based organization, and the levels of activity vary greatly across the country. In addition, the level of activity in a state varies over time. Data were not available for the analysis reported above to permit use of a continuous variable to indicate the level of activity in a state. A national office for OL was only established in the late 1980s, and uniform reporting of activity to the national office was only instigated in 1996. A follow-up analysis used information from these state-level reports from 1996 to 2002 to relate differences in activity levels between states and across time to the number of incidents and fatalities [4].

Some observations had to be dropped either because the state organization did not submit a report to the national office for a given year, or because, after consultation with the national office of OL, it was felt that the reported data were incomplete or considered unreliable. Generally, volunteer coordinators are reporting on the activities of volunteer presenters, and in some cases the reporting is not very good. Consequently, three states were excluded in their entirety, data on 14 annual observations involving 11 additional states were missing, and 16 years involving nine different states were dropped because the data were questionable or were incomplete. The total usable sample size was therefore 292 out of a possible 343 observations.

The measure of activity by OL is the number of presentations and special training events. It is expressed as a rate per thousand crossings to avoid problems of collinearity with the exposure variable. This was felt to be the most reliable and consistently reported measure of activity. Presentations make up 95% of the total. Special training events are also included because it is not clear whether certain activities such as talks to truck drivers, school bus drivers and emergency responders are consistently classified in one category or the other. State coordinators are also required to report the number of people in attendance at these events. Theoretically, this would be a preferable measure. However, in practice there are some anomalies which make use of this measure questionable. OL has other activities beside presentations, such as placing public service announcements. Casual reading of the state reports suggests that states that are very active in making presentations are also very active in other activities. So the variable used should be seen as a proxy for the total level of activity.

Analytically the biggest concern is endogeneity, caused when the level of OL activity in a state is dependent on the inherent grade crossing risk in that state. Locations with a high inherent risk may engender much OL activity, and in low-risk areas there may not been much pressure to mount extensive programming. Endogenous feedback will affect the magnitude of the estimated relationship between OL activity and crossing collisions. In reality this is not the case. Among the states with extensive OL programs are Illinois which is a high-risk state, and a number of states in the Northeast which traditionally have had a low risk of incidents. At the other end of the spectrum are ten states with exceptionally low levels of OL activity. Some of these states, such as North and South Dakota, have historically low incident risk, primarily because both highway and rail traffic is light. However others, such as Mississippi, Michigan and North Carolina, are among those with the highest rate of grade crossing incidents in the country. There are often random historical reasons explaining the level of activity in each state. These include emergence of dominant personalities that have championed the cause, differences in formal structure (charitable organization versus part of state government), and different levels of commitment from school districts.

In addition to the cross-sectional variation, there is also considerable variation across years for individual states due to a diverse set of exogenous reasons: the volunteer coordinators change and are replaced by either energetic new people or less-organized people, prolific presenters retire, school districts change their policies regarding presentations in schools, and railroads change their policies regarding allowing employees to make presentations during working hours. There can be as much time-series variability in activity as there is cross-sectional variation. Overall, there would seem to be numerous exogenous influences that determine the level of activity both across states and across time, and not much suggestion of a strong endogenous relationship.

The remaining variables and the analytical technique are the same as the primary analysis with three exceptions. The first difference is that the coefficient on the variable measuring the number of crossings was found to be statistically indistinguishable from unity. Therefore, as in the classic version of the negative binomial regression, this variable is treated as a pure “exposure” variable with its coefficient set to one. The explanation for this difference from the 1975-2001 analysis is that the number of crossings has been reasonably stable in the past decade. Most of the crossing closures due to line abandonments occurred in the decade between the mid-1970s and the mid-1980s. The second difference is that the variable measuring the proportion of locomotives fitted with ditch lights is expressed in logarithms. The third difference is that the state dummy variables are not included. This is because, unlike the primary analysis, we are now interested in quantifying differences across states as well as across time.

The regression results are shown in Table 3. The pseudo R^2 is 0.089 for the incidents equation and 0.086 for the fatalities equation. OL activity is found to have a significant effect on the number of incidents. The coefficient implies that increasing the amount of educational activity will reduce the number of collisions with a point elasticity of -0.11. A relationship between OL activity and the number of deaths cannot be established with statistical certainty. In some ways this is not surprising. Deaths are only a tenth as numerous as incidents and are heavily concentrated in a few states. Half of all the fatalities occur in just eight states, and in half the states the average number of fatalities per year is five or fewer. Consequently, there is considerable year-to-year random variability in the number of fatalities, and it is more difficult to find statistical robust relationships.

Conclusions

The number of collisions and fatalities at highway-rail intersections in the United States has declined significantly over the past thirty years, despite considerable increases in the volume of rail and highway traffic. This paper disaggregates the improvement into its constituent causes. The analysis concludes that about two-fifths of the decrease is due to factors such as reduced drunk driving and improved emergency medical response that have improved safety on all parts of the highway network. The installation of gates and/or flashing lights accounts for about a fifth of the reduction. The development in the 1970s and early 1980s of the OL public education campaign, and the installation of additional lights on locomotives in the mid-1990s, each led to about a seventh of the reduction. Finally, about a tenth is due to closure of crossings resulting from line abandonments or consolidation of little-used crossings. Further analysis, using data from 1996 to 2002, finds that increasing the amount of OL activity in a state reduces the number of incidents with a point elasticity of -0.11, but the effect on the number of deaths cannot be concluded with statistical certainty.

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Table 1: Regression Results for 1975-2001

	Incidents involving Motor Vehicles at Public Crossings		Fatalities from Incidents involving Motor Vehicles at Public Crossings	
	Coeff.	t	Coeff.	t
Constant	-1.9704	2.02	-5.7515	2.63
Log of Number of Public Crossings	0.5080	5.09*	0.2724	3.31*
Log of Average Annual Daily Non-Interstate Highway Traffic	0.0199	0.30	0.4390	2.86
Log of Average Daily Number of Trains	0.6646	7.02	0.9901	4.66
Log of Proportion of Public Crossings with Active Warning Devices	-0.4886	7.64	-0.3117	2.15
Log of Highway Fatal Crashes per 100 million Vehicle Miles Traveled (excluding grade crossing incidents)	0.8531	17.92		
Log of Highway Fatalities per 100 million Vehicle Miles Traveled (excluding grade crossing incidents)			0.5775	5.18
Operation Lifesaver Dummy Variable	-0.1586	7.68	-0.2130	4.54
Proportion of Locomotives with Ditch Lights	-0.3484	11.61	-0.5746	8.53
Also State Dummy Variables (Excluding Georgia) – see original paper [3]				
alpha	0.0258	15.98	0.0761	9.93
Observations	1323		1323	
Constant-only Log Likelihood	-7720.31		-4524.80	
Log Likelihood	-5387.62		-3259.51	
Pseudo R^2	0.3021		0.2796	

* = comparison with a null hypothesis that coefficient = 1.

Table 2: Decomposition of Change in Annual Totals

Totals may not add due to rounding	Incidents involving Motor Vehicles at Public Crossings	Fatalities from Incidents involving Motor Vehicles at Public Crossings
Actual Annual Totals		
1975	10,971	786
2001	2,695	315
Change	- 8,276	- 471
Changes Explained by Regressions		
Crossing Closures	- 1,040	- 60
Increased Highway AADT	+ 89*	+ 201
Increased Frequency of Trains	+ 556	+ 157
Increased Proportion of Active Warning Devices	- 1,786	- 115
Increased Safety Elsewhere on Highway	- 3,913	- 305
Operation Lifesaver	- 1,455	- 164
Locomotives with Ditch Lights	- 1,279	- 268
Sum of Crossproduct Terms	+ 259	- 12
Change Not Explained by Regressions		
	+ 294	+ 95

* = cannot be statistically distinguished from zero.

Table 3: Regression Results for Operation Lifesaver Analysis 1996-2002

	Incidents involving Motor Vehicles at Public Crossings		Fatalities from Incidents involving Motor Vehicles at Public Crossings	
	Coeff.	t	Coeff.	t
Constant	-11.2098	16.91	-16.1693	12.01
Number of Public Crossings	Exposure*		Exposure*	
Log of Average Annual Daily Non-Interstate Highway Traffic	0.7741	10.79	0.8372	5.99
Log of Average Daily Number of Trains	0.4803	7.43	1.0114	7.21
Log of Proportion of Public Crossings with Active Warning Devices	-0.8107	6.93	-1.1805	4.85
Log of Highway Fatal Crashes per 100 million Vehicle Miles Traveled (excluding grade crossing incidents)	0.9005	8.68		
Log of Highway Fatalities per 100 million Vehicle Miles Traveled (excluding grade crossing incidents)			1.2829	6.91
Log of Operation Lifesaver Presentations and Special Training per 1000 Crossings	-0.1089	3.26	-0.0552	0.90
Log of Proportion of Locomotives with Ditch Lights	-0.2029	3.17	-0.1988	1.73
alpha	0.1063	9.39	0.2239	5.98
Observations	292		292	
Constant-only Log Likelihood	-1284.24		-745.58	
Log Likelihood	-1169.87		-681.41	
Pseudo R^2	0.0891		0.0861	

* = Regression treats the elasticity between the number of crossings and incidents/fatalities as unity (in other words, the coefficient on the logarithm of this variable is constrained to equal 1).