Risk Analysis, Vol. 25, No. 4, 2005 DOI: 10.1111/j.1539-6924.2005.00642.x

Why Has Safety Improved at Rail-Highway Grade Crossings?

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The number of collisions and fatalities at rail-highway intersections in the United States has declined significantly over the past 30 years, despite considerable increases in the volume of rail and highway traffic. This article 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.

KEY WORDS: Accident analysis; active warning devices; Operation Lifesaver; rail-highway crossings; United States

1. INTRODUCTION

By the mid 1960s, rail-highway grade crossing safety had become an issue of great public concern. While the absolute number of fatalities had peaked in the 1928, the rate of fatalities relative to rail traffic continued to rise. In 1966 the rate of highway-user fatalities was 1.95 per million train miles compared with 1.13 in 1950. The underlying cause was the increase in road traffic coupled with the worsening financial condition of the railroads that limited the funds available to install flashing lights, gates, and warning signs. Historically, the railroads had a common law duty to determine the type of warning device to install at a particular crossing and had to bear the costs of installation and maintenance.

As early as 1962 the Interstate Commerce Commission (ICC) argued that the solution was to transfer the financial burden and planning of crossing improvements to the highway authority. They argued that this change would be equitable because "[h]ighway users are the principal recipients of the benefits."(1) A decade later, the newly formed federal Department of Transportation (DOT) concluded that it was anomalous that railroad grade crossings were "the only place along the highway where the state authorities do not have total control over the installation . . . of traffic control devices."(2)

The subsequent political debate led to the Federal-Aid Rail-Highway Crossing Program as part of the Federal Highway Act of 1973. This is commonly referred to as the Section 130 Program. Over the following 30 years, the federal government spent approximately $8 billion, at current prices, to improve grade crossings. The federal money is channeled through state agencies (often the highway authority) that play a key role in deciding which crossings should be

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improved. Federal funds typically cover 90% of the cost. The remaining 10% comes from the railroads, the state highway authority, the municipality, or a combination of the three. In fiscal year 2001, the federal government allocated $155 million to the states, a level of funding that has remained nearly constant in nominal terms over the past 15 years.

A cost-benefit manual and software,(3) an associated handbook,(4) and since 1977 a chapter in the Federal Highway Administration's (FHWA) *Manual on Uniform Traffic Control Devices*(5) give professional guidance on how to set priorities for which crossings to improve. The improvements can take many forms. The most prevalent has been the upgrading of warning devices. Crossings that previously only had signs, known as passive warning devices, were fitted with flashing lights that indicate the approach of a train. Crossings that previously had flashing lights were upgraded by the installation of gates that provide a barrier across the roadway. The proportion of public crossings with gates and/or lights, known as active warning devices, increased from 26% in 1975 to 43% in 2001. Other types of improvements have included providing warning signs at crossings that previously were unmarked, renewing existing warning devices, installing better lighting, increasing sight-distances, improving the angle at which the highway and railroad intersect, and separating trains from road traffic by building bridges for one to cross the other.

The federal government has also encouraged the closing of little-used crossings and consolidating traffic onto a smaller number of crossings, which were provided with upgraded warning devices. The railroads have a legacy, dating back to the days of horse and buggy, of providing a crossing at every intersecting street. Between 1975 and 2001, almost 30% of crossings were closed due to the crossing consolidation program or because the railroads abandoned lines following liberalization of economic regulations by the Staggers Act of 1980.

Another manifestation of the safety efforts was increased emphasis on data collection. Using this data, it would appear that the programs put in place in the early 1970s have been very successful. The annual number of collisions between motor vehicles and trains at public crossings declined by 75% between 1975 and 2001. The number of annual deaths in these collisions, which amounted to nearly 1,000 in 1976, declined by 68% to 315 in 2001. In addition, in 2001 there were 71 deaths involving collisions with pedestrians and other nonmotorized users at public crossings, and 35 deaths at "private" crossings where adjacent landowners typically are the sole users. The rate of highway-user fatalities declined from its peak of 1.95 per million train miles in 1966 to only 0.59 in 2001. The decline has been so dramatic that by 1997 grade crossings ceased to be the leading cause of death on the railroads. The number of annual trespassing victims surpassed the number of grade-crossing fatalities for the first time in more than half a century.

It would be incorrect to attribute all of the apparent improvement to the Section 130 Program. 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 declined by 52% between 1975 and 2001. Safety at rail-highway intersections has to be viewed in relation to the experience at highway-highway intersections and elsewhere on the highway network.

At the same time there were trends that would be expected to increase the number of collisions and fatalities. More cars were being driven more miles, increasing highway traffic density and increasing the chance that a highway vehicle is present when a train approaches a grade crossing. Average annual daily traffic (AADT) on nongrade-separated highways increased by 80% between 1975 and 2001. The amount of rail traffic on those parts of the network that were not abandoned has also increased. The average number of trains relative to the size of the rail network has increased by 30%. Taken together, the number of potential highway vehicle-train interactions has increased.

A perpetual problem has been highway users' poor perception of the dangers of grade crossings. Drivers misjudge the speed of approach of trains, and because they are in a hurry, they are tempted to drive around lowered gates and/or ignore the flashing lights. In some cases, where devices have been known to malfunction and no danger is visible, drivers may inappropriately suspect a false activation of the signals. In excess of 80% of the fatalities at crossings with active warning devices occur when the highway user has ignored the warning device. At crossings with passive warning devices, the conduct expected of drivers in observing for an approaching train is ill defined. Consequently, in each state nonprofit organizations called Operation Lifesaver were established to promote education and awareness of railroad-related hazards, especially the need to follow safety warnings at grade crossings. The first program was established in Idaho in 1972, and its introduction was claimed to have produced a 40% decline in crossing fatalities. The program then spread state by state across the nation by 1986.

In another 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.

This article investigates the relative contribution of these factors to the improvement in crossing safety. A difficulty faced by past researchers is that at a national level all of these factors are highly collinear. The correlations are at least 0.6 and in many cases in excess of 0.9. This article overcomes the problem by developing a panel data set for 49 states for the years between 1975 (when comprehensive data were first collected) and 2001. This introduces much more variability into the data and generally reduces correlations below 0.5, and in some cases considerably below 0.3.

Determination of the relative contributions of the various factors has political importance. The size of the Section 130 Program has been held constant in monetary terms since the mid 1980s, and consequently its resources have been eroded by inflation. In the 2003 reauthorization of the federal surface transportation funding, it was proposed that states would be free to use the money previously earmarked for crossing improvements on any safety initiative, regardless of mode. Both the railroads and state highway authorities have argued that this proposal risks diverting funds from a worthwhile program.

2. ANALYTICAL TECHNIQUE

There is a huge literature on modeling the risk at individual crossings. Models have existed for more than 60 years. Austin and Carson(6) provide a historical review and a state-of-the-art model. Explanatory variables typically include the highway AADT, the daily number of trains, maximum allowable rail speed, the number of railroad tracks, the number of highway lanes, the angle at which the highway crosses the railroad, and the types of warning devices present. These models are widely used by state highway authorities to prioritize crossings for upgrading of warning devices.

Unlike most previous models, Austin and Carson(6) use the negative binomial regression technique.(7,8) This technique has now become almost standard in the analysis of accident frequency and is used in the current article. The negative binomial regression uses a count of the number of highway-rail "incidents" and the number of fatalities in a given state in a given year as its dependent variable, rather than an incident rate. It is commonly recognized that the number of crashes in a given state in a given year will vary around some underlying mean, and the distribution is characterized by the Poisson process. Moreover, the dependent variable can only take nonnegative integer values. The estimated equation can be usefully visualized as having the form:

$$\text{Count of incidents} = e^{(\beta\,\text{exposure}+\gamma\,\text{other variables})} + \epsilon.$$

Exposure to incidents is an explanatory variable. In a model of risk at individual crossings, the exposure to incidents is the expected number of times in a day that a train and a highway user will arrive simultaneously at the crossing (i.e., the expected number of potential conflicts). This will be a scalar transformation of the product of the highway AADT and the frequency of trains at the individual crossing. The model in this article is at a much more macro level, and represents the incident experience in a state in a given year. Therefore, one should think that the appropriate measure of exposure to incidents is the number of crossings. A state with twice as many crossings, holding everything else constant, should produce twice as many potential conflicts and twice as many incidents and fatalities.

The Poisson distribution of incidents in state i for year t is characterized by a parameter λ_{it}, which represents both the mean number of incidents and its variance. The statistical technique estimates λ_{it} based on the explanatory variables in the regression. Problems can emerge with the error structure when the regression does not contain every variable that explains the differences in λ_{it} across states and years. Given the low likelihood that one is ever able to fully account for all of the idiosyncratic differences, both we and other researchers have used a modified regression technique called the negative binomial. This estimation technique assumes that the error term is distributed according to a gamma distribution. The regression model 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:

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

The statistical package used (Stata Corporation's Stata) 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. In our regressions, we reject the null hypothesis that $\alpha = 0$. Moreover, because the estimated values of α are positive, the data are referred to as overdispersed.

There are versions of the negative binomial regression that allow for the magnitude of the overdispersion to vary across different groups in the panel. This is to say that the data for, say, Texas may have a different level of overdispersion than, say, New York State. Note that this represents differences in the α values, and not possible differences in the values of the estimated coefficients between states. Regressions were conducted using a random effects model whereby the differences in α between states are not related to any of the explanatory variables. A likelihood-ratio test strongly rejected any improvement in fit in the regression with the number of fatalities as the dependent variable, and in the regression with the number of incidents as the dependent variable, the log-likelihood actually got worse. Therefore, the regressions are estimated with the data treated as a pool of time-series and cross-sectional elements.

3. VARIABLES AND DATA

The data set consists of a panel of 49 states for the years 1975–2001. Hawaii is not included because it has negligible railroad mileage and crossings, and neither is the District of Columbia, which has a negligible number of grade crossings, many of which are little used and do not even have any warning signs. There were no fatal incidents in the District over the period. Inclusion of the District would have a misleading effect on the analysis because it has extraordinary high highway AADTs, yet most of the traffic will never encounter a grade crossing.

Two separate regressions are conducted. The first is on 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 (Form FRA F 6180-57) 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 is the number of deaths that occur in these incidents. 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 in the printed Federal Railroad Administration (FRA) annual reports on grade crossing safety.(9) In addition, the FRA's website has an excellent searchable database on all grade-crossing incidents since 1975. The data from the printed volumes were double checked against the online database, and a number of minor discrepancies corrected, primarily prior to the mid 1980s.

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 given in the printed FRA annual grade-crossing safety report. In the regression, the variable is expressed in logarithms. The effect is to imply that:

$$\text{Count of Incidents} = \text{Crossings}^{\beta} \times \text{other variables.}$$

In the classic Poisson formulation, β is restricted to equal unity. Twice as many crossings should imply that there would, on average, be twice as many incidents. In this 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 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. Highway AADT and the frequency of trains will affect the number of potential conflicts at crossings. These variables vary markedly both between states and over time. The inventory of individual crossings contains information on both of these variables obtained by surveys undertaken at the crossings. Unfortunately, the data are not updated on a regular basis. Therefore, one cannot use this data source alone to construct a historical database of changes in AADT and rail traffic.

State average AADT is readily available from the FHWA's *Highway Statistics*.$^{(10)}$ The variable excludes travel on urban and rural interstate highways and urban expressways and freeways. These roads are grade-separated, and travelers do not encounter grade crossings. The state average noninterstate AADT for state i in year t is given by:

$$\text{AADT}_{it} = \frac{\text{Noninterstate Annual Vehicle Miles Traveled}_{it}}{\text{Miles of Noninterstate Highways}_{it} \times \text{Days}_t},$$

where annual vehicle miles traveled in the state are in Table VM-2 (the data are reported in millions of miles, and is multiplied by a million), and miles of highway are in Table HM-20 (prior to 1980, Table M-12). (Note that urban expressways and freeways are not shown as an explicit category prior to 1980. For these years the miles of freeway are taken to be the same as in 1980, and the amount of travel is assumed to vary from its 1980 level proportionate to total urban travel.) Days are the number of days in the year. AADT varies widely by state, ranging from an average of 4,500 in New Jersey down to 180 a day in North Dakota. The national average noninterstate AADT has increased markedly over time from 750 in 1975 to 1,350 in 2001.

Disaggregated data on train miles are not available by state. National annual data are available on the number of train miles from the FRA's annual *Accident/Incident Bulletin*.$^{(11)}$ This is for railroads of all sizes. The number of railroad road miles, which is a measure of the route length, is reported by the Association of American Railroads (AAR) annual *Railroad Facts*.$^{(12)}$ This publication includes definitive measures of route length of the large "Class I" railroads, and an estimate of the route length of the smaller railroads. Of course, not all states have the same frequency of trains. 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 website, and the average number of daily trains was 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). Data were then calculated on the average number of daily trains for state i in time period t by the formula:

$$\text{Trains per Day}_{it} = \frac{\text{National Train Miles}_t}{\text{National Railroad Route Miles}_t \times \text{Days}_t} \times \text{State Correction Factor}_i.$$

The average number of trains per day varies from 18 a day in Illinois and Nebraska down to less than 4 a day in Rhode Island, Maine, New Hampshire, and South Dakota. Over time the number of trains varies with the state of the economy. Comparing 2001 with 1975, the number of national train miles has declined by 6%, but the size of the network has declined by 28%, leading to a 31% increase in average number of trains per day from 10.4 to 13.6.

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). These data are reported in the FRA's annual reports on crossing safety. From 1975 to 2001 there was a net increase of 9,229 crossings fitted with active warning devices, about a 16% increase. In addition to fitting of active warning devices where previously there were none, Section 130 money has been used to add gates at many locations that previously only had lights. In 1975 only 20% of crossings with active warning devices were equipped with gates. By 2001 this proportion had increased to 53%.

The original intention was to include variables representing both the proportion of crossings fitted with gates, and those fitted with lights and not gates. However, the proportion of total crossings with only flashing lights has remained constant over time, at about 20% of crossings, as some crossings with passive warning devices were upgraded to lights, and some of those fitted with lights had gates added. Therefore, the preferred variable was to combine the variables to produce (the logarithm of) the proportion of total crossings with any form of active warning devices fitted.

A number of variations were tested and found to be inferior. In one version an additional variable was added to represent the proportion of crossings with active warning devices that included gates. In another version a variable representing the proportion of crossings with passive warning devices was substituted and not expressed in logarithms. This formulation allows the possibility that the crossings fitted with active warning devices early in the period experienced a larger reduction in risk than those treated later. This would be consistent with the models used in the industry that give priority to funding improvements at crossings that are particularly risky due to geometry and other physical characteristics. Neither version increased explanatory power, and some made the log-likelihood worse.

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 the current model. Our 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 (2002) 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 (obtained from the FHWA's *Highway Statistics*, Table FI-20) 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$^{(13)}$ less those occurring at grade crossings (obtained from the FRA searchable online database), divided by annual vehicle miles traveled. Ideally, one would want to use a measure reflecting crashes of all severities elsewhere on the highway. However, unlike the reporting requirements at grade crossings, data on nonfatal crashes, and especially property-damage-only crashes, elsewhere on the highway is poor and somewhat unreliable. There is considerable variation both over time and across states. Between 1975 and 2001, the highway death rate has fallen by more than 50%. The most dangerous states (New Mexico, Montana, and Mississippi) have more than twice the death rate of the safest (Massachusetts and Rhode Island).

Ideally, one would wish to represent the effect of Operation Lifesaver with a continuous variable indicating the extent of activities in a given state in a given year. Examples might be the number of presentations given, the number of displays exhibited, or the size of the annual budget. Unfortunately, information of this type is not readily available by state over the history of Operation Lifesaver. The organization is inherently local in nature. A national headquarters was only established in 1989. Data were not collected centrally in a consistent manner prior to 1996. Consequently, the existence of Operation Lifesaver is represented by a dummy variable equal to one for years in which the program was operational in a state, and zero otherwise. This information was obtained from Operation Lifesaver. The authors intend to conduct a follow-up analysis on the relationship between the amount of activity by Operation Lifesaver in a state and the crossing accident risk, but the analysis will have to be confined to the years since 1996, and even then the data for some states are missing or incomplete.

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 onward. It was not possible to determine whether the rate of installation varied by state.

A series of dummy variables were also included for each state. These variables 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 article, which is more concerned with analyzing change over time than trying to explain the differences between different parts of the country.

4. REGRESSION RESULTS

The regression results are shown in Tables I and II. Table I contains information on goodness-of-fit and the estimated coefficients for the main variables for both regressions. Table II contains the estimated coefficients for the state dummy variables. The data for both regressions are overdispersed, as indicated by the estimated values of α, which are positive and significantly different from zero. Therefore, the Poisson model can be rejected, and the use of the negative binomial is supported. The pseudo R^2 is 0.30 for the incidents equation and 0.28 for the fatalities equation.

Table I. Regression Results (Excluding State Dummy Variables)

	Incidents Involving Motor Vehicles at Public Crossings		Fatalities from Incidents Involving Motor Vehicles at Public Crossings	
	Coefficients	*t*	Coefficients	*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 noninterstate 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 Table II)				
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 II. Regression State Dummy Variables (Listed in Descending Order of Risk)

State Dummy Variables Compared with Georgia	Incidents Involving Motor Vehicles at Public Crossings			Fatalities from Incidents Involving Motor Vehicles at Public Crossings		
	Coefficient	Effect (%)	*t*	Coefficient	Effect (%)	*t*
Texas	0.8794	141	6.46	1.3110	271	6.46
Michigan	0.6066	83	4.86	0.6786	97	4.86
Indiana	0.6029	83	4.62	0.7217	106	4.62
Ohio	0.5126	67	3.71	0.6078	84	3.71
Wisconsin	0.4939	64	1.52	0.2281	26	1.52
California	0.4231	53	1.35	0.2458	28	1.35
Louisiana	0.3822	47	2.41	0.3779	46	2.41
Illinois	0.3557	43	2.46	0.5900	80	2.46
North Carolina	0.2243	25	1.39	0.2028	22	1.39
Florida	0.2042	23	1.52	0.2314	26	1.52
Minnesota	0.1704	19	3.25	0.5937	81	3.25
New Jersey	0.1226	13	2.80	−0.8740	−58	2.80
Pennsylvania	0.0365	4	1.62	−0.2667	−23	1.62
Alabama	0.0323	3	0.98	0.1504	16	0.98
Virginia	0.0199	2	4.54	−0.9807	−62	4.54
Mississippi	−0.0478	−5	1.97	0.4757	61	1.97
Iowa	−0.0800	−8	0.92	0.1677	18	0.92
Oklahoma	−0.0832	−8	3.77	0.5861	80	3.77
Washington	−0.0985	−9	0.62	−0.1320	−12	0.62
Massachusetts	−0.2118	−19	4.17	−1.7272	−82	4.17
Colorado	−0.2203	−20	0.12	0.0340	3	0.12
Delaware	−0.2598	−23	1.40	−1.0536	−65	1.40
Arkansas	−0.2635	−23	2.30	0.4620	59	2.30
Missouri	−0.2644	−23	1.30	0.1766	19	1.30
Kentucky	−0.2703	−24	3.81	−0.7196	−51	3.81
Maryland	−0.2852	−25	2.71	−1.3225	−73	2.71
South Carolina	−0.3099	−27	1.53	−0.2616	−23	1.53
Tennessee	−0.3202	−27	2.88	−0.4618	−37	2.88
Maine	−0.3704	−31	1.79	−0.9189	−60	1.79
Utah	−0.4293	−35	0.01	0.0026	0	0.01
Connecticut	−0.5148	−40	2.43	−1.4045	−75	2.43
Oregon	−0.5156	−40	1.90	−0.5282	−41	1.90
New York	−0.5312	−41	4.38	−0.7484	−53	4.38
Kansas	−0.5731	−44	2.57	0.5387	71	2.57
Arizona	−0.6729	−49	2.32	−0.9848	−63	2.32
West Virginia	−0.8581	−58	4.42	−1.3206	−73	4.42
Nebraska	−0.9485	−61	0.23	−0.0601	−6	0.23
Alaska	−0.9518	−61	2.25	−1.7882	−83	2.25
Idaho	−0.9785	−62	0.17	−0.0648	−6	0.17
New Hampshire	−1.0377	−65	2.52	−1.6340	−80	2.52
South Dakota	−1.0710	−66	1.48	−0.8417	−57	1.48
Vermont	−1.2820	−72	2.26	−1.4435	−76	2.26
North Dakota	−1.5179	−78	0.34	0.1291	14	0.34
Rhode Island	−1.5352	−78	2.54	−2.6359	−93	2.54
Montana	−1.6935	−82	2.05	−0.8170	−56	2.05
New Mexico	−1.7358	−82	2.31	−1.1146	−67	2.31
Nevada	−1.8835	−85	2.30	−1.6339	−80	2.30
Wyoming	−2.0838	−88	3.53	−2.1239	−88	3.53

Effect is calculated by ($e^{\text{coefficient}} - 1$) and expressed as a percentage. −8% means 8% below Georgia, and 141% means 141% above Georgia.

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 from 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 Operation Lifesaver 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%.

The state dummy variables, shown in Table II, are listed in descending order of their effect on the number of incidents. The negative binomial regression has an underlying multiplicative relationship between the variables. For example, Texas has an estimated coefficient in the incidents equation of 0.8794. The exponential of this is 2.41, implying the number of incidents is 2.41 times that in Georgia (the base state), or 141% higher, for identical values of the other variables. At the other end of the spectrum, Wyoming has a coefficient of negative 2.0838. The exponential is 0.124, or 88% below Georgia, all else being equal. In general, the states with the highest relative risk tend to be those in a broad band down the center of the country, which combine a flat landscape, extensive rail operations, and small towns. In contrast, the north-central and mountain west states have the lowest relative risk.

5. GOODNESS OF FIT

Figs. 1 and 2 give visual indications of the goodness of fit of the regressions. These graphs show the

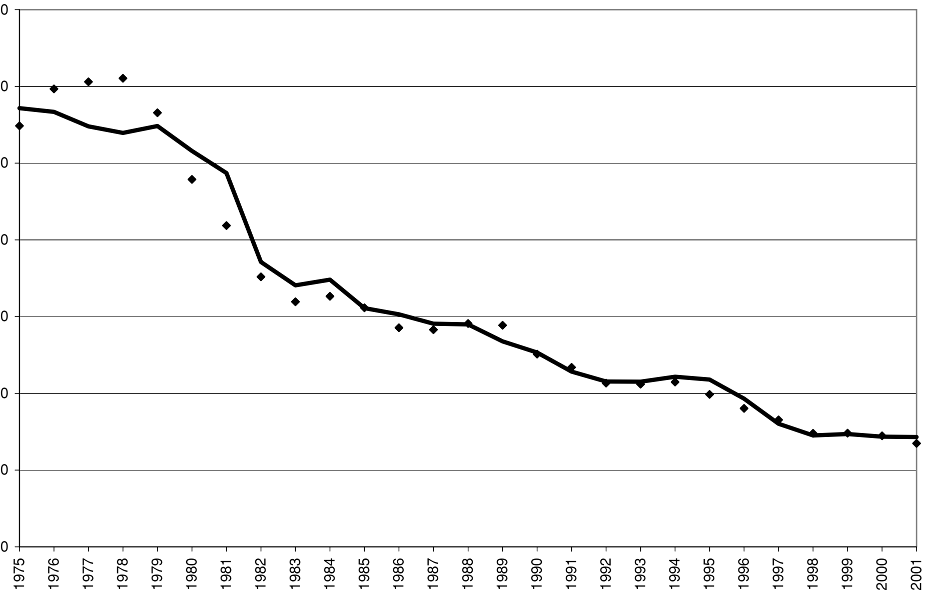

Fig. 1. Actual versus predicted annual number of incidents.

national number of incidents and fatalities in each year. The actual totals are indicated by dots, and the sum of the predicted values for the 49 states are represented by the points along the line.

Fig. 1 indicates that, in general, the regression appears to predict the actual number of incidents with remarkable accuracy. The major discrepancy is the increase in incidents from 1975 to 1979, which contrasts

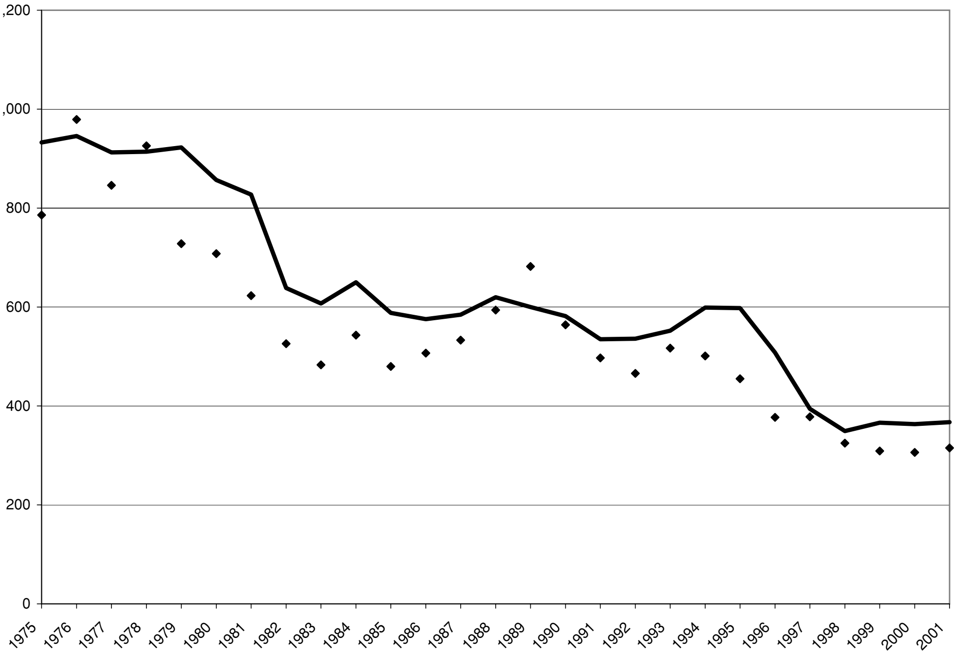

Fig. 2. Actual versus predicted annual number of fatalities.

with a predicted downward trend. There are a couple of possible explanations. The first was suggested by staff at the FRA, who suspect that there may have been underreporting by some states in the early years of the program. As the program became more established, the quality of reporting improved and this led to an increase in the recorded number of incidents. The second is related to some unusual trends in general highway safety in the mid 1970s. The 1973 energy crisis led to increases in the price of gasoline and the imposition of a national 55 miles/hour speed limit in 1974. Both the number and rate of highway crashes and fatalities dropped significantly, and to a much greater extent then would be expected, from 1973 to 1974 and 1975. Not surprisingly, this unusual improvement was eroded over the latter part of the 1970s. It is likely that the experience at grade crossings mirrored the extraordinary dip in overall highway crashes around 1975.

At least from 1979, there has been a continuous decline in the number of incidents, with a couple of periods of very swift decline. The first of these is an almost 40% drop between 1979 and 1983. This was when Operation Lifesaver was spreading across the country, and the exposure to risk declined as the economic downturn and the initial adjustments to deregulation of the railroads and the trucking industry reduced the number of trains. There is another notable decline of about 30% between 1994 and 1998, which coincided with the installation of ditch lights.

Fig. 2 shows the equivalent graph for fatalities. Compared with Fig. 1, there is much more year-to-year variability in the underlying data, and the regression appears to be less successful in accurately predicted the annual totals. The greater variability is to be expected. Annual fatalities are only about a tenth as numerous as the number of incidents and are vulnerable to fluctuations due to multiple-fatality incidents. That said, the fluctuations between 1975 and 1979 are really extreme and defy explanation.

As with the incidents graph, there are two similar periods of rapid improvement: a predicted 33% improvement between 1979 and 1983, and a 40% improvement between 1995 and 1998. An interesting feature is the apparent increases in fatalities in the late 1980s and again after 1992. The explanation appears to be the increased exposure to risk as the amount of train traffic increased with upswings in the economy. It is interesting to note that the turnaround in the increase in fatalities in the late 1980s coincided with the start of the recession in 1990. Similarly, the effect of the improvements between 1995 and 1998 might be even greater than the graph would suggest because it came at a time when the boom in the economy led to additional train traffic that would be expected to increase the numbers of fatalities.

6. 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?

The format of the estimated incidents equation for state *i* in year *t* is:

$$\begin{aligned}\text{Incidents}_{it} &= \mathrm{e}^{\alpha}\mathrm{e}^{\beta\ln(\text{crossings}_{it})}\mathrm{e}^{\gamma_1\ln(\text{AADT}_{it})}\mathrm{e}^{\gamma_2\ln(\text{Trains}_{it})}\\ &\quad\times\mathrm{e}^{\gamma_3\ln(\text{Active Devices}_{it})}\mathrm{e}^{\gamma_4\ln(\text{Highway Safety}_{it})}\\ &\quad\times\mathrm{e}^{\gamma_5\,\text{Operation Lifesaver}_{it}}\mathrm{e}^{\gamma_6\text{Ditch Lights}_t}\mathrm{e}^{\gamma_7\text{State}_i}\\ &\quad+\varepsilon_{it}.\end{aligned}$$

The change from year to year for this state can be decomposed to the following:

$$\begin{aligned}&\text{Incidents}_{it+1}-\text{Incidents}_{it}\\ &\quad=\mathrm{e}^{\alpha}[\mathrm{e}^{\beta\ln(\text{crossings}_{it+1})}-\mathrm{e}^{\beta\ln(\text{crossings}_{it})}]\mathrm{e}^{\gamma_1\ln(\text{AADT}_{it})}\\ &\quad\times\mathrm{e}^{\gamma_2\ln(\text{Trains}_{it})}\mathrm{e}^{\gamma_3\ln(\text{Active Devices}_{it})}\mathrm{e}^{\gamma_4\ln(\text{Highway Safety}_{it})}\\ &\quad\times\mathrm{e}^{\gamma_5\text{Operation Lifesaver}_{it}}\mathrm{e}^{\gamma_6\text{Ditch Lights}_t}\mathrm{e}^{\gamma_7\,\text{State}_i}\\ &\quad+\mathrm{e}^{\alpha}\mathrm{e}^{\beta\ln(\text{Crossings}_{it})}[\mathrm{e}^{\gamma_1\ln(\text{AADT}_{it+1})}-\mathrm{e}^{\gamma_1\ln(\text{AADT}_{it})}]\\ &\quad\times\mathrm{e}^{\gamma_2\ln(\text{Trains}_{it})}\mathrm{e}^{\gamma_3\ln(\text{Active Devices}_{it})}\mathrm{e}^{\gamma_4\ln(\text{Highway Safety}_{it})}\\ &\quad\times\mathrm{e}^{\gamma_5\,\text{Operation Lifesaver}_{it}}\mathrm{e}^{\gamma_6\,\text{Ditch Lights}_t}\mathrm{e}^{\gamma_7\,\text{State}_i}\\ &\quad+\cdots+\varepsilon_{it+1}-\varepsilon_{it}.\end{aligned}$$

The equation will also include (in place of the ellipses) similar terms to the first two involving changes from period *t* to $t+1$ for the variables Trains, Active Devices, Highway Safety, Operation Lifesaver, and Ditch Lights. In addition, there will be cross-product terms involving every possible combination of the value of variables in period *t* and changes in variables. There will be 127 terms in total. Of course, most of the cross-product terms will be quite small as they involve the product of two (or more) relatively small changes in the constituent variables. In addition, some of the cross-product terms will be positive and some negative, and will tend to cancel each other out.

This decomposition was carried out for each of the annual changes from 1975 to 1976 through 2000

Table III. 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 cross-product terms	+259	−12
Change not explained by regressions	+294	+95

*Cannot be statistically distinguished from zero.

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 III.

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. As inspection of Figs. 1 and 2 would suggest, the explanation is that the actual number of incidents and fatalities in 1975 was remarkably low, whereas in 2001 the actual and predicted numbers are much closer.

7. ANALYSIS AND CONCLUSIONS

A number of conclusions can be drawn. The first is that improvements in crossing safety cannot be viewed in isolation from 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 are 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 Operation Lifesaver and the installation of active warning devices. In terms of fatalities, the magnitude is the same as the *combined* effect of Operation Lifesaver 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, which 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 Operation Lifesaver 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.(14) There is considerable public misperception of the risks posed by grade crossings, the meaning of various warning signs, and the type of conduct required.(15) Consequently, there are great potential benefits from public education.

One qualification needs to be made with respect to Operation Lifesaver. The estimated equation is multiplicative in nature. The estimated coefficients predict that Operation Lifesaver reduces the number of incidents by 15% and the number of fatalities by 19%. Operation Lifesaver 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 Operation Lifesaver 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.

Operation Lifesaver is primarily a volunteer organization and operates on a shoestring budget. Funding from governments and industry sources, and the value of in-kind gifts and services (such as the provision of office space), amounts to less than $5 million a year. It is difficult to value the time of the presenters. Some are giving up their personal time, while others are permitted by their employers to make presentations during regular work hours. Each year about 30,000 presentations and special training events are held nationwide. Assuming each presentation requires an hour and that the prevailing wage rate is $20 an hour, this amounts to an annual labor cost of $600,000. Therefore, the benefits of Operation Lifesaver have been obtained for an annual cost of less than $6 million, a remarkable benefit-cost ratio.

Finally, capital expenditures on installing active warning devices have led to annual reductions in the number of incidents and fatalities. The one-time cost of installation produces a flow of annual benefits over the 30-year life of the equipment. Costs and benefits in future years have to be discounted to obtain present values. Currently, the Office of Management and Budgets recommends a discount rate of 7%.(16)

On the cost side, extending the calculations in Savage,(14) it is estimated that Section 130 capital expenditures from 1975 to 2001 have amounted to about $8.5 billion in current prices, when one includes the match funds from state and local authorities and the railroads. These costs are assumed to occur now. In addition, there are annual maintenance costs, which typically amount to $2,000 for a crossing with flashing lights, plus an additional $1,000 when gates are added.

Our research produced estimates of the number of annual deaths and incidents averted. When combined with FRA recommendations on the value of a statistical life saved, and information on typical property damages in collisions, monetary values of the benefits can be calculated. We can also infer the number of injuries of different severities based on historical relationships between the number of fatalities and injuries, and assign standard monetary values to these injuries averted.

There is a nonsafety benefit from active warning devices. These devices give the road user a positive indication of whether or not a train is approaching. Therefore, the road user does not have to slow down to reconnoiter to find out this information. A vehicle that decelerates from 50 miles/hour to 20 miles/hour starting from encountering the advanced warning sign 750 feet from the crossing, and subsequently accelerating after the crossing incurs a time penalty of 10 seconds. Using an enhanced value of travel time of $13 an hour to recognize that time spent in other than free-flow conditions is considered more disagreeable, produces a time penalty of 3.6 cents per traverse of the crossing.(14) Of course, in some locations sight lines are so good that drivers do not have to slow down to observe for a train. However, these locations are given a low priority when decisions are made on installation of warning devices.

The present value of the costs and benefits are summarized in Table IV. Footnotes to the table elaborate on the calculations and the sources for the data. About two-thirds of the total benefits come from averted deaths and the most serious injuries. The time-savings represent most of the remaining benefit. The present value of the benefits is $18.7 billion 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

Table IV. Benefit-Cost Analysis of the Section 130 Program

	Present Value ($m)
Benefits (accrue over 30 years discounted at 7% per annum)[1]	
115[2] deaths averted per year @ $3 m[3]	4,582
245[4] critical (AIS5) injuries averted per year @ $2.2875 m[3]	7,453
250[4] moderate (AIS2) injuries averted per year @ $46,500[3]	154
1,746[2] incidents of highway vehicle damage averted per year @ $5,347[5]	127
1,746[2] incidents of railroad property damage averted per year @ $8,165[6]	194
13 billion annual highway users each have time saving of 10 seconds valued at 3.6 cents[7]	6,199
Total benefits	18,710
Costs (incurred now)	
Section 130 expenditures at current prices, including matching funds[8]	8,475
Costs (accrue over 30 years discounted at 7% per annum)[1]	
Annual maintenance of 9,229[9] crossings with lights @ $2,000[10]	245
Increased annual maintenance of 23,481[9] crossings with lights and gates compared with only lights @ $1,000[10]	312
Total costs	9,032
Benefit-cost ratio	2.07

Sources:

[1] Office of Management and Budgets.(16)

[2] Estimated in this article.

[3] FRA.(17)

[4] Analysis of the database collected as part of this analysis indicates that the ratio of injuries to fatalities is 4.3:1. FRA(17) suggests that collisions involving trains traveling at greater than 25 miles/hour produce critical (Abbreviated Injury Scale 5) injuries, whereas collisions with slower moving trains result in moderate (AIS2) injuries. Publicly available data only permit observing the proportion of injuries involving trains traveling at greater than or less than 30 miles/hour. Based on this definition, 49.6% of injuries will be critical and 50.4% will be moderate.

[5] FRA,(9) year 2000 edition table 8-13.

[6] FRA,(9) year 2000 edition table 5-6 indicate that for the 210 most serious incidents the average railroad property damage was $70,368. The other 2,685 incidents must have had levels of damage below the reporting threshold of $6,600. If the latter are assumed to average $3,300, the average damage for all incidents is $8,165.

[7] FRA(9) indicates a net addition of 9,229 crossings with active warning devices from 1975 to 2001. Data in the most recent edition allow a calculation that the average AADT at crossings fitted with just flashing lights is 3,850. Hence, in a year 12.969 billion vehicles will use these crossings. See text for calculation and valuation of the time penalty.

[8] Section 130 expenditures from 1975 to 2001, adjusted to reflect 10% nonfederal matching funds, and adjusted to 2001 prices using the Consumer Price Index.

[9] FRA.(9) Figures are the net increase in crossings with lights and gates, and the implied increase in the number of crossings with just lights after adjustment for those crossings upgraded by the addition of gates.

[10] Standard industry guidelines are that annual maintenance of a crossing with flashing lights averages $2,000, which increases to $3,000 when gates are added.

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 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.

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