Investigation of Accident Data for Railroad-Highway Grade Crossings

Janet Coleman and Gerald R. Stewart, Federal Highway Administration, U.S. Department of Transportation

This paper discusses some of the results of investigations of railroad-highway accidents and accident-related inventory information that was collected from 15 states and three railroad companies. Statistical techniques were applied to tabulated data to obtain prediction equations for accident frequency and severity of various grade-crossing situations. The results of the analysis and the uses of prediction equations for the development of warrants for safety improvements are also discussed.

The 1971 and 1972 reports to the Congress on railroad-highway safety described the grade-crossing problem and presented recommendations for a nationwide program to improve safety at grade crossings (1, 2). The 1973 Federal-Aid Highway Act specifically made available to all states large sums of money for safety improvements at crossings. Moreover, this legislation requires that a ranking or priority method be used in the selection of crossings for safety improvement.

The major purpose of the safety improvement program is to reduce the number of accidents and degree of accident severity at railroad-highway grade crossings (3). The accidents, injuries, and fatalities prevented by safety improvements are viewed as benefits that can be evaluated in economic terms. Reductions in accident costs are compared with installation and maintenance costs for various types of safety improvements to give cost-benefit measures that are used for determining (a) the crossings to be improved, (b) the nature of the improvements, and (c) the priorities for improvements. The accident frequency equations and the accident severity prediction rates are, therefore, the items of major influence in the development of economic warrants and priorities for safety improvements (4).

Historically, there have been difficulties in establishing statistically significant relationships between crossing characteristics and the occurrence of accidents at the crossing (5, 6, 7). This difficulty can be partially attributed to the lack of uniform data regarding the factors that influence grade-crossing accidents. Therefore, the reliability of the methods used for assessing true accident potential is frequently questioned. Although many existing methodologies have been modified and are currently being used by state transportation agencies, no single evaluation method has been universally accepted (7).

In an effort to provide improved capabilities for evaluating grade-crossing safety, the Federal Highway Administration (FHWA) initiated a study (4, 8) to refine and extend the accident prediction and accident severity models that had been developed for the 1972 report to Congress (2). The initial tasks of the study included reviewing and refining existing railroad grade-crossing accident, inventory, and accident severity data that were collected from different states and railroad companies. Statistical analysis techniques were then used to investigate relations between characteristics of grade crossings and accident frequency and between vehicle and train speeds and accident severity. The final tasks of the study were to summarize the results of the analyses for developing prediction equations and to establish guidelines for integrating the results of the analyses with economic data for use in developing warrants and priorities for safety improvements.

GRADE-CROSSING ACCIDENT AND INVENTORY DATA

Data for accidents that involved trains at grade crossings and inventory data were received from 45 states. Due to difficulties in matching accident data with specific crossing inventory data, only data from 37 230 grade crossings in 15 states could be used in the final data base. In the tabulation of accident data, crossings were classified according to the number of tracks (single or multiple), the location (urban or rural), and the type of warning device (automatic gates, flashing lights, other active, crossbucks, stop signs, or none). A summary of these data is given in Table 1.

The sample crossings were then stratified according to the volume ranges of train and highway traffic given below.

Publication of this paper sponsored by Committee on Railroad-Highway Grade Crossings.

Average Vehicles per Day	Average Trains per Day
1 to 250	1 to 2
251 to 500	3 to 5
501 to 1 000	6 to 10
1 001 to 5 000	11 to 20
5 001 to 10 000	21 to 40
10 001 to 40 000	41 to 100

This stratification yielded 24 sets of two-way tables. For each cell within these tables, the following information was tabulated:

- N = number of grade crossings,
- N* = number of crossing-years of data (cumulative years of available accident data),
- A = total number of accidents reported for the N* crossing-years,
- $\overline{A}$ = the average number of accidents per crossing-year (A/N*),
- $\overline{V}$ = the weighted average daily traffic volume for the N crossings (the weights are the number of years of available accident data for each of the N crossings), and
- $\overline{T}$ = the weighted average train volume for the N crossings (the weights are the number of years of available accident data for each of the N crossings).

The distribution characteristics of the 37 230 sample grade crossings and 9490 accidents are shown below.

Crossing Type	Grade Crossings (%)	Reported Accidents (%)
Single track	71	52
Urban		
Percentage of total	23	26
Percentage of single tracks	32	50
Rural		
Percentage of total	48	26
Percentage of single tracks	68	50
Multiple track	29	48
Urban		
Percentage of total	16	32
Percentage of multiple tracks	54	67
Rural		
Percentage of total	13	15
Percentage of multiple tracks	46	33

GRADE-CROSSING ACCIDENT SEVERITY DATA

Three railroad companies submitted information regarding the severity of 6876 accidents involving trains. In the tabulation of severity data, accidents were classified according to the six types of warning devices and the type of collision. A summary of these data is given in Table 2. The data were further stratified according to the reported speeds of the trains and vehicles involved in the accidents. The speed ranges used in the severity tabulations are given below.

Vehicle Speed (km/h)	Train Speed (km/h)	Vehicle Speed (km/h)	Train Speed (km/h)
0	0 to 19.2	48.0 to 70.4	59.2 to 76.8
1.6 to 22.4	20.8 to 38.4	72.0+	78.4+
24.0 to 46.4	40.0 to 57.6		

The following information was computed for each of the 25 combinations of vehicle and train speeds:

- n = number of accidents,
- x = number of injuries,
- y = number of fatalities,
- $\overline{S}_V$ = average speed of the vehicle involved in the n accidents,
- $\overline{S}_T$ = average speed of the train involved in the n accidents,
- r_x = injury rate (x/n), and
- r_y = fatality rate (y/n).

Information concerning the number of tracks, the locations of crossings, and the vehicle and train traffic volumes was not available for the severity data.

ACCIDENT PREDICTION EQUATIONS

The number of accidents that will occur for a group of similar grade crossings during a fixed time period may be viewed as the product of the rate of accident occurrence per crossing per unit of time ($\overline{A}$) and the number of crossing-years of exposure to accidents. A crossing-year of exposure is defined as one grade crossing exposed to accidents for 1 year.

In previous work (5), attempts were made to develop a predicted accident rate for individual crossings. The attempts were not successful and the equations developed for individual crossings did not explain a significant amount of the variation in accidents. To account for more variation, the method presented here concentrated on analyzing groups of crossings.

For purposes of generalization, one may assume that each individual crossing within a group has an accident potential equivalent to the average rate ($\overline{A}$) for that group; therefore, the development of accident prediction equations focused on the relations between observed accident rates for groups of crossings with similar physical characteristics and the associated average daily train and vehicle volumes. As a group, crossings are considered to be similar if they fall within a common range of such characteristics as location, number of tracks, warning device, and highway and train volumes.

Seventy percent of the sample data base was randomly selected for testing alternative models for multiple linear regression, and the remaining data were reserved for validation purposes. The following models were both found to offer a reasonable and statistically significant explanation of the observed accident rates for the grouped data.

Model 1:

$$\log_{10}\overline{A} = C_0 + C_1 \log_{10}\overline{V} + C_2 \log_{10}\overline{T} \quad (1)$$

Model 2:

$$\log_{10}\overline{A} = C_0 + C_1 \log_{10}\overline{V} + C_2 \log_{10}\overline{T} + C_3 (\log_{10}\overline{T})^2 \quad (2)$$

In some situations, the additional terms $C_3(\log_{10}\overline{T})^2$ enabled model 2 to achieve an improved fit for accident rates in the higher volume categories. For this reason, the model 2 regression results given in Table 3 represent the preferred accident prediction equations. With a few exceptions, the signs of the coefficients correspond to a priori expectations.

It is important to note that the regression results give predicted logarithms of accident rates (9). Since the equations would be used in terms of expected numbers of accidents rather than the logarithms of accident rates, correlations between the observed and predicted numbers of accidents were calculated and are given in Table 4. The 30 percent sample of crossing data originally withheld were used for a cross validation (10) of the model 2 equations. The results are also given in Table 4. In a cross-validation procedure, the regression results from the analysis are applied to a separate independent sample of validation data to obtain predicted values of the depen-

Table 1. Accident data according to type of crossing.

Item	Accidents	Crossings	Crossing-Years	Item	Accidents	Crossings	Crossing-Years
Single-track urban				Multiple-track urban			
Automatic gates	240	685	2 077	Automatic gates	432	838	2 854
Flashing lights	680	1 986	6 411	Flashing lights	1087	1 439	4 725
Other active	509	668	2 837	Other active	547	607	2 491
Stop signs	60	185	1 054	Stop signs	192	185	1 076
Crossbucks	931	4 307	17 076	Crossbucks	694	2 366	9 618
None	91	716	3 358	None	60	340	1 631
Subtotal	2511	8 547	32 813	Subtotal	3012	5 775	22 395
Single-track rural				Multiple-track rural			
Automatic gates	145	508	1 558	Automatic gates	145	461	1 915
Flashing lights	480	2 441	6 714	Flashing lights	360	1 071	3 625
Other active	173	352	1 432	Other active	73	154	629
Stop signs	188	900	5 115	Stop signs	170	413	2 604
Crossbucks	1477	13 005	63 026	Crossbucks	702	2 672	12 052
None	45	772	3 779	None	9	159	716
Subtotal	2508	17 978	81 624	Subtotal	1459	4 930	21 541
				Total	9490	37 230	158 373

Table 2. Distribution of accidents, injuries, and fatalities by warning device and type of collision.

Item	Accidents	Injuries	Fatalities
Warning device			
Automatic gates	284	115	38
Flashing lights	2031	1096	304
Other active	325	176	43
Crossbucks	3602	1608	449
Stop signs	57	24	5
No warning	577	107	16
Total	6876	3125	855
Collision type			
Train strikes automobile	4055	1795	530
Train strikes truck	1107	324	115
Train strikes other	183	63	37
Automobile strikes train	1242	785	140
Truck strikes train	223	108	18
Other strikes train	46	44	11
Total	6856	3119	851

dent variable. The correlation between the observed and predicted values is an estimate of the validity of the derived regression results.

One may conclude from the results in Tables 3 and 4 that the accident prediction equations for crossbucks, flashing lights, and other active devices will generally be reliable for translating the train and vehicle volume characteristics for grouped crossings into predicted numbers of accidents. On the other hand, the relation between volume characteristics and accidents seems to be much weaker in the case of automatic gates. Also the prediction equations for stop signs are weak except for the single-track crossings.

Figures 1 through 4 show the comparison of model 2 automatic gates, flashing lights, and crossbuck equations for combinations of location and number of tracks with train volume fixed at 10 trains/d. Examination of these curves shows that gates generally have the lowest predicted accident rates for all four cases. In the low average daily traffic values for urban single-track crossings, rural single-track crossings, and rural multiple-track crossings, the accident rates for crossings with gates are higher than the rates for crossings with flashing lights or crossbucks. This may be due to the small sample of gate-protected crossings available in these traffic ranges. For urban areas at both single- and multiple-track crossings, the curves for flashing lights are higher than the curves for crossbucks. Additional variables may be needed in these cases to fully explain accident occurrence patterns. For multiple-track crossings in rural areas, the curves for flashing lights and crossbucks are extremely close and intersect at 3000 vehicles/d. Again, further analysis with additional variables might result in an improved discrimination between crossbucks and flashing lights.

ACCIDENT SEVERITY PREDICTION RATES

The purpose of the severity analysis was to explain the structure of the relations between differences in severity rates for different groups of accidents. The expected number of fatalities and injuries that would result from a group of similar accidents may be viewed as the product of the rate of injury or fatality per accident and the number of accidents for which the rate applies. For a group of similar accidents, the ratio of the observed number of injuries or fatalities to the number of accidents in the group may be considered as a measure of the rate of injury or fatality for those accidents. In general, it may be assumed that severity rates will be lower for slow-speed crashes and higher for high-speed crashes. However, in some cases, injury rates will be lower for high-speed crashes because greater numbers of fatalities occur in these cases.

Accidents were stratified into groups according to train and vehicle speeds and the type of warning device. The relations between severity rates and the speed characteristics of the 6876 sample accidents were analyzed using the following two-way analysis of variance model:

$$r_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij} \quad (3)$$

where

r_{ij} = rate of injury or fatality,
μ = mean rate,
α_i = effect of vehicle speed class,
β_j = effect of train speed class, and
ϵ_{ij} = error.

It was assumed that r_{ij} would exhibit the behavior of a binomial proportion (11). This allowed the assumption that r_{ij} has approximately a normal distribution with variance

$$V(r_{ij}) = [p_{ij}(1 - p_{ij})]/n_{ij} \quad (4)$$

where

p_{ij} = probability of injury or fatality in a typical acci-

Table 3. Model 2 regression results.

Item	C_0	C_1	C_2	C_3	R^2	Item	C_0	C_1	C_2	C_3	R^2
Single-track urban						Multiple-track urban					
Automatic gates	-2.17	0.16	0.96	-0.35	0.186	Automatic gates	-2.58	0.23	1.30	-0.42	0.396
Flashing lights	-2.85	0.37	1.16	-0.42	0.729	Flashing lights	-2.50	0.36	0.68	-0.09	0.691
Crossbucks	-2.38	0.26	0.78	-0.18	0.684	Crossbucks	-2.49	0.32	0.63	-0.02	0.706
Other active	-2.13	0.30	0.72	-0.30	0.770	Other active	-2.16	0.36	0.19	0.08	0.65
Stop signs	-2.98	0.42	1.96	-1.13	0.590	Stop signs	-1.43	0.09	0.18	0.16	0.35
None	-2.46	0.16	1.24	-0.56	0.24	None	-3.00	0.41	0.63	-0.02	0.58
Single-track rural						Multiple-track rural					
Automatic gates	-1.42	0.08	-0.15	0.25	0.200	Automatic gates	-1.63	0.22	-0.17	0.05	0.142
Flashing lights	-3.56	0.62	0.92	-0.38	0.857	Flashing lights	-2.75	0.38	1.02	-0.36	0.674
Crossbucks	-2.77	0.40	0.89	-0.29	0.698	Crossbucks	-2.39	0.46	-0.50	0.53	0.780
Other active	-2.25	0.34	0.34	-0.01	0.533	Other active	-2.32	0.33	0.80	-0.35	0.31
Stop signs	-2.97	0.61	-0.02	0.29	0.689	Stop signs	-1.87	0.18	0.67	-0.34	0.32
None	-3.62	0.67	0.22	0.26	0.756	None	—[a]	—[a]	—[a]	—[a]	—[a]

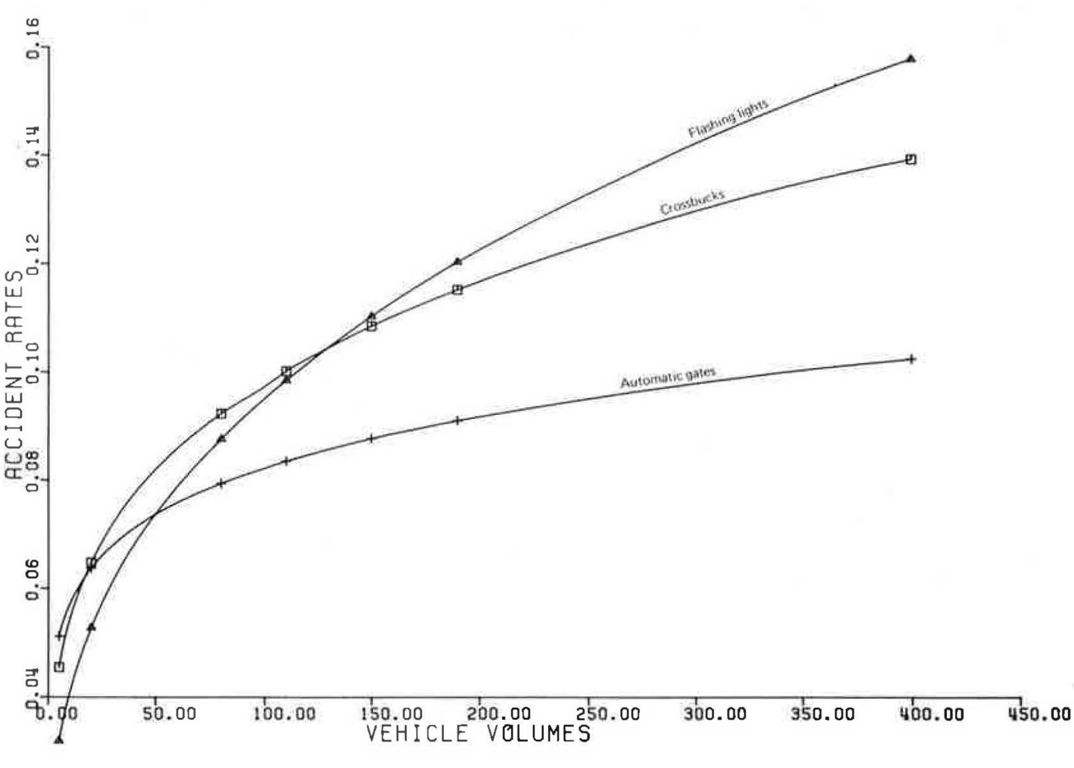
[a]Insufficient data.

Table 4. Model 2 validation results.

Item	Correlation Between Accidents: Regression Data	Correlation Between Accidents: Validation Data	Item	Correlation Between Accidents: Regression Data	Correlation Between Accidents: Validation Data
Single-track urban			Multiple-track urban		
Automatic gates	0.7916	0.5959	Automatic gates	0.8954	0.8705
Flashing lights	0.9183	0.7309	Flashing lights	0.9129	0.7567
Crossbucks	0.9308	0.7963	Crossbucks	0.8775	0.7629
Other active	0.9421	0.7564	Other active	0.9130	0.6046
Stop signs	0.7377	0.8451	Stop signs	0.9142	0.5565
None	0.6804	0.4938	None	0.4548	-0.2921
Single-track rural			Multiple-track rural		
Automatic gates	0.7107	-0.4573	Automatic gates	0.8027	0.7443
Flashing lights	0.9640	0.8564	Flashing lights	0.6728	0.4148
Crossbucks	0.9229	0.8892	Crossbucks	0.7670	0.6570
Other active	0.8675	0.7652	Other active	0.9442	0.9898
Stop signs	0.7976	0.7414	Stop signs	0.9081	0.7952
None	0.7490	0.8095	None	—[a]	—[a]

[a]Insufficient data.

Figure 1. Single-track crossings in urban areas (10 trains/d).



dent occurring for a given range of vehicle and train speeds and

n_{ij} = total number of observed accidents.

These assumptions suggested performing a weighted least squares analysis using estimated weights:

$$w_{ij} = n_{ij}/[r_{ij}(1 - r_{ij})] \quad (5)$$

The results of the analysis give estimates for the parameters μ, α_i, and β_j that were then used to predict accident rates for each of the 25 combinations of vehicle and train speed classifications. The predicted rates of injury and fatality for crossbucks and flashing lights are given in Tables 5 and 6. These tables also give the observed distribution of accidents by vehicle and train speed. Severity prediction rates for other types of protection were not developed because of insufficient data.

The validity of the severity analysis results was considered by computing correlations between predicted

Figure 2. Multiple-track crossings in urban areas (10 trains/d).

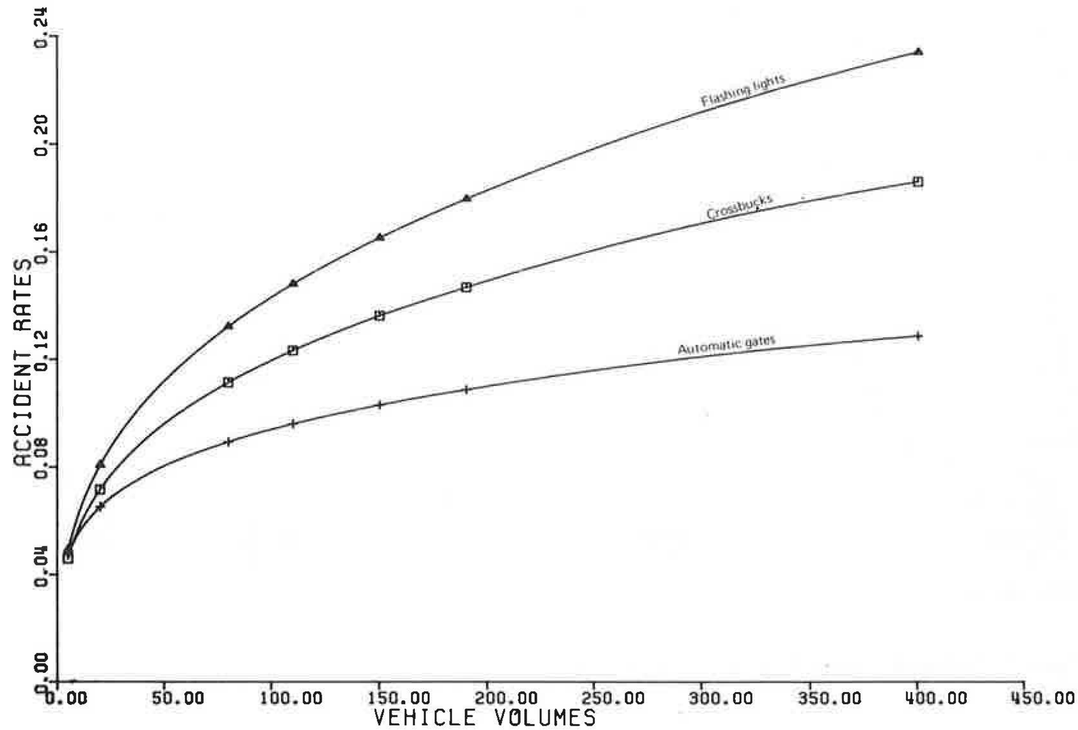
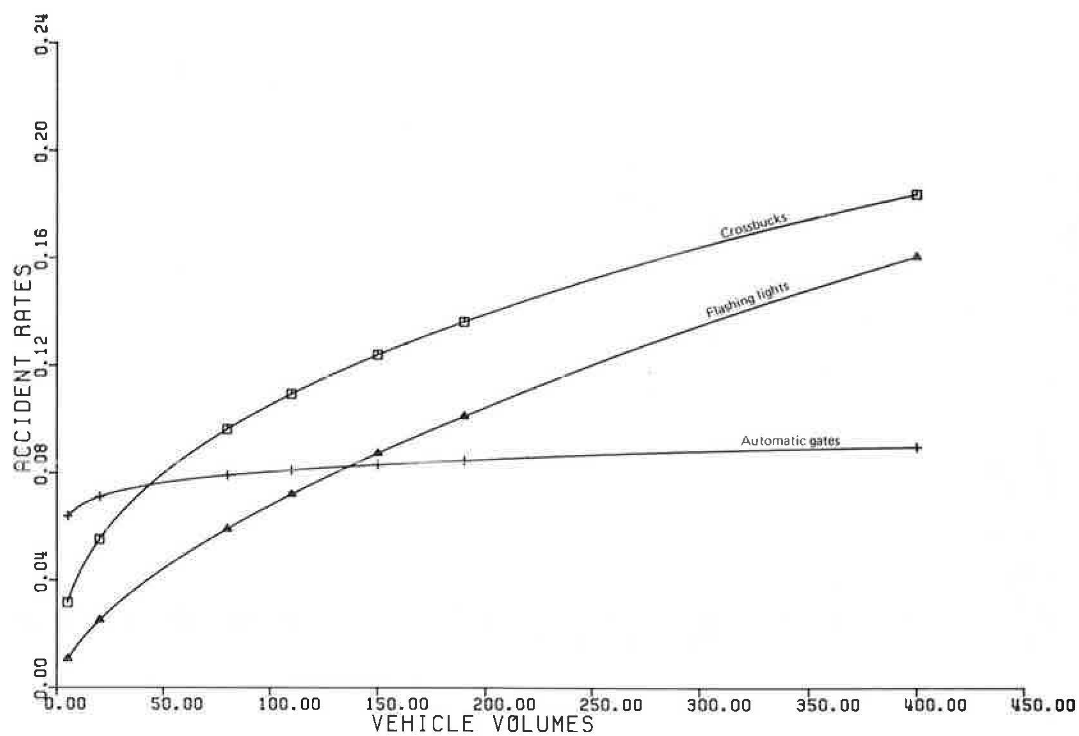


Figure 3. Single-track crossings in rural areas (10 trains/d).



values and observed values. For the crossbuck analysis, the correlations for number of injuries and number of fatalities were 0.97 and 0.69 respectively. For flashing lights, the correlations for number of injuries and number of fatalities were 0.97 and 0.85 respectively.

Investigations of the distribution of accidents over the speed classifications revealed that, for all forms of warning, 37 percent of the accidents occurred when vehicles were standing on the tracks, 33 percent when vehicle speeds were between 1.6 and 22.4 km/h (1 and 14 mph), and 19 percent when vehicle speeds were between 24.0 and 46.4 km/h (15 and 29 mph). Only 11 percent of the accidents occurred at speeds greater than 48 km/h (30 mph). Forty-six percent of the accidents occurred for train speeds between 0 and 19.2 km/h (0 and 12 mph), 17 percent for train speeds between 20.8 and 57.6 km/h (13 and 24 mph), and 21 percent for train speeds between 40 and 57.6 km/h (25 and 36 mph). The remaining 16 percent of the accidents occurred at train speeds greater than 57.6 km/h (36 mph).

Figure 4. Multiple-track crossings in rural areas (10 trains/d).

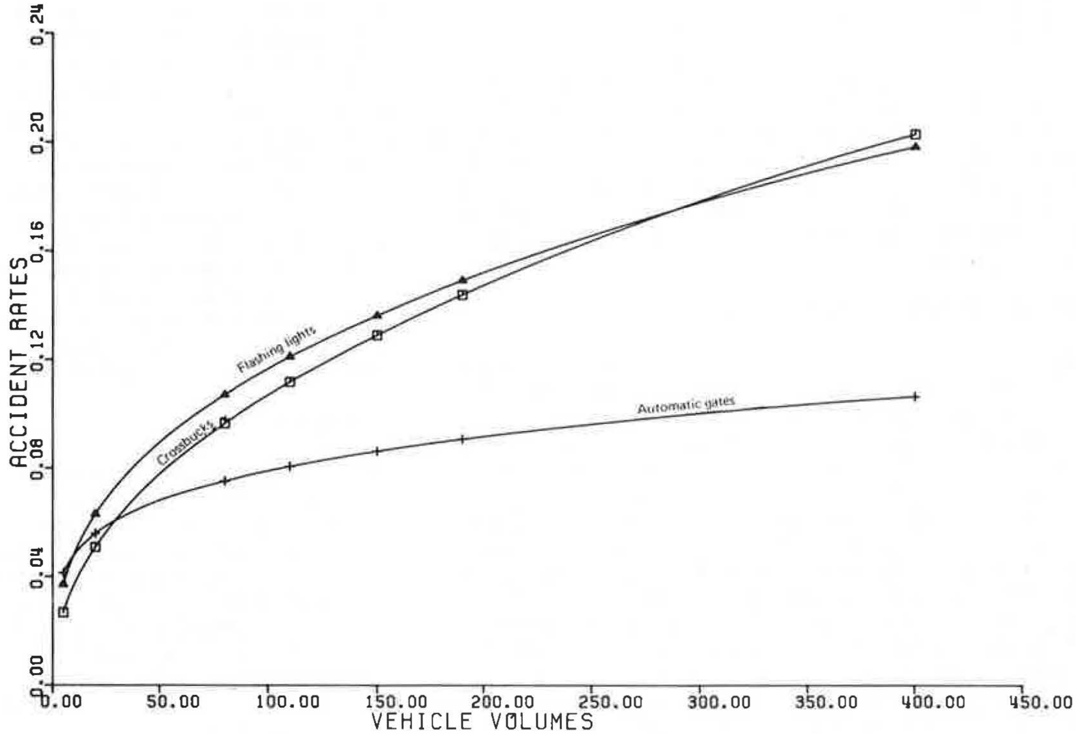


Table 5. Accident severity results for crossbucks.

Vehicle Speed (km/h)	Distribution of Accidents (%)					Predicted Rate of Injury					Predicted Rate of Fatalities				
	Train Speed (km/h)					Train Speed (km/h)					Train Speed (km/h)				
	0 to 19.2	20.8 to 38.4	40.0 to 57.6	59.2 to 76.8	78.4+	0 to 19.2	20.8 to 38.4	40.0 to 57.6	59.2 to 76.8	78.4+	0 to 19.2	20.8 to 38.4	40.0 to 57.6	59.2 to 76.8	78.4+
0	10.1	6.8	8.6	5.6	2.7	0.085	0.283	0.376	0.341	0.149	—[a]	—[a]	0.061	0.150	0.210
1.6 to 22.4	15.8	5.6	7.0	4.3	2.2	0.316	0.513	0.606	0.572	0.380	0.001	0.097	0.167	0.256	0.316
24.0 to 46.4	6.4	4.1	4.3	2.3	1.1	0.542	0.739	0.832	0.797	0.605	0.052	0.147	0.218	0.306	0.366
48.0 to 70.4	3.6	1.8	2.4	0.7	0.4	0.596	0.794	0.887	0.852	0.660	0.049	0.144	0.214	0.303	0.363
72.0+	1.7	0.8	1.0	0.4	0.3	0.630	0.827	0.920	0.885	0.694	0.193	0.288	0.358	0.447	0.507

Note: 1 km/h = 0.6 mph.

[a]Negative model predictions.

Table 6. Accident severity results for flashing lights.

Vehicle Speed (km/h)	Distribution of Accidents (%)					Predicted Rate of Injury					Predicted Rate of Fatalities				
	Train Speed (km/h)					Train Speed (km/h)					Train Speed (km/h)				
	0 to 19.2	20.8 to 38.4	40.0 to 57.6	59.2 to 76.8	78.4+	0 to 19.2	20.8 to 38.4	40.0 to 57.6	59.2 to 76.8	78.4+	0 to 19.2	20.8 to 38.4	40.0 to 57.6	59.2 to 76.8	78.4+
0	13.9	7.3	6.7	3.1	1.7	0.242	0.520	0.476	0.459	0.273	0.054	0.112	0.181	0.346	0.401
1.6 to 22.4	17.5	5.3	5.8	2.4	1.0	0.399	0.676	0.633	0.615	0.430	0.049	0.108	0.176	0.341	0.396
24.0 to 46.4	10.1	3.2	5.2	1.5	0.5	0.634	0.912	0.868	0.851	0.666	0.064	0.122	0.191	0.356	0.411
48.0 to 70.4	4.4	1.8	2.1	0.9	0.6	0.653	0.930	0.887	0.870	0.684	0.141	0.199	0.267	0.433	0.487
72.0+	1.8	1.0	1.3	0.5	0.5	0.612	0.890	0.846	0.829	0.643	0.212	0.270	0.339	0.504	0.559

Note: 1 km/h = 0.6 mph.

As stated earlier, insufficient data precluded the development of prediction rates for severity in the warning-device categories except for crossbucks and flashing lights. In lieu of formal prediction rates, the overall average number of injuries and fatalities per train-involved accident, for crossings afforded gates, other active devices, stop signs, and no protection is given below.

Warning Device	Injury Rates	Fatality Rates
Automatic gates	0.40	0.13
Other active	0.54	0.13
Stop signs	0.42	0.09
None	0.19	0.03

The rates refer to the average number of injuries or fatalities that are expected for an average train-involved collision. The average rates for stop signs and no warning in particular are not considered representative due to the small sample of accidents at stop-sign-protected crossings and the disproportionate number of collisions at a reported motor vehicle speed of zero at crossings with no protection.

USE OF PREDICTION MODELS

One possible application of the accident prediction equations and severity prediction rates is to study the potential accident experience for groups of crossings over a certain period of time. To do this, the crossing inventory data must first be stratified into similar groups determined by type of warning device, type of area, and number of tracks. The mean train and vehicle volumes for each group are then calculated. Next, the coefficients shown in Table 3 are applied to the mean vehicle and train volumes to obtain a predicted accident rate for each group. These values are adjusted by the appropriate number of crossing-years of exposure (product of number of crossings and length of analysis period) to yield the predicted number of accidents for each group of crossings with the current type of warning device.

Additional insight can be obtained by computing the predicted number of injuries and fatalities associated with these accidents. The total number of predicted accidents for each group can be distributed into the vehicle-train speed categories by using the results given in Table 5. The corresponding average injury and fatality rates are then selected from Table 5 and applied to the predicted number of accidents.

One approach for the development of a grade-crossing protection improvement program would be to evaluate the potential reduction in number of accidents, injuries, and fatalities for several mixes of protection improvement. Calculating the accidents, injuries, and fatalities for the existing conditions can be useful in indicating which groups of crossings offer the best opportunities. Many different sets of candidate crossing improvements may be considered. The purpose of safety improvements is to reduce the numbers of accidents, injuries, and fatalities as much as possible with the most economical expenditure of funds. Differences in numbers of accidents, injuries, and fatalities for various improvement plans can be related to the differences in the warning devices and their cost of installation and maintenance. This relation can then be used to formulate cost-benefit measures for various safety improvement programs (12).

The final selection of those grade crossings within a given group that are to receive an improved type of protection must be based on an engineering assessment of the relative hazard associated with the unique features at each crossing. Although the accident prediction equations and severity prediction rates that resulted from this research can be an important input in the development of a grade-crossing improvement program, they are not a substitute for an on-site evaluation of potential hazard on a crossing-by-crossing basis (6, 13).

SUMMARY AND CONCLUSIONS

This research has resulted in improved techniques for predicting railroad-highway grade-crossing accidents and accident severity. Although many variables could not be investigated in the study, the capability for considering subsequent variables has been established. A framework for using accident prediction equations has been outlined and may be expanded as additional factors relating to safety improvements are investigated.

There are still many unanswered questions regarding the occurrence of accidents and degree of severity at grade crossings. In this study, the ratio of the number of accidents for a group of crossings to the number of crossing-years of exposure has evolved as a measure of the accident potential for a group of crossings. Future studies based on the nationwide grade-crossing inventory by the U.S. Department of Transportation and Association of American Railroads and the revised Federal Railroad Adminstration accident information will be helpful in establishing many other useful relations between crossing characteristics and accident potential.

REFERENCES

1. Railroad-Highway Safety—Part I: A Comprehensive Statement of the Problems. U.S. Department of Transportation, Nov. 1971.
2. Railroad-Highway Safety—Part II: Recommendations for Resolving the Problems. U.S. Department of Transportation, Aug. 1972.
3. The Effectiveness of Automatic Protection in Reducing Accident Frequency and Severity at Public Grade Crossings in California. Transportation Division, California Public Utilities Commission, San Francisco, 1972.
4. P. Huntington, J. Coleman, J. Eicher, and R. Hunter. Warrants for Safety Improvements at Railroad-Highway Grade Crossings. Proc., 1972 National Conference on Railroad-Highway Grade-Crossing Safety, Aug. 29-31, 1972.
5. Factors Influencing Safety at Highway-Rail Grade Crossings. NCHRP, Rept. 50, 1968.
6. W. E. Blevins. Railroad-Highway Cooperation Increases Crossing Safety. Railway Systems Controls, May 1972.
7. J. L. Sanford. Criteria Used by State Highway Agencies to Determine Warrants and Priorities for Protective Devices at Railroad-Highway Crossings. Illinois Department of Transportation, Springfield, Jan. 13, 1975.
8. J. Coleman and G. Stewart. Accident and Accident Severity Prediction Equations. Proc., 1974 National Conference on Railroad-Highway Crossing Safety, Colorado Springs, Aug. 19-22, 1974.
9. D. Bradu and Y. Mundlak. Estimation in Lognormal Linear Models. Journal of the American Statistical Association, Vol. 65, March 1970, pp. 198-211.
10. C. N. Park and A. L. Dudycha. A Cross-Validation Approach to Sample Size Determination for Regression Models. Journal of the American Statistical Association, Vol. 69, No. 345, March 1974.
11. G. W. Snedecor and W. G. Chochran. Statistical Methods. Iowa State Univ. Press, Ames, 1967.
12. J. B. Hopkins. Model for Evaluation of Alternative Grade-Crossing Resource Allocation Strategies.

Proc., 1974 National Conference on Railroad-Highway Crossing Safety, Colorado Springs, Aug. 19-22, 1974.

13. L. G. Goldstein. Administration of Grade Crossing Programs. Proc., 1969 National Conference on Rail-Highway Grade-Crossing Safety, Feb. 11-13, 1969.