Effectiveness of Automatic Warning Devices in Reducing Accidents at Grade Crossings

William R. Schulte, California Public Utilities Commission, San Francisco

In the last 17 years, California has experienced more than 17 000 vehicle-train accidents, which have claimed more than 550 lives. The California Public Utilities Commission and the California State Legislature have attempted to reduce the continuing human and economic loss by promoting the installation of flashing light signals and automatic crossing gates. This study is intended to gauge the effect of automatic warning devices on the frequency of vehicle-train accidents and to examine specific crossing locations to appraise the capabilities of automatic warning devices in reducing the number and severity of vehicle-train accidents. To determine the effectiveness of automatic warning devices under varying conditions, the before-and-after accident histories at 1552 grade crossings where automatic devices were installed between 1960 and 1970 were compared on a crossing-year basis and segregated by type of warning device, rural versus urban conditions, and the number of railroad tracks. While some limitations and adverse side effects do exist, the results indicate that the installation of automatic gates can be expected, on the average, to reduce vehicle-train accidents by approximately 70 percent per crossing-year and to reduce related deaths and injuries by 89 and 83 percent per year respectively. In addition, it would appear that the use of automatic gates eliminates many of those accidents that represent the greatest potential severity, since there were 64 percent fewer deaths per accident, 43 percent fewer injuries per accident, and 36 percent fewer deaths per injury. The data obtained on vehicle-train accidents and their severity were combined with average installation, maintenance, and operation costs for flashing lights and automatic gates to provide a brief economic analysis of the most cost-effective alternative.

Since 1958, there have been more than 17 000 vehicle-train accidents in California. These accidents have claimed more than 550 lives and resulted in an additional 7500 injuries, many of which the California Public Utilities Commission staff believes could have been averted by the installation of automatic railroad warning devices, especially automatic gates (1, 2).

It is the purpose of this paper to examine (a) automatic railroad warning devices, (b) what can be expected in terms of vehicle-train accident reduction, (c) how warning devices affect accident severity, (d) whether the effectiveness of automatic warning devices is dependent on the location of grade crossings or such physical conditions as the number of railroad tracks, (e) what the limitations of any warning-device system are, and (f) how the results can be used in economic analyses to point out the relative cost-effectiveness of each alternative.

The examination includes a comparison of accident histories at 1552 grade-crossing locations where automatic warning devices were installed between 1960 and 1970. Documented for each location are (a) the type of automatic warning device installed, (b) the previous type of warning device in service, (c) the accident history both before and after the installation of devices, (d) the number of vehicle-train accidents and related deaths and injuries before and after the installation of devices, (e) the current number of railroad tracks, and (f) the location of the grade crossing in terms of rural or urban characteristics.

California has for more than 20 years maintained a local assistance program aimed at promoting the installation of automatic warning devices. In conjunction with a maintenance fund program established in 1965 that pays the local agency's entire share of maintaining automatic warning devices, the California grade-crossing program has assisted in the installation of automatic warning devices at more than 2700 grade crossings.

Since the emphasis of the program changed from flashing lights to the installation of automatic gates, the results of the program have been dramatic. Since 1965, there has been a 50 percent reduction in the number of vehicle-train accidents (1219 in 1965 versus 608 in 1974), a 57 percent reduction in related deaths (110 in 1965 versus 47 in 1974), and a 36 percent reduction in resultant injuries (515 in 1965 versus 330 in 1974); this is in spite of an 87 percent increase in vehicle registration (11 191 199 in 1965 versus 20 933 000 in 1974) and an estimated 50 percent increase in the number of vehicle-kilometers (vehicle-miles) traveled in California. The number of vehicle-train accidents per registered vehicle has been reduced by more than 70 percent, and the number of vehicle-train accidents per vehicle-kilometer has been reduced by more than 66 percent. This reduction in vehicle-train accidents compares favorably with data on all California highway accidents per registered motor vehicle, which have only been reduced by approximately 20 percent since 1965, and the number of highway acci-

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dents per vehicle-kilometer, which has been reduced by only 1 percent since 1965. Railroad reporting requirements for grade-crossing accidents changed January 1, 1975, eliminating any possibility for updating accident trends.

Since 1953, the results of the California program have cost more than $9 500 000 in state funds, representing a total construction cost of more than $38 000 000. The accidents cited in this study include any and all accidents involving railroads and motor vehicles at crossings of public streets.

AGGREGATE RESULTS

The major thrust of this examination, a comparison of before-and-after accident histories at selected grade crossings where automatic warning devices were installed, was designed to help evaluate the capabilities of automatic devices to reduce vehicle-train accidents and casualties. The 1552 locations examined had at least three train crossings per day and included all crossings at which automatic warning devices were installed between 1960 and 1970. At the time of the study, these crossings represented 44 percent of all crossings in California with either flashing light signals or automatic gates. The 1960 through 1970 span was chosen to allow for a reliable accident history while considering only those factors (train and vehicular patterns) relevant to the current rail-street crossing situation.

Each crossing was examined individually, and the number and severity of accidents during the 10-year period before the installation of automatic warning devices were compared with the number and severity of accidents experienced from the date of installation until August 1, 1972. Ten-year accident histories were used for all cases except those in which the warning device had been previously upgraded within the 10-year period or in which new crossings had been established. Prior accident history was not considered at new crossings. For those crossings upgraded to flashing lights before being upgraded to automatic gates, only the period with flashing light signals was considered as the prior accident history. The gross accident figures divided by the number of years the device was in service were compared to determine the effectiveness of automatic warning devices for reducing accident and casualty rates.

Until the mid-1960s, the normal or predominant type of automatic device installed was flashing lights. After that, however, automatic gates were installed at the most hazardous crossings, and flashing lights were relegated to less hazardous locations. This change in policy made some of the flashing lights installed during the study period appear to be overly effective in comparison with similar devices installed before the study period and with flashing light devices at crossings that were upgraded to automatic gates. Although the results for the 434 locations where flashing lights were installed are furnished, the emphasis will be on those 1118 locations where automatic gates were installed (Table 1).

Tables 2 and 3 show that the use of automatic devices resulted in reductions per crossing-year of 69 percent in vehicle-train accidents, 86 percent in deaths, and 80 percent in injuries. For the automatic gates alone, the results are even more impressive: Reductions per crossing-year were 70 percent in vehicle-train accidents, 89 percent in deaths, and 83 percent in injuries. The data also indicate, at least superficially, that automatic gates are adaptable to all types of situations and can drastically reduce accidents at crossings no matter what the previous warning devices were. The accident rates before and after the installation of automatic gates ranged from a low of 0.24 and 0.03 accidents per crossing-year for crossings that previously had crossbuck warnings to 0.41 and 0.14 accidents per crossing-year for those that previously had flashing light warnings. The data on fatality rates coincided with the pattern established for accident rates; crossings that previously had crossbuck warnings exhibited the greatest rate of change.

This difference between accident- and casualty-rate reductions on a crossing-year basis indicated that automatic warning devices, in addition to reducing accident frequency, reduce disproportionately the expected death and injury rates for those infrequent accidents that do occur after the installation of flashing light signals or automatic gates. Tables 3 and 4 show that, in addition to the 70 percent reduction in accidents experienced at grade crossings upgraded to automatic gates, there were reductions of 64 percent in the number of deaths per recorded accident and 43 percent in expected injuries per accident. An additional measure of accident severity, deaths per injury, was reduced from 0.29 to 0.18 (more than 36 percent) by the installation of automatic gates.

The results shown in Table 4 seem to indicate that automatic gates eliminated most of the accidents that involved the greatest potential severity. Of the 745 vehicle-train accidents that occurred in 1973, roughly 66 percent were tentatively attributed to failure of the motor vehicle to stop in accordance with the California Motor Vehicle Code; this contributed to roughly 80 percent of the total casualties. Since automatic gates have an inherent ability to drastically reduce the options available to a vehicle driver, they eliminate most of the accidents involving a moving vehicle. Indeed, a close examination of accidents occurring at crossings with automatic gates between 1970 and 1972 revealed that the greatest number of these accidents was attributable to stalled vehicles or vehicles that stopped but did not clear the tracks; these accidents often gave the driver time to abandon his vehicle prior to impact. Although categories of causes of accidents may be oversimplified or biased to some degree, they can be relied on in a general sense to show basic trend lines and patterns.

The aggregate results clearly indicated the superiority of automatic gates in reducing accident frequency and eliminating accidents that are potentially the severest. The effectiveness of the automatic gates is undoubtedly due in part to visual and auditory signals that attract a driver's attention and to the barrier effect that eliminates any decision a driver might want to make. This effect is not shared by any other type of warning device, even flashing lights. Although crossings with flashing lights constituted only about 15 percent of the total number of crossings in California at the end of 1973, more than 26 percent of the vehicle-train accidents that occurred during 1973 occurred at crossings with flashing lights; although automatic gates were found at more than 21 percent of the total crossings, only 18 percent of the accidents occurred at these crossings.

RURAL VERSUS URBAN CONDITIONS

Each of the 1552 crossings examined was classified as either rural or urban according to its location within an incorporated or unincorporated community of 2500 persons or more. Unfortunately, it was not possible to check each crossing to verify whether it was truly urban or rural. This inadequacy should be weighed when comparing the results of the effectiveness of automatic devices at the 913 urban and 639 rural crossings in the sample.

Tables 5 and 6 give the accident rates before and after the installation of automatic warning devices at rural

Table 1. Accident experience at all crossings.

Category	Number of Crossings	Accident Experience							
		Before Installation				After Installation			
		Accidents	Deaths	Injuries	Crossing-Years	Accidents	Deaths	Injuries	Crossing-Years
Protection prior to installation of flashing light signals									
None (new crossing)	75	1	—	—	0.17[a]	49	6	24	631
Crossbucks	245	611	134	451	2 431.25	173	20	58	2019
Wigwag	98	290	10	148	972.83	118	6	54	781
Miscellaneous	16	60	4	20	160.00	28	1	7	135
Subtotal	434	962	148	619	3 564.25	368	33	143	3566
Protection prior to installation of automatic gates									
None (new crossing)	91	—	—	—	—	36	—	6	441
Crossbucks	243	565	139	370	2 396.83	36	2	14	1095
Wigwag	248	969	110	454	2 480.00	169	8	31	1332
Flashing light	498	1861	258	842	4 516.50	333	21	108	2462
Miscellaneous	38	221	6	90	365.25	43	1	13	274
Subtotal	1118	3616	513	1756	9 758.58	617	32	172	5607
Total	1552	4578	661	2375	13 322.83	985	65	315	9174

[a] Accident occurred before crossing was officially opened.

Table 2. Accident experience per crossing-year at all crossings.

Category	Number of Crossings	Accident Experience per Crossing-Year					
		Before Installation			After Installation		
		Accidents	Deaths	Injuries	Accidents	Deaths	Injuries
Protection prior to installation of flashing light signals							
None (new crossing)	75	6.00	—	—	0.08	0.01	0.04
Crossbucks	245	0.25	0.06	0.19	0.09	0.01	0.03
Wigwag	98	0.30	0.01	0.15	0.15	0.01	0.07
Miscellaneous	16	0.37	0.02	0.12	0.21	0.01	0.05
Subtotal	434	0.27	0.04	0.17	0.10	0.01	0.04
Protection prior to installation of automatic gates							
None (new crossing)	91	—	—	—	0.08	—	0.01
Crossbucks	243	0.24	0.06	0.15	0.03	—	0.01
Wigwag	248	0.39	0.04	0.18	0.13	0.01	0.02
Flashing light	498	0.41	0.06	0.19	0.14	0.01	0.04
Miscellaneous	38	0.61	0.02	0.25	0.16	—	0.05
Subtotal	1118	0.37	0.05	0.18	0.11	0.01	0.03
Total	1552	0.34	0.05	0.18	0.11	0.01	0.03

Table 3. Effectiveness results at all crossings.

Category	Number of Crossings	Percentage of Reduction After Installation					
		Accident Factor per Crossing-Year			Accident Severity per Accident		
		Accidents	Deaths	Injuries	Deaths	Injuries	Casualties
Protection prior to installation of flashing light signals							
None (new crossing)	75	-98.67	—	—	—	—	—
Crossbucks	245	-64.00	-83.33	-84.21	-45.45	-54.05	-53.13
Wigwag	98	-50.00	—	-53.33	+66.67	-9.80	-5.56
Miscellaneous	16	-43.24	-50.00	-58.33	-42.86	-24.24	-27.50
Subtotal	434	-62.96	-75.00	-76.47	-40.00	-39.06	-40.00
Protection prior to installation of automatic gates							
None (new crossing)	91	—	—	—	—	—	—
Crossbucks	243	-87.50	-100.00	-93.33	-76.00	-40.00	-51.11
Wigwag	248	-66.67	-75.00	-88.89	-54.55	-61.70	-60.34
Flashing light	498	-65.85	-83.33	-78.95	-57.14	-28.89	-33.90
Miscellaneous	38	-73.77	-100.00	-80.00	-33.33	-26.83	-23.26
Subtotal	1118	-70.27	-89.00	-83.33	-64.29	-42.86	-47.62
Total	1552	-68.60	-85.60	-80.05	-54.00	-38.46	-41.75

and urban crossings. The rates are significantly lower at rural crossings (0.28 accidents/crossing-year before and 0.08 after) than at urban crossings (0.39 before and 0.13 after). The percentage of reduction in all accident and casualty rates is also higher at rural crossings (Tables 7 through 10).

These results appeared reasonable since it was assumed that there was a significant physical difference between rural and urban locations. Urban crossings were assumed to carry much more vehicular traffic and to possess additional hazards such as obstructions to continuous traffic flow (intersections, driveways, lane interaction, access control), sight restrictions, and possibly inadequate or restrictive geometrics. It was

Table 4. Accident severity at all crossings.

Category	Number of Crossings	Accident Severity per Accident					
		Before Installation			After Installation		
		Deaths	Injuries	Casualties	Deaths	Injuries	Casualties
Protection prior to installation of flashing light signals							
None (new crossing)	75	—	—	—	0.12	0.49	0.61
Crossbucks	245	0.22	0.74	0.96	0.12	0.34	0.45
Wigwag	98	0.03	0.51	0.54	0.05	0.46	0.51
Miscellaneous	16	0.07	0.33	0.40	0.04	0.25	0.29
Subtotal	434	0.15	0.64	0.80	0.09	0.39	0.48
Protection prior to installation of automatic gates							
None (new crossing)	91	—	—	—	—	0.17	0.17
Crossbucks	243	0.25	0.65	0.90	0.06	0.39	0.44
Wigwag	248	0.11	0.47	0.58	0.05	0.18	0.23
Flashing light	498	0.14	0.45	0.59	0.06	0.32	0.39
Miscellaneous	38	0.03	0.41	0.43	0.02	0.30	0.33
Subtotal	1118	0.14	0.49	0.63	0.05	0.28	0.33
Total	1552	0.14	0.52	0.66	0.07	0.32	0.39

Table 5. Accident experience per crossing-year at rural crossings.

Category	Number of Crossings	Accident Experience per Crossing-Year					
		Before Installation			After Installation		
		Accidents	Deaths	Injuries	Accidents	Deaths	Injuries
Protection prior to installation of flashing light signals							
None (new crossing)	35	—	—	—	0.06	0.01	0.02
Crossbucks	137	0.23	0.07	0.22	0.06	0.01	0.02
Wigwag	23	0.26	—	0.15	0.13	0.01	0.06
Miscellaneous	4	0.50	0.07	0.30	0.26	0.03	0.08
Subtotal	199	0.24	0.06	0.22	0.08	0.01	0.03
Protection prior to installation of automatic gates							
None (new crossing)	47	—	—	—	0.09	—	0.01
Crossbucks	156	0.23	0.07	0.15	0.03	—	0.01
Wigwag	67	0.29	0.06	0.16	0.10	0.01	0.02
Flashing light	168	0.35	0.07	0.16	0.13	0.01	0.03
Miscellaneous	2	0.34	—	0.11	—	—	—
Subtotal	440	0.29	0.07	0.16	0.08	0.01	0.02
Total	639	0.28	0.07	0.17	0.08	0.01	0.02

Table 6. Accident experience per crossing-year at urban crossings.

Category	Number of Crossings	Accident Experience per Crossing-Year					
		Before Installation			After Installation		
		Accidents	Deaths	Injuries	Accidents	Deaths	Injuries
Protection prior to installation of flashing light signals							
None (new crossing)	40	6.00	—	—	0.09	0.01	0.05
Crossbucks	108	0.28	0.04	0.14	0.12	0.01	0.04
Wigwag	75	0.31	0.01	0.15	0.16	0.01	0.07
Miscellaneous	12	0.33	0.01	0.07	0.19	—	0.04
Subtotal	235	0.30	0.03	0.14	0.13	0.01	0.05
Protection prior to installation of automatic gates							
None (new crossing)	44	—	—	—	0.07	—	0.02
Crossbucks	87	0.24	0.03	0.16	0.05	—	0.01
Wigwag	181	0.43	0.04	0.19	0.14	0.01	0.02
Flashing light	330	0.44	0.05	0.20	0.14	0.01	0.05
Miscellaneous	36	0.62	0.02	0.25	0.16	—	0.05
Subtotal	678	0.42	0.04	0.20	0.12	—	0.04
Total	913	0.39	0.04	0.18	0.13	0.01	0.04

further assumed that the outstanding characteristic at rural crossings was the speed of vehicle and train. Before the installation of automatic warning devices, rural crossings experienced 28 percent fewer accidents than urban crossings but suffered 55 percent more casualties per accident. However, after the automatic warning devices were installed, many of the previously severe accidents were eliminated and there were 38 percent fewer accidents at rural crossings than at urban crossings, although there was approximately the same number of casualties per accident at rural and urban crossings.

Table 7. Effectiveness results at rural crossings.

Category	Number of Crossings	Percentage of Reduction After Installation: Accident Factor per Crossing-Year: Accidents	Deaths	Injuries	Accident Severity per Accident: Deaths	Injuries	Casualties
Protection prior to installation of flashing light signals							
None (new crossing)	35	—	—	—	—	—	—
Crossbucks	137	-73.91	-85.71	-90.91	-58.06	-70.71	-67.69
Wigwag	23	-50.00	—	-60.00	250.00	-24.14	-13.33
Miscellaneous	4	-48.00	-57.14	-73.33	-33.33	-50.00	-46.67
Subtotal	199	-66.67	-83.33	-86.36	-56.00	-63.74	-61.21
Protection prior to installation of automatic gates							
None (new crossing)	47	—	—	—	—	—	—
Crossbucks	156	-86.96	-100.00	-93.33	-64.52	-15.15	-30.93
Wigwag	67	-65.52	-83.33	-87.50	-77.27	-60.00	-64.47
Flashing light	168	-62.86	-85.71	-81.25	-47.62	-40.91	-43.94
Miscellaneous	2	-100.00	—	-100.00	—	-100.00	-100.00
Subtotal	440	-72.41	-89.60	-87.50	-62.50	-49.06	-54.55
Total	639	-70.80	-88.30	-86.20	-59.82	-53.10	-55.00

Table 8. Accident severity at rural crossings.

Category	Number of Crossings	Accident Severity per Accident: Before Installation: Deaths	Injuries	Casualties	After Installation: Deaths	Injuries	Casualties
Protection prior to installation of flashing light signals							
None (new crossing)	35	—	—	—	0.11	0.37	0.47
Crossbucks	137	0.31	0.99	1.30	0.13	0.29	0.42
Wigwag	23	0.02	0.58	0.60	0.07	0.44	0.52
Miscellaneous	4	0.15	0.60	0.75	0.10	0.30	0.40
Subtotal	199	0.25	0.91	1.16	0.11	0.33	0.45
Protection prior to installation of automatic gates							
None (new crossing)	47	—	—	—	—	0.11	0.11
Crossbucks	156	0.31	0.66	0.97	0.11	0.56	0.67
Wigwag	67	0.22	0.55	0.76	0.05	0.22	0.27
Flashing light	168	0.21	0.44	0.66	0.11	0.26	0.37
Miscellaneous	2	—	0.33	0.33	—	—	—
Subtotal	440	0.24	0.53	0.77	0.09	0.27	0.35
Total	639	0.25	0.63	0.87	0.10	0.30	0.39

Table 9. Accident severity at urban crossings.

Category	Number of Crossings	Accident Severity per Accident: Before Installation: Deaths	Injuries	Casualties	After Installation: Deaths	Injuries	Casualties
Protection prior to installation of flashing light signals							
None (new crossing)	40	—	—	—	0.13	0.57	0.70
Crossbucks	108	0.13	0.48	0.61	0.10	0.37	0.47
Wigwag	75	0.04	0.49	0.53	0.04	0.46	0.51
Miscellaneous	12	0.02	0.20	0.22	—	0.22	0.22
Subtotal	235	0.09	0.46	0.55	0.08	0.42	0.50
Protection prior to installation of automatic gates							
None (new crossing)	44	—	—	—	—	0.22	0.22
Crossbucks	87	0.13	0.64	0.77	—	0.22	0.22
Wigwag	181	0.09	0.45	0.54	0.05	0.17	0.22
Flashing light	330	0.11	0.46	0.56	0.04	0.35	0.39
Miscellaneous	36	0.03	0.41	0.44	0.02	0.30	0.33
Subtotal	678	0.10	0.47	0.56	0.04	0.28	0.32
Total	913	0.09	0.47	0.56	0.05	0.33	0.38

Although the effectiveness of automatic warning devices appears to be somewhat dependent on the site of the crossing, significant benefits in terms of reduction in the number and severity of accidents are realized at both rural and urban locations.

TRACK INFLUENCE

There is reluctance in some circles to install automatic gates except at double-track main-line locations ("main line" is an actual railroad designation that distinguishes the important lines from the less important lines), since these locations are the only ones where sufficient benefits are received to justify the cost. Although the records could not be constructed to reflect the previous physical conditions, 1269 of the crossings included in the sample were segregated into three distinct categories: (a) single-track crossings, (b) crossings with two or more main or branch tracks, and (c) other multiple-track crossings with fewer than two main or branch tracks but with additional spur tracks.

The results in Tables 11 and 12 show that, while the percentage of reduction in accident rates is nearly identical for all three categories, there is a more than 80 percent greater chance of accident at double-track main- or branch-line crossings than at single-track crossings, before and after the installation of automatic warning devices. In terms of casualties per accident, severity rates, at least before the installation of automatic gates, were 25 percent greater at single-track crossings than at double-track main-line crossings. The number of casualties per crossing-year was higher at double-track main- or branch-lines due to the significant difference in accident frequency, and the results seem to show that improving the warning device at double-track main- or branch-line crossings provides the greatest amount of benefit in absolute numbers. The effectiveness of automatic gates in terms of the percentage of reduction in accident frequency, however, is nearly equal for all categories. This reduction indicates that automatic gates have a similar effect in most instances and are clearly adaptable to and productive in varied crossing conditions.

ECONOMIC ANALYSIS

Although the effectiveness results developed in this study are useful in formulating a balanced grade-crossing safety program, the vehicle-train accident frequency and severity comparisons can also be used to test the economic feasibility of installing various warning devices at individual crossings or at a group of crossings. Complete examples and explanations of the technique have been published (3, 4, 5).

One method, which considers only a single crossing location, involves estimating the future potential for vehicle-train accidents by comparing the expected frequency and severity of accidents with the existing warning devices and with the more sophisticated devices installed, taking into account the monetary difference. The reduction in expected annual economic loss through the installation of higher order warning devices on an incremental basis compared with the annual cost of installing, maintaining, and operating each of the various devices on an incremental annual basis would indicate which warning device would be the most cost-effective.

To compare the relative effectiveness of the various types of warning devices, two distinct considerations are involved: accident frequency and accident severity. The data from Tables 2 and 4 indicate that both accident frequency and accident severity, as well as the number of recorded deaths and injuries per accident, are reduced by the installation of flashing light signals or automatic gates. It is imperative that both accident frequency and accident severity be included in any comparative economic analysis. Therefore, the factors considered for a reasonable estimate of the relative value of warning devices in California are as follows:

Warning Device	Accident Frequency	Accident Severity: Deaths per Accident	Accident Severity: Injuries per Accident
Crossbucks	1.00	1.00	1.00
Flashing lights	0.33	0.54	0.57
Automatic gates	0.13	0.25	0.46

The first unknown, and one that is subject to considerable critical speculation, is the potential accident frequency and severity at a crossing with or without improvement of the warning device. There are several methods available for determining these potentials; the least attractive is to extend past accident rates and to use a simple hazard index or sufficiency rating equations that may or may not correlate with actual accident experience. The more reasonable method, if a significant correlation exists, is to develop predictive equations by using multiple regression techniques that forecast vehicle-train accidents as a function of the physical conditions that describe each crossing such as train and vehicle volumes, respective speeds, and geometrics or distractions. Regression equations estimate as much as possible of the variation in the dependent variable—the vehicle-train accident experience—by simultaneously combining several independent variables. The equations can be used, with differing levels of confidence, for individual crossings or for groups of similar crossing types. The California Public Utilities Commission has attempted to develop regression equations for use in California, but for a variety of reasons, including a limited data base, it has failed to arrive at a set of equations that could be used with any degree of certainty for individual crossings. For this analysis, the typical accident and severity rates (accidents per year, deaths per accident, and injuries per accident) shown in Tables 2 and 4 are used in Table 13 to determine the economic loss expected per year with each type of warning device.

Once the predicted accident frequency and severity rates have been developed, the economic benefits are estimated by defining the cost of the unit hazard—the economic loss incurred by vehicle-train accidents, deaths, and injuries. As in the case of estimating accident potential, there is little conformity among public agencies; estimates vary considerably, depending on the source and the method. For this analysis, the National Highway Traffic Safety Administration (NHTSA) figures of $133 000 per fatality and $3500 per injury are used (6). Although the NHTSA actually uses figures of $200 000 and $7300 respectively, only discounted wage loss and medical costs were considered applicable. Flashing lights reduce the anticipated economic loss by $9410 from what would be expected with crossbucks, and automatic gates reduce the expected economic loss by $1870 from what would be expected with flashing lights.

To determine which device offers the most cost-effective alternative, it is necessary to calculate the annual cost of installing, maintaining, and operating each type of warning device. This is computed in Table 14. The installation cost figures of $16 250 for flashing lights and $27 290 for automatic gates are actual 1975 California estimates; the $190 for crossbucks is a 1972 figure, updated by using a construction cost index. The maintenance and operation cost figures of $500 for

flashing lights and $1000 for automatic gates are based on Association of American Railroads figures that use a unit cost of $30, which the Public Utilities Commission currently recognizes. The annual cost of capital recovery was calculated by using a useful life of 30 years and an interest rate of 10 percent. On an incremental basis, it costs $2190/year more to install, maintain, and operate flashing lights than crossbucks and $1670 more for automatic gates than for flashing light signals.

Given the accident frequencies and severity and accident costs, the most effective alternative would be automatic gates. This sample analysis acts only as a brief outline; a detailed analysis should include consideration of vehicular delay, property damage, and accidents that do not involve trains. In addition, it is evident that such

Table 10. Effectiveness results at urban crossings.

Category	Number of Crossings	Percentage of Reduction After Installation					
		Accident Factor per Crossing-Year			Accident Severity per Accident		
		Accidents	Deaths	Injuries	Deaths	Injuries	Casualties
Protection prior to installation of flashing light signals							
None (new crossing)	40	-98.50	—	—	—	—	—
Crossbucks	108	-57.14	-75.00	-71.43	-23.08	-22.92	-22.95
Wigwag	75	-48.39	—	-53.33	—	-6.12	-3.77
Miscellaneous	12	-42.42	-100.00	-42.86	-100.00	10.00	—
Subtotal	235	-56.67	-66.67	-64.29	-11.11	-8.70	-9.09
Protection prior to installation of automatic gates							
None (new crossing)	44	—	—	—	—	—	—
Crossbucks	87	-79.17	-100.00	-93.75	-100.00	-65.63	-71.43
Wigwag	181	-67.44	-75.00	-89.47	-44.44	-62.22	-59.26
Flashing light	330	-68.18	-80.00	-75.00	-63.64	-23.91	-30.36
Miscellaneous	36	-74.19	-100.00	-80.00	-33.33	-26.83	-25.00
Subtotal	678	-71.43	-100.00	-80.00	-60.00	-40.43	-42.86
Total	913	-67.60	-82.25	-77.00	-45.79	-29.79	-32.14

Table 11. Effect of type of railroad track on number of accidents.

Type of Crossing	Number of Crossings	Accident Experience per Crossing-Year								
		Before Installation			After Installation					
					Accidents		Deaths		Injuries	
		Accidents	Deaths	Injuries	Number	Decrease (%)	Number	Decrease (%)	Number	Decrease (%)
Crossings upgraded to flashing light signals										
Single track	179	0.29	0.06	0.25	0.09	-69	0.01	-83	0.04	-84
Double main line or branch track	14	0.48	0.01	0.22	0.24	-50	0.01	0	0.09	-59
Other multiple track	108	0.26	0.04	0.13	0.13	-50	0.01	-75	0.03	-77
Crossings upgraded to automatic gates										
Single track	482	0.31	0.06	0.17	0.08	-74	0.01	-83	0.02	-88
Double main line or branch track	119	0.57	0.06	0.28	0.16	-74	0.00	-100	0.05	-86
Other multiple track	367	0.37	0.05	0.15	0.12	-68	0.01	-80	0.04	-73

Table 12. Effect of type of railroad track on severity of accidents.

Type of Crossing	Number of Crossings	Accident Severity per Accident								
		Before Installation			After Installation					
					Deaths		Injuries		Casualties	
		Deaths	Injuries	Casualties	Number	Decrease (%)	Number	Decrease (%)	Number	Decrease (%)
Crossings upgraded to flashing light signals										
Single track	179	0.21	0.86	1.07	0.08	-61	0.45	-47	0.54	-50
Double main line or branch track	14	0.02	0.45	0.47	0.03	-50	0.39	-13	0.42	-11
Other multiple track	108	0.16	0.49	0.66	0.11	-31	0.27	-45	0.38	-42
Crossings upgraded to automatic gates										
Single track	482	0.19	0.56	0.75	0.09	-53	0.22	-61	0.31	-59
Double main line or branch track	119	0.10	0.50	0.60	0.03	-70	0.29	-46	0.32	-52
Other multiple track	367	0.13	0.41	0.54	0.05	-62	0.32	-22	0.37	-31

Table 13. Economic analysis of incremental benefit calculation.

Warning Device	Fatalities per Accident		Injuries per Accident		Total Cost per Accident ($)	Total Accidents per Year		
	Number	Cost ($)	Number	Cost ($)		Number	Cost ($)	Incremental Difference From Next Highest Alternative (rounded $)
Crossbucks	31 920	0.24	2345	0.70	34 265	0.34	11 650	–
Flashing light	17 290	0.13	1340	0.40	18 630	0.12	2 236	9410
Automatic gates	7 980	0.06	1072	0.32	9 052	0.04	362	1870

Table 14. Economic analysis of incremental cost calculation.

Warning Device	Installation Cost ($)	Annual Maintenance and Operation Cost ($)[a]	Annual Cost of Capital Recovery ($)[b]	Total Annual Cost ($)	Incremental Cost Over Next Lowest Alternative ($)
Crossbucks	190	15	20	35	–
Flashing light	16 250	500	1725	2225	2190
Automatic gates	27 290	1000	2895	3895	1670

[a] From Association of American Railroads. [b] Useful life of 30 years at 10 percent interest.

an analysis must be sensitive to several of the unknowns that deserve close scrutiny, including (a) predicted vehicle-train accident rates; (b) installation, maintenance, and operational costs of the various devices; and (c) the economic value placed on human life.

LIMITATIONS OF AUTOMATIC WARNING DEVICES

Much has been said about the reduction in the frequency of vehicle-train accidents that can be expected from the installation of automatic warning devices; however, certain limitations do exist. Some trends have developed in California that indicate that considerable research is still required. The most obvious disadvantage entailed in the installation of automatic warning devices is the increased number of secondary or gate accidents that occur. In 1973, there were 745 vehicle-train accidents in California but there were also 2197 crossing gate accidents, and that number is expected to increase steadily with increased gate installations. The key point, however, is severity of accidents. While 59 persons were killed and almost 300 injured because of vehicle-train accidents in 1973, there was not a single reported casualty in any of the 2197 gate accidents recorded. The effectiveness of automatic gates is partially dependent on and limited by street design and crossing geometrics. Between 1970 and 1972, there were more than 200 recorded vehicle-train accidents at crossings with automatic gates that were classified as being caused by stalled vehicles or vehicles that stopped but did not clear the tracks.

Another limitation of automatic gates that indicates a trend that should be viewed with dismay is the increasing number of vehicle-train accidents at crossings with automatic gates that are caused by failure of the vehicle driver to stop at the crossing. While the number of such accidents is still small compared with other causes, during the same period there were 150 accidents attributed to failure of the vehicle to stop. Part of the increase in such accidents is probably due to the increased number of gate installations, but there has been an unaccountable increase in vehicles driving around or through lowered gates. Driving around lowered gates is probably a result of frustration or disrespect, but driving through lowered gates can be due to inattention or excessive speed, both of which should be examined closely to determine whether the underlying hazard could be mitigated by improving the warning design, either at the crossing or through more sophisticated advance warning devices.

CONCLUSIONS

Automatic warning devices are quite effective in reducing vehicle-train accidents and casualties at public railroad-highway grade crossings in California. The installation of automatic crossing gates can be expected, on the average, to result in 70 percent fewer vehicle-train accidents per year and an additional 48 percent fewer casualties per accident. Theoretically, if automatic gates were in service for the entire study period, there would have been about 2500 fewer accidents, 450 fewer deaths, and 1450 fewer injuries.

Automatic gates eliminate many of those accidents involving moving vehicles that offer the greatest potential severity; they reduce the number of deaths by 64 percent/accident, injuries by 43 percent/accident, and deaths by more than 36 percent/injury. The effectiveness of automatic warning devices is dependent, in part, on crossing locality. Accident rates before and after the installation of automatic warning devices were far lower at rural than at urban crossings. The percentage of reduction in all accident and casualty rates was higher at rural crossings.

While the percentage of reduction in vehicle-train accidents was equal for single-track and double-track main or branch crossings, the latter were far more hazardous in terms of accidents per crossing-year and, therefore, showed the greatest benefit in terms of numbers of accidents and casualties reduced. The equal percentage of reduction would seem to indicate, however, that automatic gates were adaptable and effective at all crossing situations. Automatic gates are superior to other types of warning devices because they have a visual and auditory impact on driver response. Gates act as a physical or psychological barrier and drastically reduce or simplify any decision a vehicle driver might want or need to make. However, automatic devices may have a practical limit, and the final responsibility for preventing accidents must rest with the vehicle driver. Automatic warning devices will help prevent vehicle-train accidents caused by natural conditions such as inadequate sight distance or the general inability to see or perceive an approaching train; accidents caused by traffic or rail volumes; accidents caused by trains operating on multiple tracks; and, in part, accidents caused by distractions and other road hazards. Automatic devices will probably

not prevent vehicle-train accidents caused by complete driver inattention, excessive vehicular speed, violations of the law, or lack of sound driver judgment. Automatic warning devices are a preventive tool, but they will only fulfill their potential if the driver is aware of his or her obligation to face the hazards involved when approaching a rail-street crossing.

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