Further Investigation of the Effectiveness of Warning Devices at Rail-Highway Grade Crossings

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ABSTRACT

The main objective of the study was to analyze the national inventory of the U.S. Department of Transportation-Association of American Railroads and the accident files of the Federal Railroad Administration to develop measures of effectiveness for the following rail-highway grade-crossing upgrade stratifications: (a) passive systems to flashing lights on single track, (b) passive systems to gates on single and multiple track, and (c) flashing lights to gates on single and multiple track. Other objectives included determining the influence of crossing angle, train speed ratio, and train speed difference on the effectiveness of warning devices. Overall results confirmed effectiveness values developed previously (but with smaller data bases) for upgrades from passive systems to flashing lights (69 percent) and from passive systems to gates (84 percent). The only marked change from previous studies occurred in the flashing-lights-to-gates category; the effectiveness value determined in this study (72 percent) was higher than values obtained in previous work. Upgrades of warning devices on single track had higher effectiveness values than those on multiple tracks. Variation in train speeds at grade crossings, as measured by the speed-ratio and speed-difference concepts, had no apparent influence on the effectiveness of warning devices. Additional detailed conclusions as well as recommendations for further study are also included in the paper.

Safety at rail-highway grade crossings has long been a concern of many communities and public and private organizations. Although railroad grade-crossing accidents account for less than 1 percent of all motor vehicle accidents nationwide, the ratio of persons killed and injured to the number of grade-crossing accidents is an order of magnitude higher than that of all motor vehicle accidents. Consequently, substantial sums of money are spent each year to install warning devices at rail-highway grade crossings.

Attempts to apply warning devices to reduce the number of accidents at rail-highway grade crossings have a long history, dating from the earliest days of motor vehicle travel. The recent emphasis on grade-crossing safety has focused on optimizing the use of the limited funds available for upgrading crossings. A resource allocation model to assist states and railroads in determining the most effective allocation of funds for rail-highway crossing safety improvements has recently been developed by the U.S. Department of Transportation (DOT). The model, which has been described by Farr and Tustin (1), determines which crossings should have warning devices installed so as to achieve the maximum crossing safety benefit for a given level of funding. A brief description of the model is presented in the following paragraphs.

The typical approach in decision making on improvement of crossing safety is first to rank all crossings under consideration by using a hazard model. The most hazardous crossings are selected from this list of candidates for further review. The final decision is based on information gathered from on-site visits, the applicability of available alternatives, and the expected safety improvement. The resource allocation model includes a quantitative measure of safety benefit and equipment installation cost, along with a hazard value. Instead of providing a list of the most hazardous crossings, the model provides a list of the most cost-effective improvement decisions. These decisions are then examined and either adopted or rejected based on site-specific information.

The model is designed to rank crossings in the order that they need improvement and to recommend the warning device that should be installed to be the most cost and safety effective. Inputs to the resource allocation model include the predicted accident rates of the crossings, costs and effectiveness values of the different safety improvement options (such as flashing lights and gates), and the budget level available for safety improvement. To support the resource allocation model, costs and effectiveness values of different safety improvements were developed by using national data.

Several aspects of the model suggest that additional research is needed. One aspect is the effectiveness of different types of grade-crossing improvements. Effectiveness of a warning device is defined as the fraction by which accidents are reduced after installation of the warning device. This issue is important not only because it affects allocation of scarce highway resources, but also because it could affect the legal liability of railroads and states due to choice of crossing protection at a particular location.

Until the development of the resource allocation model, most measures of effectiveness of using gates versus using flashing light signals had been based on a study performed by the California Public Utilities Commission (PUC) in the early 1970s (2). Measures of effectiveness were developed for three types of improvements: passive system to flashing lights, passive system to gates, and flashing lights to gates. However, the universal applicability of the California PUC results has been questioned. Morrissey (3) noted that the effectiveness values from the PUC study were frequently criticized as being too high in view of accident statistics published by the Federal Railroad Administration (FRA).

Morrissey (3) undertook a study to improve the quality of and confidence in the data required for the DOT resource allocation model by determining new effectiveness values by using national data. The new effectiveness values were based on an analysis of the accident history of about 50 percent of the crossings (2,994) in the United States that had warning device upgrades during the period January 1, 1975, to December 31, 1978. Necessary data for the analysis were obtained from the DOT-Association of American Railroads (AAR) National Rail-Highway Crossing Inventory and the FRA Railroad Accident/Incident Reporting System. Morrissey's (3) effectiveness values almost equaled the results of the PUC study; that is, the California PUC results were within the 95-percent confidence intervals of the results of Morrissey's study.

The close agreement between Morrissey's results and those of the California PUC is not surprising because his study essentially repeated the PUC study, although with a much larger and more current data base. However, several aspects of Morrissey's study suggested a need for additional research. Since then, several more years of data have become available, thereby expanding opportunities for determining the effectiveness of various warning devices.

To address some of the questions raised by Morrissey's study, FHWA conducted additional investigations into the effectiveness of warning devices at rail-highway crossings. In addition to examining the three warning device upgrade categories studied by the PUC and Morrissey, Farr and Hitz (4) also obtained effectiveness values for upgrades to illumination and to cantilevered and mast-mounted flashing lights. Furthermore, they determined the influence of number of highway lanes, number of tracks, and train speed on the effectiveness of warning devices. The new effectiveness values determined for flashing lights and gates revealed results that were different from those of Morrissey's study. However, the results were claimed to be more accurate because the larger sample size used resulted in smaller confidence intervals than resulted from the sample size used by Morrissey. Farr and Hitz (4) also found that the effectiveness of warning devices declined with increasing number of tracks for grade crossings with two highway lanes. In general, train speed did not influence the effectiveness of warning devices.

Currently there are a number of issues concerning the effectiveness of warning devices that need to be addressed. Questions might be raised about the effectiveness of gates versus flashing lights at locations where warrants for gates are not met (e.g., a single track crossing with low to moderate train speeds). This is an important question because it affects the resource allocation model, and thereby influences the legal liability of railroads and states because of a choice of flashing lights rather than flashing lights and gates at a particular location. Additional efforts to stratify the data further to develop measures of effectiveness for the installation or upgrading of devices under various circumstances are definitely needed and have been noted by Farr and Hitz (4). Estimates of the effectiveness of stop signs would be desirable. This is a standard highway sign that may have a level of effectiveness that is greater than crossbucks. Several other potentially important factors should be analyzed to determine their influence on the effectiveness of warning devices. These factors include crossing angle and the ratio of maximum timetable speed to actual train speeds. For the latter factor, a crossing with a high timetable speed but a predominance of slow-speed trains that is not protected by a constant-warning-time device may create problems of credibility with motorists.

STUDY OBJECTIVES

The overall objective of the proposed research was to analyze further the national DOT-AAR inventory and FRA accident files to develop measures of effectiveness for the installation or upgrading of rail-highway grade-crossing protection devices under various conditions. Specific objectives of the study were

1. To develop measures of effectiveness for the following crossing upgrade stratifications: (a) passive warning device to flashing lights (single track), (b) flashing lights to gates (single track) either due to accidents or high train speeds ($\geq$ 50 mph), (c) flashing lights to gates (multiple track), (d) passive warning device to gates (single track), and (e) passive warning device to gates (multiple track);
2. To determine the influence of angle of crossing on the effectiveness of warning devices; and
3. To determine the influence of speed ratio (ratio of maximum timetable speed to typical minimum speed) and speed difference (difference between maximum timetable speed and typical minimum speed) on the effectiveness of warning devices for upgrades from (a) passive warning devices to flashing lights, (b) passive warning devices to crossing gates, and (c) flashing lights to crossing gates.

DATA ANALYSIS

The DOT-AAR Crossing Inventory File and the FRA Accident Data File for the period January 1, 1975, through December 31, 1982, were obtained from FRA. Of particular interest in this study was the classification of warning devices. The inventory file assigned a warning device class to each grade crossing. The FRA classes include eight categories of warning devices that reflect the level of motorist warning present. In general, the higher the class, the more warning information is provided to the motorist.

The first four warning device classes (no signs, other signs, stop signs, and crossbucks) are referred to as passive devices. Classes 5, 6, and 7 (special devices, wigwags or bells, and flashing lights, respectively) have usually been grouped into the flashing-light category (active devices). However, because classes 5 and 6 are infrequently used and often do not meet appropriate traffic engineering guidelines, these two classes were deleted from the flashing-light category in this study to provide more meaningful results. Class 8 of warning devices (flashing lights with gates) represents the most extensive type of crossing protection.

The data set that was created after working with the inventory data base included 13,852 warning device changes at public grade crossings. This data set was then merged with the accident file data base. To determine the effectiveness value for each upgrade category, or warning device, the average accident rates (accidents per crossing year) for crossings before and after installation of warning devices were compared.

The following formula (3) was used to calculate the effectiveness of the warning devices:

$$E = (A_b/Y_b - A_a/Y_a)/(A_b/Y_b) \quad (1)$$

where

E = effectiveness of a particular warning device;

TABLE 1 Summary of Results of Effectiveness Values for Flashing Lights and Gate Upgrades

Upgrade Category[a]	No. of Crossings	Before Upgrade Accidents	Before Upgrade Crossing Years	After Upgrade Accidents	After Upgrade Crossing Years	Effectiveness Value (%)	Standard Deviation of Effectiveness Value (%)	95 Percent Confidence Interval (%)
P to FL	2,786	1,407	10,824	448	11,234	69	1.6	66-72
P to G	2,781	2,157	10,934	352	11,291	84	0.9	82-86
FL to G	2,167	2,139	8,179	639	8,838	72	1.2	70-75
Total	7,734	5,703	29,937	1,439	31,363	76	0.7	74-77

[a] P = passive, FL = flashing lights, and G = flashing lights with gates.

A_b = total number of accidents before warning device installation;
Y_b = total number of cross years before warning device installation;
A_a = total number of accidents after warning device installation; and
Y_a = total number of crossing years after warning device installation.

Results of the computations of effectiveness values are presented in the following section.

RESULTS

Overall Effectiveness

Currently, the rail-highway crossing resource allocation model considers three categories of warning device upgrades: (a) passive systems to flashing lights, (b) passive systems to gates, and (c) flashing lights to gates. Effectiveness values and confidence intervals for upgrades within these warning device categories were calculated and compared with similar results from earlier studies. This was done both to serve as a check on the methodology used herein and to examine whether there would be any changes in effectiveness values with the larger sample size used in this study. Results are presented in Table 1. As the data in Table 2 indicate, the results are slightly different from those obtained in previous studies. Because of the additional data used in the current study, the results are more accurate, as indicated by the smaller confidence intervals.

A review of the data in Table 2 indicates that only effectiveness values for flashing-lights-to-gate upgrades have changed markedly from previous studies. Farr and Hitz (4) had noticed a similar phenomenon and noted that it was difficult to explain. They hypothesized that flashing-light crossings more recently selected for upgrading to gates had unique characteristics that caused gates to be particularly effective relative to flashing lights.

It is also possible that the increased effectiveness is because of improved traffic engineering (as it applies to the layout of the displays) at crossings that have been recently upgraded. When flashing lights are upgraded to flashing lights and gates, an entirely new crossing installation, including both displays and control circuitry, generally results. Further, since the completion of the California PUC study (2), motion sensors and predictors have come into common use. This increases the credibility of the device and may contribute to the higher effectiveness value.

Single-Track Upgrades

Three different stratifications of warning device upgrades on single tracks were examined: (a) passive systems to flashing lights, (b) passive systems to gates, and (c) flashing lights to gates. The data in Table 3 present the effectiveness values and confidence intervals for each of these upgrade categories. Unexpectedly, warning device upgrades on single tracks had a higher effectiveness value than those on multiple tracks.

As anticipated, the highest effectiveness value (86 percent) was associated with upgrades from passive devices to flashing lights with gates. Upgrades from flashing lights to gates had an effectiveness value of 74 percent. The lowest effectiveness value of the three upgrades was associated with the passive-to-flashing-lights condition (71 percent). Because of the large sample size involved, confidence intervals were of approximately the same width as those for the overall analysis presented previously.

As a subset of the analysis just described, the upgrading of warning devices from flashing lights to gates on single track under the circumstances of (a) accidents and (b) high train speeds (maximum timetable speed of 50 mph or greater) was examined. The data in Table 4 present effectiveness values for those crossings that experienced accidents before the upgrade occurred. Also presented in Table 4 are effectiveness values for crossings that experienced one or more accidents either before the upgrade or after. Crossings that did not experience accidents before or after the upgrade were excluded because it was thought that such crossings would not aid in the

TABLE 2 Comparison of Effectiveness Values for Flashing Lights and Gate Upgrades for Current and Previous Studies

Upgrade Category[a]	Effectiveness Values: Current Study	Effectiveness Values: Farr and Hitz (1982)	Effectiveness Values: Morrissey (1981)	Effectiveness Values: California PUC (1974)	95 Percent Confidence Interval: Current Study	95 Percent Confidence Interval: Farr and Hitz (1982)	95 Percent Confidence Interval: Morrissey (1981)	95 Percent Confidence Interval: California PUC (1974)
P to FL	69	71	65	64	66-72	66-75	57-73	NA
P to G	84	82	84	88	82-86	79-85	80-89	NA
FL to G	72	69	64	66	70-75	65-73	56-71	NA

Note: NA = not available.

[a] P = passive, FL = flashing lights, and G = flashing lights with gates.

TABLE 3 Summary of Results of Effectiveness Values for Single- and Multiple-Track Upgrades

Upgrade Category[a]	No. of Crossings	Before Upgrade Accidents	Before Upgrade Crossing Years	After Upgrade Accidents	After Upgrade Crossing Years	Effectiveness Value (%)	Standard Deviation of Effectiveness Value (%)	95 Percent Confidence Interval (%)
Single Track								
P to FL	2,488	1,287	9,686	390	10,079	71	1.63	68–74
P to G	2,089	1,584	8,110	234	8,609	86	0.95	84–88
FL to G	1,626	1,539	6,187	437	6,703	74	1.34	71–76
Multiple Track								
P to G	567	520	2,311	113	2,202	77	2.27	73–81
FL to G	483	569	1,961	193	1,894	65	2.70	60–70

[a] P = passive, FL = flashing lights, and G = flashing lights with gates.

TABLE 4 Effectiveness Values for Upgrades from Flashing Lights to Gates on Single Tracks

Maximum Train Speed (mph)	No. of Crossings	Before Upgrade Accidents	Before Upgrade Crossing Years	After Upgrade Accidents	After Upgrade Crossing Years	Effectiveness Value (%)	95 Percent Confidence Interval (%)
Crossings with Accidents Before							
0–49	456	1,054	2,137	140	1,671	83	80–86
≥ 50	231	475	1,062	80	959	81	77–85
Crossings with or without Accidents Before							
0–49	1,007	1,054	4,062	253	4,000	76	72–79
≥ 50	619	475	2,252	184	2,705	68	63–73

examination of high accident experience in which train speeds were 50 mph or greater. Although the effectiveness values for the 0-to-49-mph category were slightly higher than values for the high-speed category (83 and 81 percent, respectively), the difference was not significant. This result was unexpected because it was thought that installation of gates would be more effective at crossings where high train speeds are encountered.

When the crossings were added to the analysis that did not experience accidents before the upgrade but did have accidents after the upgrade, the effectiveness values for the two speed categories were significantly different. As expected, the effectiveness values were lower than for crossings that experienced accidents before the upgrade. The 0-to-49-mph category again revealed a higher effectiveness value (76 versus 68 percent) than did the high-speed category. Once again, this is contrary to the notion that effectiveness of gates should be higher at crossings with high-speed trains. One possible explanation for these results is the credibility problem created when the majority of rail traffic on a line travels at speeds substantially less than the timetable speed. This problem will be discussed in a subsequent section.

Multiple-Track Upgrades

Two different stratifications of warning device upgrades on multiple tracks were examined: (a) passive systems to gates and (b) flashing lights to gates. Effectiveness values and confidence intervals for each of these categories are given in Table 3. Note that these upgrades had a lower effectiveness value than did the corresponding upgrades on single track.

As expected, upgrades from passive devices to flashing lights had a higher effectiveness value (77 percent) than did upgrades from flashing lights to gates (65 percent). In both cases the confidence intervals were larger than those obtained in the overall or single-track analyses because of the relatively small sample sizes involved.

It is hypothesized that the lower effectiveness value associated with multiple-track upgrades is due to the greater exposure (product of train times vehicular volumes) likely to be found at these crossings. Accidents continue to occur because of high exposure levels even after gates have been installed at the crossing. Ideally, the accident rates used in developing the effectiveness values should include a measure of exposure.

A further investigation involving improvement types and before-accident rates for active and passive devices was made to determine if any additional conclusions could be drawn. Before-accident rates in terms of accidents per crossing year were computed; these are given in Table 5. Note the relatively high rates in the flashing-lights-to-gates category for both single and multiple track. It can be inferred from the data that flashing lights are upgraded to gates in response to an accident problem. Although this is good management, it does tend to bias the effectiveness data.

TABLE 5 Before-Accident Rates for Single- and Multiple-Track Upgrades

Upgrade Category[a]	Accidents per Crossing Year Single Track	Accidents per Crossing Year Multiple Track
P to FL	0.133	-
P to G	0.195	0.225
FL to G	0.250	0.290

[a] P = passive, FL = flashing lights, and G = flashing lights with gates.

Influence of Crossing Angle

The effectiveness of crossing warning devices would be expected to be related to the angle of the crossing. Effectiveness of devices should be greatest at oblique-angle crossings because it is at these locations that motorists may have difficulty determining the exact location of the track. They may also have trouble detecting an approaching train because of sight obstructions in the vehicle or because of uncertainty in determining where to look along the tracks.

In this part of the research, crossing-angle categories of 0 to 30 degrees, 30 to 60 degrees, and 60 to 90 degrees were analyzed for their influence on the effectiveness of warning devices. The influence of angle of crossing on the effectiveness of warning devices is given in Table 6 for both single- and multiple-track categories.

For the single-track condition, a review of the data in Table 6 indicates that for upgrade categories of passive to flashing lights and flashing lights to gates, the effectiveness values are greatest in the angle-of-crossing category of 60 to 90 degrees. This is contrary to the hypothesis stated at the beginning of this section. As expected, the effectiveness of single-track upgrades from passive devices to gates was greatest in the oblique-angle categories, with an 88-percent effectiveness. Note that the confidence intervals were rather wide because of the relatively small sample sizes in each of the upgrade categories.

Results for multiple-track crossings did not reveal a definite pattern like the single-track crossings. Highest effectiveness value (83 percent) was for the passive-to-gates upgrade with a crossing angle of 0 to 29 degrees. This outcome was expected. However, it was not expected that, for this same type of upgrade, the angle-of-crossing category of 30 to 59 degrees would be associated with the lowest effectiveness value (70 percent). The opposite results were obtained for the flashing-lights-to-gates upgrades. In this case, the 30-to-59-degree category had the highest effectiveness value (70 percent). The 0-to-29-degree category was associated with the lowest effectiveness value (63 percent). Because of the small number of crossings in the multiple-track categories, some of the effectiveness values had large confidence intervals.

Although the lack of any definite pattern as far as variation in effectiveness with angle of crossing was unexpected, the results may be explained by two items of information that are not included in the data base. The first of these is sight distance. Sight distance is not quantified in the data base nor are sight obstructions (such as vegetation or structures) noted. The second factor is the direction of approach of vehicular and train traffic. Both of these factors are important in determining when drivers first detect the presence of trains, yet neither is included in the data base.

Influence of Train Speed

At a number of crossings, activation of warning devices is based on the maximum timetable speed of trains. However, the majority of rail traffic on the line may travel at speeds substantially slower than the timetable speed. This creates credibility problems with motorists in that some drivers may try to proceed past flashing lights or maneuver around crossing gates because of the lengthy time interval between signal activation and actual passage of the train through the crossing. The influence of train speed on the effectiveness of warning devices was examined by using two different measures. One concept was the speed-difference approach, in which speed difference was calculated as the algebraic difference between maximum timetable speed and typical minimum speed. Also, a speed-ratio concept was examined, in which the ratio of maximum timetable speed to typical minimum speed was computed for crossings. Influence of train speed on the effectiveness of warning devices was determined for the three categories of flashing lights and gate upgrades.

Figures 1 and 2 show that there was no relationship between train speed difference and effectiveness values in any upgrade category for single-track and multiple-track crossings, respectively. Spearman's Rho statistical tests for trend were performed; they indicated that there were no trends (either upward or downward) at the 95-percent confidence level.

Figures 3 and 4 show the plots of effectiveness values versus train speed ratio. Spearman's Rho tests revealed no significant trends in any of the

TABLE 6 Influence of Angle of Crossing on Effectiveness of Warning Device

			Before Upgrade		After Upgrade			
Upgrade Category[a]	Angle of Crossing (degree)	No. of Crossings	Accidents	Crossing Years	Accidents	Crossing Years	Effectiveness Value (%)	95 Percent Confidence Interval (%)
Single Track								
P to FL	0–29	246	160	990	52	983	67	57–77
	30–59	436	177	1,739	60	1,776	67	57–76
	60–90	1,774	950	6,948	278	7,313	72	69–76
P to G	0–29	252	208	898	31	1,127	88	84–92
	30–59	266	194	1,048	25	1,095	88	83–93
	60–90	1,550	1,182	6,165	178	6,386	85	83–88
FL to G	0–29	119	158	678	59	749	66	57–76
	30–59	225	157	818	65	975	65	56–75
	60–90	1,221	2,214	4,691	313	4,971	76	73–79
Multiple Track								
P to G	0–29	66	91	288	13	238	83	73–92
	30–59	73	59	303	16	278	70	55–86
	60–90	428	370	1,719	84	1,685	77	72–82
FL to G	0–29	39	59	159	21	153	63	47–79
	30–59	60	64	258	17	227	70	55–85
	60–90	384	446	1,543	155	1,514	65	59–71

[a] P = passive, FL = flashing lights, and G = flashing lights with gates.

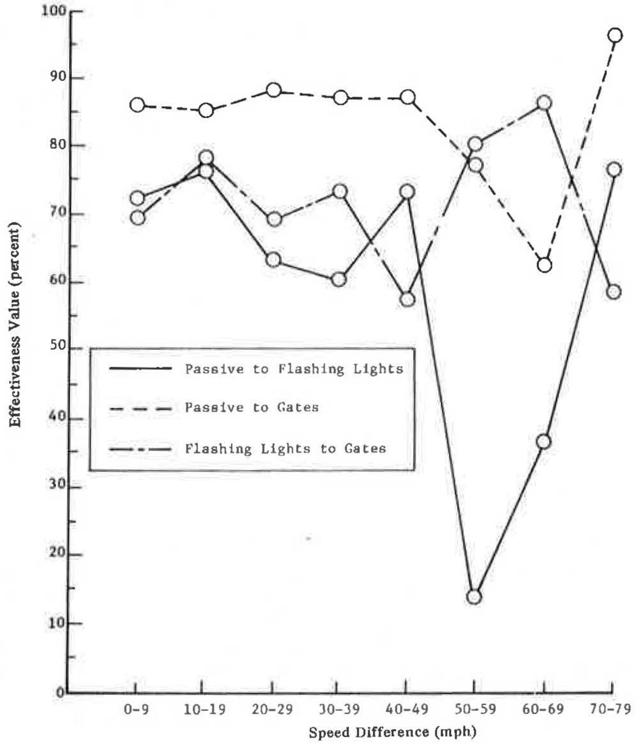

FIGURE 1 Relationship between speed difference and effectiveness values for flashing lights and gate upgrades at single-track crossings.

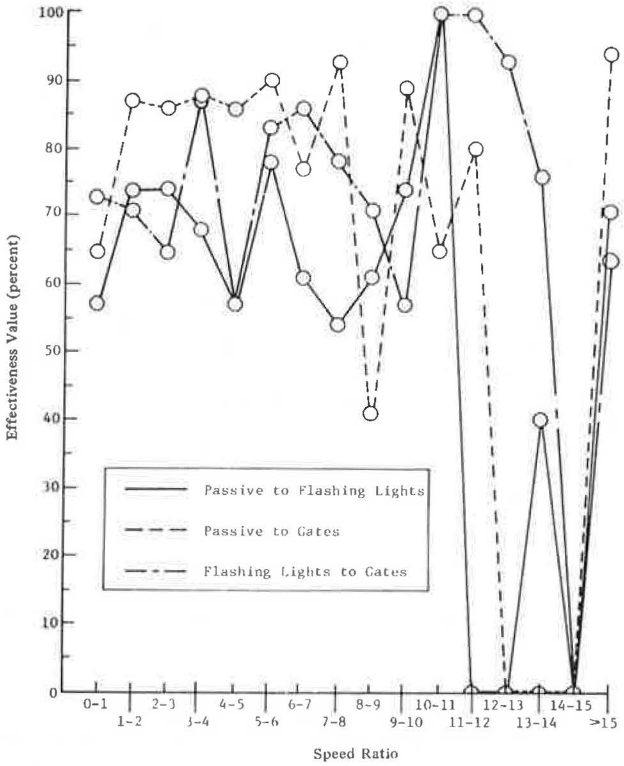

FIGURE 3 Relationship between speed ratio and effectiveness values for flashing lights and gate upgrades at single-track crossings.

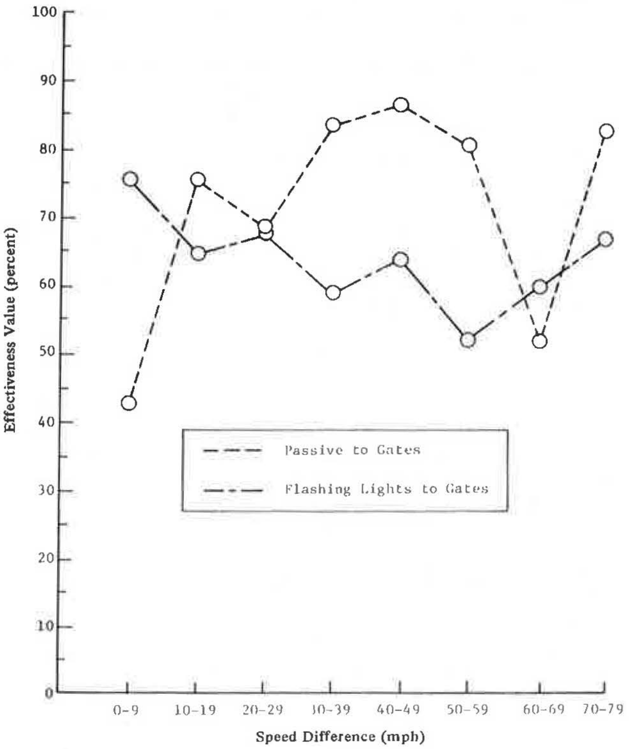

FIGURE 2 Relationship between speed difference and effectiveness values for flashing lights and gate upgrades at multiple-track crossings.

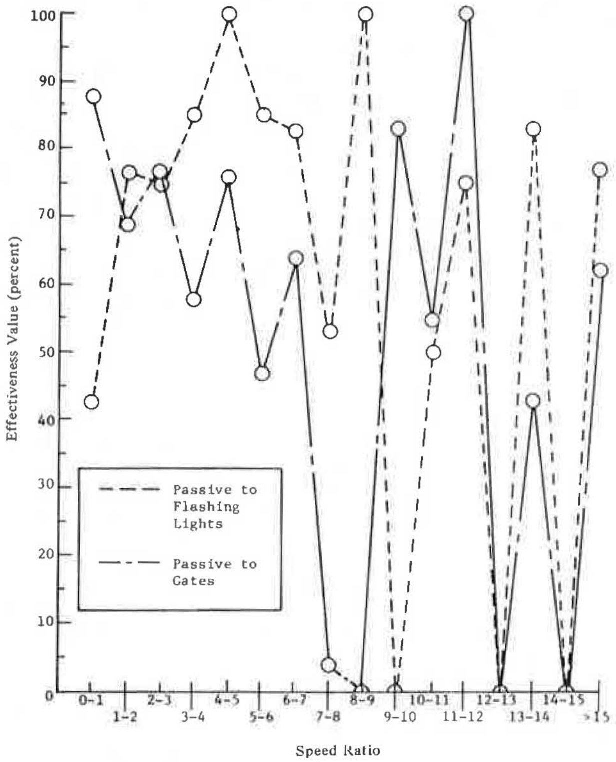

FIGURE 4 Relationship between speed ratio and effectiveness factors for flashing lights and gate upgrades at multiple-track crossings.

upgrade categories. Thus it was concluded that train speed ratio had no influence on the effectiveness of warning devices.

The results of these analyses were unexpected. Train speed, as measured by the two concepts used here, has no apparent influence on the effectiveness of warning devices for flashing lights and gate upgrades.

CONCLUSIONS

Results of this study generally confirmed the effectiveness values that were developed previously for upgrades from passive systems to flashing lights and from passive systems to gates. Upgrades from passive systems to flashing lights had an effectiveness value of 69 percent, whereas upgrades from passive systems to gates had an effectiveness value of 84 percent. The only marked change from results of previous studies occurred in the flashing-lights-to-gates upgrade category. The effectiveness value determined in this study was 72 percent. This is higher than values obtained in previous studies. There is no readily available explanation for this phenomenon.

Other important conclusions drawn from the study are as follows:

1. Warning device upgrades on single track had higher effectiveness values than those on multiple track. In both cases the highest effectiveness value was associated with upgrades from passive devices to flashing lights with gates.
2. There was no significant difference in effectiveness values between the 0-to-49-mph and the 50-mph-and-greater speed categories, for upgrades from flashing lights to gates at single-track crossings that had accidents before the upgrade.
3. Flashing lights appear to be upgraded to gates in response to an accident problem. Although this is good management, it tends to bias the effectiveness data.
4. Effectiveness of upgrades from passive devices to gates at single-track crossings was greatest in the oblique-angle categories (88-percent effectiveness). However, for passive-to-flashing-lights and flashing-lights-to-gates upgrades, effectiveness values were greatest in the 60-to-90-degree-angle category. Results for multiple-track crossings failed to show a definite pattern.
5. Variation in train speeds at crossings, as measured by the speed-difference and speed-ratio concepts, had no apparent influence on the effectiveness of warning devices for flashing lights and gate upgrades.

RECOMMENDATIONS

Results of this study suggest a number of areas in which additional research could prove fruitful. These are outlined in the following paragraphs.

Reference was made in a preceding section to the motorist credibility problem that exists at certain grade crossings that are equipped with active warning devices. There are two basic types of control systems for active devices: (a) fixed-distance concept and (b) constant-warning-time concept. With fixed-distance systems, trains activate the signals or gates a predetermined distance from the crossing. The major drawback to such systems is that warning devices operate continuously while the train is on the approach track circuit, regardless of train speed. Motorists may become impatient in situations in which the warning device is active for a long time (e.g., slow train speed). Constant-warning-time equipment has the capability of sensing a train in the approach section, measuring its speed and distance from the crossing, and activating the warning device. Thus, regardless of train speed, a uniform warning time is provided. With constant-warning-time systems, trains can move or switch on the approaches without reaching the crossing and, depending on their speed, never cause the crossing warning devices to be activated.

It could be hypothesized that the greater the difference between typical train speeds and maximum timetable speed (the basis on which the signals were designed), the higher the accident rate at crossings equipped with fixed-distance systems. Additional research is warranted to analyze the DOT-AAR data files to determine if accident frequency and characteristics at crossings with fixed-distance systems differ from those crossings with constant-warning-time systems. Note, however, that the results will have little meaning unless the accident data are normalized for exposure (traffic volume times train volume).

The need to develop a means to normalize exposure data is critical. This affects the analysis of constant-warning-time devices and may also account for the lower effectiveness of cantilever flashers noted by Farr and Hitz (4). Constant-warning-time devices tend to be used on more important rail lines on which there are more train movements and thus higher exposure. Similarly, cantilever flashers are frequently used at crossings on multilane highways, at which vehicular exposure would be higher.

Results of this study indicated no definite relationship between angle of crossing and effectiveness values. It was hypothesized that this was due to lack of information about sight distances and directions of approach of vehicular and train traffic at the grade crossing. Further study is warranted, perhaps involving field investigations, to determine the influence of these variables on accident experience. Development of a simple yet meaningful way to incorporate such factors into either the inventory or accident data base appears to be appropriate.

Another fruitful area of future research would be the development of capital and life-cycle costs for each of the upgrade categories studied in this project. These are needed if the results of this project are to be applied to the resource allocation model. This information can also be used to determine the relative cost-effectiveness of various improvement alternatives (such as flashing lights versus lights with gates on a single-track crossing).

There is one other area, closely related to the determination of effectiveness values, in which additional research would be desirable. In this study, confidence intervals were calculated by using a relationship developed by Morrissey (3). However, calculation of appropriate confidence intervals for effectiveness factors is subject to some interpretation because of the unique statistical nature of crossing accidents. Statisticians contacted by the investigators pointed out the need for a more thorough derivation of confidence interval formulas for the effectiveness studies. Determining the variance of ratios, such as the accident rates considered here, was beyond the scope of this project because of its theoretical complexity. Additional research of a statistical nature is needed to determine whether the confidence interval used here and in previous studies is appropriate and, if not, to develop a true confidence interval.

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Effectiveness of Constant-Warning-Time Versus Fixed-Distance Warning Systems at Rail-Highway Grade Crossings

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ABSTRACT

The study objective was to determine the influence of road classification, angle of crossing, and train speed on the effectiveness of fixed-distance and constant-warning-time systems at public rail-highway grade crossings. Data were acquired from the U.S. Department of Transportation-Association of American Railroads Crossing Inventory File and the FRA Accident/Incident Reporting System for the period January 1, 1975, through December 31, 1982. Fixed-distance and constant-warning-time systems revealed similar effectiveness values (82 and 85 percent, respectively) when changed from passive devices. For changes from fixed-distance to constant-warning-time systems, the effectiveness value was 26 percent. This result tended to confirm the hypothesis that constant-warning-time systems have greater credibility with motorists than do fixed-distance systems. Functional class of road had no apparent influence on the effectiveness of warning systems for upgrades to fixed-distance systems and constant-warning-time systems. The effectiveness of upgrades in the fixed-distance-to-constant-warning-time class was greatest for the angle-of-crossing category of 0 to 29 degrees (68 percent). For passive-to-fixed-distance and passive-to-constant-warning-time upgrades, effectiveness values in the 60-to-90-degree-angle category were essentially equal to those in the oblique-angle categories (82 percent). For constant-warning-time systems, effectiveness increased with increase in variation of train speed. Train speed, as measured by the concepts of speed ratio and speed difference, had no apparent influence on warning system effectiveness for either system.