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

JOHN A. HALKIAS and RONALD W. ECK

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.

The Federal Railroad Safety Act of 1970 and the Federal Highway Safety acts of 1970 and 1973 required the Secretary of Transportation to take action to improve rail-highway grade crossing safety. In response to these mandates, the National Rail-Highway Crossing Inventory and the Railroad Accident/Incident Reporting System were implemented (1). These data bases, which are updated on a regular basis, are used extensively by federal, state, and railroad company planners and decision makers as well as by researchers. The files are important inputs to the U.S. Department of Transportation (DOT) resource allocation procedure and accident prediction equations for rail-highway grade crossings. The generally declining trend in rail-highway grade-crossing fatalities since the mid-1970s can probably be at least partially attributed to the improved decision making made possible by these data bases.

To support resource allocation decisions, costs and effectiveness values of different safety improvements are needed (2) and have been developed by using national data. The effectiveness values used represent the percentage reduction in accidents expected from installation of a particular type of warning device at a typical crossing. Currently (3), effectiveness values are required for the three types of warning device installations considered by the DOT resource allocation procedure: (a) flashing lights installed at passively signed crossings, (b) gates installed at passively signed crossings, and (c) gates installed at crossings with flashing lights.

The existence of the FRA data bases has prompted a number of recent research efforts (4,5) to develop effectiveness values for other types of warning device installations for possible consideration by the resource allocation procedure. The authors (6) developed measures of effectiveness for warning devices under a variety of conditions. It was found that variation in train speed had no apparent influence on warning device effectiveness for flashing lights and gate upgrades. This result was unexpected, as will be discussed later.

There are two basic types of control systems for active (i.e., flashing lights or gates) warning devices: (a) fixed-distance concept and (b) constant-warning-time concept. With fixed-distance systems, trains activate the signals or gates at a predetermined distance from the crossing. This distance is calculated by using the speed of the fastest train and a specified minimum warning time. 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). 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.

Constant-warning-time systems provide the most desirable type of train detection at crossings where trains traveling at widely different speeds use the crossing. 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.

It could be hypothesized that the greater the difference between typical train speeds and maximum timetable speed (the basis on which signals are typically designed), the greater the effectiveness of devices upgraded to constant-warning-time systems. The results just mentioned (6), from situations in which variation in train speeds had no influence on the effectiveness of warning devices, included the aggregate of fixed-distance and constant-warning-time systems; no detailed breakdown was available from the FRA data base. Additional study appeared warranted to analyze the DOT data base to determine if the effectiveness of warning devices at crossings with fixed-distance systems differs from that at crossings with constant-warning-time systems.

Farr and Hitz (3) investigated the effectiveness of constant-warning-time devices. Two crossing upgrade categories were examined: (a) flashing lights without constant warning time upgraded to flashing lights with constant warning time, and (b) gates without constant warning time upgraded to gates with constant warning time. The results were unsatisfactory because there were only 39 upgrades in the first category (117.6 crossing years of data before upgrade and 113.2 crossing years of data after upgrade) and 80 upgrades in the second category (213.4 crossing years before and 259.9 crossing years after). The confidence intervals were too large to provide any meaningful estimates of effectiveness. Further investigation of this issue using additional data available in the inventory and accident files appears appropriate.

The overall goal of the study described here was to develop measures of effectiveness for fixed-distance and constant-warning-time systems under several conditions. Specific objectives of the study were to determine the influence of each of the following variables on the effectiveness of the two different warning systems:

1. Road classification,
2. Angle of crossing, and
3. Train speed, in particular, speed difference, speed ratio, and maximum speed.

DATA ANALYSIS

The DOT-Association of American Railroads (AAR) Crossing Inventory File and the FRA Accident Data File for the period of 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 assigns 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 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 the warning devices (flashing lights with gates) represent the highest type of crossing warning. The existence of constant-warning-time systems at crossings with active devices was indicated in the inventory as a positive response to the question: Does crossing signal provide speed selection for trains?

The data set that was created for the overall effectiveness of fixed-distance and constant-warning-time systems, after working with the inventory data base, included 3,195 warning device changes at public grade crossings. These 3,195 changes (Table 1) are warning device changes to fixed-distance and

TABLE 1 Number of Warning Device Change Records by System Type for Active Devices (1975-1982)

	Warning Device System Type After Change				
	Fixed Distance		Constant Warning Time		
Warning Device System Type Before Change	Flashing Lights	Gates	Flashing Lights	Gates	Total
No signs, stop signs, other signs, or crossbucks	1,061	1,103	192	405	2,761
Flashing lights with fixed distance	NC	NC	68	222	290
Flashing lights with constant warning time	19	0	NC	NC	19
Gates with fixed distance	NC	NC	0	122	122
Gates with constant warning time	0	3	NC	NC	3
Total	1,080	1,106	260	749	3,195

Note: NC indicates not considered in this study; these are changes from one warning device system to the same warning device system.

constant-warning-time systems (for both flashing lights and gates). Note that the number of warning device changes is substantially larger than that found by Farr and Hitz (3). This is believed to be due to the larger data base used in the current study and the fact that all warning device changes were examined, whereas Farr and Hitz (3) examined only the most recent change.

The inventory data base described in the preceding paragraph was then merged with the accident file data base. To determine the effectiveness value for each upgrade category, or warning device system, the average accident rates (accidents per crossing year) for populations of crossings before and after installation of warning devices were compared. The following formula (4) was used to calculate the effectiveness of the warning device systems:

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

where

E = effectiveness of a particular warning device system,
A_b = total number of accidents before warning device installation,
Y_b = total number of crossing 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. In reviewing the data it should be noted that the FRA accident data base, which was used in compiling effectiveness values, has not been independently verified and represents only reflections of accident data as reported by railroad carriers.

RESULTS

Overall Effectiveness

Three main categories of warning system upgrades were considered in this study: (a) passive to fixed-distance system, (b) passive to constant-warning-time systems, and (c) fixed-distance to constant-warning-time systems. Effectiveness values and confidence intervals for upgrades within these categories were calculated and, where appropriate, compared with general results from earlier studies. Note that "downgrades" from constant-warning-time to fixed-distance systems were investigated initially, but this category had to be eliminated from further consideration because of its extremely small sample size. Overall results of effectiveness values are presented in Table 2. To provide additional insight,

TABLE 2 Summary of Results of Effectiveness Values for Upgrades to Fixed-Distance and Constant-Warning-Time Systems

		Before Upgrade		After Upgrade			
Upgrade Category	No. of Crossings	Accidents	Crossing Years	Accidents	Crossing Years	Effectiveness Value (%)	95 Percent Confidence Interval (%)
Passive to fixed distance							
Lights	1,061	449	3,715	156	4,706	73	68 to 78
Gates	1,103	802	4,310	102	4,506	88	86 to 90
Total	2,164	1,251	8,025	258	9,212	82	81 to 83
Passive to constant warning time							
Lights	192	80	551	31	925	77	68 to 86
Gates	405	266	1,395	44	1,785	87	83 to 91
Total	597	346	1,946	75	2,710	85	81 to 89
Fixed distance to constant warning time							
Lights	68	34	167	54	331	20	-11 to 51
Gates	122	23	258	39	608	28	-8 to 64
Total	190	57	425	93	939	26	3 to 49
Lights to gates	222	122	578	49	1,028	77	59 to 95

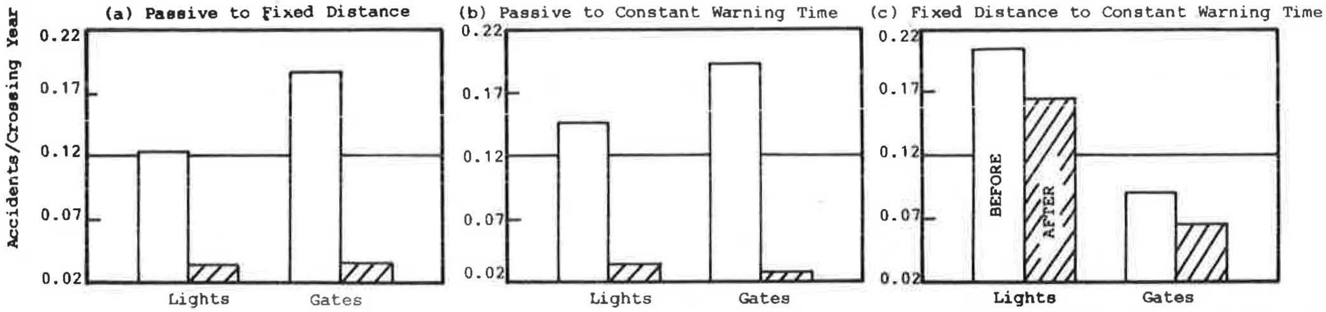


FIGURE 1 Graphical comparison of before-and-after accident rates for upgrades to fixed-distance and constant-warning-time systems.

graphical comparisons were made of the before-and-after accident rates on which the effectiveness values were calculated; these are shown in Figure 1.

Both fixed-distance and constant-warning-time systems revealed high effectiveness values (82 and 85 percent, respectively) when changed from passive devices. This is due in part to the change from use of passive devices to use of active warning devices. It was expected that these values would be high whether the system was a fixed-distance system or a constant-warning-time system. It was not expected that both upgrades would have essentially the same effectiveness value.

For changes from fixed-distance to constant-warning-time systems, two principal types of upgrades were considered: (a) flashing lights (or gates) of fixed distance to flashing lights (or gates) of constant warning time, and (b) flashing lights of fixed distance to gates of constant warning time. For the former case, the effectiveness was 26 percent. The 95-percent confidence interval, although rather wide because of the small sample size, did not include zero; thus there was a significant degree of effectiveness. Note that Farr and Hitz (3) had examined similar cases (but with smaller sample size) and found negative effectiveness values.

TABLE 3 Influence of Road Classification on Effectiveness of Active Warning Systems

Upgrade Category	No. of Crossings	Before Upgrade Accidents	Before Upgrade Crossing Years	After Upgrade Accidents	After Upgrade Crossing Years	Effectiveness Value (%)	95 Percent Confidence Interval (%)
Rural							
Passive to fixed distance							
Principal arterial	20	3	58	1	103	81	39 to 100
Minor arterial	78	39	237	6	386	91	83 to 99
Major collector	327	125	1,096	45	1,520	74	65 to 83
Minor collector	277	108	905	25	1,302	84	77 to 91
Local	683	346	2,730	57	2,714	83	78 to 88
Passive to constant warning time							
Principal arterial	11	1	24	1	64	63	-39 to 100
Minor arterial	23	11	62	5	117	76	52 to 100
Major collector	65	25	202	6	301	84	70 to 98
Minor collector	68	29	220	2	318	95	88 to 100
Local	199	89	659	25	917	80	71 to 89
Fixed distance to constant warning time							
Principal arterial	12	2	30	6	61	-48	-275 to 100
Minor arterial	23	7	47	6	126	68	35 to 100
Major collector	38	12	74	8	192	74	52 to 96
Minor collector	34	3	106	2	156	55	-25 to 100
Local	39	7	88	8	194	48	-3 to 99
Urban							
Passive to fixed distance							
Freeway	4	3	15	1	18	72	0 to 100
Principal arterial	67	50	257	9	271	83	71 to 95
Minor arterial	177	167	651	37	759	81	75 to 87
Collector	155	138	612	23	616	83	76 to 90
Local	367	269	1,433	52	1,491	81	76 to 86
Passive to constant warning time							
Freeway	2	2	5	6	11	-36	-200 to 100
Principal arterial	18	16	65	3	76	84	65 to 100
Minor arterial	48	41	153	9	229	85	75 to 95
Collector	62	58	215	5	276	93	87 to 99
Local	101	74	340	13	463	87	80 to 94
Fixed distance to constant warning time							
Freeway	8	6	23	4	41	63	20 to 100
Principal arterial	71	58	173	41	329	63	50 to 76
Minor arterial	72	44	182	24	325	69	55 to 83
Collector	34	13	76	15	160	45	7 to 83
Local	79	24	203	23	386	50	22 to 78

The effectiveness of upgrades from flashing lights of fixed distance to gates of constant warning time was rather high (77 percent). This is actually a special case of the fixed-distance-to-constant-warning-time category. Much of the effectiveness is probably caused by the concurrent upgrade in warning device type from flashing lights to gates; previous work (6) has indicated that such upgrades have effectiveness values in the range of 70 to 75 percent.

Influence of Road Classification

The influence of road classification on warning system effectiveness was analyzed to determine whether certain roadway types demonstrated different warning system effectiveness values than others. Implicitly associated with each roadway functional type would be information about certain crossing characteristics such as average daily traffic and urban versus rural environment. For example, Farr and Hitz (3) noted that the greater visual confusion that confronts motorists in urban areas may be responsible for the significantly lower effectiveness values for certain categories of warning device upgrades at urban crossings. Results of this analysis, given in Table 3 and shown in Figure 2, do not indicate any trends or significant differences in effectiveness values for either the urban or rural road classifications. Some effectiveness values are higher than others, but because of the large confidence intervals attributable to the relatively small sample sizes, no significant differences were noted.

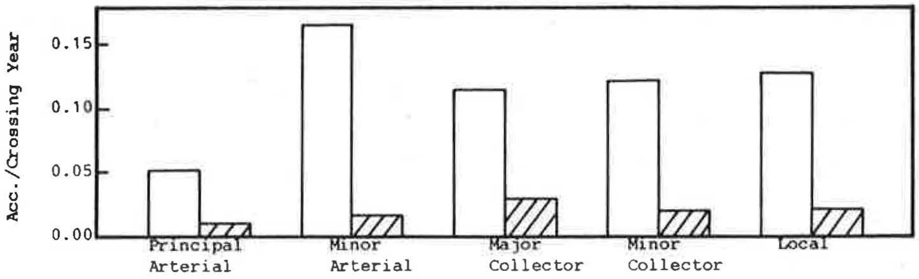
Influence of Crossing Angle

The effectiveness of crossing warning devices would be expected to be related to the angle of the crossing. Device effectiveness should be greatest at oblique-angle crossings because it is at these locations that motorists otherwise might not be able to detect the crossing in advance. 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.

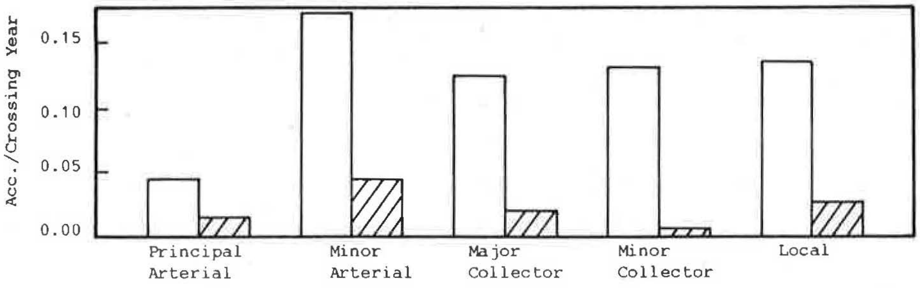
Crossing-angle categories of 0 to 29 degrees, 30 to 59 degrees, and 60 to 90 degrees were analyzed to determine their influence on the effectiveness of warning systems. Data on the influence of angle of crossing on the effectiveness of warning systems are given in Table 4 and shown in Figure 3. Review of the data in Table 4 indicates that for two upgrade categories, passive to fixed distance and passive to constant warning time, effectiveness values in the

(a) RURAL

Passive to Fixed Distance



Passive to Constant Warning Time



Fixed Distance to Constant Warning Time

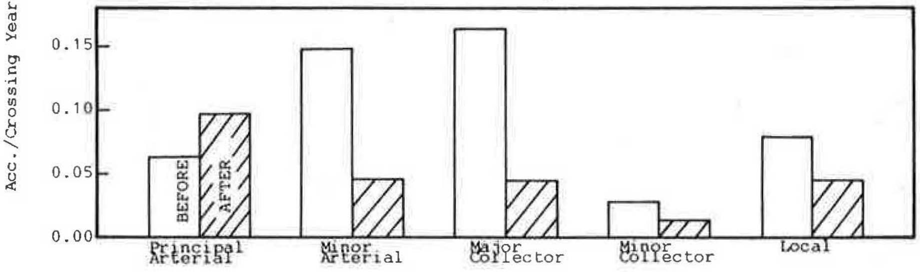


FIGURE 2 Graphical comparison of before-and-after accident rates for active system upgrades as a function of road classification.

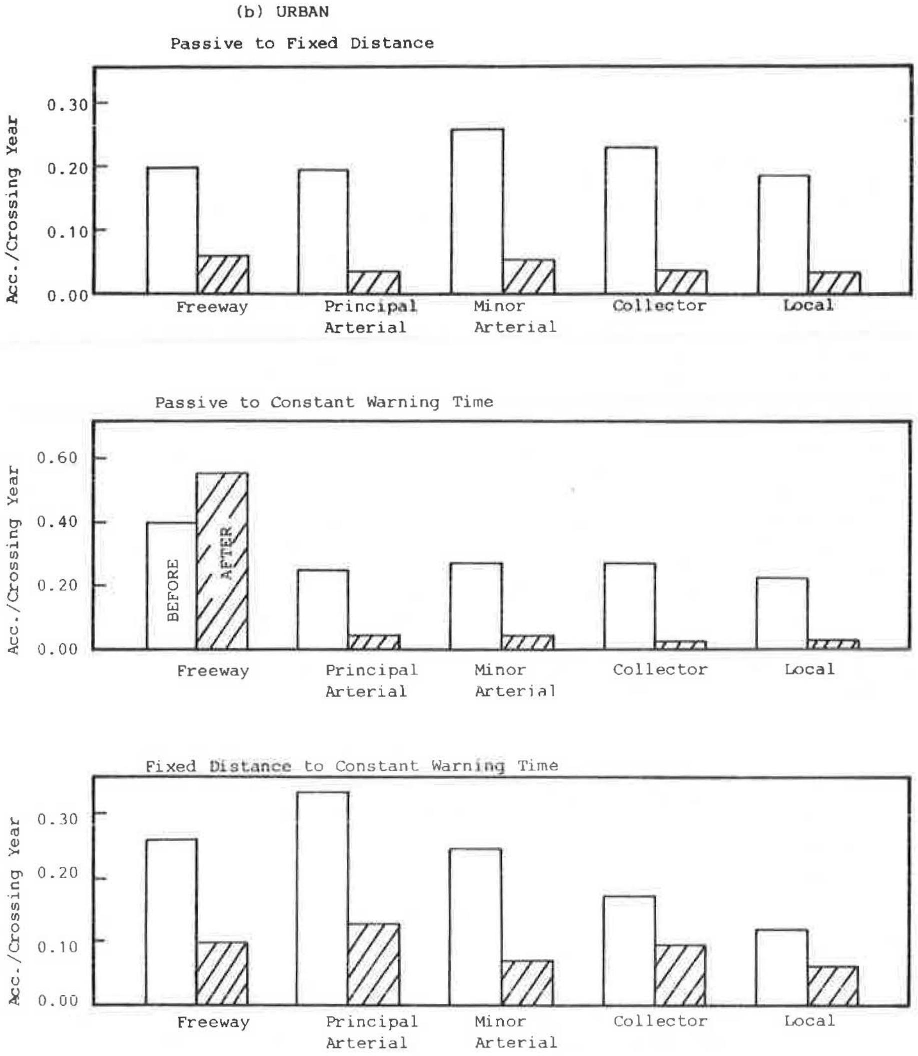


Figure 2 continued.

60-to-90-degree-angle category are roughly equal to or greater than those in the oblique-angle categories. This is contrary to the hypothesis stated at the beginning of this section. As expected, the effectiveness of upgrades in the fixed-distance-to-constant-warning-time category was greatest in the 0-to-29-degree-angle class, in which there was an effectiveness value of 68 percent. In most cases the confidence intervals were rather large because of the relatively small sample sizes. There was an overlap in the confidence intervals of the three upgrade angle categories; this indicated that there was no significant difference between effectiveness values at the 95-percent confidence level.

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 not included in the data base. The first of these is sight distance. Sight distance is not quantified in the data base and sight obstructions (such as vegetation or structures) are not noted. The second factor is the direction of ap-

TABLE 4 Influence of Angle of Crossing on Effectiveness of Active Warning Systems

Upgrade Category	Angle of Crossing (degree)	No. of Crossings	Before Upgrade Accidents	Before Upgrade Crossing Years	After Upgrade Accidents	After Upgrade Crossing Years	Effectiveness Value (%)	95 Percent Confidence Interval (%)
Passive to fixed distance	0-29	189	148	695	29	814	83	77 to 89
	30-59	330	163	1,200	41	1,448	79	72 to 86
	60-90	1,639	940	6,120	188	6,942	82	79 to 85
Passive to constant warning time	0-29	81	57	263	15	379	82	72 to 92
	30-59	75	33	229	9	358	83	70 to 96
	60-90	441	256	1,454	51	2,032	86	82 to 90
Fixed distance to constant warning time	0-29	37	19	75	11	134	68	46 to 90
	30-59	54	32	175	29	333	52	30 to 74
	60-90	321	128	763	103	1,510	59	49 to 69

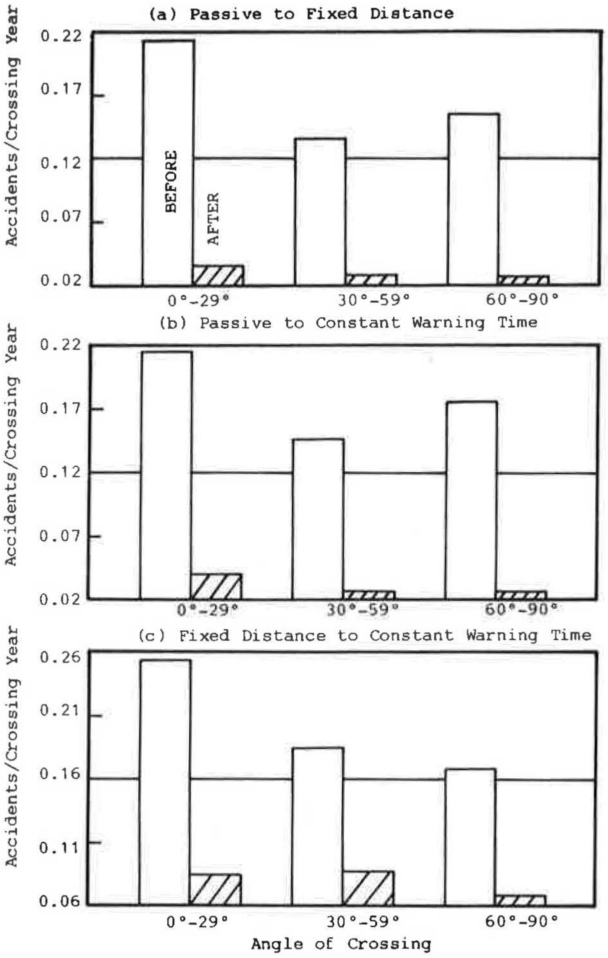


FIGURE 3 Graphical comparison of before-and-after accident rates for active system upgrades as a function of crossing angle.

proach 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

The introduction to this paper alluded to the motorist credibility problem associated with fixed-distance systems at crossings at which there is significant variation in train speed. At locations where the time interval between signal activation and actual passage of the train through the crossing is lengthy, some drivers may try to proceed past flashing lights or maneuver around crossing gates. Because they provide a shorter and more uniform waiting time, constant-warning-time systems would be expected to be more effective than fixed-distance systems at crossings at which there are large variations in train speed.

It should be pointed out that warning device credibility is a function of the track circuit design speed and the frequency distribution of actual train speeds. Neither variable was considered in this study. The inventory data base did not include information on track circuit design speed. A preliminary analysis was made of the actual train speeds reported in the accident data base. It became apparent that, in some cases, the reported speed was not accurate, and many times speed data were not reported at all.

The influence of train speed on the effectiveness of warning systems was examined by using three different measures. One concept was the speed-difference approach, in which speed difference was the algebraic difference between maximum timetable speed and typical minimum speed. Second, a speed-ratio concept was examined, in which the ratio of maximum timetable speed to typical minimum speed was computed. It was hypothesized that large speed differences and large speed ratios would be associated with high accident rates (or greatest danger) for crossings equipped with fixed-distance warning systems. Finally, a maximum timetable speed was used to check the effectiveness of the two different warning systems, because high speed is usually associated with the highest accident rates.

Figure 4 shows the relationship between train speed difference and effectiveness values for the three upgrade categories being considered. It was recognized that these points do not represent continuous data; nevertheless, this format was chosen to make it easier to identify any trends that might exist. Although the fixed-distance-to-constant-warning-time upgrade had the lowest effectiveness value, it was the only upgrade category to show an increasing trend when tested using Spearman's Rho statistical test. This tends to confirm the hypothesis stated earlier in this section; that is, the effectiveness of constant-warning-time systems should increase as variation in train speed increases. To provide additional insight, graphical comparisons of the before-and-after accident rates, on which the effectiveness values were calculated, were made (see Figure 5).

Figures 6 and 7 present the relationship between speed ratio and effectiveness values for the three upgrade categories. Spearman's Rho tests revealed no significant trends in any of the upgrade categories. To investigate the relationship further, train speed ratios were grouped differently than those shown in Figure 6 (results are not shown here). There was still no significant relationship between train speed ratio and effectiveness values.

The relationship between maximum timetable speed and effectiveness value is shown in Figures 8 and 9. Spearman's Rho revealed no significant trends in any of the upgrade categories. Thus it was concluded that neither speed ratio nor maximum timetable speed had an influence on the effectiveness of warning systems.

CONCLUSIONS

This study carried the analysis of the rail-highway grade-crossing inventory and accident data bases one step farther than had been done in the past. Rather than considering the effectiveness of active warning devices in general, effectiveness values were developed for fixed-distance and constant-warning-time systems for several different stratifications of variables. Upgrades from passive devices to fixed-distance and constant-warning-time systems had almost equal effectiveness values--82 and 85 percent, respectively. 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.

Other important conclusions drawn from the study are as follows:

1. Functional class of road had no apparent influence on the effectiveness of warning systems

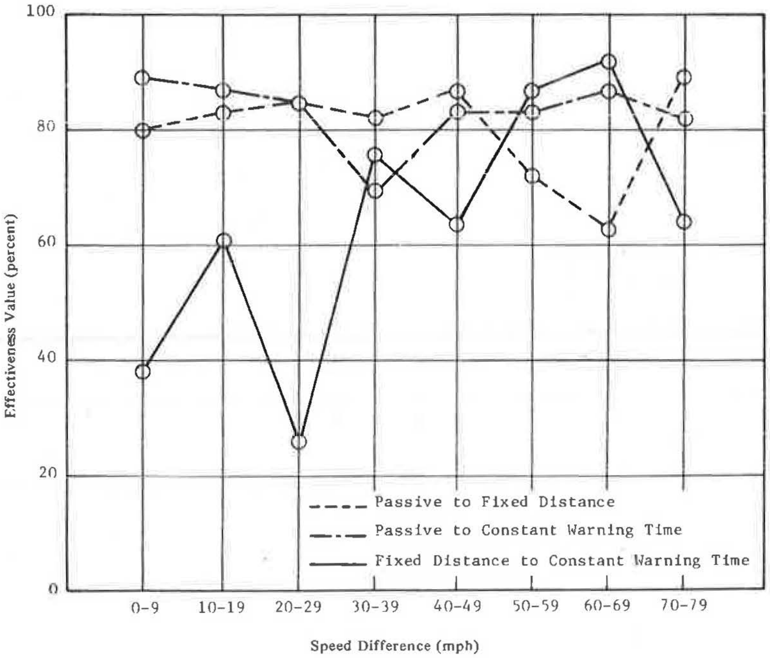


FIGURE 4 Relationship between effectiveness values and train speed difference for constant-warning-time and fixed-distance system upgrades.

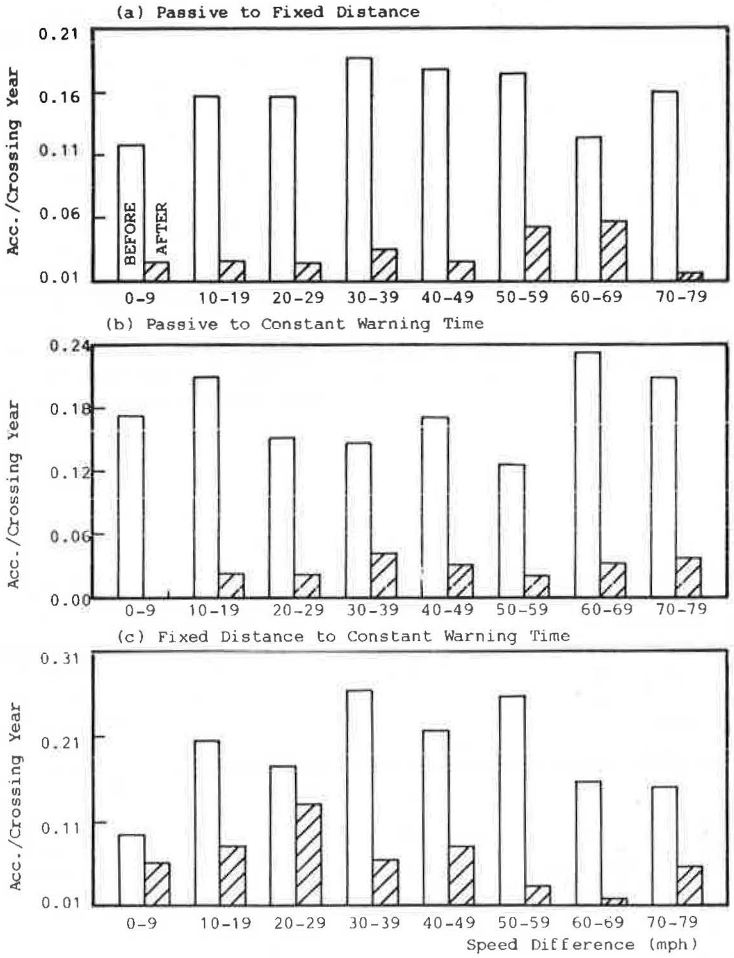


FIGURE 5 Graphical comparison of before-and-after accident rates for constant-warning-time and fixed-distance system upgrades as a function of train speed difference.

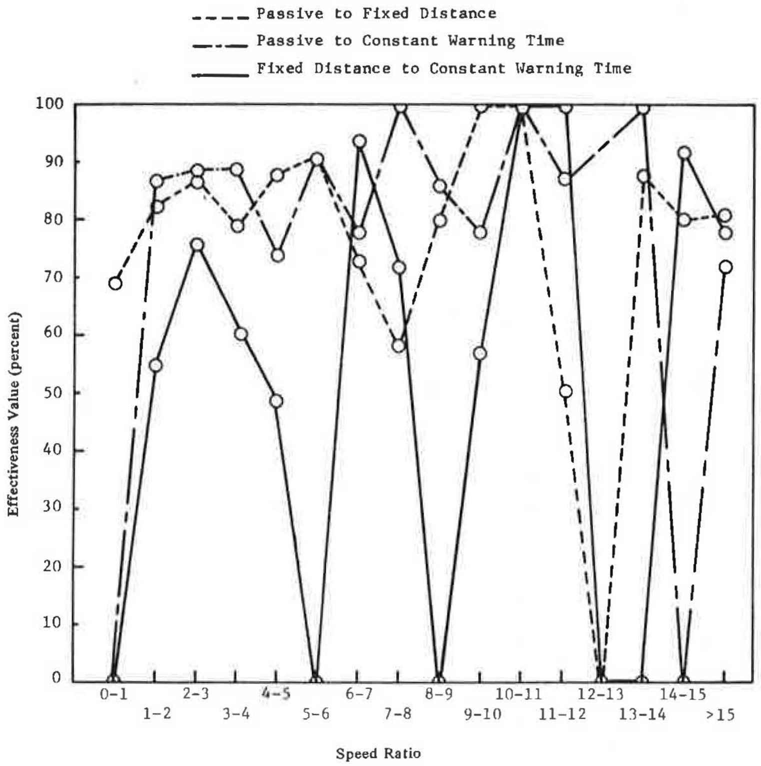
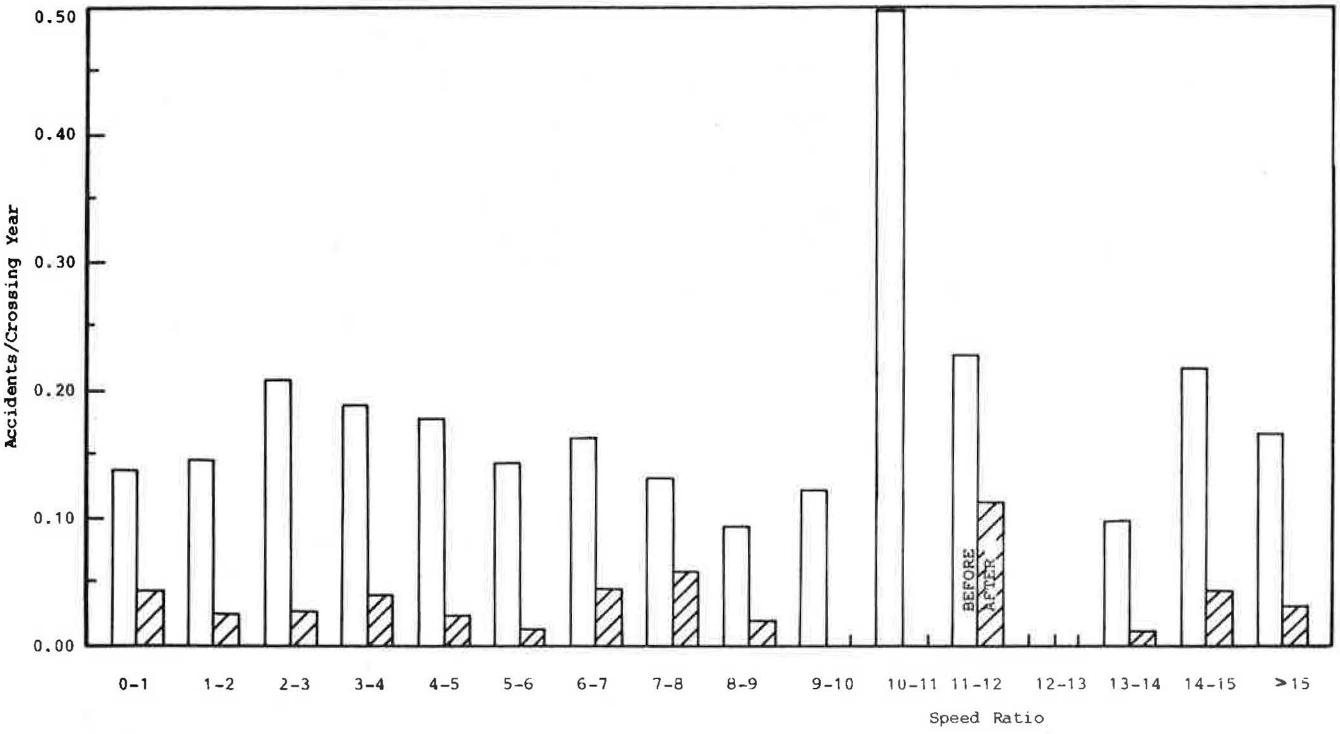
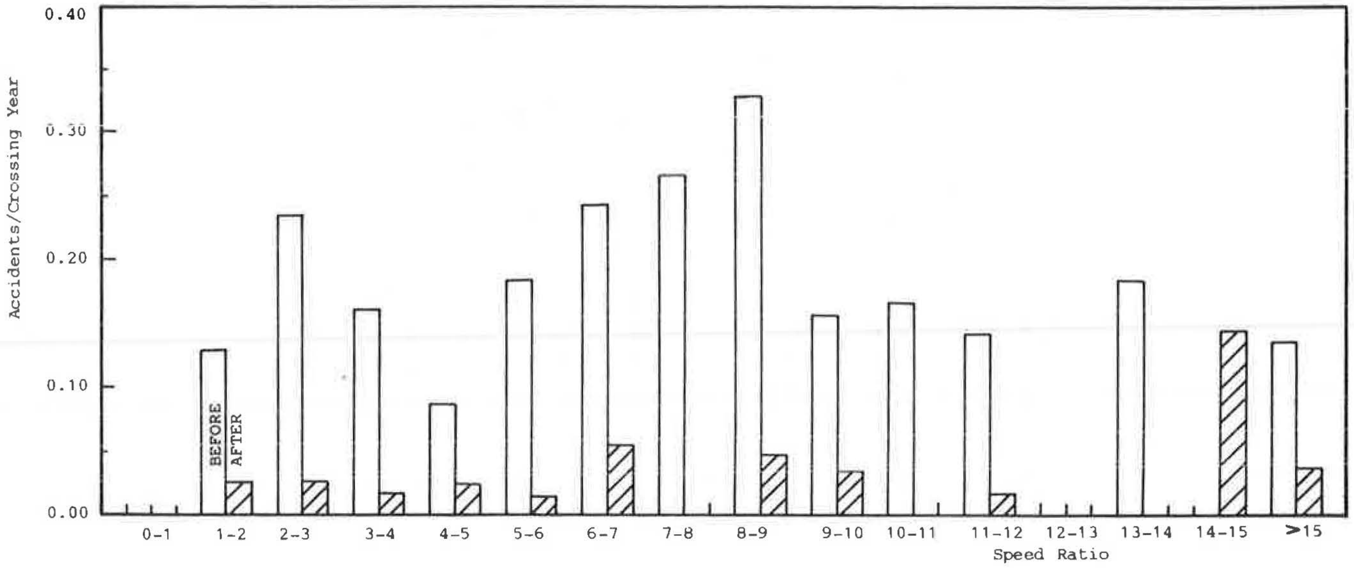


FIGURE 6 Relationship between effectiveness values and train speed ratio for constant-warning-time and fixed-distance system upgrades.

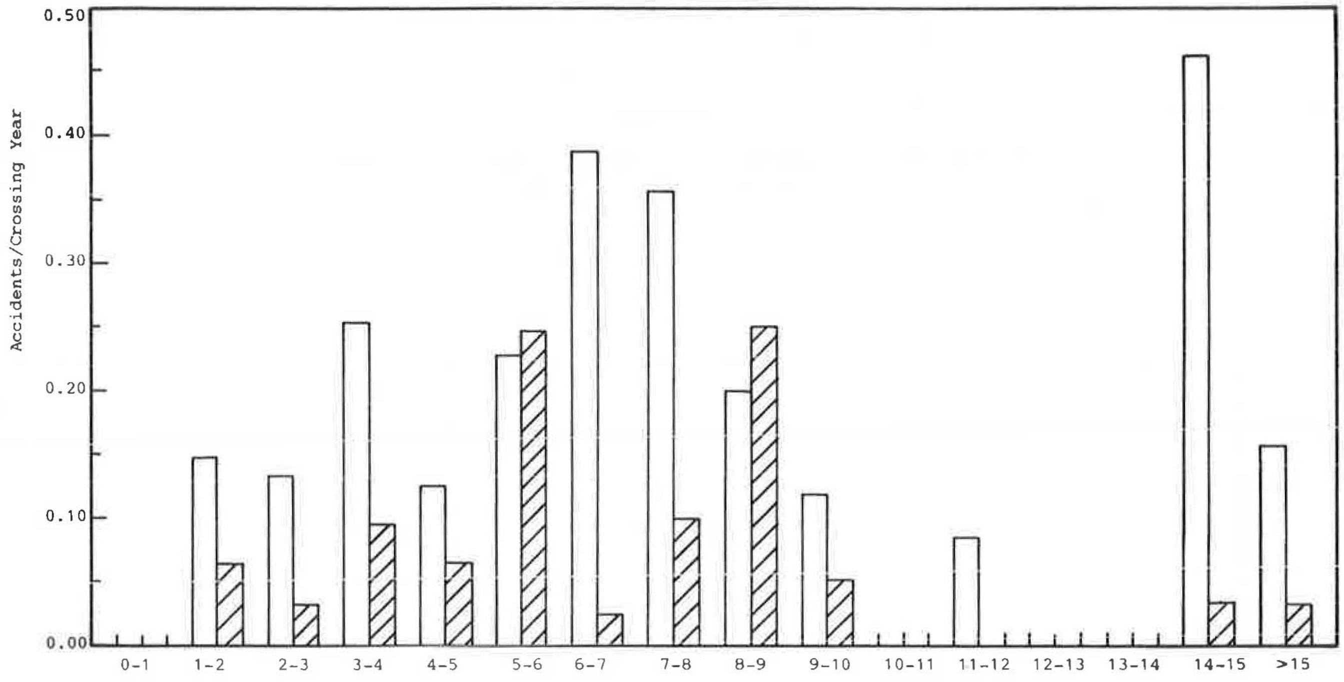


(a) Passive to Fixed Distance

FIGURE 7 Graphical comparison of before-and-after accident rates for constant-warning-time and fixed-distance system upgrades as a function of train speed ratio.



(b) Passive to Constant Warning Time



(c) Fixed Distance to Constant Warning Time

Figure 7 continued.

for fixed-distance and constant-warning-time upgrades.

2. 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 or slightly greater than those in the oblique-angle categories (approximately 82-percent effectiveness).

3. As expected, the effectiveness of upgrades in the fixed-distance-to-constant-warning-time category was greatest for the angle-of-crossing class of 0 to 29 degrees, which had 68-percent effectiveness.

4. A significant relationship was found between train speed difference and constant-warning-time systems; that is, system effectiveness increased as the variation in train speeds at a location increased.

5. Train speed, as measured by the speed ratio and maximum timetable speed, had no apparent influence on the effectiveness of warning systems for fixed-distance and constant-warning-time upgrades.

RECOMMENDATIONS

Results of this study suggest several areas in which additional research is recommended. These are outlined in the following paragraphs.

Additional research is warranted to analyze the DOT-AAR data files to determine if, when normalized

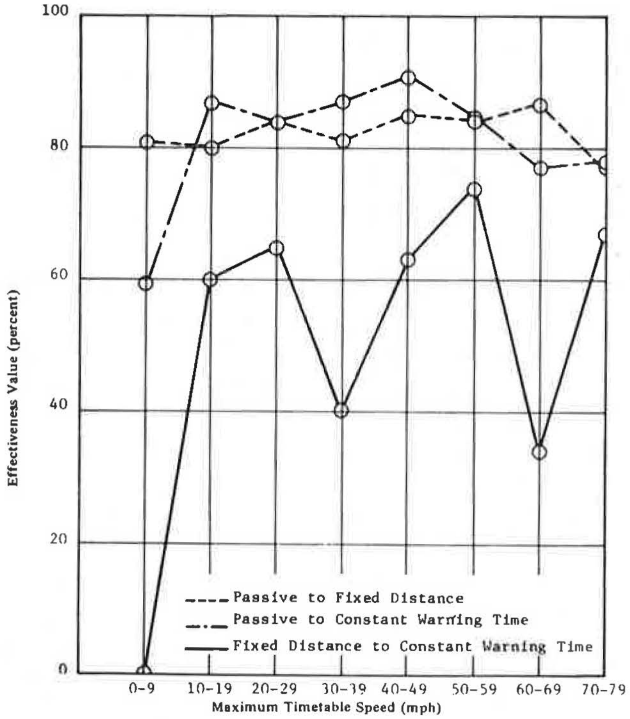


FIGURE 8 Relationship between effectiveness values and train maximum timetable speed for constant-warning-time and fixed-distance system upgrades.

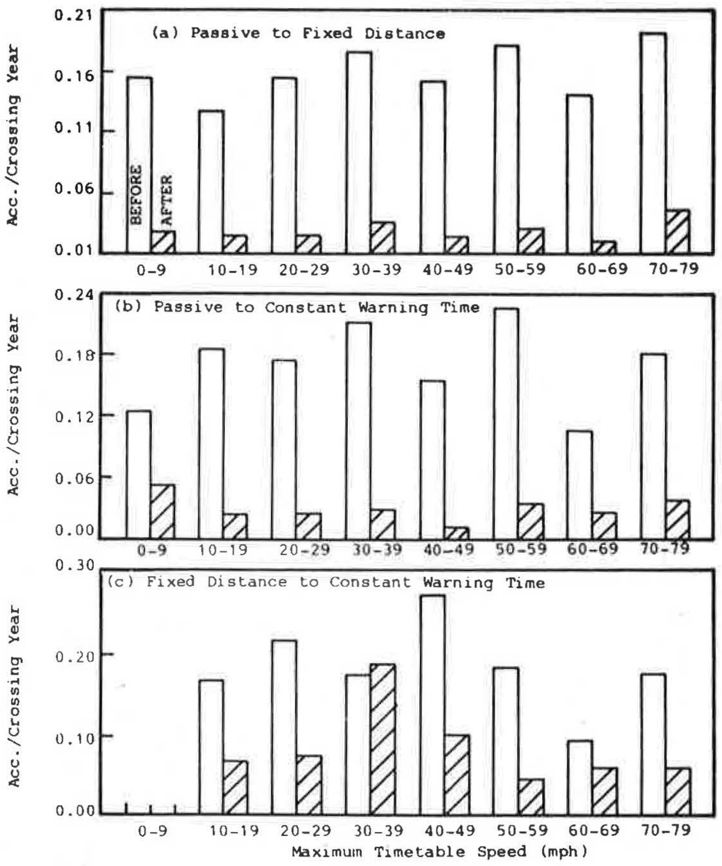


FIGURE 9 Graphical comparison of before-and-after accident rates for constant-warning-time and fixed-distance system upgrades as a function of maximum timetable speed.

by exposure, accident rates at crossings with fixed-distance systems differ from those at crossings with constant-warning-time systems. Only by normalizing the accident rates by exposure (traffic volume times train volume) can the credibility issue be addressed. In this way, the hypothesis that accident rates at crossings equipped with fixed-distance systems would be expected to increase with increasing difference between typical train speeds and maximum timetable speeds could be tested.

Similarly, it would be desirable to make the comparisons described in this paper for different exposure levels. The authors are currently conducting analyses of accident rates by exposure. Although the results are not yet in a form suitable for inclusion in this paper, it is anticipated that they will be published at a later date.

Another area of future research would be the development of statistical models to identify variables that are significantly related to grade-crossing accident rates (normalized by exposure) for fixed-distance and constant-warning-time systems. Identification of such factors would be useful in refining guidelines or warrants for installing fixed-distance and constant-warning-time systems. In addition, the development of capital and life-cycle costs of the two different warning systems would provide another source of input for the development of installation guidelines.

ACKNOWLEDGMENTS

This study relied heavily on data contained in the national DOT-AAR inventory and FRA accident files. The assistance of the West Virginia Department of Highways (WVDOH) in cooperation with the FHWA, U.S. Department of Transportation, in sponsoring a previous study that established the data base at West Virginia University is acknowledged. Special appreciation is expressed to Ray Lewis (WVDOH) and Janet Coleman (FHWA) for their assistance and encouragement throughout the study.

Discussion

Brian L. Bowman*

Halkias and Eck are to be commended for identifying the need for, and their willingness to conduct, an independent study on the effectiveness of constant-warning-time devices. Determinations on the effectiveness of improvements at rail-highway grade crossings is a difficult undertaking. The task is made complex by the relatively low number of accidents that involve trains, the accuracy of requisite operational and physical data, and the determination of appropriate exposure factors.

Review of the study effort prompts the following comments:

1. The DOT-AAR Crossing Inventory File was used to provide information on crossings for the study. This file provides the only means to obtain national information on the physical and operational characteristics of crossing without contacting individual railroads and states. The inventory requires the active support of both railroads and states to maintain current data. Often this support is not as universal as desired and changes take place without accompanying inventory updates. The result is that the inventory, although probably the best tool available for obtaining information on crossings, does not always contain current and accurate data.

This problem has been found to be prevalent in train speeds, traffic and train volumes, and the entry used to designate the presence of train speed selection equipment (i.e., constant-warning-time devices). Some of these discrepancies become evident when the inventory is closely scrutinized. For example, the inventory was searched for all crossings that had (a) a positive response to speed selection capabilities, and (b) only passive warning devices. This search revealed that more than 201 crossings have constant-time-control capabilities in conjunction with passive warning devices. This result is contradictory because if train detection equipment exists there are probably active warning devices present at the crossing.

The authors have recognized these difficulties and provided partial control by including only crossings with positive responses to both speed selection and active warning. This will serve to eliminate the erroneous passive warning entries. However, those crossings with active warning devices and erroneously coded as having speed selection capabilities are still included in the study. Unfortunately, the only solution to this problem is to verify that the correct combinations of detection and warning devices exist on a site-by-site basis. This would be a huge task and, possibly, outside the scope of the authors' study. Without the verification, however, it is unknown if we are actually analyzing crossings with the desired combination of detection and warning devices.

2. As mentioned by the authors, constant-warning-time devices are intended to prevent train accidents that are attributable to driver impatience. Therefore, these accidents would be characterized by vehicles being impacted by or striking the first unit of the train. For example, the installation of constant-warning-time devices would not be expected to reduce the number of accidents in which the tenth consist of the train is impacted. This type of accident indicates that (a) the vehicle was not stopped at the crossing, (b) the driver was not subjected to an excessive wait time, and (c) driver impatience was not a factor in the accident.

The measures of effectiveness chosen for an evaluation should have at least a casual relationship with the project objectives. Because the study analyzed total number of accidents without consideration to specific accident types, there is an uncertainty as to the proper interpretation of the study results.

3. The authors performed comparisons between analysis groups without investigating the need to stratify sites by physical and operational characteristics. Consideration should have been given as to why constant-warning-time devices are installed to determine if stratification of analysis sites is required. If, for example, the devices are primarily installed to alleviate problems caused by large train speed ratios, then all analysis categories should possess the same train speed ratio. The failure to stratify creates no problems as long as comparisons within groups, such as before-and-after analysis on the same sites, are performed. If, however, analysis between groups that have different

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physical and operational characteristics (i.e., fixed distance with flashing lights versus constant warning with flashing lights) takes place without stratification, then the results can be confounded. Thus the conclusions of this study, which are based on comparisons between groups without investigation of the need for stratification of analysis sites, should be interpreted with caution.

4. The authors used confidence intervals to infer significance by inspecting the data range and to compare data from different populations. The use of confidence intervals is good and actually provides more information than only reporting a hypothesis test or a significance level. However, statistical significance should not be inferred by inspecting the range that exists between the confidence limits. This range is established by relationships between data items within the analyzed sample and the sample size. Observing values outside of the confidence band indicates a relatively unlikely event, given the hypothetical situation analyzed. Stating that significance exists because zero is not within the limit is misleading. Similarly, comparisons of confidence limits between different analysis groups, with different physical and operational characteristics, are confounded and also misleading.

5. The authors hypothesized that the effectiveness of constant-warning-time devices would be expected to be related to crossing angle. Whether this would be expected or not is questionable and the question is not resolved by the results of this study. Changes from fixed-distance systems to constant-warning-time systems were analyzed by grouping sites with flashing lights and sites with gates together. The presence or absence of gates may, however, have a greater influence on accidents than the type of train detection circuitry. Failure to identify the degree of improvement that was attributable to constant-warning-time devices and that which was due to gate installation precludes any conclusions on the effectiveness of constant-warning-time upgrades with respect to different crossing angles.

6. The need for using exposure factors, considering both roadway and train volumes, was identified by the authors. This is especially important because the analysis consisted of accidents occurring during a 7-year period. A considerable amount of change, both in roadway and train volumes, can be expected to occur in a 7-year period. This change should be accounted for by using exposure factors or controlled by employing either comparative or control site experimental plans. Because this was not done in the study, it is not known what portion of the observed change is caused by the analysis variables and what portion is caused by changes in train and traffic volumes.

In summary, the authors have identified an issue that is in need of further research. Constant-warning-time devices are often installed because "everything else has been tried." Knowledge about their effectiveness will enable device deployment based on their probable effect and not on intuitive judgment. This, however, requires a strong experimental design to minimize validity threats and confounding effects. The need for a stronger evaluation has been identified by the authors, but the resources for such an evaluation were probably beyond the scope of this study. The applicability of the conclusions and effectiveness factors are therefore constrained, and caution should be exercised in interpreting the study results.

Discussion

William D. Berg*

The research conducted by Halkias and Eck has revealed that the use of constant-warning-time track circuits can have a positive influence on safety. However, the level of effectiveness that can be expected under various real-world conditions remains undetermined. Several comments will be offered about interpretation of the findings presented by Halkias and Eck, as well as about the direction of future research in this area.

Data on the overall effectiveness of constant-warning-time track circuits are presented in Table 2 and Figure 1. Because the estimated effectiveness for upgrades to flashing lights or gates with a constant-warning-time track circuit fall within the 95-percent confidence interval for the corresponding upgrades with a fixed-distance track circuit, the effectiveness of the track circuit design cannot be distinguished from the obvious benefits created by the upgrade to an active warning device. For those crossings at which only a change in track circuit occurred, the confidence interval for the effectiveness factor includes zero for both flashing-light and gate systems. Thus, based on the data presented by the authors, it cannot be concluded that type of track circuit has a statistically significant impact on safety. This does not mean that no benefit exists, but simply that the data base was not able to permit its measurement. When the data are aggregated over both flashing-light and gate systems, the estimated 26-percent effectiveness of constant-warning-time track circuits is significant. This supports the hypothesis that this type of track circuit can be more effective than traditional fixed-distance designs, but it does not explain under what conditions these benefits can be expected to occur.

Examination of Figures 1a and b reveals that the after-accident rates for both flashing-light and gate upgrades are approximately equivalent, regardless of track circuit design. In addition, the before-accident rates for gate upgrades are larger than for the flashing-light upgrades. This suggests that the effectiveness of automatic warning devices, as measured by the actual change rather than the percentage change in accident rate, is principally a function of the before-accident rate. Restated, automatic warning devices appear to provide a given absolute level of safety, and the relative change to that level depends on the accident rate that existed before the improvement.

The comparison of the accident rates shown in Figure 1c indicates that constant-warning-time track circuits can provide an accident reduction of about 0.03 to 0.04 accident per year (although as noted previously these estimates are not statistically significant). In addition, for those flashing-light crossings that received an upgrade to a constant-warning-time track circuit, the data suggest that a substantially greater accident reduction could have been achieved if gates had been installed and no change had been made to the track circuit. This would certainly be intuitively reasonable. Finally, the grade crossings represented in Figure 1c exhibit much larger accident rates (both before and after the change in track circuit) than the similarly

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equipped crossings represented in Figures 1a and b. This probably reflects substantially different exposure levels, because the former crossings were upgraded to active warning devices at an earlier time because of high train and traffic volumes. This observation also points out the importance of incorporating exposure in accident rate calculations and comparisons.

The data presented in Figure 3 show that grade crossings with acute angles of less than 30 degrees are more hazardous that those with larger acute angles. As noted by the authors, the principal influencing factor is probably the corner sight distance at the crossing, a factor that is not available in the data base. The implied 52- to 68-percent effectiveness for track circuit upgrades is misleading and should be considered unreliable because, of the 412 grade crossings in the sample, 54 percent involved a concurrent upgrade from flashing lights to gate. The effectiveness of this improvement virtually obscures the benefits of the more responsive track circuit. As noted previously, Figure 1c suggests that constant-warning-time track circuits can reduce accident rates by 0.03 to 0.04 accident per year.

The data in Figures 4-9 reveal that speed difference and speed ratio do not provide any useful insight into the effectiveness of constant-warning-time track circuits. This should not be unexpected because the benefits of these train detection systems is due to their credibility, and this is a function of the track circuit design speed and the range of actual train operating speeds. The speed-difference and speed-ratio variables are poor indicators because they rely on maximum train speed rather than on track circuit design speed. The typical credibility problem occurs when the maximum train speed over a crossing is reduced without a concurrent change in the track circuit. This causes an increase in warning times beyond the desired 25-sec time interval, thereby creating a situation in which there sometimes is more than ample time for a motorist to safely traverse the crossing even though the warning devices are operating. The greater the difference between the track circuit design speed and the minimum train speed, the greater the credibility problem. A constant-warning-time track circuit virtually eliminates the credibility problem.

In conclusion, the research conducted by Halkias and Eck does tend to confirm the hypothesis that constant-warning-time track circuits can provide greater safety when conditions warrant their use. However, it is doubtful that estimates of the magnitude of these benefits are necessary for resource allocation studies for two reasons. First, existing accident prediction procedures are not sufficiently accurate to reliably distinguish the small differences in accident rates associated with alternative track circuit designs. Second, decisions regarding the type of track circuit that should be used at a crossing are quite properly a design decision rather than a resource allocation decision. Guidelines for selecting type of track circuit, as well as placement of signals (cantilevered versus mast mounted), are already available (7). Therefore, it is not clear that further research on the effectiveness of constant-warning-time track circuits will lead to useful and implementable results. If additional work is to be conducted, it should be based on data that include the design speed of fixed-distance track circuits and accident rates normalized for exposure, and the experimental design should use a treatment-control type of before-and-after comparison (8).

Discussion

John S. Hitz*

Thank are extended to the Committee on Railroad-Highway Grade Crossings for this opportunity to comment on the paper by Halkias and Eck. This subject is of great personal interest to me because I have been involved in similar research at the Transportation Systems Center (TSC), U.S. DOT, during the past several years. Comments are addressed in particular to determining the effectiveness of constant-warning-time devices.

Efforts to determine the effectiveness of constant-warning-time devices are worthwhile. Because these devices add significantly to the costs of warning device improvement projects, their use should be justified by a resultant increase in effectiveness. If they can be shown to be cost-effective, then they constitute an additional "weapon" in the arsenal of preferred means of improving crossing safety. It should be mentioned that these devices have additional benefits in their ability to improve highway traffic flow, which further justifies their use in certain applications.

The Halkias and Eck study determined an average effectiveness of 26 percent for constant-warning-time-device additions to flashing lights and gates compared with fixed-distance systems. The 95-percent confidence interval for this value is quite large, however. The true value of effectiveness could lie anywhere between 3 and 49 percent. This large uncertainty is a reflection of the small amount of data available for analysis. However, practical insight of crossing safety suggests that these devices should have some positive level of safety improvement. Increasing the credibility of warning devices should result in fewer instances of motorists taking risks to avoid long waits at railroad grade crossings. Results of a similar study at TSC tend to support this notion and are consistent with the Halkias and Eck study. At TSC it was found that the effectiveness of all flashing lights and gates tended to be lower at crossings with large variations in train speed. Although the results of these studies suggest that constant-warning-time devices are effective, it would be desirable to have more confident answers on this issue. I would like to provide some suggestions on how it is possible to move toward this goal through further analysis of the available data. Any such study, however, must recognize and resolve to the extent possible problems with both the quality and quantity of the data.

The limited quantity of data available on constant-warning-time devices lowers the confidence that can be placed in resulting effectiveness values. This problem is aggravated when the data are sectionalized to analyze specific factors that influence effectiveness, as is inevitably the case. Therefore, as much as possible of the data that are available for analysis should be used. This can be accomplished by concentrating further analysis on the data for upgrades from passive devices to lights and gates that do and do not include constant-

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warning-time devices. This is the largest group of upgrades and will thus yield the most confident results. Halkias and Eck investigated this group but found no difference in effectiveness between upgrades that did and did not include constant-warning-time systems. These results should be investigated further by addressing some of the following issues regarding data quality.

Several problems with data quality result from an inability of the data to fully describe features of crossings that may influence the effectiveness of warning devices (e.g., restricted sight distance). If constant-warning-time devices are systematically chosen for installation at crossings with restricted sight distance, the data may reveal the devices to have a lower-than-actual level of effectiveness. This problem can be minimized by ensuring that the two groups of crossings being compared (upgrades to fixed-distance and constant-warning-time devices) are equivalent in terms of potential for accidents before the upgrade. This will tend to control for those factors not in the inventory that may influence the hazard level of a crossing and thus the effectiveness of warning devices. It is recommended that the DOT basic accident prediction formula be used because it is the best indicator of the hazard level of the crossing before upgrade. This does not necessarily require that the crossings in each group be categorized into subgroups of equal hazard, which would reduce sample sizes. A reasonable requirement would simply be that the two groups have the same distribution of hazard levels.

A similar data quality problem is failure of the data to describe the full extent of improvements that may take place when a constant-warning-time device is installed. For example, flashing lights may frequently be replaced with larger, more effective lights at the same time that constant-warning-time devices are installed. With the data available it is difficult to determine if resultant safety improvements are caused by the improved lights or by the addition of constant-warning-time devices. This problem will be largely avoided by investigating upgrades from passive devices because only new lights of similar effectiveness will be involved.

Another problem with data quality to be addressed is the vagueness with which constant-warning-time devices are defined. The existence of a constant-warning-time device can only be implied from the data by a positive response to the ambiguous question, Does crossing signal provide speed selection for trains? The type of constant-warning-time device is not indicated. Many of the devices could be of the motion-detector type. These devices are intended more to reduce long traffic delays and congestion than to provide a constant warning time. Therefore, they would tend to have little impact on reducing accident statistics, because the crossings involved would generally have low-speed switching movements and few accidents to begin with. If significant numbers of motion detectors are included in the data, then the effectiveness results for constant-warning-time-devices could be biased downward. To reduce the occurrence of this problem, the constant-warning-time-device group should be screened to eliminate most motion detectors by excluding crossings with large numbers of switch trains or primarily low-speed trains or both.

Regarding train speeds, a more detailed analysis of train speed variation should be enlightening. Do crossings in the constant-warning-time group actually have large variations in train speed? How does this compare with the same information for the fixed-distance group? One would expect that the constant-warning-time group would have the greatest train speed variation. When determining the effectiveness of a constant-warning-time device relative to a fixed-distance device, the comparison should be made between locations with equivalent levels of train speed variation. The basic question that is being addressed is whether constant-warning-time devices are more effective than fixed-distance devices under conditions of large train speed variations. If level of train speed variation is not controlled, the results could be significantly biased.

Another type of data limitation results from possible changes to crossing characteristics that may influence effectiveness after a warning device upgrade has taken place. For example, significant changes to train and highway traffic could occur after an upgrade, thus increasing the likelihood of an accident. Anticipated changes in such characteristics of crossings may lead to some decisions about upgrades. If the inventory does not account for these changes or if they are not considered in the analysis, effectiveness results could be biased. Unfortunately, this is a particularly difficult problem to overcome. Even if various editions of the inventory are analyzed to determine crossing changes over time, there is no assurance that the actual changes that have taken place have been reported.

If the precautions that are outlined in this discussion are considered, it is possible that the results may have a sufficiently high level of confidence to be of practical use. In any event, the data will have been used for all its useful information. The suggestions in this discussion are consistent with proposals by Halkias and Eck for future work. I wish them success and look forward to working with them in these efforts.

Authors' Closure

We greatly appreciate the thoughtful and constructive reviews made by Hitz, Bowman, and Berg of our paper. We agree with their comments concerning clarification of certain items in the national data base and on the need for a sound experimental design (including choice of appropriate variables) in any work of this nature. Although we were remiss in neglecting certain critical points in our analysis (for example, analysis of total accidents without consideration of specific accident types) lack of resources constrained us in other areas, most notably the site-by-site verification of the existence of the correct combination of detection and warning devices.

The only specific issue we wish to address concerns Bowman's comments on statistical significance and comparisons of confidence limits. Stating that significance exists because zero is not within the confidence limit is valid, as in the case of the 26-percent effectiveness of fixed-distance to constant-warning-time upgrades at a specified confidence level. For situations such as the one encountered here, that is, working with ratios, comparisons of confidence limits between two sample means are appropriate and valid tests, because confidence intervals not only provide information on the true mean of a sample but are also used as hypothesis tests for differences between means.

We recognize that, in general, our paper may have raised more questions than it answered. Although the effectiveness factors developed may not be directly applicable at this point in time, the process of producing these "first-cut" effectiveness factors has resulted in new information regarding the use and effect of different types of grade-crossing warning devices. We did not mean to imply in our recommendations that decisions regarding what type of track circuit to use were resource allocation decisions. As Berg correctly pointed out, they are design decisions. The point to be made is that even though the designer may not use the actual quantities developed in our work, the insights provided by our findings should lead to improved decision making.

Perhaps the greatest value of the paper, and the discussion that has taken place relative to it, is the explicit identification of data limitations and areas in which additional research is needed. It is hoped that the identification of these limitations will encourage maintenance of a current and accurate DOT-AAR Crossing Inventory File and even serve as an impetus to making some minor modifications to the data base that will enhance its use as a decision-making tool. Identification of research needs should prove of interest to both researchers and funding agencies.

Based on the information in this paper and in the discussions, the major data base and research issues relative to rail-highway grade crossings in general and fixed-distance versus constant-warning-time systems in particular have been outlined. These are as follows:

1. The inventory file does not always contain current and accurate information.
2. Certain additional crossing features (mainly sight distance and extent of improvements made) should be added to the data base.
3. The definition of constant-warning-time devices in the data base needs to be improved.
4. It is imperative that exposure be incorporated into accident rate calculations and comparisons.
5. The use of track circuit design speed rather than maximum train speed is needed to provide insight into the effectiveness of constant-warning-time systems.
6. A treatment-control type of before-and-after experimental design is recommended for work of this nature.
7. The comparisons described in this paper should be made for different stratifications of physical and operational characteristics (including exposure).
8. In examining device effectiveness versus angle of crossing, the degree of improvement attributable to constant-warning-time systems and that due to gate installation must be determined.

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