Evaluation of Six Active Warning Devices for Use at Railroad-Highway Grade Crossings

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ABSTRACT

Six new active railroad-highway grade crossing warning devices were evaluated under controlled laboratory testing conditions. The six devices included two alternatives for each of three basic systems--four-quadrant gates (with and without skirts), four-quadrant flashing light signals (with and without strobes), and highway traffic signals (with one and with three white bar strobes). The evaluation involved testing the performance of each of the six devices in a near realworld environment to identify the three most desirable devices for subsequent field testing. Thirty-two test subjects drove an instrumented vehicle repeatedly over a private two-lane highway. On each trip down the roadway, the test driver encountered three full-scale active warning devices, any one of which may or may not have been actuated as the vehicle approached. The experimental design included different actuation distances as well as day and night conditions. In addition to driver behavior data, attitudinal data on the effectiveness of the six devices were obtained from each subject. All six active warning devices tested were perceived to be superior to standard active warning devices currently in use at railroad-highway grade crossings. Generally speaking, alternative B of each system (i.e., with skirts, with overhead stobes, and with three white bar strobes) was more effective. Four-quadrant gates with skirts tended to be a superior system in all categories of analysis. The relative effectiveness of flashing light signals and highway traffic signals tended to alternate depending on the category of analysis; there was not a consistent ordering of effectiveness of these two systems.

Research to improve safety at railroad-highway grade crossings has been going on for some 50 years, but the methods used for warning motorists of impending danger at a crossing have not changed significantly. During this time many innovative warning systems have been developed for use both at and in advance of crossings and millions of dollars have been spent in developing, testing, and evaluating these devices. Yet field implementation of new concepts has been minimal.

As part of a research project that addresses these issues, eight innovative active warning devices were identified as having potential for improving safety at railroad-highway grade crossings (1). A prioritization of these eight devices identified five of them for detailed laboratory evaluation. However, careful review of these five devices determined that they were in fact variations of three conceptually different systems (i.e., gates, flashing light signals, and highway traffic signals). For this reason, it was proposed that laboratory testing evaluate six devices consisting of two variations of each of the three basic systems. The devices chosen for testing were

1. Four-quadrant gate system with and without skirts,
2. Four-quadrant flashing light signal system with and without overhead strobes, and
3. Highway traffic signal system with one and with three white bar strobes.

The evaluation process involved testing the performance of each of these devices in a near realworld environment to identify the three most desirable devices for subsequent field testing. The configuration of each prototype device was in accordance with the Manual on Uniform Traffic Control Devices (2) and standard highway engineering practice. Figures 1-3 show the installation of the six devices as they were evaluated in the laboratory testing. The results of this study are summarized in this paper; supporting documentation is contained in another report (3).

EXPERIMENTAL PLAN

The laboratory evaluation of the active warning devices involved 32 test subjects each of whom drove

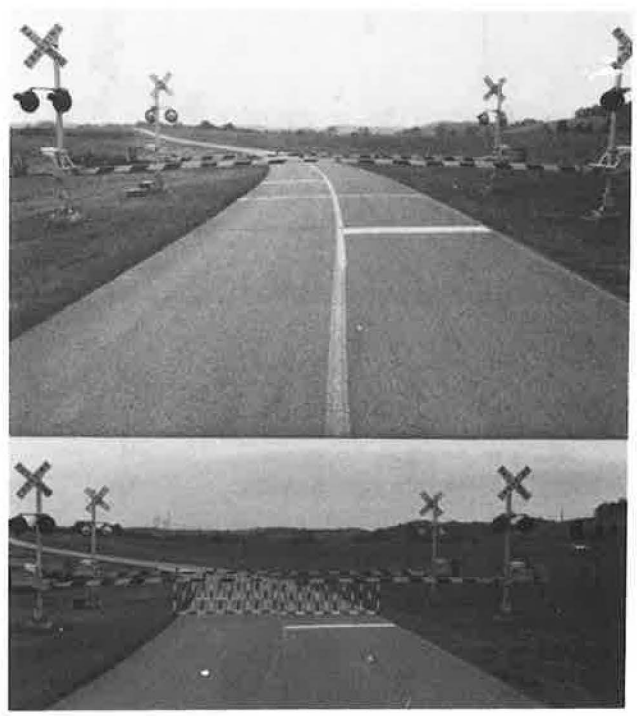

FIGURE 1 Four-quadrant gate system: top, alternative A, without skirts on gate arms; bottom, alternative B, with skirts added to all gate arms.

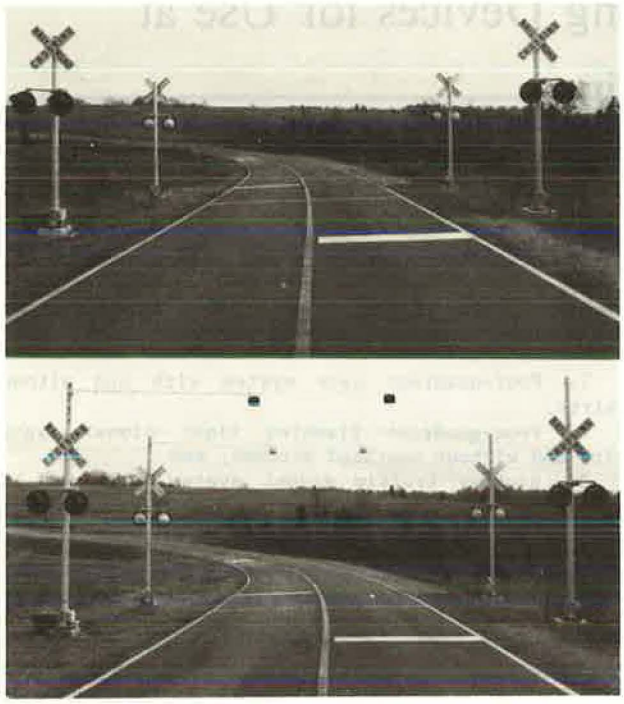

FIGURE 2 Four-quadrant flashing light signal system: top, alternative A, without strobes; bottom, alternative B, with red strobe lights over traffic lanes.

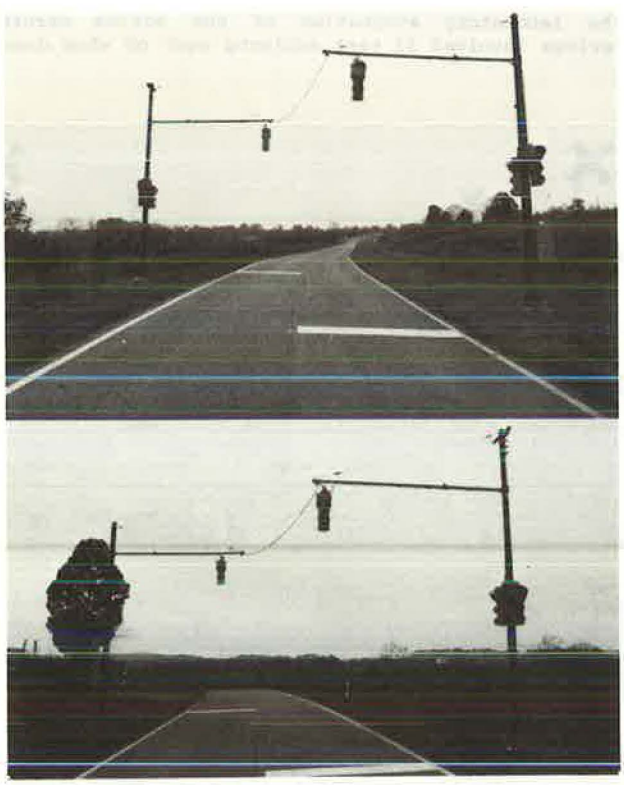

FIGURE 3 Highway traffic signal system: top, alternative A, white bar strobe in overhead red signal lens; bottom, white bar strobe in each red signal lens.

an instrumented vehicle at approximately 40 mph repeatedly over a 1.5-mile stretch of private two-lane highway. On each trip down the roadway, the test driver encountered three full-scale active railroad-highway grade crossing warning devices, any one of which may or may not have been actuated as the vehicle approached. Subjects were requested to respond to the traffic control devices as they would under normal driving conditions. An experimental design was developed in which the effects of the following independent variables could be evaluated (4):

1. Alternative active warning devices (alternative A versus alternative B for each system);
2. Basic active warning systems (system A versus system B versus system C);
3. Signal actuation distance (null, long, medium, and short); and
4. Lighting conditions (day versus night).

Each subject experienced two replications of each of the 48 treatment combinations. All of the variables are self-explanatory with the exception of actuation distance that was defined as the distance the test vehicle was from the device when the device communicated a changing of right-of-way (i.e., flashing light signals were actuated or the highway traffic signal changed to yellow).

RESULTS

Subject Characteristics

Half of the 32 subjects were male and half were female; each group was further divided into an equal number of younger (under 25) and older (over 60) drivers. The younger subjects had been driving an average of 4.1 years and the older drivers an average of 45.8 years. In both age groups, the males drove almost twice as many miles per year as did their female counterparts. The average educational level of the subject population was similar for each of the four groups; however, individuals within the groups ranged from those who did not complete high school to college graduates.

When the subjects' simple reaction times were measured, the young male subjects were the fastest (0.41 sec) of any of the four groups. Times for the other three categories were all about 0.48 sec. When vision was tested, the average corrected visual acuity of the younger subjects was about 20/20. For the older subjects, the average was about 20/30, which is the legal requirement for operating a motor vehicle in Tennessee. However, two younger and five older drivers did not meet this criterion.

Attitudinal Data

After completing all of the test runs, each subject was asked to compare the effectiveness of each of the six alternative devices with that of existing signals. An absolute scale of 1 to 5 was used for this purpose, with 3 being about the same as existing signals, 1 being much less effective, and 5 being much more effective. Responses were solicited for both day and night driving conditions. All six of the devices were ranked higher than existing signals in both situations. In each case, the four-quadrant flashing lights was the lowest ranked alternative. The rank order of the other four devices varied by time of day. For day driving, the order was four-quadrant gates, highway traffic signals,

and four-quadrant flashing light signals. However, this was not true for night; one of the four-quadrant flashing light signal alternatives was rated as the second most effective device at night.

In addition to the absolute rankings, the subjects were asked to pick the more effective device from a series of two alternatives. Thurstone's method of paired comparisons (5) was used to determine a relative ranking of the six alternative devices. Figure 4 shows the results of these rankings for both day and night conditions. As shown, the two highest ranked alternatives involved four-quadrant gates with and without skirts. The third ranked device was the four-quadrant flashing light signals with overhead strobes. The next two ranked devices involved the highway traffic signal. The lowest ranked alternative was the four-quadrant flashing light signals without overhead strobes. This ranking technique clearly shows the gate system with skirts to be much preferred to the other systems.

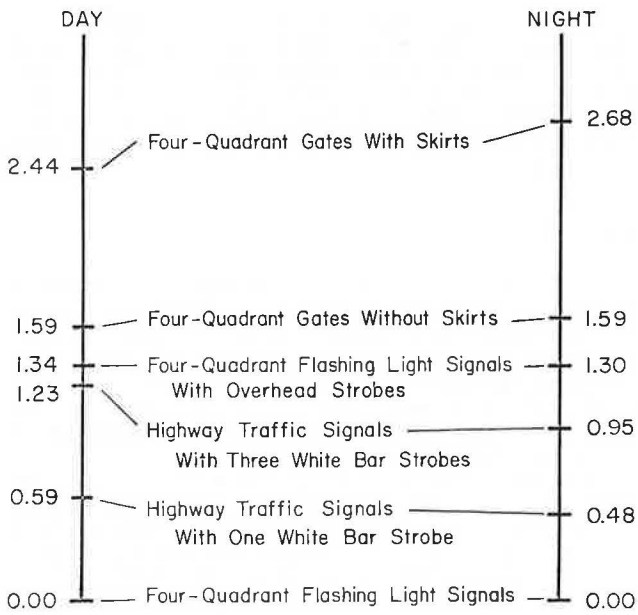

FIGURE 4 Relative ranking of the six alternative active warning devices.

Driver Behavior Data

To investigate the effects of the six innovative devices on subject behavior, each of 3,024 observations was classified according to device type, actuation distance, and lighting condition. This resulted in a model with 48 cells (6 devices x 4 distances x 2 conditions). Brake reaction time and maximum deceleration rate were selected as the most meaningful variables from the candidate list of variables describing a subject's reaction to a traffic control device. The cell means for these variables were calculated and stored in tabular format. An attempt was made to analyze the number of extreme deceleration rates in the data set; however, because only 13 of the observed rates could be classified as extreme, a further analysis was not conducted.

To determine whether the cell mean differences were real or simply a result of chance, three-way analysis of variance (ANOVA) tests for statistical significance were performed. Duncan's test (6) was used to test the differences for each of the three main effects in the full model. Results are as follows:

1. When response to the six device types is averaged across all levels of actuation distance and lighting condition, there is not a significant difference between the two gate systems and the two flashing light systems; however, the difference in response to these four devices and to the two highway traffic signal systems is significant.
2. When response to four actuation distances is averaged across all levels of device type and lighting condition, there are significant differences between each of the four distances.
3. When response to the two lighting conditions is averaged across all levels of device type and actuation distance, there is significant difference between day and night; however, the magnitude of the difference (0.23 sec) is very small.

Because actuation distance explained most of the variation in the data set, it was decided to run separate two-way ANOVA tests for each of the four actuation distances. The results are summarized in Table 1. Interpretation of this table is rather complex because both variables are represented and each column depicts a separate ANOVA test. There are only 12 cells (6 devices x 2 conditions) in each model, and there are 4 models for each variable. For each model, cells with the same letter are not significantly different.

As an example, for the brake reaction time variable and the medium actuation distance, response to the two types of four-quadrant gates is significantly different (faster) than response to the other four devices; however, differences within the two groups (two types of gates and the other four devices) are not statistically significant. For the short actuation distance, response to the four-quadrant gates with skirts is significantly different from response to the two types of highway traffic signals. In addition, response to the two types of four-quadrant gate systems and the two types of four-quadrant flashing light signal systems is significantly different from the response to two types of highway signals. Because the four-quadrant gates without skirts belong to both groups A and B, there is no significant difference between the four-quadrant gate systems and four-quadrant flashing light signal systems.

Basically, the four-quadrant gates with skirts always belong to the fastest group, and the two types of highway traffic signals are always associated with the slowest. The placement of the four-quadrant gates without skirts and the two types of four-quadrant flashing light signals varies with actuation distance. In addition, at both the medium and long distances, response to the devices is significantly different between day and night conditions.

Interpretation of the maximum deceleration rates is not as clear-cut. There is not a significant difference in deceleration at the short actuation distance, but at the other distances there are differences. However, there appears to be no pattern to the results. As with the brake reaction time variable, response to the devices at the medium and long actuation distances was significantly different under day and night conditions.

CONCLUSIONS

All six innovative active warning devices were perceived as superior to standard active warning devices currently in use at railroad-highway grade crossings. The subjects always perceived the four-quadrant gates with skirts as the most effective and four-quadrant flashing light signals without strobes as the least effective on both an absolute and rela-

TABLE 1 Comparison of Average Brake Reaction Times and Maximum Deceleration Rates for Various Actuation Distances

Variable	Type of Traffic Control	Actuation Distance			
		Short (330 ft)	Medium[a] (440 ft)	Long[a] (670 ft)	Null (0 ft)
First brake, time	Four-quadrant gates without skirts	A,B	A	A	A
	Four-quadrant flashing light signals without strobes	B	B	A	A
	Highway traffic signals--one white bar strobe	C	B	B	B
	Four-quadrant gates with skirts	A	A	A	A
	Four-quadrant flashing light signals with overhead strobes	B	B	A	A
	Highway traffic signals--three white bar strobes	C	B	B	B
Maximum deceleration, rate	Four-quadrant gates without skirts	A	A,B	A	A,B
	Four-quadrant flashing light signals without strobes	A	C	B	B,C
	Highway traffic signals--one white bar strobe	A	A,B,C	A	A
	Four-quadrant gates with skirts	A	B,C	A	A
	Four-quadrant flashing light signals with overhead strobes	A	B,C	B	C
	Highway traffic signals--three white bar strobes	A	A	A	A

Note: Cells with the same letter are not significantly different.
[a]Significant differences between day and night.

tive ranking basis. The perceived effectiveness of the other four devices tended to cluster together and was not significantly different on the absolute ranking basis for either day or night conditions. However, on the relative ranking basis, there was a consistent order of perceived effectiveness for both conditions.

At both the short and medium actuation distances, four-quadrant gates with skirts resulted in significantly quicker brake reaction times than either highway traffic signals or four-quadrant flashing light signals. In addition, at all actuation distances, the two highway traffic signal alternatives resulted in significantly slower brake reaction times than either of the other two systems. At the short actuation distance, there was no significant difference in the resultant deceleration rates for any of the six active warning devices, but there was for medium and long activation distances.

Generally speaking, alternative B of each system (i.e., with skirts, with overhead strobes, and with three white bar strobes) was more effective; four-quadrant gates with skirts tended to be a superior system in all categories of analysis; and the effectiveness of four-quadrant flashing light signals and highway traffic signals tended to alternate relative to one another depending on the category of analysis; there was not a consistent ordering of the effectiveness of these two systems.

RECOMMENDATIONS

Because the overall research project is directed toward determining the cost-effectiveness of alternative active warning devices and the cost of each basic system tested varies over a wide range, it is recommended that one alternative of each basic system be field tested. Because alternative B of each basic system was generally superior, it should be the one that is field tested. One field test of each alternative should be begun initially rather than two installations of each alternative. Field experience is needed before additional crossings are implemented.

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