Evaluation of Two Active Traffic Control Devices for Use at Railroad-Highway Grade Crossings

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Two active traffic control devices with the potential for improving safety at railroad-highway grade crossings were identified by a detailed laboratory evaluation as candidates for field testing under normal traffic conditions at actual crossings. Two crossings with active warning devices already in place were identified as potential study sites, and train and driver behavior data were collected both before and after the experimental traffic control devices were installed. The two devices evaluated for use at railroad-highway grade crossings were four-quadrant flashing light signals with overhead strobes and standard highway traffic signals. Based on the results of the field evaluation, there were no measurable differences in driver behavior between four-quadrant flashing light signals with overhead strobes and the standard two-quadrant flashing light signals. The warning system itself was operationally feasible and may have some limited application. The highway traffic signal proved to be both feasible and effective as a grade crossing traffic control device. Driver response to the highway traffic signal was excellent, with the traffic signal outperforming standard flashing light signals on several key safety and driver behavioral measures of effectiveness. Additional testing of this system is recommended.

Safety improvement at railroad-highway grade crossings over the past 10 years is well documented (*1*). Much of this improvement can be attributed to the availability of federal funds for grade crossing improvement projects (*2*), the majority of which involved upgrading passive crossings to active ones. As a result of the increase in these projects, over one in four of the 192,454 public grade crossings had active warning devices in 1986. Of concern, however, is the fact that over 50 percent of all car-train accidents occur at crossings with active warning devices (*3*), even though these crossings account for only 28 percent of all crossings. Although this high number of accidents may be a result of higher vehicle and train volumes and more complex railroad-highway geometrics at active crossings, it is likely that some of the accidents are caused by motorists either not seeing or not understanding the active warning devices presently used at railroad-highway grade crossings. For these reasons, it is clear that driver response to active warning devices at railroad-highway grade crossings could be improved.

Research aimed at improving driver response to active warning devices at railroad-highway grade crossings has been going on for some 50 years. Although there have been significant improvements in both electronic equipment and system components, the warning devices that are seen and responded to by the motorists have not changed significantly during this period of time. Even though many innovative warning devices have been developed for use both at and in advance of crossings, implementation of new devices during the past 50 years has been minimal.

Recognizing the need to fully address more extensively the issues and problems concerning active warning devices at railroad-highway grade crossings, the FHWA sponsored a research project at the University of Tennessee to identify and evaluate innovative active warning devices with potential for improving safety at railroad-highway grade crossings. As part of this research, three innovative traffic control devices were identified as having potential for improving safety and were chosen for subsequent field evaluation under normal traffic conditions at existing crossings (*4*). The objective of this paper is to compare driver performance measures in response to the existing traffic control devices at two of the crossings with that of two innovative active traffic control devices at the same crossings.

PREVIOUS RESEARCH

There are two types of warning devices for use at railroad-highway grade crossings: passive devices and active devices. Passive devices provide static warning of a grade crossing's location and are required at virtually all at-grade crossings. Active devices supplement passive ones at locations where the accident potential is high to warn drivers of the approach or presence of a train. The active warning devices currently in use were developed over 50 years ago. Guidelines for their use and some practical interpretations are offered in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*5*) and the *Traffic Control Devices Handbook* (*6*); however, the general public does not fully understand the responsibilities various warning devices place on approaching drivers (*7,8*).

Driver performance measures are a means of assessing the adequacy of a traffic control system in meeting a driver's needs. The better those needs are met, the better the driver performs. The challenge lies in defining what constitutes good driver behavior. Surprisingly, few studies have attempted to quantify driver behavior at railroad-highway grade crossings. Those studies that have examined driver behavior have focused on such measures as looking behavior, speed profiles and

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changes, deceleration levels, conflicts, and violations. As a result of these studies, several interesting and somewhat unexpected conclusions were reached.

Looking behavior is a poor measure of driver performance because although drivers look, one does not know why or if they even see specific things in their field of view (*9*). In addition, looking behavior appears to be more related to past experience than the need to look, i.e., at various crossings, familiar drivers tend to look more when train volumes are high, and at the same crossing they tend to look less than unfamiliar drivers (*10*). Speed profiles of familiar drivers on the approach to a grade crossing are a function of the crossing surface, making it virtually impossible to compare various crossings; however, they are useful when comparing various warning systems at the same crossing.

When studying approach speed profiles, drivers should be grouped into categories of similar expected behavior based on the stimulus for stopping at the crossing (*11*). Basically, the greater the stimulus, the sooner and more gradually drivers will begin to slow down (*12*). Lowered gate arms result in the smoothest speed profiles and surprisingly, activated flashing lights result in speed profiles similar to those at passive crossings (*13*). As for speed changes of individual vehicles approaching the crossing, there are no apparent patterns other than the fact that their variance increases as the vehicles get closer to the crossing (*9*).

Extreme deceleration levels and large numbers of conflicts and violations are good indicators of potential grade crossing safety problems. Unfortunately, very few drivers exceed a practical deceleration level when stopping, thus requiring large data bases (*12*). Conflicts and violations are more common and easily observed. The key to their use is a clearly defined behavior that can be measured in the field.

Driver behavior at signalized intersections is different from that at railroad-highway grade crossings since changes in right-of-way are expected at intersections and unexpected at grade crossings; however, several research findings are worth noting. The 85th percentile perception-brake reaction time in response to a yellow signal has been estimated as 1.2 seconds (*14*). This value does not change with either distance from the intersection or day-night or wet-dry conditions. The 85th percentile deceleration level is 10.5 ft/sec^2, which is also unchanged for all conditions other than approach grade (*14*). As with grade crossings, few drivers select higher-than-practical deceleration levels when stopping. Ninety-five percent of the drivers that do not stop enter the intersection within 4.5 seconds of the onset of yellow regardless of their approach speed (*14*).

STUDY PROCEDURE

Two active warning devices for use at railroad-highway grade crossings were identified by a detailed laboratory evaluation process as candidates for field testing under normal conditions at actual crossings. Two crossings in the Knoxville area, Ebenezer Road and Cedar Drive, were identified as potential study sites, and driver behavior was studied before and after the new devices were installed. Both crossings, with standard railroad flashing light signals already in place, had relatively high train and traffic volumes and a history of at least some accidents. A four-quadrant flashing light signal system (with red strobe lights over the traffic lanes) was installed at the Ebenezer Road crossing and a highway traffic signal system (with white bar strobes in each red signal lens) was installed at the Cedar Drive crossing.

Data on driver behavior approaching and at the two crossings were collected using three pole-mounted video cameras, with each of the cameras covering approximately 300 ft of roadway with overlapping fields of view. The video recorders were automatically turned on before the activation of the warning devices and ran for approximately 2.5 to 3 minutes. For each study at a particular crossing, data were collected for a minimum of 30 trains. One existing and one improved condition study was conducted at each of the study sites.

Data tapes were taken to the university's computer lab for processing. The tapes were transferred to and played back on a high-quality video reproductive machine that could stop action and produce sequential scenes separated by 1/60 of a second. Speed profiles were determined by using successive frames and noting the distances that the vehicle had traveled between frames. Since the cameras were fixed, any point on the vehicle moved on a surface dictated by the roadway. By use of an electronic cross hair, the coordinates of this reference point were calculated for successive frames and manually recorded. This information was used to construct each individual vehicle's speed-distance profile.

Other measures of driver performance that were recorded include perception-brake reaction times and violation and vehicle crossing rates in response to device activation. Statistical comparisons of these measures were made between both devices and conditions. The general hypotheses tested were that installation of these new devices improved the conspicuity of and compliance with active warning devices at railroad-highway grade crossings, thus providing for safer operations at the crossing.

Ebenezer Road

The four-quadrant flashing light signals with overhead strobes were installed at the Ebenezer Road crossing during the week of October 14, 1985. Before this time, active warning devices at the crossing were standard two-quadrant flashing light signals. Both train movement and driver behavior data were collected for approximately 2 months before (July and August 1985) and 2 months after (May and August 1986) the new devices were installed. During these two periods, a total of 226 train movements were observed. There were 157 trains observed in the before study (two-quadrant flashing light signals), and 79 trains observed in the after study (four-quadrant flashing light signals with overhead strobes). For each observation in the two studies, the environmental and lighting conditions, train's direction of travel and warning time, and approaching vehicle's clearance time, speed profile and brake reaction time were recorded and subsequently analyzed.

The approach roadway's horizontal and vertical alignments limit visibility of the Ebenezer Road crossing from both directions. Thus, the visibility of the standard two-quadrant flashing light signals at the crossing was also limited. The primary change in driver performance that was expected as a result of the installation of the four-quadrant flashing light signals with overhead strobes was an earlier reaction to the active warning devices. As a result of this change in behavior, the

approach speeds were expected to be slower, the brake reaction times were expected to be quicker, and the deceleration levels were expected to be more gradual; however, differences in these driver performance measures were not expected to be easy to quantify and the related safety benefits are not straightforward.

Driver behavior at the crossing itself (i.e., clearance times, violation rates, and vehicle crossing rates) was not expected to change, since the new device neither changed the train detection system nor physically blocked the roadway. The only legal requirements placed on motorists approaching a flashing light signal are that they bring their vehicle to a stop in advance of the crossing and then proceed when it is safe to do so. Thus, violations at a crossing with flashing light signals were defined as the failure of drivers to reasonably stop in response to the warning device. Because of the difficulty in determining whether a vehicle came to a complete stop, violations were not counted for either of the two flashing light signal systems.

Cedar Drive

Highway traffic signals were installed at the Cedar Drive crossing during April 1986. Before this time, the active warning devices at the crossing were standard two-quadrant flashing light signals; however, because it was felt that long warning times at this crossing might lessen the traffic signal's credibility, predictors were installed during November 1985 to provide shorter and more consistent warning times. Both train movement and driver behavior data were collected for approximately 2 months before the highway traffic signals were installed (February and March 1986) and 2 months after the highway traffic signals were installed (July and August 1986).

During these two periods, a total of 142 train movements were observed. A total of 50 train movements were observed in the before study (flashing light signals with predictors) and 92 train movements were observed in the after study (highway traffic signals with predictors). For each observation, the environmental and lighting conditions, train's direction of travel and warning time, and approaching vehicle's clearance time, speed profile, and perception-brake reaction time were recorded and subsequently analyzed.

The Cedar Drive crossing had severe safety problems as evidenced by its high hazard ranking (31st most dangerous crossing in the state) and the three car-train accidents that occurred at this site during the past 5 years. It was hypothesized that these safety problems were a result of a combination of the relatively high train and traffic volumes, limited sight distance at the crossing, and long warning times, resulting in numerous motorists crossing in front of approaching trains. Because highway traffic signals have a relatively high level of driver credibility and respect, their installation at the Cedar Drive crossing should discourage most motorists from crossing in front of approaching trains.

Since the highway traffic signals legally rather than physically prohibit crossing, the average clearance time between the last vehicle to cross and the train's arrival at the crossing may or may not have increased. The average number of vehicles crossing per train arrival, however, was expected to decrease. These behavioral modifications have implied safety benefits since they provide greater spatiotemporal separation between trains and motor vehicles. The anticipated secondary change in driver performance was better response to the new devices (i.e., quicker perception-brake reaction times and lower deceleration levels) as a result of the greater conspicuity of the white bar strobes and credibility of the traffic signal. As noted previously, differences in these performance measures were not expected to be as easy to quantify, and the related safety benefits are not expected to be as straightforward.

RESULTANT MEASURES OF EFFECTIVENESS

Warning Time

Warning time was defined as the difference in time between activation of the flashing light signals and the train's arrival at the crossing. It is the same as the maximum time a motorist would have to wait between activation of the flashing light signals and a train's arrival at the crossing. Since there were no changes to the train detection system at either crossing when the new warning devices were installed, there should have been no difference in the average warning times observed in the before-and-after studies. To verify this premise, the total data set from each study was first subdivided into observations that occurred during the day and observations that occurred during the night to insure that similar train and traffic volume conditions were compared. These two subsets, together with the total data set, were then analyzed.

As shown in Table 1, the mean and standard deviation of the warning times from the two data sets at the Ebenezer Road Crossing were slightly shorter in the after study (flashing light signals with strobes); however, the Mann-Whitney U test for two independent, continuously distributed populations (*15*) indicated that these differences were not significantly different at the 95 percent confidence level for either the day, night, or total data sets. This means that, as expected, installation of the four-quadrant flashing light signals with overhead strobes had no effect on the warning times at the crossing. The Mann-Whitney test also indicated that there was not a statistically significant difference at the 95 percent confidence level between the day and night data sets from either of the two studies. Thus, warning times were not different during day and night operations for either the two-quadrant flashing light signals or the four-quadrant flashing light signals with overhead strobes.

The mean warning times from the two data sets at the Cedar Drive crossing (shown in Table 1) were also slightly shorter in the after study (highway traffic signals with predictors). In this case, however, the Mann-Whitney test for two or more independent, continuously distributed populations (*15*) indicated that these differences were statistically significant at the 99 percent confidence level. The Mann-Whitney test also indicated that there was a statistically significant difference at the 95 percent level between the night data sets from the two studies. These results were unexpected, since the train detection system did not change between the two studies; however, the results indicate that warning times were significantly shorter in the after study.

Clearance Time

Clearance time was defined as the difference in time between the last vehicle to cross and the train's arrival at the crossing.

TABLE 1 WARNING TIMES AT EBENEZER ROAD AND CEDAR DRIVE CROSSINGS[1]

EBENEZER ROAD CROSSING	Flashing Light Signals			Flashing Light Signals with strobes		
	Day	Night	Total	Day	Night	Total
Sample Size	106	51	157	60	19	79
Mean (seconds)	42.2	38.1	40.8	39.7	41.7	40.2
Standard Deviation	15.6	11.1	14.4	9.5	18.6	12.2
Range (seconds)	24-153	26-106	24-153	14-62	32-116	14-116
CEDAR DRIVE CROSSING	**Flashing Light Signals with Predictors**			**Highway Traffic Signals with Predictors**		
	Day	Night	Total	Day	Night	Total
Sample Size	22	28	50	67	25	92
Mean (seconds)	40.5	42.7	41.7	38.1	31.5	36.3
Standard Deviation	15.5	19.9	18.0	21.7	8.4	19.2
Range (seconds)	27-89	28-121	27-121	23-161	8-57	8-161

[1] Time between either activation of flashing lights or onset of yellow and the train's arrival at the crossing.

Since the four-quadrant flashing signals with overhead strobes changed nothing at the crossing itself, their installation was expected to have no effect on the observed clearance times. Thus, there was no expected increase in the temporal separation between cars and trains as a result of the installation of the new devices. Installation of the traffic signal, however, may give enough credibility to the warning devices to increase average clearance times at the Cedar Drive crossing. If, in fact, this does occur, the additional temporal separation between the cars and trains would be a definite safety benefit. This benefit is expected to be the result of the installation of both the predictors and the highway traffic signal at the Cedar Drive crossing.

Clearance times were recorded only for those train arrivals during which a vehicle arrived at the crossing between the activation of the flashing light signals and the train's arrival at the crossing, i.e., there was an opportunity for a vehicle to cross in front of the train while the signals were activated. Thus, the number of clearance times will always be less than or equal to the number of train arrivals. As with the warning time data set, the total data from each study was subdivided into observations that occurred during the day and observations that occurred during the night so as to insure that similar train traffic volume conditions were compared. The two subsets along with the total data set were then analyzed.

As shown in Table 2, the mean and standard deviation of the clearance times from all data sets at the Ebenezer Road Crossing were slightly shorter in the after study. The Mann-Whitney test (*15*), however, indicated that these differences were not statistically significant at the 95 percent confidence level for either the day, night, or total data sets. These values mean that installation of the four-quadrant flashing light signals with overhead strobes had no effect on the average time between the last vehicle to cross and the train's arrival at the crossing. This finding is shown clearly in the illustration of the frequency distribution of the clearance times from the two data sets in Figure 1. The Mann-Whitney test also failed to indicate a statistically significant difference at the 95 percent confidence level between the day and night data sets from either of the studies. These values mean that the clearance times were no different between day and night operation for either the two-quadrant flashing light signals or the four-quadrant flashing light signals with overhead strobes.

At the Cedar Drive crossing, the mean clearance times from the total data sets were approximately the same for both studies (see Table 2). The Mann-Whitney test for two or more independent, continuously distributed populations (*15*) confirmed that these differences were not statistically significant at the 95 percent confidence level. There was also no significant difference between the day and night data sets from either of the two studies, meaning that installation of the highway traffic signals in combination with the predictors had no effect on the clearance times observed at the Cedar Drive crossing.

Speed Profiles

The average speed at which drivers approach the two crossings whenever the warning devices were activated may or may not have been different after the installation of the new warning devices. Hypothetically, the greater conspicuity of the new

TABLE 2 CLEARANCE TIMES AT EBENEZER ROAD AND CEDAR DRIVE CROSSINGS[1]

EBENEZER ROAD CROSSING	Flashing Light Signals			Flashing Light Signals with Strobes		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	92	17	109	53	10	63
Mean (seconds)	19.1	27.9	20.5	15.6	24.8	17.1
Standard Deviation	9.9	20.5	12.4	6.8	10.3	8.1
Range (seconds)	7-64	8-99	7-99	5-36	4-38	4-38
CEDAR DRIVE CROSSING	**Flashing Light Signals with Predictors**			**Highway Traffic Signals with Predictors**		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	19	20	39	20	9	29
Mean (seconds)	16.2	26.3	21.4	20.7	21.4	20.9
Standard Deviation	5.8	18.9	14.9	8.4	10.5	8.9
Range (seconds)	7-28	6-96	6-96	5-34	10-45	5-45

[1] Time between the last vehicle to cross and the train's arrival at the crossing.

[2] Includes only those observations in which vehicles were present before the train's arrival.

warning devices, especially that of the overhead strobes, should cause drivers to see the warning devices earlier and slow down sooner. Even if this behavioral change occurs, however, it may not be large enough to be statistically significant, and even if it were, it still might not be large enough to be meaningful from a practical point of view (*16*). Also, the safety benefits of such a speed change are not easily quantified.

Although not illustrated in the paper, several observations can be made concerning the average approach speed profiles in the before-and-after data sets at the two crossings. First, the average speeds in the after studies were lower than the average speeds in the before studies. This finding indicates that the flashing signals with strobes and the highway traffic signals with strobes may have been visible farther from the crossing than the flashing light signals. Closer examination of the data, however, revealed that the average speeds in the before study and those in the after study were in fact relatively close to one another. Second, vehicles stopping in response to either the two-quadrant flashing light signals, the four-quadrant flashing light signals with overhead strobes, or the highway traffic signal did so in a safe, gradual, and consistent manner. As a result, the speed profiles appeared to pose no safety problems.

Perception-Brake Reaction Time

Perception-brake reaction time is defined as the difference in time between activation of the flashing light signals and the illumination of a vehicle's brake lights. It was expected that the greater conspicuity of the new traffic control devices would cause motorists to brake sooner and as a result decelerate more gradually. It was also expected that if these differences did exist, they would be very small and difficult to measure. To compound this problem, braking for a flashing light signal is an unexpected event and also does not represent a pressure situation unless a train is also visible. Thus, driver response can be relatively long and highly variable.

Average brake reaction times in response to the activation of the flashing light signals at the Ebenezer Road crossing were 15.6 seconds in the before study and 14.3 seconds in the after study. These differences were not large enough to be either statistically or practically significant, indicating that installation of the flashing light signals with overhead strobes had no measurable effect on the perception-brake reaction time of approaching motorists.

Average perception-brake reaction times in response to the activation of either the flashing light signals or the onset of the traffic signal's red indication were 17.1 seconds (before study), and 19.2 seconds (after study), respectively. In both cases the standard deviation was almost as large or larger than the mean. These differences also were not large enough to be either statistically or practically significant, indicating that installation of the highway traffic signal had no measurable effect on the perception-brake reaction time of approaching motorists.

These data confirm the premise that braking in response to either a flashing light signal or a highway traffic signal at

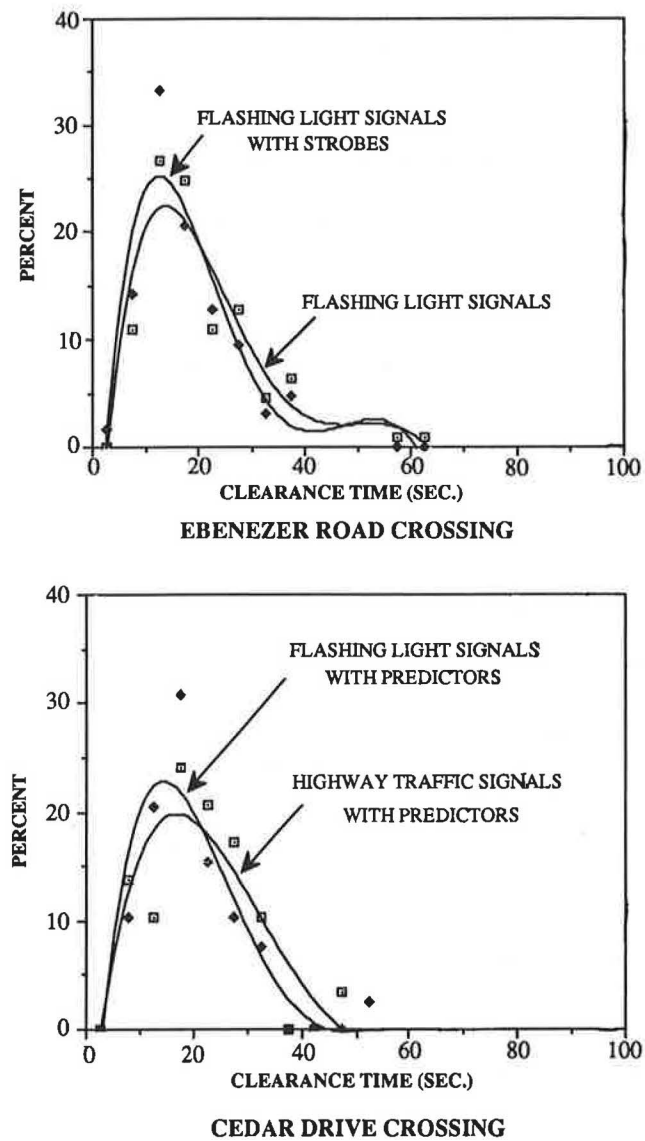

FIGURE 1 Frequency distribution of observed clearance times at Ebenezer Road and Cedar Drive crossings.

a railroad highway grade crossing did not represent a pressure situation (i.e., long reaction times) and, because of this, was highly variable. An additional complication with measuring brake reaction times was the difficulty in determining whether the vehicle of interest was braking in response to the activation of the warning device, a more slowly moving vehicle ahead of it, the horizontal alignment of the road, or simply because of the roughness of the crossing itself.

Deceleration Levels

In terms of deceleration, drivers approaching warning devices at the Ebenezer Road or Cedar Drive crossing were no different than those reported in the literature (*11,12*). None of the observed deceleration levels in either the before or the after studies exceeded a practical deceleration level, again indicating nonemergency stops. It could, however, also indicate that drivers had already slowed their vehicles because of the horizontal or vertical alignment of the road. If this were the case, continuance of this initial slowdown to a stop may have resulted in low decelerations. Whatever the reason, the maximum deceleration levels observed at the Ebenezer Road and Cedar Drive crossings did not indicate a potential safety problem for either the two-quadrant flashing light signals, the four-quadrant flashing light signals with overhead strobes, or the highway traffic signals.

Violations

At a crossing with flashing light signals, violations were defined as the failure of motorists to reasonably stop in response to the warning device. Because of the difficulty in determining whether a vehicle came to a complete stop, however, violations were not counted for the flashing light signal systems. Even if the number of violations had been counted, installation of the four-quadrant flashing light signals with overhead strobes was not expected to change the frequency of occurrence because there were no changes to either the train detection system or the crossing itself.

At a crossing with highway traffic signals, violations were defined as a motorist driving through the crossing while the signal displayed a red indication, i.e., a violation of the motor vehicle laws. Since the highway traffic signals did not physically block the roadway, their installation was not expected to eliminate violations at the Cedar Drive crossing; however, installation of the predictors in combination with the highway traffic signals may provide enough credibility in the warning devices to significantly reduce the number of violations at the crossing. Unfortunately, because of the different definitions, a direct comparison of the violation rates between the two conditions was not possible.

When the highway traffic signal was installed at the Cedar Drive crossing, the average and maximum number of motorists per train arrival who "ran the red" (illegal behavior) was 0.68 and 6, respectively. These statistics were based on the 78 observations in which vehicles were in the crossing area before the train's arrival. Of this total there were 50 observations in which no motorists behaved illegally, 15 observations in which one motorist behaved illegally, and 13 observations in which more than one motorist behaved illegally.

Vehicles Crossing

The average number of vehicles crossing between activation of the flashing light signals and the train's arrival at the Ebenezer Road crossing are shown in Table 3. As there was no statistically significant difference in the warning times observed during the two studies, there should have been no difference in the number of vehicles crossing. The results of the Mann-Whitney test (*15*) verified this premise at the 95 percent confidence level. Interestingly, almost 28 percent of the total observations resulted in five or more vehicles crossing after the flashing light signals were activated. This appears to be a clear indication that motorists will drive through a crossing while the signals are flashing as long as a train is not believed to be in close proximity.

The effects of warning times on the number of vehicles crossing while the flashing light signals were activated at the

TABLE 3 VEHICLES CROSSING AT EBENEZER ROAD AND CEDAR DRIVE CROSSINGS[1]

EBENEZER ROAD CROSSING	Flashing Light Signals			Flashing Light Signals with Strobes		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	101	22	123	58	11	69
Mean (vehicles)	3.83	1.59	3.43	3.84	2.18	3.58
Standard Deviation	3.41	1.37	3.26	2.61	1.47	2.53
Percent >0 Crossing	91.1	77.3	88.6	91.4	90.9	91.3
Percent >1 Crossing	74.3	45.5	69.1	81.0	54.6	76.8
Range (vehicles)	0-21	0-5	0-21	0-11	0-4	0-11
CEDAR DRIVE CROSSING	**Flashing Light Signals with Predictors**			**Highway Traffic Signals with Predictors**		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	21	24	45	59	19	78
Mean (vehicles)	3.86	2.92	3.35	0.80	0.53	0.73
Standard Deviation	3.34	2.50	2.92	1.47	0.61	1.32
Percent >0 Crossing	90.5	83.3	86.7	33.3	47.4	37.2
Percent >1 Crossing	71.4	62.5	66.7	20.3	5.3	16.7
Range (vehicles)	0-12	0-9	0-12	0-7	0-2	0-7

[1] Vehicles crossing after either activation of the flashing light signals or the traffic signal changing to yellow and the train's arrival at the crossing.

[2] Includes only those observations in which vehicles were present before the train's arrival.

Ebenezer Road crossing is shown in Figure 2. Even though the majority of the warning time observations were in the 30- to 40-second range, there is clearly an identifiable trend—the longer the warning time, the greater the number of vehicles that will cross while the signal is flashing. Note that if the warning time is less than 30 seconds, an average of one to two drivers will cross in front of the train; whereas, if the warning time is longer than 30 seconds, an average of three to four drivers will cross in front of the train. Although they were never in immediate danger, the more the drivers in these observations had to decide whether or not it was safe to cross, the greater the probability of one of them making the wrong decision.

The average number of vehicles crossing between activation of either the flashing light signals or the traffic signal's clearance interval and the train's arrival at the Cedar Drive crossing are also shown in Table 3. Because of the highway traffic signal's additional credibility, it was hypothesized that there would be a significant difference in the number of vehicles crossing. The Mann-Whitney test verified this premise at the 99 percent confidence level for the day, night, and total data sets, i.e., a significant reduction in the number of vehicles crossing was realized as a result of the installation of the highway traffic signals. The predictors in combination with the highway traffic signal reduced the average number of vehicles crossing per train arrival from 3.35 to 0.73. Thus, when predictors were installed in both systems, the additional credibility of the highway traffic signal reduced the average number of vehicles that crossed in front of an oncoming train by a factor of five (80 percent) compared with the flashing light signals.

The effects of warning times on the number of vehicles crossing while the flashing light signals were activated or the traffic signals were red at the Cedar Drive crossing is shown in the bottom of Figure 2. Even though the total observations are not distributed evenly throughout the warning time categories, there is clearly an identifiable trend, i.e., the longer the warning time, the greater the number of vehicles that will cross while the warning devices are activated. Note that if the warning time at the flashing light signals was less than 30 seconds, an average of one or two drivers will cross in front of the train, whereas if the warning time is greater than 30 seconds, an average of three to five drivers will cross in front of the train. If the warning device was a highway traffic signal, however, an average of only one driver crossed in front of the train no matter how long the warning time.

Interestingly, the average number of vehicles crossing at the Cedar Drive crossing compares favorably with the results

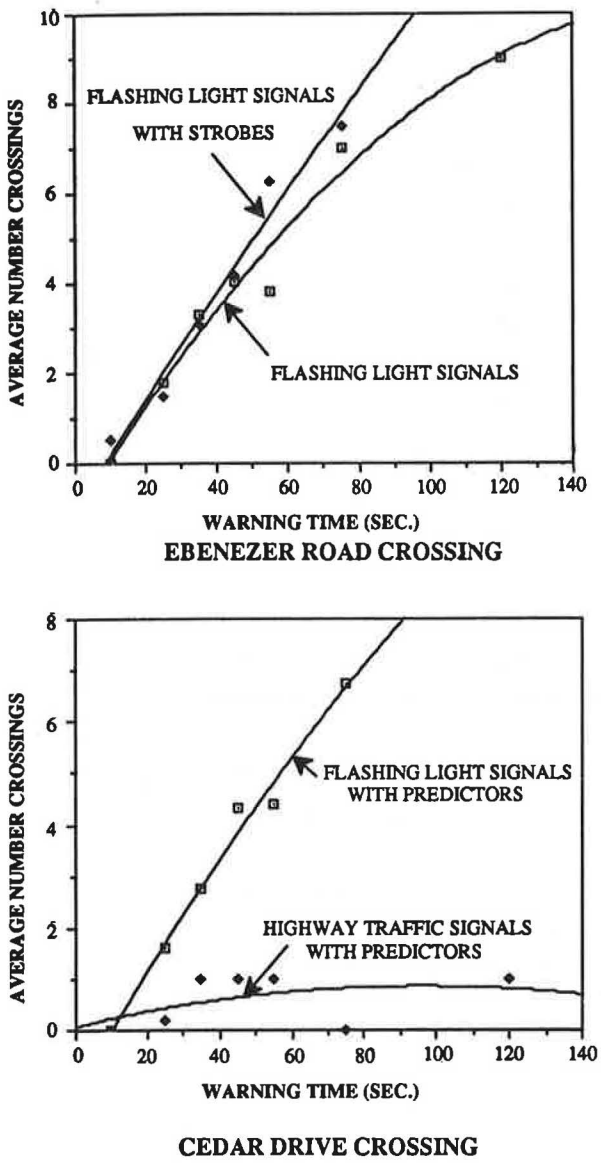

FIGURE 2 Average number of vehicles crossing as a function of warning time at Ebenezer Road and Cedar Drive crossings.

from the Ebenezer Road crossing—if the warning time is less than 30 seconds, an average of one driver will cross in front of an oncoming train, whereas if the warning time is as long as 50 seconds, an average of three to four vehicles will cross in front of the train. This result is not altogether surprising, since the active warning devices at both the Ebenezer Road crossing and the Cedar Drive crossing were exposed to similar traffic volumes, and both provided comparable average warning times. Thus, it appears that traffic volume and the average warning times may be a good indication of the average number of vehicles that will cross in front of an oncoming train.

Crossings Less Than 20 Seconds (CL20)

Vehicles crossing within 20 seconds of a train's arrival at the crossing were defined as an indication of aggressive behavior, i.e., there is some, but not much, room for driver and vehicular error. Although such behavior is not illegal, it represents those drivers that choose to cross within the 20-second minimum warning time presently required by the MUTCD (*7*). Installation of the four-quadrant flashing light signals with overhead strobes at the Ebenezer Road crossing should have no effect on this driver performance measure since nothing was changed at the crossing itself; however, installation of the highway traffic signals at the Cedar Drive crossing should have an effect because of the traffic signal's additional credibility.

As shown in Table 4, the average number of vehicles crossing within 20 seconds of a train's arrival at the Ebenezer Road crossing was not noticeably different for either the before or after study. Additionally, the Mann-Whitney test (*15*) indicated that there were no statistically significant differences at the 95 percent confidence level. Thus, as expected, installation of the four-quadrant flashing light signals with overhead strobes had no effect on the CL20 rate (i.e., aggressive behavior) at the Ebenezer Road Crossing. Surprisingly, over 55 percent of the observations in each study resulted in at least one CL20 and more than 30 percent of the observations in each study resulted in multiple CL20s.

Most of the observed warning times at the Ebenezer Road crossing were in the 30- to 50-second range. This left very few observations in the other warning time ranges and precluded any development of relationships between warning times and the CL20 rates. An additional complication in the development of relationships was the fact that the time available for CL20s to occur did not increase with an increase in warning time. It is interesting to note, however, that in the 30- to 40-second warning time range, there were approximately 1.3 CL20s per train arrival in the before study and 1.4 CL20s per train arrival in the after study.

As shown in Table 4, the average number of vehicles crossing within 20 seconds of the train's arrival at the Cedar Drive crossing was noticeably lower in the after study where the highway traffic signals were installed. The Mann-Whitney test (*15*) indicated that these reductions were statistically significant for both the day and total data sets at the 99 percent confidence level. Thus, installation of the highway traffic signals significantly reduced the number of CL20s at the crossing. There was no difference in the average CL20 rates for either of the nighttime data sets. The most effective warning device as far as preventing CL20s was the predictors in combination with the highway traffic signal—82 percent of the observations in the data set resulting in no CL20s.

The average CL20 rate was approximately 0.78 after predictors were installed, and 0.24 after both predictors and traffic signals were installed; however, there did not appear to be a relationship between warning time and CL20 rates. It should be noted that in the 30- to 40-second warning time range for the flashing light signal with predictor study, there were approximately 0.83 CL20s per train arrival, and whenever traffic signals were installed, the CL20 rate in this warning time range was approximately 0.33. This seems to indicate that highway traffic signals with predictors are more effective in reducing CL20s than are standard active warning devices currently found at railroad-highway grade crossings.

Crossings Less Than 10 Seconds (CL10)

Vehicles crossing within 10 seconds of a train's arrival at the crossing were defined as an indication of risky behavior, i.e.,

TABLE 4 CL20S AT EBENEZER ROAD AND CEDAR DRIVE CROSSINGS[1]

EBENEZER ROAD CROSSING	Flashing Light Signals			Flashing Light Signals with Strobes		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	101	22	123	58	11	69
Mean (vehicles)	1.30	0.41	1.14	1.44	0.45	1.29
Standard Deviation	1.50	0.67	1.43	1.39	0.69	1.34
Percent >0 Violations	70.3	31.8	55.3	70.6	36.4	65.2
Percent >1 Violation	36.6	4.6	30.9	41.4	9.1	36.2
Range (vehicles)	0-7	0-2	0-7	0-5	0-2	0-5
CEDAR DRIVE CROSSING	**Flashing Light Signals with Predictors**			**Highway Traffic Signals with Predictors**		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	21	24	45	59	19	78
Mean (vehicles)	0.95	0.63	0.78	0.24	0.26	0.24
Standard Deviation	0.86	1.10	1.00	0.63	0.45	0.59
Percent >0 Violations	66.7	41.7	53.3	15.3	26.3	18.0
Percent >1 Violation	33.8	8.3	15.5	6.8	0.0	5.2
Range (vehicles)	0-3	0-5	0-5	0-3	0-1	0-3

[1] Vehicles crossing within 20 seconds of the train's arrival at the crossing.

[2] Includes only those observations in which vehicles were present before the train's arrival.

there is little room for either driver or vehicular error. Although also not illegal, such behavior intuitively increases the likelihood of an accident occurring. It was expected that installation of the four-quadrant flashing light signals with overhead strobes at the Ebenezer Road crossing would have no effect on this driver performance measure since nothing was changed at the crossing itself; however, installation of the highway traffic signal at the Cedar Drive crossing might have an effect because of the traffic signal's additional credibility.

As shown in Table 5, 14 CL10s were observed at the Ebenezer Road crossing in the before study—13 during the day and 1 during the night, i.e., 14 motorists crossed the tracks within 10 seconds of the train's arrival. In fact, in at least one case, two motorists crossed the tracks within 10 seconds of a train's arrival. A total of 12 CL10s were observed in the after study—11 during the day and 1 during the night. A Pearson's chi-square statistic calculated from a two-by-two contingency table indicated that the observed CL10s in the before (i.e., two-quadrant flashing light signals) and after (i.e., four-quadrant flashing light signals with overhead strobes) data sets were not significantly different at the 95 percent confidence level. It is interesting to note, however, that 24 of the 26 observed CL10s occurred during the day. The obvious conclusion is that CL10s were more likely to occur during this period; however, the reasons why are not so clear. For example, it is not clear whether fewer drivers take risk at night because they have poorer visibility of approaching trains, or whether fewer drivers take risk at night because there are fewer of them in a position to take the risk, i.e., less exposure.

Unfortunately, there was such a small number of observed CL10s in the two studies at the Cedar Drive crossing (four in both the before and after studies) that meaningful statistical comparison could not be made between them. Therefore, the premise that the additional credibility of the highway traffic signal might further reduce the number of CL10s could not be tested.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the field evaluation, there were no significant differences in driver response or safety measures between the four-quadrant flashing signals with overhead strobe lights and the standard flashing light signals. This innovative traffic control system was found to be operationally feasible, and it may have some limited application. Specific conclusions

TABLE 5 CL10S AT EBENEZER ROAD AND CEDAR DRIVE CROSSINGS[1]

EBENEZER ROAD CROSSING	Flashing Light Signals			Flashing Light Signals with strobes		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	101	22	123	58	11	69
Mean (vehicles)	0.13	0.05	0.11	0.19	0.09	0.17
Standard Deviation	0.37	0.21	1.34	0.48	0.30	0.45
Percent >0 Conflicts	11.9	4.6	10.6	15.5	9.1	14.5
Percent >1 Conflict	1.0	0.0	0.8	3.5	0.0	2.9
Range (vehicles)	0-2	0-1	0-2	0-2	0-1	0-2
CEDAR DRIVE CROSSING	**Flashing Light Signals with Predictors**			**Highway Traffic Signals with Predictors**		
	Day	Night	Total	Day	Night	Total
Sample Size[2]	21	24	45	59	19	78
Mean (vehicles)	0.19	0.08	0.13	0.05	0.05	0.05
Standard Deviation	0.51	0.41	0.46	0.22	0.22	0.22
Percent >0 Conflicts	14.3	4.2	8.9	5.1	5.3	5.1
Percent >1 Conflict	4.8	4.2	4.4	0.0	0.0	0.0
Range (vehicles)	0-2	0-2	0-2	0-1	0-1	0-1

[1] Vehicles crossing within 10 seconds of the train's arrival at the crossing.

[2] Includes only those observations in which vehicles were present prior to the train's arrival.

and recommendations regarding four-quadrant flashing light signals with strobes are summarized below:

1. Four-quadrant flashing light signals with strobes offered no apparent driver response or safety advantages over standard two-quadrant flashing signals at the test crossing.
2. Four-quadrant flashing light signals with strobes did not significantly affect violations, clearance times, approach speed profiles, maximum deceleration levels or perception-brake reaction times at the test crossing.
3. There were no accidents, confusion, or motorist diversions while the four-quadrant flashing light signals with strobes were installed.
4. The overhead strobes performed adequately throughout the 12-month test period. Their alignment was not critical to visibility, and their brightness did not "wash out" other traffic control devices. They produced no known hypnotic effects on drivers.
5. Four-quadrant flashing light signals with strobes are generally not recommended as an enhancement of standard two-quadrant flashing light signals.
6. Four-quadrant flashing light signals with strobes may be considered for use at special problem crossings where visibility to the crossing is restricted; however, cantilever signals would probably be a better or equally effective alternative.

Based on the results of the field evaluation, the highway traffic signal proved to be both feasible and effective as a grade crossing traffic control device. Driver response to the highway traffic signal was excellent, with the highway traffic signal outperforming standard flashing light signals on several key safety and driver response measures. Specific conclusions and recommendations for the highway traffic signal results are summarized below:

1. Compared to flashing light signals with predictors, the highway traffic signal reduced the number of crossings per signal activation from 3.35 to 0.73.
2. Compared with flashing light signals with predictors, the highway traffic signal reduced the risky behavior per train arrival from 0.13 to 0.05. (Risky behavior refers to the number of vehicles crossing while the flashing light signals are activated and within 10 seconds of the train.)
3. The highway traffic signal did not significantly change drivers' approach speed profile, perception-brake reaction time, or maximum deceleration level at the test crossing.

4. During the entire time that the highway traffic signal was installed at the test crossing, there were no accidents, confusion, diversions, or unnecessary delays to motorists.

5. The highway traffic signal appeared to be well understood and respected at the test crossing by the overwhelming majority of motorists.

6. From limited observation and engineering experience, there was no evidence that the use of traffic signals at grade crossings would in any way diminish their effectiveness at highway intersections; however, there were no data collected to prove or disprove this fact.

7. Credibility problems would be expected if traffic signals were used at crossings where detector malfunctions were frequent or where train warning times were long and highly variable.

8. Highway traffic signals should be tested at additional crossing sites under varying conditions and in various parts of the country. Research is needed to evaluate the long-term performance of highway traffic signals.

9. Research should be undertaken to determine if the inherent fail-safe mode of highway signals is sufficient for grade crossing applications and, if it is, if back-up power requirements can be eliminated.

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