Evaluation of Constant Warning Times Using Train Predictors at a Grade Crossing with Flashing Light Signals

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This paper documents the results of field studies conducted to evaluate the effects of train predictors and constant warning time (CWT) on crossing safety and driver response measures. The studies were conducted at a single-track urban crossing controlled by flashing light signals. The test crossing is frequented by variable-speed trains. Before train predictors were installed, highly variable and long warning times were observed. The studies involved comparing data gathered before and after installation of train predictors at the test crossing. The data included warning times, vehicle clearance times (relative to a train's arrival), vehicles crossing, and vehicle speed and deceleration profiles. These data were collected using video camera-recorder systems that were activated automatically whenever a train approached the test crossing. Data were collected for a 2-month period before the train predictors were installed, and for a 2-month period after installation. A total of 139 train movements were observed—89 train movements during the before study and 50 movements during the after study. On the basis of the results of the field studies, the predictor hardware proved to be operationally reliable. Installation of the predictors resulted in more CWTs, a lower mean warning time, and fewer excessively long warning times at the study crossing. Installation of predictors (and the CWT they provide) also improved the overall safety of the study crossing and enhanced driver respect for the flashing light signals. Vehicle clearance times were significantly increased, and risky driver behavior was reduced. Speeds, driver reaction times, and deceleration levels were not influenced adversely.

Since 1973, over $2.3 billion in federal and state funds have been spent to improve railroad-highway grade crossing safety (*1*). Most of these funds have been used to install or upgrade active warning devices, i.e., flashing light signals with or without automatic gates. By 1986, 17 percent of the nation's 205,339 public crossings were equipped with flashing light signals and over 9 percent had flashing light signals with automatic gates (*1*). As illustrated by the reduction in grade crossing accident casualties, the increased use of these active devices has undoubtedly enhanced grade crossing safety. In 1985, 537 motorists and pedestrians were killed in train accidents, compared to a high of 1,780 fatalities in 1966 (*1*).

Notwithstanding the obvious safety benefits of flashing light signals with or without automatic gates, there is increasing concern about the length of the warning time period for these active devices. (Warning time refers to the time between device activation and arrival of a train at the crossing.) Specifically, research (and good common sense) suggests that variable and excessively long warning times may have negative impacts on crossing safety and traffic operations. For example, Hopkins (*2*) reports that frequent users of a crossing become aware that signals flash too long in advance of a train's arrival and proceed through the crossing when the warning device is activated. In a study of crossing accidents (*3*), the predominate contributing factor was excessive warning time. Long warning times resulted in drivers' disregarding the hazard and proceeding across the track in front of an approaching train. A driver behavior study (*4*) also found problems with excessive warning times. It was concluded that by eliminating unnecessarily long warning times and false activations, the rate of disobedience towards crossing signals would be reduced, thus reducing train-involved accidents at active crossings.

Guidelines for warning times at active crossings are presented in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*5*). The MUTCD states only that reasonably constant notice must be provided; it does not specify any maximum warning time for active crossings. At crossings with flashing light signals, the MUTCD does specify a minimum warning time of 20 sec. As a result of these somewhat vague guidelines, warning times vary greatly at active crossings. Sanders (*6*) observed warning times ranging from 5 to over 300 sec at a group of crossings. Heathington et al. (*7*) reported a range in warning times at three study crossings of 14–161 sec.

Warning times are usually controlled by the type of train detection system at a crossing. With standard train detection circuitry, the warning time depends on train speed and the fixed location of the track circuitry relative to the crossing. Therefore, if a crossing with standard detection circuitry has variable-speed trains or switching operations, warning times can be highly variable and excessively long. Likewise, motion sensors, a second type of train detector, cannot provide constant warning time (CWT) if variable-speed trains are present; however, a motion sensor can eliminate the excessive warning times resulting from many switching operations.

The third type of train detector, called a train predictor, can provide a fixed CWT, even at crossings with variable-speed trains or switching operations. Train predictors have been installed at over 6,300 active crossings in the United States, and it is estimated that an additional 13,100 crossings could benefit from this more sophisticated (but more expensive) type of detector (*8*).

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The concept of providing reasonable and consistent warning times at active crossings is well accepted by most groups involved with grade crossing safety. However, the implementation of this concept has been somewhat slow and haphazard, possibly due to the lack of substantive data on the effectiveness and benefits of train predictors and CWT. That is, there is a need to show that consistent and reasonable warning times do significantly enhance safety and traffic operations at active crossings, and that the added expense of train predictors at crossings with variable-speed trains is justified.

In order to more fully evaluate the impacts of train predictors and CWT on crossing safety and driver behavior, a series of field studies was conducted at a single-track, urban crossing in Knoxville, Tenn. (*7*). This crossing, which is controlled by flashing light signals, is frequented by variable-speed trains and switching operations. The studies involved comparing safety and performance data gathered before and after installation of train predictors (and CWT) at the crossing. The following sections describe the study approach and research findings.

FIELD EVALUATION PLAN

Study Approach

A before-and-after study approach was used to evaluate the impacts of train predictors and CWT on driver behavior and safety. That is, performance data were collected at an existing active crossing with conventional detectors, and then again at the same crossing after predictors had been installed. This approach allowed a direct comparison between conventional detectors (which can result in variable and sometimes very long warning times) and train predictors (which provide a reasonable CWT).

The before set of crossing studies (before predictor installation) was conducted in May and June of 1985; predictors were installed in November 1985; the after set of studies was conducted in February and March 1986. The purpose of the 2-month delay following predictor installation was to ensure that drivers had some time to become familiar with the change in warning time conditions at the crossing.

Study Site

The site of the studies was an active crossing (Inventory No. 730643K) in Knoxville, Tenn., located in the northern part of the city on Cedar Drive. The existing active warning devices at the crossing were standard railroad flashing light signals with 8⅜-in. roundels and a bell. The crossing was ranked as the 31st most dangerous crossing in the state in 1985. As shown in Figure 1, Cedar Drive in the vicinity of the crossing is two lanes wide and straight on both approaches to the crossing. The vertical alignment on the westbound approach limits the motorists' line of sight to the crossing. In addition, the thick vegetation in the vicinity of the crossing restricts the drivers' view of approaching trains. The average daily traffic at this site is approximately 14,000 veh/day, and the average through train volume is approximately 10 trains per day. The speed limit on Cedar Drive is 40 mph, and train speeds at the crossing range from 5 to 40 mph. As shown by its hazard ranking and the three car-train accidents that occurred at this site in the past 5 years, this is a hazardous location.

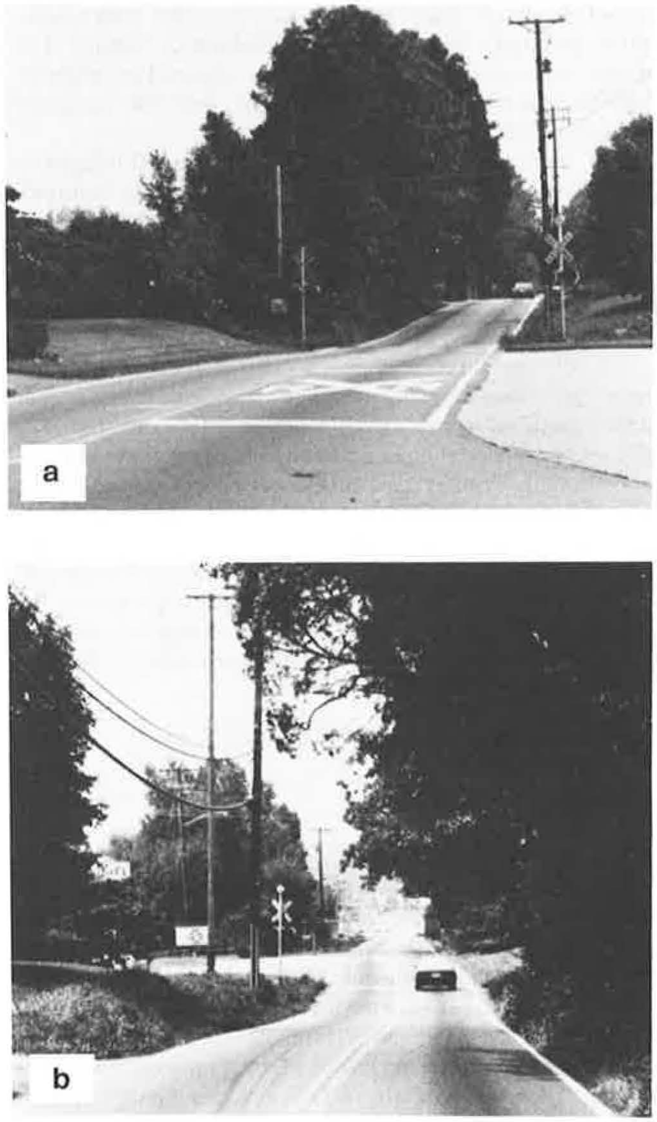


FIGURE 1 Cedar Drive crossing: a, looking east; b, looking west.

Data Collection and Reduction

The key to determining motorist response to the predictors and CWT was to obtain accurate and pertinent data on driver behavior at the crossing and in the decision zone, i.e., the area in which drivers must decide to either stop or proceed through the crossing. Data were automatically recorded on portable video recorders whenever a train was approaching the crossing and reduced by an image processing and pattern recognition process.

Three complete video camera-recorder systems were used for data collection. The video recorders were portable, battery powered, and used standard ½-in. T120 VHS cassettes. The video cameras used with the recorders were black-and-white, closed-circuit television cameras that provided high-quality videotapes under both day and night lighting conditions. The cameras operated on 12-volt DC current and used the recorder batteries as a power source; therefore, they were only energized when the recorders were activated.

Each camera was mounted on a 20-ft pole and located as far from the centerline of the roadway as possible (approximately 60 ft). The first camera-recorder unit was located approximately 300 ft from the crossing, the second approximately 500 ft from the crossing, and the third approximately 700 ft from the crossing. The cameras were aimed towards the crossing, and had overlapping fields of view.

It was important to activate the video camera-recorder systems just before activation of the flashing light signals so that driver response to the signals could be fully evaluated. For this reason, a special pole-mounted train detector system separate from the regular track circuitry was developed and used. The detector system projected an infrared light beam across the track. When a train broke the beam, the detector transmitted an audio (FM radio) signal that activated the camera-recorders. A detector was placed on each approach to the crossing, such that the camera-recorder activation signal was transmitted at least 10 sec before a train's activating the flashing light signals at the crossing.

Measures of Effectiveness

Evaluation of the train predictors and CWT depended on the selection of suitable measures of effectiveness (MOEs). To avoid influencing drivers' behavior, MOEs were selected that could be obtained with a minimum of interference and detection by drivers. One obvious MOE used was warning time (the time elapsed between device activation and train arrival). In addition, several driver performance measures were used to evaluate the safety impacts of warning time and train predictors. These safety-related MOEs included number of vehicles crossing, clearance time, perception-brake reaction time (PBRT), and speed profile and maximum deceleration level, as described in the following sections.

1. *Number of Vehicles Crossing.* This measure was defined as the total number of vehicles crossing the tracks between activation of the warning device and the train's arrival at the crossing. The total number of vehicles crossing was manually counted from the videotapes, and the numbers of vehicles crossing within 10 and 20 sec of the train's arrival at the crossing were specially noted. Vehicles that crossed within 10 sec of an oncoming train (called "CL10s") were considered an indication of risky behavior, because this represents a level of driver performance in which there is little, if any, room for error. This representation was based on 2.5 sec of PBRT, a 20-ft long vehicle starting from a stop 20 ft away from the crossing, accelerating at a normal rate of 4.8 ft/sec^2, and clearing a point 20 ft on the far side of the crossing 2.5 sec before the train's arrival. Vehicles that crossed within 20 sec of an oncoming train (called "CL20s") were considered indicative of aggressive behavior, representing a level of driver performance in which there is some, but not much, room for driver, vehicle, and warning system error. The MUTCD appears to address this point by requiring a minimum warning time of 20 sec (*5*).

2. *Clearance Time.* Clearance time was defined as the difference in time between the time of the last vehicle's crossing and that of the train's arrival.

3. *Perception-Brake Reaction Time.* PBRT was defined as the difference in time between activation of the warning device and activation of the vehicle's brake lights. Only those vehicles whose brake lights were activated were included in the data set. As the observations were not necessarily expected to be normally distributed, nonparametric techniques in the Statistical Analysis Systems program were used to ascertain whether or not observed differences were statistically significant (*9*).

4. *Speed Profile and Maximum Deceleration Rate.* Speed profile data gathered before and after installation of the predictors were evaluated and compared. In addition, a maximum deceleration level was computed from each individual speed profile. These values were then tabulated and plotted as a cumulative frequency distribution. The number of drivers accepting an undesirable level of deceleration (>8 ft/sec^2) was also used for evaluation purposes. In each of the previously described comparisons, the Kolmogorov-Smirnov goodness-of-fit test was used to determine whether any observed differences in distributions were statistically significant (*10*).

The general hypotheses tested in the field studies were that use of the predictors, when compared with conventional train detectors, would result in (1) more consistent warning times and fewer excessive warning times; (2) fewer vehicles crossing in front of the train; (3) fewer undesirable and uncomfortable decelerations; and (4) quicker driver PBRTs. Thus, the overall null hypothesis was that there were no differences in driver performance measures resulting from the installation of train predictors and CWT at the test crossing.

STUDY RESULTS

The results are reported as two studies—a before study (flashing light signals without predictors) and an after study (flashing light signals with predictors). Combining both of these studies, 139 train movements were observed. There were 89 train movements observed in the before study and 50 train movements observed in the after study. For each train movement, the environmental and lighting conditions, train's direction of travel and warning time, number of vehicles crossing, and approaching vehicle's clearance time, speed profile, and PBRT were recorded and subsequently analyzed.

Warning Time

Warning time was defined as the time duration between activation of the flashing light signals and a train's arrival at the crossing. It is the same as the maximum amount of time a motorist would have to wait between activation of the warning devices and the train's arrival at the crossing. It was expected that the installation of the predictors at the Cedar Drive crossing would result in shorter and more consistent warning times.

To verify these premises, the total data set from both studies was subdivided into day and night to ensure that similar train and traffic volume conditions were compared. These two subsets, together with the total data set, were then analyzed. As presented in Table 1, the mean warning time in the before study was significantly longer than in the after study. The mean warning time in the before study was 75.2 sec compared with 41.7 sec in the after study. The Kruskal-Wallis test for two or more independent, continuously distributed populations (*10*) indicated that these differences were statistically significant at the 99 percent confidence level. This result means that, as expected, installation of the predictors decreased the average warning time at the crossing. This finding is shown clearly in the illustration of the frequency and cumulative frequency distributions of the warning times from the two data sets shown in Figure 2. In addition to the before-and-after study results, the Mann-Whitney U test indicated that there was no statistically significant difference at the 95 percent level between the day and night data sets from the two studies.

It should also be noted from Table 1 that, even after predictors were installed, a few very long warning times were observed at the crossing. This was due to the fact that there was a siding track just a few hundred feet north of the Cedar Drive crossing, and predictors were not installed on the siding. As a result, slowly moving southbound trains coming off the siding produced the longer warning times, i.e., these trains activated the signals while still on the siding.

Vehicles Crossing

Average numbers of vehicles crossing in the interval between activation of the flashing light signals and a train's arrival at the crossing are presented in Table 2. As there was a statistically significant difference in the warning times observed during the before and after studies, it was hypothesized that there would be a significant difference in the numbers of such vehicles. The Kruskal-Wallis 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 predictors being installed. The predictors reduced the average number of vehicles crossing per train arrival from 10.86 to 3.35 when compared to flashing light signals without predictors. Thus, the predictors and reasonable CWT they provide reduced the number of vehicles that crossed in front of an oncoming train by more than a factor of three.

The effects of warning times on the number of vehicles crossing while the flashing light signals were activated are presented in Table 3. 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 crossed while the warning devices were activated. This relationship is shown in Figure 3.

TABLE 1 WARNING TIMES AT THE CEDAR DRIVE CROSSING

Summary Statistics	Flashing Light Signals without Predictors			Flashing Light Signals with Predictors		
	Day	Night	Total	Day	Night	Total
Sample Size	53	36	89	22	28	50
Mean (seconds)	73.7	77.6	75.2	40.5	42.7	41.7
Standard Deviation	20.6	13.4	17.9	15.5	19.9	18.0
Range (seconds)	47-141	56-119	47-141	27-89	28-121	27-121

Warning Times[a] (seconds)	Flashing Light Signals without Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage	Flashing Light Signals with Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage
>20	0	0.0	0.0	0	0.0	0.0
20-30	0	0.0	0.0	6	12.0	12.0
30-40	0	0.0	0.0	28	56.0	68.0
40-50	4	4.4	4.4	6	12.0	80.0
50-60	13	14.5	18.9	5	10.0	90.0
60-90	57	64.5	83.4	4	8.0	98.0
>90	15	16.6	100.0	1	2.0	100.0
Total	89			50		

[a]Time between activation of flashing lights and the train's arrival at the crossing.

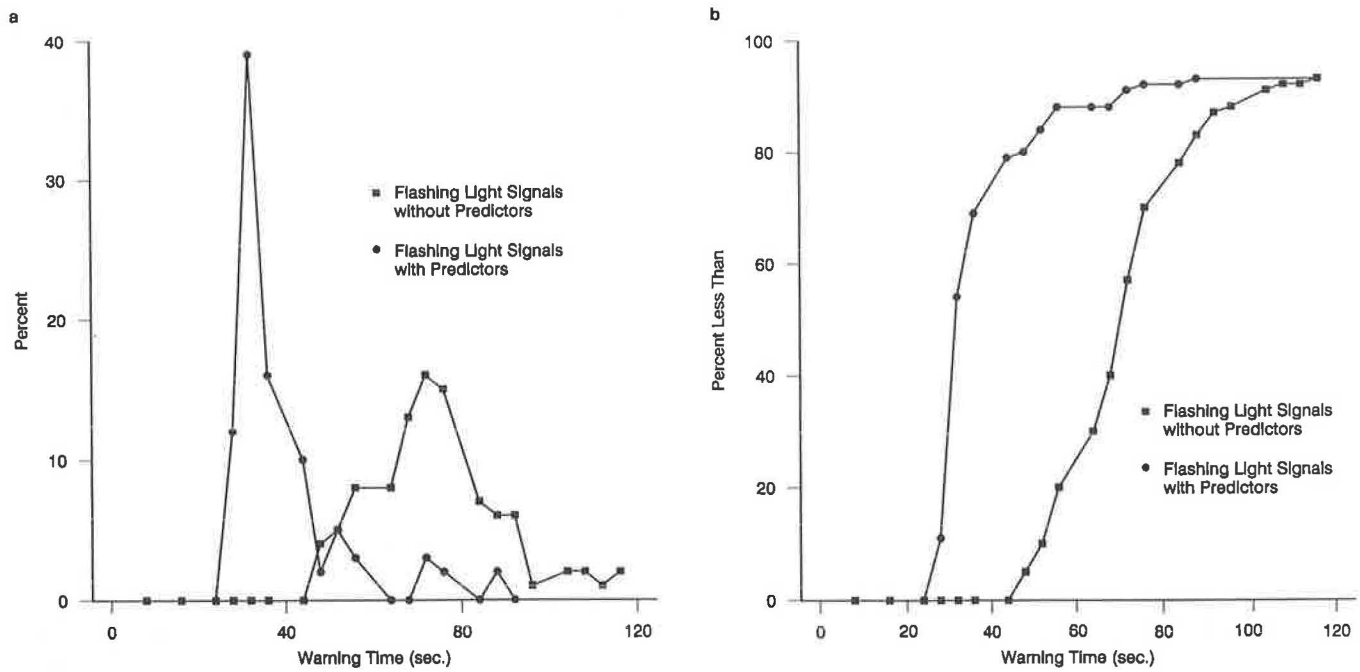


FIGURE 2 (a) Frequency and (b) cumulative frequency distribution of observed warning times at the Cedar Drive crossing.

TABLE 2 VEHICLES CROSSING AT THE CEDAR DRIVE CROSSING

Summary Statistics	Flashing Light Signals without Predictors: Day	Night	Total	Flashing Light Signals with Predictors: Day	Night	Total
Sample Size[a]	53	30	83	21	24	45
Mean (vehicles)	13.28	6.40	10.86	3.86	2.92	3.35
Standard Deviation	7.74	6.28	7.91	3.34	2.50	2.92
Percent >0 Crossing	100.0	97.6	98.8	90.5	83.3	86.7
Percent >1 Crossing	98.1	86.7	94.0	71.4	62.5	66.7
Range (vehicles)	1-40	0-24	0-40	0-12	0-9	0-12

Crossings[b] (vehicles)	Flashing Light Signals without Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage	Flashing Light Signals with Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage
0	1	1.2	1.2	6	13.3	13.3
1	4	4.8	6.0	9	20.0	33.3
2	5	6.0	12.0	6	13.3	46.6
3	8	9.7	21.7	6	13.3	59.9
4	2	2.4	24.1	7	15.7	75.6
>4	63	75.9	100.0	11	24.4	100.0
Total	83			45		

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

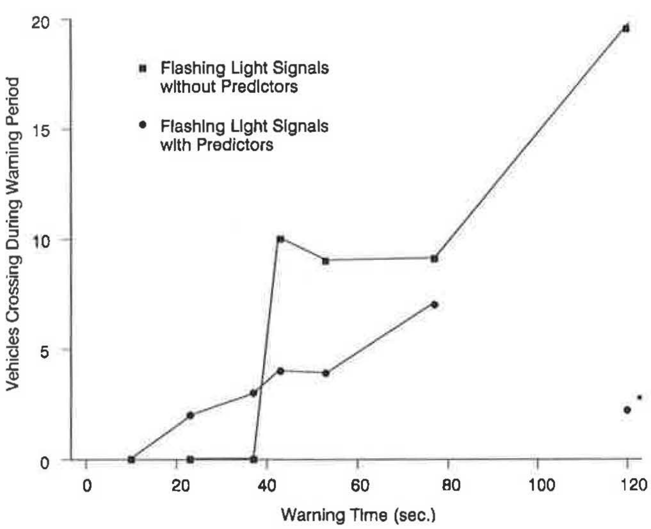
[b] Vehicles crossing after activation of the flashing light signals or the traffic signal changing to yellow and the train's arrival at the crossing.

TABLE 3 EFFECTS OF WARNING TIMES ON NUMBER OF VEHICLES CROSSING AT THE CEDAR DRIVE CROSSING

Study	Warning Time (Sec.)[a]		Observed Train Arrivals[b]	Average No. Crossing (per Arrival)
Flashing Light Signals without Predictors	<20		-	-
	20-30		-	-
	30-40		-	-
	40-50		4	10.00
	50-60		11	9.17
	60-90		53	9.24
	>90		15	19.00
		Total	83	
Flashing Light Signals with Predictors	<20		0	-
	20-30		5	1.60
	30-40		24	2.75
	40-50		6	4.33
	50-60		5	4.40
	60-90		4	6.75
	>90		1	2.00
		Total	45	

[a]Time between activation of flashing lights and train's arrival at the crossing.

[b]Includes only those observations in which vehicles were present.



*There were a few long warning times after predictors caused by slow-moving trains coming off the siding track near the crossing. This data point represents these few observations.

FIGURE 3 Average number of vehicles crossing as a function of warning time at the Cedar Drive crossing.

The general increase in vehicles crossing at higher working times was expected; however, what was not expected was the difference in vehicles crossing with and without predictors. For example, without predictors, warning times in the 40–50-sec range resulted in an average of 10.0 vehicles crossing per train arrival, whereas with predictors, the same warning times resulted in an average of 4.33 vehicles crossing per train arrival (Table 3). This difference is attributed to the shorter and more consistent warning times with predictors.

Crossings Within 20 sec of Train's Arrival

Vehicles (CL20s) crossing within 20 sec of a train's arrival at the crossing have previously been defined as indicative of aggressive behavior, i.e., there is some, but not much, room for driver and vehicular error. Although such behavior is not necessarily illegal, it is characteristic of those drivers who choose to cross within the 20-sec minimum warning time presently required by the MUTCD (*5*). As presented in Table 4, the average number of vehicles crossing within 20 sec of the train's arrival at the Cedar Drive crossing was noticeably less in the after study (in which the predictors were installed), being reduced from an average of 1.82 to 0.78. The Kruskal-Wallis test (*10*) indicated that the reductions were statistically significant for both the daytime and total data sets at the 99 percent confidence level. Thus, as expected, installation of the predictors significantly reduced the number of CL20s at the crossing. There was little difference in the average CL20 rates between any of the nighttime data sets.

A frequency distribution of the observed CL20s at the Cedar Drive crossing is also presented in Table 4. In the before study (flashing light signals without predictors), there were 30 observations with no CL20s, 11 observations with one CL20, and 42 observations with two or more violations. The number of observations in each category was smaller and the percentages were different in the after study (with predictors present). A Pearson's chi-square statistic calculated from a 2-by-3 contingency table (two studies by three CL20 rate categories) substantiated the fact that the differences (fewer multiple CL20s) were significant at the 95 percent confidence level.

The effects of warning times on the CL20 rates at the Cedar Drive crossing are presented in Table 5. From the table, the CL20 rates observed during the before study (without predictors) appear to be higher than those corresponding rates observed after predictor installation. However, the differences cannot be statistically confirmed because of the small numbers of warning times above 40 sec during the after study. That is, there are simply too few corresponding observations to compare between the two studies.

Crossings Within 10 sec of Train's Arrival

Vehicles (CL10s) crossing within 10 sec of a train's arrival at the crossing have previously been defined as an indication of risky behavior; there is little room for either driver or vehicular error. Although not necessarily illegal at a flashing light signal, such behavior intuitively increases the likelihood of an accident's occurring. It was anticipated that installation of the predictors might reduce this type of behavior by providing shorter and more consistent warning times and increased credibility of the warning devices.

As presented in Table 6, 29 CL10s (15 single CL10s and 7 double CL10s) were observed at the Cedar Drive crossing in the before study, i.e., 29 motorists crossed the tracks within 10 sec of the train's arrival. Twenty-five CL10s (13 single CL10s and 6 double CL10s) occurred during the day and four CL10s (2 single CL10s and 1 double CL10) occurred at night. In seven different cases, at least two motorists crossed the tracks within 10 sec of the train's arrival. On the average, there were 0.39 CL10s per train arrival in the before study.

In the after study, 6 CL10s (2 single CL10s and 2 double CL10s) were observed. Four of these CL10s (2 single CL10s and 1 double CL10) occurred in the daytime, and two CL10s (1 double CL10) occurred at night. On the average, there were 0.13 CL10s per train arrival in the after study. A Pearson's chi-square statistic calculated from a 2 by 3 contingency table (two studies by three CL10 categories) indicated that the observed CL10s in the before study (without predictors)

TABLE 4 CL20s AT THE CEDAR DRIVE CROSSING

Summary Statistics	Flashing Light Signals without Predictors: Day	Night	Total	Flashing Light Signals with Predictors: Day	Night	Total
Sample Size[a]	53	30	83	21	24	45
Mean (vehicles)	2.34	0.83	1.82	0.95	0.63	0.78
Standard Deviation	1.74	1.60	1.84	0.86	1.10	1.00
Percent >0 Violations	79.2	34.5	63.9	66.7	41.7	53.3
Percent >1 Violations	67.9	17.3	50.6	33.8	8.3	15.5
Range (vehicles)	0-6	0-6	0-6	0-3	0-5	0-5

CL20s[b] (vehicles)	Flashing Light Signals without Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage	Flashing Light Signals with Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage
0	30	36.1	36.1	21	46.7	46.7
1	11	13.3	49.4	17	37.8	84.5
2	13	15.7	65.1	5	11.1	95.6
3	12	14.5	79.6	1	2.2	97.8
>3	17	20.4	100.0	1	2.2	100.0
Total	83			45		

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

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

TABLE 5 EFFECTS OF WARNING TIMES ON CL20 RATES AT THE CEDAR DRIVE CROSSING

Study	Warning Time (Sec.)[a]	Observed Train Arrivals[b]	Average CL20s (per Arrival)
Flashing Light Signals without Predictors	<20	0	-
	20-30	-	-
	30-40	-	-
	40-50	4	3.75
	50-60	11	2.45
	60-90	53	1.63
	>90	15	1.53
	Total	83	
Flashing Light Signals with Predictors	<20	0	-
	20-30	5	0.80
	30-40	24	0.83
	40-50	6	1.00
	50-60	5	0.60
	60-90	4	0.50
	>90	1	0.00
	Total	45	

[a]Time between activation of flashing lights and train's arrival at the crossing.

[b]Includes only those observations in which vehicles were present.

TABLE 6 CL10s AT THE CEDAR DRIVE CROSSING

Summary Statistics	Flashing Light Signals without Predictors			Flashing Light Signals with Predictors		
	Day	Night	Total	Day	Night	Total
Sample Size[a]	53	30	83	21	24	45
Mean (vehicles)	0.53	0.13	0.39	0.19	0.08	0.13
Standard Deviation	0.77	0.43	0.69	0.51	0.41	0.46
Percent with Conflicts	35.9	10.0	26.5	14.3	4.2	8.9
Range (vehicles)	0-3	0-2	0-3	0-2	0-2	0-2
0 CL10s[b]/Arrival	34	27	61	18	23	41
1 CL10s[b]/Arrival	13	2	15	2	0	2
2 CL10s[b]/Arrival	6	1	7	1	1	2

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

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

and the after study (with predictors) were significantly different at the 95 percent confidence level. This results means that installation of the predictors appears to have been successful in reducing the amount of risky behavior that took place at the crossing.

Clearance Time

Because predictors significantly shortened the average warning time and reduced vehicles crossing, it was hypothesized that they might give enough credibility to the warning system to increase average clearance times at the crossing. If in fact this was to occur, the overall temporal separation between the cars and trains would be a definite safety benefit.

Clearance times were only recorded for those train arrivals in which a vehicle arrived at the crossing between the activation of the flashing light signals and the train's arrival at the crossing; that is, when there was an opportunity for a vehicle to cross in front of the train. Thus, the number of clearance times observed had to be equal to or less than the number of train arrivals. As presented in Table 7, there were 83 clearance times observed in the before study (without predictors) and 39 clearance times observed in the after study (with predictors). As with the warning time data set, the total data from each study was subdivided into day and night observations to ensure that similar train and traffic volume conditions were compared. These two subsets, together with the total data set, were then analyzed.

The mean clearance times from the total data sets were approximately the same for both studies, ranging from 20.1 to 21.4 sec. The Kruskal-Wallis test for two or more independent, continuously distributed populations confirmed that these differences were not statistically significant at the 95 percent confidence level (*10*). Therefore, installation of the predictors had no measurable effect on the mean clearance times observed at the crossing.

Interestingly, the Mann-Whitney test indicated a statistically significant difference at the 99 percent confidence level for clearance times between the day and night data sets from the two studies. This means that the clearance times observed for day and night operations in both the before and after studies were different. The frequency and cumulative frequency distributions of clearance times from both data sets are shown in Figure 4.

Although the predictors did not affect the mean clearance time at the crossing, they did reduce the occurrence of very short clearance times. This trend is presented in the bottom of Table 7. From the table, 27.7 percent of the clearance times in the first before study would be classified as risky (less than 10 sec), whereas only 10.3 percent of the clearance times observed in the after study would be classified as risky. This is another strong indication of the positive impacts of predictors and CWT on crossing safety.

Speed Profiles

Speed data were analyzed to determine whether the predictors had an effect on approach speeds. In order to compare characteristics of similar vehicles, approach speed profiles for the first vehicle to stop at the crossing in the before study as well

TABLE 7 CLEARANCE TIMES AT THE CEDAR DRIVE CROSSING

Summary Statistics	Flashing Light Signals without Predictors: Day	Night	Total	Flashing Light Signals with Predictors: Day	Night	Total
Sample Size[a]	53	30	83	19	20	39
Mean (seconds)	15.7	28.2	20.1	16.2	26.3	21.4
Standard Deviation	13.2	15.0	15.0	5.8	18.9	14.9
Percent >20 seconds	79.3	31.0	62.6	73.7	50.0	61.5
Percent >10 seconds	37.7	10.3	27.7	15.8	5.0	10.3

Clearance Times[b] (seconds)	Flashing Light Signals without Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage	Flashing Light Signals with Predictors: Observed Train Arrivals	Percent of Total Arrivals	Cumulative Percentage
>10	23	27.7	27.7	4	10.3	10.3
10-20	29	34.9	62.6	20	51.3	61.5
20-30	15	18.1	80.7	10	25.6	87.2
>30	16	19.3	100.0	5	12.8	100.0
Total	83			39		

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

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

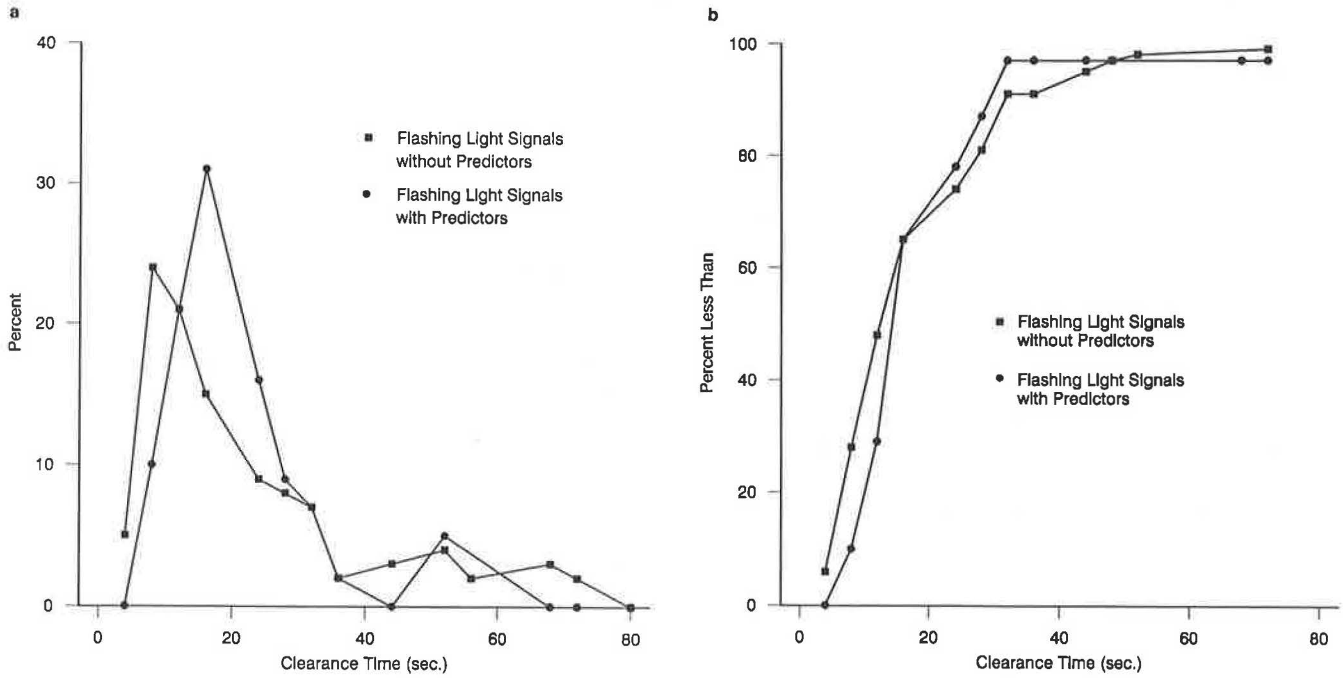


FIGURE 4 (a) Frequency and (b) cumulative frequency distribution of observed clearance times at the Cedar Drive crossing.

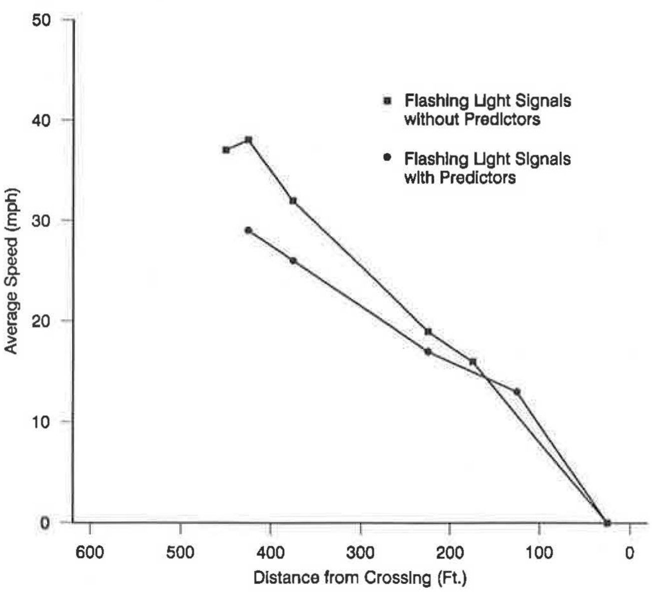


FIGURE 5 Average approach speed profiles for vehicles in advance of the Cedar Drive crossing.

as the after study were plotted as shown in Figure 5. Each data point represents average speeds over 50-ft sections of roadway in advance of the stop bar at the crossing and is plotted at the midpoint of the section. Data in the range of 50–200 ft from the stop bar were obtained from Camera 1 and in the range of 250–450 ft from the stop bar from Camera 2. Insufficient data were available from Camera 3 to plot approach speeds further than 500 ft from the crossing.

Several observations can be made concerning the average approach speed profiles in the before and after data sets. First, the average speeds in the before study were about 5 mph faster than they were in the after study. This speed difference is statistically significant at the 95th percentile and suggests that predictors and the CWT they provide may influence drivers' approach speeds. That is, motorists' increased confidence in the traffic control system may result in their early acceptance of the fact that they will have to stop, and therefore they slow down sooner (in excess of 450 ft from the crossing). It is also important to note that in both studies, the stopping vehicles did so in a safe, gradual, and consistent manner. In addition, the resultant speed profiles appeared to pose no safety problems for approaching motorists.

Perception-Brake Reaction Time and Deceleration

It was expected that the additional credibility resulting from the predictors and CWT may cause motorists to brake sooner and, as a result, slow down more gradually. However, it was also expected that if these differences did exist, they would be small and very difficult to measure. To compound this problem, braking for a flashing light signal is an unexpected event but does not represent a pressure situation to a driver unless a train is also visible. Drivers know that there is at least some length of time before a train's arrival at the crossing, thus driver response to activation of a flashing light signal should be relatively long and probably highly variable.

Average PBRTs in response to the activation of the flashing light signals were 26.6 sec in the before study and 17.1 sec in the after study. For both studies, the standard deviation was almost as large or larger than the mean. The Kruskal-Wallis test indicated that the differences were not statistically significant at the 95 percent confidence level. In other words, the variability in the brake time data precluded being able to find any significant differences that might exist. These long reaction times confirm the premise that braking in response to a flashing light signal at a railroad-highway grade crossing did not represent a pressure situation (short reaction times) and, because of this, was highly variable (large standard deviations). 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 slower moving vehicle ahead of it, the roughness of the crossing itself, or something else.

Cost of Train Predictors

The research was not intended to evaluate the cost-effectiveness of train predictors. However, because predictors (and the CWT they provide) were found to be extremely beneficial, a brief discussion of predictor costs is appropriate. First of all, the total cost of the predictors at the single-track Cedar Drive crossing, including hardware and installation cost, was $13,960.97. This cost estimate was provided by the Tennessee Department of Transportation.

From a more general perspective, a basic predictor unit with the redundancy feature costs between $11,500 and $14,000, depending on the supplier and purchase quantity; this cost estimate is based upon input from two railroads (*7*). The cost of a train predictor unit without redundant or backup capability is about 30 percent less. This cost does not include installation costs, battery costs, wiring and relay costs, etc. It should be noted that a single predictor unit normally can handle both approaches of a single track crossing. Multiple-track crossings or crossings with insulated joints nearby will require multiple predictors or sets of unidirectional predictors.

One of the railroads also provided general cost comparisons for installing train predictors versus motion sensors in conjunction with flashing light signals with and without gates. Based on the railroad's estimates, it would cost approximately $42,840 to install flashing light signals with train predictors, whereas it would cost approximately $34,240 to install the same flashing light signals with motion sensors. Thus, the use of predictors versus motion sensors would result in an increased total installation cost of approximately $8,600. For the case of gated crossings, the railroad estimates that it would cost about $61,930 to install standard two-quadrant gates and flashing lights with train predictors, whereas it would cost $50,930 to install gates and signals with motion sensors. In this case, the use of predictors would result in an increased total installation cost of approximately $11,000. These cost estimates are for a typical single-track crossing in Tennessee, and they assume a maximum train speed of 60 mph.

CONCLUSIONS AND RECOMMENDATIONS

The effects of train predictors and CWT on crossing safety and driver response measures were evaluated at a typical grade crossing with flashing light signals. A before and after study approach was used and the results of the studies are as follows:

1. During the 2-month evaluation period, the train predictors performed without a failure or incident.
2. At the test crossing, the installation of train predictors reduced the average length of train warning time from 75.2 to 41.7 sec.
3. Train predictors and CWT they provide reduced the average number of vehicles crossing the tracks while the flashing light signals were activated from 1,086 crossings per 100 train arrivals to 335.
4. The predictors reduced the number of CL20s from 182 to 78 per 100 train arrivals.
5. The predictors reduced the number of CL10s from 39 to 13 per 100 train arrivals.
6. Predictors did not have any adverse effects on speed profiles, brake reaction times, or deceleration at the test crossing.
7. There have been no train-car accidents at the test crossing since the predictors were installed.
8. Based on railroad industry cost estimates, a basic train predictor unit costs between $11,500 and $14,000. It would cost approximately $8,600 to $11,000 more to install predictors at an active crossing, compared to motion sensors.

Based on the study results, the length of the warning time period at active grade crossings is critical to crossing safety and traffic operations. Therefore, it is recommended that train predictors be installed at active crossings that have highly variable and long train warning times. At these crossings, predictors and the CWT they provide will significantly improve crossing safety and enhance motorist respect for the active traffic control systems. Motorist delays at the crossings should also be reduced. As noted previously, there may be as many as 13,100 crossings nationwide with conventional train detectors or motion sensors that would benefit from predictors.

The studies, in documenting the benefits that can be attained by providing predictors and CWT, also emphasized the critical need for additional research. Specifically, research is needed to determine the optional warning time at crossings equipped with predictors, or for that matter, at any crossing with active traffic control. Warrants and guidelines for the use of predictors also need to be developed.

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