The Effectiveness of Railroad Constant Warning Time Systems

BRIAN L. BOWMAN

Presented in this paper are the results of two tasks of a study sponsored by the Federal Highway Administration. The purpose of these tasks was to determine the effectiveness of railroad constant warning time (CWT) systems in (a) reducing motorists violation of activated at-grade warning systems, and (b) reducing vehicle-train accidents. CWT systems have the capability of measuring train motion, direction of movement, and distance from the crossing. These parameters are interpreted by the control logic to provide estimates of train speed and arrival time. When the estimated arrival time achieves a preselected minimum, such as 20 sec, the warning displays at the crossing are activated. Analysis of operational data indicated that CWT systems are effective in providing both a uniform amount of advance warning and in reducing motorist violation of the warning system. A comparative analysis of vehicle-train accidents occurring from 1980 through 1984 was also performed. This analysis indicated that, in the majority cases, crossings with CWT systems have a lower accident rate than crossings without CWT. Nevertheless, this difference was not large enough to be statistically significant at the 95 percent confidence level.

The ability to command the respect of motorists is a key factor in establishing the effectiveness of traffic control devices. A genuine need, proper device placement, and consistent operation are all important in obtaining and retaining motorist respect. Failure to consider these factors leads to motorist contempt, disregard for traffic controls, and potentially to accidents.

Train-activated traffic controls at railroad-highway grade crossings are particularly susceptible to the loss of motorists' respect. This is primarily the result of variations in warning time and the need for fail-safe design. The majority of train-activated devices now in use are based on track circuits and control logic initially developed approximately 100 years ago. This system is based on an approach track circuit length designed to provide a preselected warning time for the fastest train. The use of island circuits permits the system to determine train direction and cease signal operation after the train has passed the crossing. Such a system, unless configured with overriding capabilities, provides continuous detection while a train is on the approach. Trains traveling slower than the design speed or stopping on the approach length result in prolonged activation of the railroad-highway warning system.

The fail-safe design is required because the crossing warning devices are active in the presence of a train and unactivated at all other times. The absence of the flashing lights is intended to indicate to the motorist that it is safe to proceed. This requires that the warning system be provided with standby power in

Goodell-Grivas, Inc., 17320 W. Eight Mile Road, Southfield, Mich. 48075.

case of a commercial power failure and that the system revert to the active mode if failure of an element or component of the system, including the rails, occurs. Prolonged and fail-safe activation have resulted in motorists often disregarding the warning and driving through or around the warning devices (1). Accident statistics indicate that more than 49 percent of all train-involved accidents and 45 percent of crossing fatalities occur at locations with some form of active warning (2).

The potential consequences associated with excessively long warning times resulted in the development of a constant warning time (CWT) track circuit and control logic system. The CWT system, developed during the 1960s, differs from other systems in that it is capable of detecting train speed in addition to train motion, direction, and distance from the crossing. The ability to measure train speed and distance from the crossing enables a continuous update on the actual arrival time. When the estimated arrival time achieves a preselected minimum, such as 20 sec, the warning displays at the crossing are activated. Trains that enter the approach section and subsequently stop or reverse direction without reaching the roadway crossing are interpreted by the control logic as not requiring activation of the crossing warning system. Motorists are not, therefore, subjected to long delays caused by slow or stopped trains and can expect the arrival of a train within a uniform and reasonable length of time following the initiation of the crossing controls.

The research reported here was sponsored by the FHWA to determine how effective CWT systems are in reducing vehicle-train accidents and increasing motorist compliance with activated at-grade warning devices. This task was accomplished by analyzing data obtained from railroads, individual states, the Federal Railroad Administration, and operational data collected at railroad crossings.

EFFECTIVENESS OF CONSTANT WARNING TIME SYSTEMS IN REDUCING ACCIDENTS

The selection of accident-based measures of effectiveness was based on the probable impact of providing a uniform amount of warning time. This involved analyzing only those accidents where the roadway vehicle was struck by or strikes the first unit of the train. The rationale behind this analysis was that motorists who believe that there is an excessive amount of warning time will cross in front of an oncoming train after stopping or try to race the train to the crossing. Accidents where the train was fully in the crossing and the roadway vehicle strikes subsequent train units cannot be corrected by the installation of CWT systems. These accidents are more a result of driver

inattention, excessive speed, sight restrictions, or improper warning device operation than the influence of train detection and control logic systems used at the crossing.

Accidents where the train struck the vehicle and the vehicle struck the first unit of the train were further stratified into two categories: (a) characteristics of the accident and (b) physical and operational characteristics of the crossing.

Site Selection Criteria

The effectiveness of CWT systems in reducing accidents was determined by performing analyses between different combinations of warning devices and track circuit-control logic systems. The following combinations of crossing types were used in the analysis:

- Flashing lights without CWT,
- Flashing lights with CWT,
- Gates without CWT, and
- Gates with CWT.

The site selection process was initiated by stratifying the

FRA's national inventory, by crossing type, into categories of average daily traffic (ADT) and trains per day. Approximately 60 crossings, for each device type, were randomly selected from the cells that maximized ADT and train volumes. The complete inventory for each crossing was obtained and the operating railroad and the geographic location of the crossing were identified. Information was requested from the railroads to verify the type of warning device and track circuit and the respective date of installation as well as operational and physical characteristics of the crossing. When possible, the respective highway agencies were also contacted to request updates on the number of roadway lanes and ADT counts. If verified information pertaining to the type of warning device and the presence of a CWT system was not received on a crossing, it was eliminated from further analysis. A flowchart of the site selection and verification process is shown in Figure 1.

The number of crossings verified for each crossing type, and subsequently used in the accident analysis, is summarized in Table 1. The smallest number of crossings occurs in the flashing light with CWT category because there are relatively few crossings that have flashing lights with CWT capabilities. The majority of CWT installations occur in conjunction with gates.
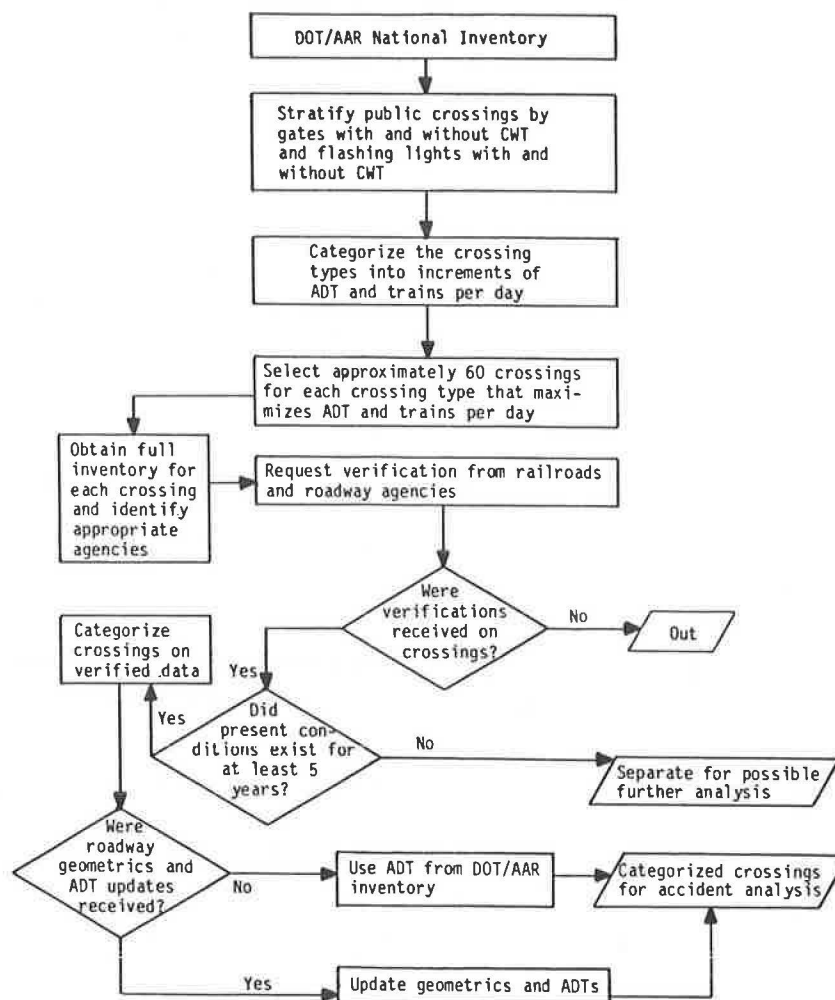

FIGURE 1 Flowchart of site selection and verification process used for accident analysis.

TABLE 1 NUMBER OF CROSSINGS WITH VERIFIED TYPES OF WARNING AND TRACK CIRCUITRY DEVICES USED FOR ACCIDENT ANALYSIS

	Gates With CWT	Gates Without CWT	Flashing Lights With CWT	Flashing Lights Without CWT
Number of crossings	27	39	13	26

Many of the replies returned for flashing lights with CWT indicated that either CWT systems were not in place or gates had been installed.

Measure of Exposure

Comparative accident analysis between independent groups requires the use of exposure rates because the probability of an accident occurring is directly related to the number of available opportunities. For train-involved crossing accidents, the number of opportunities are represented by the roadway volume and the amount of time that the crossing is occupied by the train. The only exposure factors that are prominent in analyzing the effectiveness of CWT installations are, however, roadway and train volumes. This is because the only accidents that can be reasonably associated with the effect of CWT systems are those occurring with the first unit of the train. Determination of train occupancy time at the crossing is, therefore, not required. The exposure measure used in the analysis to obtain the accident rate is displayed as follows:

$$\text{Accident rate} = \frac{(\text{number of accidents}) \, (1 \times 10^9)}{(\text{ADT}) \, (\text{trains per day}) \, (365) \, (\text{years})}$$

Results of Accident Analysis

A search of the computerized train-involved accident files provided by the FRA was performed for all of the crossings that were verified as possessing the required warning and track circuitry devices. Information pertaining to crossing geometrics, operational data, and accident characteristics were coded for computer analyses. Analyses were performed on all accidents occurring from 1980 through 1984.

Summaries of accident frequency categorized by accident characteristics and physical-operational characteristics are given in Tables 2 through 4. Because a different number of

TABLE 2 SUMMARY OF ACCIDENT TYPES FOR YEARS 1980 TO 1984

	Crossing Type			
Accident Type	Gates With CWT	Gates Without CWT	Flashing Lights With CWT	Flashing Lights Without CWT
Struck by train	8	16	5	17
Striking first unit of train	0	1	2	4
Striking other unit of train	2	1	3	0
Total	10	18	10	21

TABLE 3 SUMMARY OF ACCIDENT CHARACTERISTICS REPRESENTED AS FREQUENCIES

Accident Characteristics	Gates With CWT Struck	Gates With CWT 1st Unit	Gates Without CWT Struck	Gates Without CWT 1st Unit	Flashing Lights With CWT Struck	Flashing Lights With CWT 1st Unit	Flashing Lights Without CWT Struck	Flashing Lights Without CWT 1st Unit
Driver Action								
Drove around or through	2	0	5	0	0	0	0	0
Stopped and then proceeded	1	0	1	0	0	0	3	0
Did not stop	2	0	4	1	5	2	8	2
Other	2	0	4	0	5	0	8	1
Unknown	3	0	6	0	0	0	6	1
Severity								
Fatal	0	0	2	0	0	0	2	0
Personal injury	2	0	2	0	0	0	8	2
Property Damage only	6	0	12	1	5	2	7	2

TABLE 4   SUMMARY OF ACCIDENT FREQUENCY CATEGORIZED BY PHYSICAL AND OPERATIONAL CHARACTERISTICS PRESENT AT TIME OF ACCIDENTS

Physical or Operational Characteristics	Gates With CWT		Gates Without CWT		Flashing Lights With CWT		Flashing Lights Without CWT	
	Struck	Striking 1st Unit	Struck	Striking 1st Unit	Struck	Striking 1st Unit	Struck	Striking 1st Unit
Crossing Angle								
0-29	0	0	0	0	0	0	0	0
30-60	1	0	1	0	1	0	1	0
60-90	7	0	15	1	4	2	16	4
Number of Tracks								
1	1	0	4	0	2	0	10	0
2	3	0	10	0	2	0	5	3
3	2	0	0	0	0	0	2	1
>3	2	0	2	1	1	2	0	0
Maximum train speed (mph)								
<10	0	0	0	0	3	2	0	0
11-20	1	0	3	0	0	0	0	1
21-40	3	0	3	0	1	0	4	1
41-60	4	0	4	1	1	0	8	0
>60	0	0	6	0	0	0	5	2
Train Speed Ratio								
<2:1	3	0	6	0	1	0	9	3
2:1	2	0	0	0	2	1	0	0
3:1	0	0	1	0	0	0	2	1
>3:1	3	0	9	1	2	1	6	0
Switching Ratio								
0	1	0	6	0	2	0	9	3
0.1-0.9	1	0	0	0	0	0	0	1
1.0-1.9	1	0	0	0	0	0	0	0
2.0-2.9	5	0	3	0	1	1	6	0
3.0-3.9	0	0	3	1	1	0	2	0
4.0-5.9	0	0	0	0	1	1	0	0
6.0-7.9	0	0	1	0	0	0	0	0
>8.0	0	0	3	0	0	0	0	0

crossings with indigenous ADT and train volumes comprise the population of each crossing category, it was necessary to normalize the accident frequencies by the 5-year exposure. The exposure measure used for accident type and accident characteristics was based on the total 5-year exposure for each crossing type as presented in Table 5.

For the purposes of analysis it was necessary to combine these categories that had no crossings with the attributes being analyzed with adjacent categories to reduce the number of missing values. When feasible, those instances of zero accidents were also combined with adjacent categories. When this occurred, the exposure rate of the adjacent categories was also used in determining the accident rate. A summary of the accident frequency for the physical and operational characteristics is given in Table 6.

The data were analyzed by performing the Mann-Whitney U-test on the accident rates. The rates were determined by adding accidents in which the vehicle was struck by the train and struck the first unit of the train. This sum was then divided by the appropriate measure of exposure. This nonparametric test was used to determine if the independent categories of similar warning devices with and without CWT were from the same population. All of the tests were conducted at a 95 percent level of confidence. If the two-tailed probability of

TABLE 5   FIVE-YEAR TOTAL ACCIDENT EXPOSURE FACTOR (BILLION VEHICLE TRAINS) AND NUMBER OF CROSSINGS IN EACH CATEGORY

Crossing Type							
Gates With CWT		Gates Without CWT		Flashing lights with CWT		Flashing lights without CWT	
Number	Exposure	Number	Exposure	Number	Exposure	Number	Exposure
27	12.40	39	14.00	13	4.39	26	8.83

TABLE 6   SUMMARY OF THE NUMBER OF CROSSINGS AND THE 5-YEAR EXPOSURE (BILLION VEHICLE TRAINS) FOR SELECTED PHYSICAL AND OPERATIONAL CROSSING CHARACTERISTICS

Crossing Characteris- tics	Gates with CWT		Gates without CWT		Flashing lights with CWT		Flashing lights without CWT	
	Number	Exposure	Number	Exposure	Number	Exposure	Number	Exposure
Crossing Angle								
0-29	2	0.77	1	0.21	0	0	0	0
30-60	4	1.14	4	1.85	3	0.87	3	0.56
61-90	21	10.50	34	11.90	10	3.52	23	8.27
Number of Tracks								
1	11	4.09	5	1.72	9	3.07	8	2.57
2	6	4.20	22	8.30	3	1.00	8	2.62
3	3	1.32	9	2.99	0	0	6	2.16
>3	7	2.77	3	0.95	1	0.32	4	1.49
Maximum train speed (mph)								
<10	0	0	2	0.73	2	0.72	6	2.37
11-20	4	1.18	7	2.28	1	0.43	6	1.52
21-40	9	3.94	12	4.85	4	1.29	7	2.77
41-60	11	5.81	10	3.16	5	1.74	3	1.37
>60	3	1.45	8	2.94	1	0.22	4	0.80
Train Speed Ratio								
<2:1	1	0.57	15	5.88	6	2.22	6	1.80
2:1	4	2.72	2	0.76	1	0.34	2	0.69
3:1	0	0	6	1.97	1	0.22	10	3.33
>3:1	22	9.10	16	5.65	5	1.60	8	3.01
Switching Ratio								
0	4	2.12	10	3.64	5	1.82	11	3.47
0.1-0.9	4	1.97	3	0.81	0	0	6	1.79
1.0-1.9	6	1.47	4	1.01	3	1.02	1	0.46
2.0-2.9	6	3.47	5	1.87	0	0	2	0.96
3.0-3.9	3	1.34	6	2.02	1	0.20	2	0.95
4.0-5.9	0	0	2	0.99	2	0.50	1	0.39
6.0-7.9	3	1.38	4	1.64	0	0	0	0
>8.0	1	0.65	5	1.98	2	0.85	3	0.81

occurrence from the test was equal to or less than 5 percent, it was concluded that CWT systems had an impact on accidents.

Inspection of Tables 7 through 9 indicates that there were no significant differences at the 95 percent confidence level in the distribution of accident rates between crossings with CWT systems and those without. The accident rate at crossings equipped with CWT systems was in the majority of instances lower than comparable crossings without CWT systems. This difference was not large enough, however, to state with a 95 percent level of confidence that accident rates are lower at crossings equipped with CWT systems.

COLLECTION AND ANALYSIS OF OPERATIONAL DATA

Traffic accidents are the most acceptable and widely used measure of highway safety. However, the stochastic nature of accidents requires relatively large sample sizes collected over long periods of time. This does not pose a problem for locations with high accident frequencies but for relatively low-accident frequency locations, such as at-grade railroad crossings, the use of accident statistics becomes increasingly problematic. As a result of the recognized shortcomings associated

TABLE 7   RESULTS OF MANN-WHITNEY U-TEST ON THE ACCIDENT RATES (ACCIDENTS PER BILLION VEHICLE TRAINS) FOR ACCIDENT TYPE

Accident Type	Crossing Type			
	Gates with CWT	Gates without CWT	Flashing lights with CWT	Flashing lights without CWT
Struck by Train	0.645	1.143	1.139	1.925
Striking 1st unit	0	0.071	0.456	0.453
Striking other unit	0.161	0.071	0.683	0
Test statistic and 2-tail probability	Z = 0.2214 P = 0.8248		Z = 0.6457 P = 0.5127	

TABLE 8 RESULTS OF MANN-WHITNEY *U*-TEST ON THE ACCIDENT RATES (ACCIDENTS PER BILLION VEHICLE TRAINS) FOR CHARACTERISTICS OF THE ACCIDENT

Accident Characteristics	Crossing Type			
	Gates with CWT	Gates without CWT	Flashing lights with CWT	Flashing lights without CWT
Driver Action				
Drove around or through	0.161	0.357	0	0
Stopped and then pro-ceeded	0.081	0.071	0	0.340
Did not stop	0.161	0.357	1.595	1.133
Other	0.161	0.286	1.139	1.019
Unknown	0.242	0.429	0	0.793
Test statistic and 2-tail probability	$Z = 1.5910$ $P = 0.1116$		$Z = 0.2155$ $P = 0.8294$	
Severity				
Fatal	0	0.143	0	0.227
Personal injury	0.161	0.143	0	1.133
Property Damage only	0.484	0.929	1.595	1.019
Test statistic and 2-tail probability	$Z = 0.2214$ $P = 0.8248$		$Z = 0.6642$ $P = 0.5066$	

TABLE 9 RESULTS OF MANN-WHITNEY *U*-TEST ON THE ACCIDENT RATES (ACCIDENTS PER BILLION VEHICLE TRAINS) FOR PHYSICAL AND OPERATIONAL CHARACTERISTICS OF THE CROSSING

Physical and Operational Characteristics	Crossing Type			
	Gates with CWT	Gates without CWT	Flashing lights with CWT	Flashing lights without CWT
Crossing Angle				
0-60	0.523	0.485	0.115	0.180
61-90	0.667	1.345	1.705	2.418
Test statistic and 2-tail probability	$Z = 0.0000$ $P = 1.0000$		$Z = 0.7746$ $P = 0.4386$	
Number of Tracks				
1	0.244	2.326	0.651	3.891
2	0.714	1.205	2.002	3.053
>3	0.978	0.762	9.434	0.822
Test statistic and 2-tail probability	$Z = 1.5275$ $P = 0.1266$		$Z = 0.2182$ $P = 0.8273$	
Maximum train speed (mph)				
0-19	0.847	1.316	4.348	0.257
20-39	0.761	0.619	0.775	1.805
>40	0.551	1.803	0.512	6.912
Test statistic and 2-tail probability	$Z = 1.0911$ $P = 0.2752$		$Z = 0.2182$ $P = 0.8273$	
Train Speed Ratio				
<2:1	5.245	1.075	0.450	6.667
2:1,3:1	0.735	0.366	5.319	0.747
>3:1	0.330	1.770	1.875	1.993
Test statistic and 2-tail probability	$Z = 0.2182$ $P = 0.8273$		$Z = 0.6547$ $P = 0.5127$	
Switching Ratio				
0.0-0.9	0.489	1.349	1.099	2.472
1.0-2.9	1.214	1.042	0.980	4.222
>3	0	1.206	1.931	0.929
Test statistic and 2-tail probability	$Z = 1.0911$ $P = 0.2752$		$Z = 0.6547$ $P = 0.5127$	

with using accidents as the sole measure of safety, the accident analysis was complemented with observations of driver behavior. This analysis was conducted at 12 railroad crossings with the following CWT-crossing control combinations:

- Three crossings with automatic gates and CWT systems.
- Three crossings with automatic gates and no CWT systems.
- Three crossings with flashing lights (only) and CWT systems.
- Three crossings with flashing lights (only) and no CWT systems.

Selection of Measures of Effectiveness

Constant warning time systems are intended to have an indirect impact on accidents by increasing the credibility of at-grade warning devices. This increase in credibility results from the ability of CWT systems to provide a uniform amount of warning time until train arrival at the crossing. The uniform warning time is intended to provide motorists with a consistent expectation of train arrival thereby resulting in fewer violations of the flashing lights and, hence, fewer train accidents. The relationship between the intended purpose of CWT systems, the intermediate objectives, and the ultimate objective of reducing accidents is shown in the causal chain of Figure 2.

The collection of field data was concentrated on obtaining quantifiable measures of effectiveness that (a) indicated whether CWT systems actually do provide a uniform warning time and that (b) could be directly related to the intermediate objectives. The measures of effectiveness selected for the study are given in Table 10.

Test Site Selection Procedure

The measures of effectiveness determined as being appropriate for the analysis of the operational CWT data required observations of motorists' action only during the activated state. In addition, the observational opportunities during the activated state, in most instances, were only present for the first vehicle on each approach lane. This necessitated that the site selection process consider only those crossings with relatively high vehicle and train volumes to maximize the observational opportunities. Other key locational characteristics were desired to help ensure homogeneity between analysis sites. This homogeneity was necessary to increase the probability that observed differences between the test sites were a result of the train detection and type of warning device and not extraneous factors. The key locational variables for which similarities between the 12 locations were desired included

- Sight distance to crossing flashers on the approach,
- Number of tracks,
- Railroad-highway intersecting angle,
- Sight distance along the tracks,
- Roadway grade, and
- Elevation of railroad-highway crossing with respect to roadway elevation.

The initial site selection process was performed by selecting crossings that had been verified as having CWT systems for the accident analysis. Each prospective site was visited to determine the presence of a suitable observer refuge area, proper warning device, and correct locational variables. The respective highway agencies and operating railroads were then contacted for those sites that satisfied all of the preliminary selec-
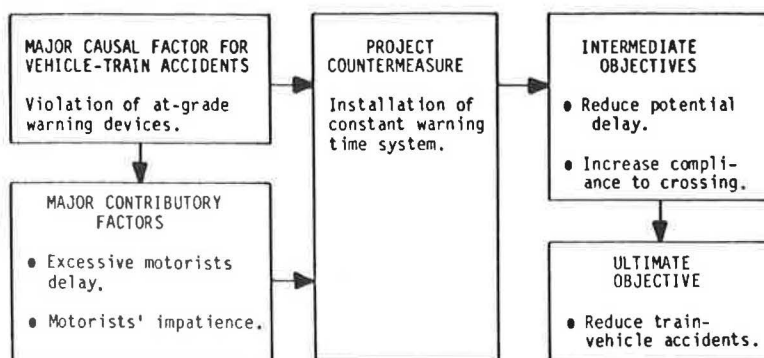
FIGURE 2 Causal chain for the reduction of vehicle-train accidents by installing CWT systems.

TABLE 10 RELATIONSHIP OF MEASURES OF EFFECTIVENESS TO ANALYSIS OBJECTIVES

Purpose	Measure of Effectiveness
To determine if CWT systems provide a uniform amount of warning time.	Warning time until train arrival analyzed in conjunction with train speed.
To determine if CWT systems reduce vehicle delay.	Warning time until train arrival.
To determine if CWT systems result in increased vehicle compliance to warning devices.	Violation rate.

tion criteria. These contacts provided information pertaining to hourly roadway counts, daily train volume, train schedule, and additional verification of the type of train detection and control logic present at the site. Twelve locations, three in each category of train detection system and warning device, were selected that maximized train and vehicle exposure.

Field Data Collection Procedure

Data were obtained manually with the use of radar guns and stop-watches. One observer was placed on each crossing approach. The stopwatches were initiated on first activation of the warning device at the crossing. The observers noted the time of vehicle arrival for the first vehicle in each lane, the time of violation if the flashers were activated, the time of train arrival and departure, and the speed of the train. Violation time was recorded for each vehicle that went through the activated flashers or that drove around the gates. The time of arrival for each vehicle that had the opportunity to violate (the first vehicle in the queue of each lane) was the time at which the vehicle arrived at the stop-bar of the approach.

Analysis of Operational Data

Effectiveness of CWT in Providing Uniform Warning Time

The variations in train speed given in Table 11 indicate that accompanying variations in warning time could be expected at each crossing. This variation in warning time would be proportional to the train speed unless the train detection and control logic compensated for the variation. For example, for crossings without CWT capabilities, if 30 sec was the observed warning time at 40 mph (64 km/h), then 240 sec (8 times 30 sec) would be required for a train traveling 5 mph (8 km/h). The track circuits and control logic prevented this wide variation in warning time from occurring at all of the crossings studied. Those crossings that were not equipped with CWT systems were equipped with motion sensors. The observed instances of very low speeds were caused by switching activities in the approach circuit before the train entered the crossing. Therefore, the lower train speeds were the result of trains accelerating from a stop on the approach circuit.

The effectiveness of CWT systems in providing uniform warning times was analyzed by performing an analysis of variance (ANOVA) and plotting intervals of train speed versus average warning time. The results of the two-way analysis of variance given in Table 12 indicate that there is a significant difference at the 95 percent level of confidence between the effect of the different types of crossings and the average warning times. This difference was further analyzed with the Scheffe contrast test to determine where these differences resided. The results of the Scheffe test given in Table 13 indicate that there are significant differences, at a 95 percent level of confidence, between crossings equipped with CWT systems and those without such systems. Crossings equipped with CWT systems, therefore, display different characteristics in their

TABLE 11   MAXIMUM, MINIMUM, AND STANDARD DEVIATION OF TRAIN VELOCITIES (mph) OBSERVED BY TYPE OF CROSSING (1 mph = 1.6 km/h)

Parameter	Flashing lights without CWT	Flashing lights with CWT	Gates without CWT	Gates with CWT
Maximum speed	41	31	44	35
Minimum speed	5	1	3	2
Standard deviation	9.3	17.5	17.0	12.9
Ratio of minimum to maximum speed	1:8	1:31	1:15	1:18

TABLE 12   ANOVA ON THE MEAN WARNING TIME (sec) PER TRAIN VELOCITY GROUP (mph) FOR DIFFERENT CROSSING TYPES

Speed Group	Crossing Type			
	Flashing lights without CWT	Flashing lights with CWT[1]	Gates without CWT	Gates with CWT[1]
0-5	81.6	35.5	57.5	36.3
6-10	77.6	35.0	47.8	32.2
11-15	80.6	27.0	49.5	31.7
16-20	68.8	30.8	65.2	33.0
21-25	60.4	30.1	68.6	33.0
26-30	50.3	34.4	50.1	37.2
31-35	43.2	33.0	50.5	29.2
36-40	33.0	19.9	40.0	38.0
>40	48.9	33.0	42.0	38.0

Source	df	SS	MS	F_{ij}	95% critical F value
Crossing type	8	3535.2	441.9	2.43*	2.38
Speed group	3	1251.3	417.08	2.29	3.03
Error	23	4190.0	182.17		

[1] - missing value estimated to minimize SS error
1 mi/h = 1.6 km/h
Asterisk (*) indicates significance

TABLE 13   SCHEFFE CONTRAST TEST ON THE EFFECT OF CROSSING TYPE ON MEAN WARNING TIME (sec)

	Flashing lights without CWT	Flashing lights with CWT	Gates without CWT	Gates with CWT
Flashing lights without CWT	----	----	----	----
Flashing lights with CWT	265.7*	----	----	----
Gates without CWT	73.2	192.5*	----	----
Gates with CWT	235.8*	29.9	162.6*	----

95 percent Scheffe contrast value = 159.3
1 mi/h = 1.6 km/h
Asterisk (*) indicates significant difference.

average warning time than crossings not equipped with CWT systems.

The values in Table 12 were plotted and the linear best fit regression line obtained. An inspection of these plots, shown in Figure 3, indicates a negative slope for all crossing types except for gates with CWT. With one exception, this indicates that as train velocity increases, the amount of advance warning time decreases. The linear approximation for crossings with flashing lights and CWT has the least slope. The presence of a truly uniform warning time would be characterized by a slope of zero magnitude. Because crossings with CWT are closer to the desirable zero slope, the differences demonstrated by the ANOVA and Scheffe contrast tests can be interpreted as differences in uniformity of warning time. Crossings equipped with CWT systems do, therefore, provide a more uniform warning time to motorists.

Effectiveness of CWT in Reducing Warning Time Violation

Each of the crossings at which data were collected was located on relatively high-volume roadways. The high volumes resulted in a queue of vehicles on each approach lane at every test crossing during activation of the warning devices. The occupied roadway approaches resulted in the number of opportunities for vehicles to proceed through the activated warning devices (violations) being similar, per unit of time, for each test site. Because the violation opportunities are time dependent, however, a greater number of opportunities exist when the amount of time from device activation to train arrival is increased.

The effectiveness of CWT systems in reducing violations of the warning system was determined by analyzing violations in conjunction with both the total amount of warning time and the
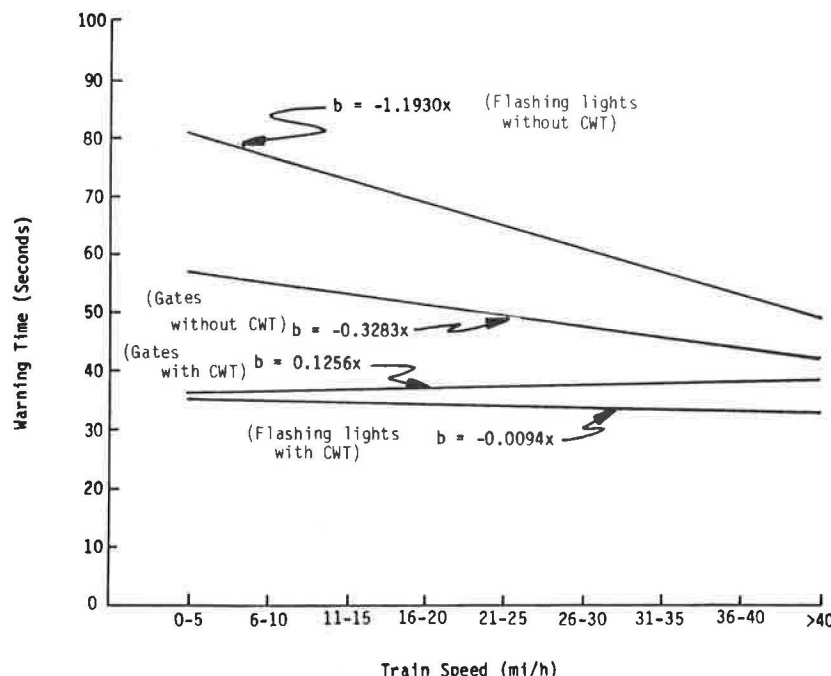
FIGURE 3   Best fit linear approximations and the resultant slopes for each crossing type on speed groups and mean warning time.

TABLE 14 OBSERVED VIOLATIONS OF THE ACTIVATED
WARNING DEVICE CATEGORIZED BY TOTAL WARNING TIME FOR
DIFFERENT CROSSING TYPES

Total Warning Time (Seconds)	Number of Violations by Crossing Type			
	Flashing lights without CWT	Flashing lights with CWT	Gates without CWT	Gates with CWT
11-15	0	0	2	0
16-20	0	0	1	0
21-25	3	0	1	0
26-30	7	33	5	2
31-35	6	30	1	14
36-40	25	27	2	4
41-45	41	4	4	0
46-50	22	0	9	0
>50	265	0	192	0
Totals	369	94	217	20

TABLE 15 OBSERVED VIOLATION OF THE ACTIVATED WARNING
DEVICE AND CUMULATIVE PROPORTIONS CATEGORIZED BY
TIME UNITL TRAIN ARRIVAL FOR DIFFERENT CROSSING TYPES

Time until train arrival (seconds)	Number of Violations by Crossing Type			
	Flashing lights without CWT	Flashing lights with CWT	Gates without CWT	Gates with CWT
0-5	1	1	0	3
6-10	17	4	3	2
11-15	34	13	13	4
16-20	30	26	13	4
21-25	35	20	18	6
26-30	38	19	17	1
31-35	29	10	11	0
36-40	29	1	20	0
>40	156	0	122	0
Totals	369	94	217	20

TABLE 16 KOLMOGOROV-SMIRNOV TEST ON THE NUMBER OF
VIOLATIONS OCCURRING WITHIN CATEGORIES OF ADVANCE
WARNING TIME (sec) FOR CROSSINGS EQUIPPED WITH GATES

Total Warning Time Interval	Gates Without CWT		Gates With CWT		Absolute Differences in Cumulative Occurrences
	Occurrences	Cumulative Occurrences	Occurrences	Cumulative Occurrences	
0-5	----	----	----	----	----
6-10	----	----	----	----	----
11-15	2	0.009	----	0.000	0.009
16-20	1	0.014	----	0.000	0.014
21-25	1	0.018	----	0.000	0.018
26-30	5	0.041	'2	0.100	0.059
31-35	1	0.046	14	0.800	0.754
36-40	2	0.055	4	1.000	0.945
41-45	4	0.074	----	1.000	0.926
46-50	9	0.115	----	1.000	0.885
>50	192	1.000	----	1.000	0.000
Total	217		20		

Maximum difference = 0.945   95 percent critical K-S value = 0.318

time from vehicle violation to train arrival. There were a large number of violations especially at those locations that were not equipped with CWT systems. Inspection of Table 14 indicates that the majority of these violations occurred when the amount of warning time exceeded 50 sec. This occurred even at those locations where motorists had to drive around the gates. There is a definite increase in the number of violations for crossings with flashing lights and no CWT when the total warning time exceeds 35 sec.

A summary of the amount of time remaining from vehicle violation (the rear of the vehicle clearing the tracks) until the train entered the crossing is given in Table 15. It is interesting to note that five of these observations included clearance times of less than 6 sec.

The Kolmogorov-Smirnov two-sample tests was used to determine if the violations observed at crossings equipped with CWT systems exhibited the same population characteristics as those obtained at crossings without CWT systems. The analysis was performed by comparing crossings with similar types of warning devices. The analyses for violations occurring within categories of total warning time are given in Tables 16 and 17. Similar analyses for violations by time before train arrival are given in Tables 18 and 19. Each of these tests indicates that at the 95 percent level of confidence, there are significant differences between crossings with comparable types of warning devices, with and without CWT. CWT systems reduce the number of violations and, because they provide a more uniform amount of warning time, result in a greater proportion of violations occurring with smaller clearance time (interval of time between a vehicle clearing the tracks and the time of train arrival) than at crossings without CWT systems. The majority of vehicles that violate the warning devices at crossings

TABLE 17 KOLMOGOROV-SMIRNOV TEST ON THE NUMBER OF VIOLATIONS OCCURRING WITHIN CATEGORIES OF ADVANCE WARNING TIME (sec) FOR CROSSINGS EQUIPPED WITH FLASHING LIGHTS

Total Warning Time Interval	Flashing Lights With CWT		Flashing Lights Without CWT		Absolute Differences in Cumulative Occurrences
	Occurrences	Cumulative Occurrences	Occurrences	Cumulative Occurrences	
21-25	3	0.008	----	0.000	0.008
26-30	7	0.027	33	0.351	0.324
31-35	6	0.043	30	0.670	0.627
26-40	25	0.111	27	0.957	0.846
41-45	41	0.222	4	1.000	0.778
46-50	22	0.282	----	1.000	0.718
>50	265	1.000	----	1.000	0.000
Total	369		94		

Maximum difference = 0.846   95 percent critical K-S value = 0.157

TABLE 18 KOLMOGOROV-SMIRNOV TEST ON TIME (sec) FROM VEHICLE VIOLATION UNTIL TRAIN ARRIVAL FOR CROSSINGS EQUIPPED WITH GATES

Time from Violation Until Train Arrival	Gates Without CWT		Gates With CWT		Absolute Differences in Cumulative Occurrences
	Occurrences	Cumulative Occurrences	Occurrences	Cumulative Occurrences	
0-5	----	----	3	0.150	0.150
6-10	3	0.014	2	0.250	0.236
11-15	13	0.074	4	0.450	0.376
16-20	13	0.134	4	0.650	0.516
21-25	18	0.217	6	0.950	0.733
26-30	17	0.295	1	1.000	0.705
31-35	11	0.346	----	1.000	0.654
36-40	20	0.438	----	1.000	0.562
>40	122	1.000	----	1.000	0.000
Total	217		20		

Maximum difference = 0.733   95 percent critical K-S value = 0.318

TABLE 19 KOLMOGOROV-SMIRNOV TEST ON TIME (sec) FROM VEHICLE VIOLATION UNTIL TRAIN ARRIVAL FOR CROSSINGS EQUIPPED WITH FLASHING LIGHTS

Time from Violation Until Train Arrival	Flashing Lights Without CWT		Flashing Lights With CWT		Absolute Difference in Cumulative Occurrences
	Occurrences	Cumulative Occurrences	Occurrences	Cumulative Occurrences	
0-5	1	0.003	1	0.011	0.008
6-10	17	0.049	4	0.053	0.004
11-15	34	0.141	13	0.191	0.050
16-20	30	0.222	26	0.468	0.246
21-25	35	0.317	20	0.681	0.364
26-30	38	0.420	19	0.883	0.463
31-35	29	0.499	10	0.989	0.490
36-40	29	0.577	1	1.000	0.423
>40	156	1.000	----	1.000	0.000
Total	369		94		

Maximum difference = 0.490   95 percent critical K-S value = 0.157

equipped with CWT systems are, therefore, exposed to an increased probability of being struck by a train than violators at crossings without CWT systems. However, the number of violators is much smaller at crossings with CWT systems.

CONCLUSIONS

CWT systems are effective in providing a uniform warning time and in reducing motorist violations of the activated warning devices at the crossing.

The comparative analysis of vehicle-train accidents occurring from 1980 through 1984 indicated that crossings equipped with CWT systems have a lower accident rate than crossings without CWT. This difference was not, however, large enough to be statistically significant at the 95 percent confidence level.

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