The Use of Constant Warning Time Systems at Rail-Highway Grade Crossings

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ABSTRACT

The results are presented of one task of a study sponsored by FHWA to determine the use and installation criteria of railroad constant warning time (CWT) systems. These systems measure train speed, direction, and distance from the crossing and estimate train arrival time. When a preselected minimum estimated arrival time is reached, the warning displays at the crossing are activated. The result is a more uniform warning time until train arrival for motorists than that provided by traditional train detection systems. Results of task activities indicate that no quantitative guidelines have been established by either the states or the railroads as to when CWT systems should be installed. Switching activity, annual average daily traffic maximum speed, and train speed variation were found to be variables, however, that were inherently considered when the need for CWT installations was determined. The necessary limits on each of these variables or their combinations that justify installation are apparently judgmental and performed on a crossing-by-crossing basis. Using information from the U.S. Department of Transportation (DOT)/Association of American Railroads (AAR) National Railroad-Highway Crossing Inventory along with the purchasing information supplied by CWT manufacturers, it was estimated that 6,300 crossings already have CWT installations. Discriminant analysis indicated that of all crossings, 19,400 may require CWT systems, which indicates that an additional 13,100 crossings have the physical and operational characteristics that may require CWT systems.

Constant warning time (CWT) systems have the potential to provide a more precise and thereby credible warning to motorists. The more precise warning of time until train arrival is accomplished by the ability of CWT systems to measure train speed, direction, and distance data into a computer, enabling a continuous update on the estimated arrival time at the crossing. When a minimum preselected estimated arrival time is reached, such as 20 sec, the warning equipment at the crossing is activated. The actual warning time provided may vary because of changes in train speed after device activation, but measures can be taken to decrease the effect of these speed changes. CWT systems decrease the probability that slow-moving or stopped trains in the approach circuits will activate the warning devices before the preselected minimum time. Motorists are therefore not subjected to long waits at activated crossings and can expect the arrival of a train within a uniform and reasonable length of time.

CWT systems are not currently used to their full potential, even though these systems have been available for many years. Reasons postulated for this lack of use are related to perceived issues of reliability, compatibility, and cost (1). In addition there is no definite measurement of the effectiveness of CWT systems or of criteria establishing when they should be installed. The combination of these inhibiting factors has resulted in a relatively low rate of CWT installation.

Recognition that CWT systems are not used to their full potential prompted FHWA to sponsor a research effort to determine the current use and effectiveness of CWT systems. Preliminary findings pertaining to the use of CWT systems are presented in this paper.

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ESTIMATE OF CWT USE

The primary purpose for identifying the users of CWT systems was to determine the existence of CWT installation criteria to (a) serve as a base for determining the number of crossings nationwide that should have CWT systems and (b) provide an opportunity to assess criteria validity.

Two separate activities were undertaken to determine the major users of CWT systems. These activities consisted of analyzing the DOT/AAR national inventory and obtaining information from manufacturers.

Analysis of National Inventory

The DOT/AAR national inventory contains an entry regarding the presence of CWT systems: "Do crossing signals provide speed selection for trains?" An answer of yes indicates that CWT systems are present at the crossing. The entire inventory was searched to ascertain the number of crossings with CWT systems, the physical and operational characteristics of each crossing, and the major users of CWT systems.

This search resulted in discovery of a number of crossings coded as having both CWT capabilities and passive warning devices, which is a contradiction. If train detection circuitry is present at a crossing, there must be active devices present. This contradiction was resolved by searching the inventory to locate only those public crossings that had CWT

capabilities in conjunction with active warning devices.

This process indicated that there were 6,337 crossings equipped with CWT systems:

Highest Warning-Device Class	No.	Percent of Total
Flashing lights	2,473	39.0
Gates	3,781	59.7
Highway signals	83	1.3
Total	6,337	

Information pertaining to the crossing inventory number, operating railroad, intersecting roadway, state, city, county, and nearest timetable station were obtained on 201 crossings from 20 different railroads. The railroads were requested to verify the presence of CWT systems, the date of installation, type of warning device, and train volume for each crossing. Some results of the verification survey are presented in Table 1, in which the data indicate that approximately 42 percent of the crossings were erroneously coded on the national inventory as having CWT capabilities (total of last column divided by totals of last two columns). Because of the high error rate, it was determined that the national inventory could not be used to identify crossings that are equipped with CWT systems.

Information from Manufacturers

The accuracy problems identified in using the national inventory prompted queries to the manufacturers of CWT systems. Safetran Systems and SAB Harmon were identified as the only current manufacturers of CWT systems. They were contacted and requested to provide information on the number and model of the systems sold, the year purchased, and, if possible, the purchaser and location of the installation.

Safetran Systems was willing to provide information, but representatives stated that identifying the individual locations for which the systems were purchased was difficult because railroads often purchase the units in quantity and provide either just one or no location of installation. In addition, providing information on the possible installation locations required a time-consuming manual file search. Because of the large amount of time required and the questionable accuracy of the information, locational information was only provided for Michigan, Ohio, Illinois, and Indiana.

According to Safetran's files, 12,113 CWT units were sold in the United States. All of these units were believed to have been purchased as CWT systems. The possibility does exist, however, that some of the Model 600 units were purchased for use as motion sensors only. This is especially true of one railroad that purchased 2,307 Model 600 units, of which 75 percent (1,730) were estimated by Safetran to be CWT systems. Estimating the number of crossings with CWT systems from the sales data required consideration of the following: (a) unidirectional or bidirectional deployment, (b) the number of units sold as replacements or for future installation, (c) units sold by manufacturers other than Safetran, and (d) the number of crossings with more than one set of tracks in need of CWT capabilities.

Bidirectional installations require only one unit per track per deployment. Unidirectional installations require two units per installation, one for each approach, if both approach directions require CWT capabilities. Information was not available on the number of units that were purchased with bidirectional capabilities. An attempt to estimate the number of units with bidirectional capabilities would require an assessment of the CWT model in addition to the physical and operational characteristics of each crossing. For example, in urban areas the proximity of adjacent streets often places one crossing within the approach circuitry of another. The overlapping approaches require that a different frequency be used for each crossing. However, in heavily congested areas where several streets are close together, a sufficient number of distinct frequencies may not be available for all crossings. In such cases, a unidirectional system may be used periodically to isolate sections of the track, thereby allowing frequencies to be duplicated (2). The proper choice of either a bidirectional or a unidirectional CWT system is therefore site specific and cannot be estimated by information from the national inventory or the individual manufacturer.

The purchase of a CWT unit does not necessarily imply that a new crossing will be equipped with CWT capabilities because new units may have been purchased as replacements for older models. In addition, there may be instances in which a number of units would be required at multiple-track crossings where more than one set of tracks require CWT capabilities.

Because only Safetran was willing to provide information on the number of units purchased, the number of systems supplied by other manufacturers was estimated. Safetran was the only major supplier of CWT systems until approximately 1981, so it was estimated that only 500 units had been supplied by other manufacturers. Estimates of CWT units sold and crossings equipped are as follows:

Source	CWT Units Sold	Crossings with CWT Units
Manufacturer list	12,113	6,057
Other	500	250
Subtotal	13,613	6,307
Known as out of service	-8	-4
Total	12,605	6,303

TABLE 1 Verification Results for CWT Installations

Responding Railroad	Total Crossings Requested	No. with Incorrect Code for Operating Railroad	CWT Coding on National Inventory: No CWT Correct	No CWT Incorrect	CWT Correct	CWT Incorrect
1	15	3	9	–	–	3
2	5	1	3	–	–	1
3	1	–	–	–	1	–
4	22	3	7	–	7	5
5	24	8	8	–	3	5
6	16	–	6	–	9	1
7	19	1	3	3	7	5
8	4	–	4	–	–	–
9	5	–	3	1	1	–
Total	111	16	43	4	28	20

The number of crossings estimated to be equipped with CWT systems was assumed to be 50 percent of the total units sold for the following reasons:

- Bidirectional CWT units have been available only relatively recently. Because of application restrictions, the majority of CWT installations have been unidirectional. Only the most recent models have the option of built-in bidirectional capabilities.
- An assumption that every CWT purchase was for a new installation would result in overestimating the number of crossings with CWT capabilities. A number of the units purchased may have been replacement units for existing installations, but there is no way to accurately estimate the number of replacement installations.
- A majority of the CWT units currently available have the capability of either unidirectional or bidirectional application, but information was only available on the number of units sold, not on their application capability.
- A number of crossings consist of multiple tracks where more than one track requires CWT capabilities. If it was assumed that every CWT purchase equipped a total crossing with CWT capabilities, multiple-track crossings would not be accounted for.

SURVEY RESULTS FROM RAILROADS AND STATES

The manufacturer's information was also used to identify the major users and nonusers of CWT systems. Surveys were developed and administered to each group of railroads and to states to determine the reasons for use or nonuse, problems encountered with CWT systems, and the existence of any installation criteria.

Survey of Users

The manufacturer's list revealed that 15 railroads had purchased at least 60 CWT units. Nine railroads, designated CWT users, were randomly selected from this list and forwarded a survey consisting of questions oriented toward determining the existence of installation criteria, number of units purchased, mean time between failures (MTBF), prevalent causes of failure, alternatives to the installation of CWT systems, and physical conditions at the crossing that limit deployment.

A summary of the survey responses is shown in Figure 1, inspection of which reveals that none of the surveyed railroads have any formal criteria for CWT installation. Primary concerns for determining the need for CWT systems were the variation in train speed and the presence of switching operations. There should exist, however, a strong relationship between train speed variation and switching operations at locations that have through train movement in conjunction with switching operations. Train speed variation and ratio of through trains to switching trains are therefore factors that should be considered in determining installation need. Other factors considered in CWT installations were train and roadway volumes and the proximity of signalized control points. The last factor is essentially one that limits the compatibility of CWT systems with the crossing environment.

The primary causes of CWT failure were identified as electrical storms, component failure, track cir-

Question Summary	Response Summary	Number of Responses[a]
1. Is the selection of locations for the installation of CWT devices based on established warrants?	a) Based on unusual and numerous train movements.	1
	b) No warrants, but some States have guidelines.	1
	c) No.	2
2. Please provide a copy or describe any warrants.	a) No response.	1
	b) No formal warrants.	4
3. If no formal warrants exist, what factors are taken into consideration for CWT installation?	a) Variation in train speed.	4
	b) Proximity of signalized control points.	2
	c) Switching operations.	3
	d) Train traffic.	2
	e) Vehicle traffic.	2
	f) Traffic signal preemption.	1
4. CWT devices are primarily installed as:	a) Sole corrective countermeasures.	2
	b) One part of a crossing upgrading project.	3
	c) No response.	1
5. Approximately how many CWT devices have been purchased from manufacturers other than Safetran?	a) SAB Harmon.	503
	b) Others.	
6. What are the most prevalent causes of CWT failure?	a) Lightning.	5
	b) Component failure.	3
	c) Track circuit failure.	3
	d) Relay contacts high resistance.	1
	e) Poor ballast conditions.	2
	f) Out of adjustment.	1
	g) Tuned joint couplers fail.	1
	h) Temperature changes.	3
	i) Broken bonds.	1

[a]The total responses for each question vary due to multiple responses.

FIGURE 1 Survey responses from railroads identified as users of CWT systems.

cuitry failure, temperature changes, and varying ballast resistance. These factors also cause failure in other types of train detection and control logic systems. Ballast resistance was also identified as the most prevalent criterion limiting the installation of CWT systems.

Survey of Nonusers

Nonusers were identified by randomly selecting nine of the largest railroads that either were not included in the manufacturer's list or had purchased a small quantity of CWT systems. The survey forwarded to the nonusers pertained to the reasons for not using CWT systems more extensively, the existence of installation criteria, problems that would prompt CWT installation, and changes that would need to be accomplished to make CWT systems more attractive.

A summary of the survey responses is given in Figure 2, which reveals that CWT systems are frequently perceived as not being required. This can conceivably be the case if operation on the line consists primarily of one type of movement, such as freight, with little switching activity near crossings. Additional reasons for nonuse were perceived high purchase and maintenance costs and device complexity requiring maintenance expertise not available to the railroad.

Wide variations in train speed and switching activities were identified as operational conditions that indicate the need for CWT systems. There were no formal criteria for installation, but five of the eight respondents stated that the installation of CWT systems is considered to address specific crossing problems. Alternatives to the installation of CWT systems included modifications to existing timing circuits and changing the time of day during which switching operations occur.

Cost was identified as the most important factor in increasing the attractiveness of CWT systems. Responses pertaining to cost included lower purchase price, less maintenance cost, and governmental cost sharing. Greater dependability and simplified installation, maintenance, and testing were also mentioned as a means of increasing CWT acceptability.

Survey of States

Surveys were also forwarded to nine states to determine whether any criteria existed for the installation of CWT devices. Included in this survey were queries pertaining to activities performed during grade crossing inspections and recommendations given to the railroads. No states were identified that had criteria for the installation of CWT devices or procedures for identifying the need for these devices.

ESTIMATING TOTAL CROSSINGS THAT MAY REQUIRE CWT CAPABILITIES

To estimate the number of crossings that would benefit from the enhanced warning-time capabilities of CWT systems, it was necessary to establish the prevalent physical and operational characteristics that exist at crossings currently equipped with CWT systems. Because no quantitative installation criteria were received from the states or the railroads, these characteristics were established by performing discriminant analysis on groups of crossings with and without CWT capabilities.

Discriminant Analysis

Discriminant analysis is a statistical technique for studying the differences between two or more groups

Question Summary	Response Summary	Number of Responses[a]
1. What are reasons for not using CWT devices more extensively?	a) No new installations.	1
	b) CWT devices do not always fail in restrictive mode.	1
	c) High initial cost.	2
	d) High maintenance cost.	1
	e) Not needed.	4
	f) Too complicated for railroad personnel to install and maintain.	1
	g) Recently started using CWT devices.	2
	h) Considered as undependable.	2
2. What guidelines or warrants were used to determine where CWT devices should be installed?	a) None.	4
	b) Inspection of crossing.	1
	c) Wide variations in train speeds.	2
	d) Excessive switching.	1
3. Is the installation of CWT devices considered as a possible countermeasure?	a) Not considered necessary.	2
	b) Yes.	5
	c) No.	1
4. What operational characteristics and identified problems prompt the consideration of CWT devices?	a) Variation in train speeds.	6
	b) Switching activity.	6
	c) Maximum train speed.	1
	d) Roadway volume.	2
	e) Ballast condition.	1
5. What alternatives to the installation of CWT devices have been used?	a) Modifications to conventional timing circuits.	1
	b) Installation of forestalling devices.	1
	c) Changing times of switching operations.	2
	d) None.	4

[a]The total responses for each question vary due to multiple responses.

FIGURE 2 Survey responses from railroads identified as nonusers of CWT systems.

of objects with respect to several variables simultaneously. The technique selects common variables from two or more mutually exclusive groups and provides measures of how well these variables discriminate between the two groups and which variables are the most powerful discriminators. After the discriminating variables have been identified, the extraneous variables can be dropped and the resultant discriminant model can be used to place individual members of the total population into specific groups. For example, there exist two distinct groups of crossings: crossings with and crossings without CWT capabilities. Discriminant analysis compares common variables [maximum speed, number of tracks, average annual daily traffic (AADT), etc.] between those two groups. Those variables that exhibit the greatest difference between the two groups are designated as discriminating independent variables. A discriminating function is developed from the selected variables by developing a weighting coefficient for each variable. The resultant function can be used to inspect the entire crossing inventory to determine the total number of crossings that should have CWT capabilities.

Discriminant analysis was used to determine the appropriateness of CWT installations, because no quantitative criteria were obtained from either the railroads or the states. The considerations used by the railroads and the states were, however, used to select the following initial input variables:

- Maximum timetable speed,
- Minimum speed,
- Smallest crossing angle,
- AADT,
- Total trains,
- Number of tracks,
- Through-to-switch ratio (i.e., daily through trains/daily switching movements), and
- Speed ratio (maximum speed/minimum speed).

The discriminant function was developed in a two-step process, using a total of 402 crossings. The first step involved building the discriminant function from a randomly selected 60 percent sample of the total 402 crossings. The second step involved checking the accuracy of the developed function by applying it to the remaining 40 percent of the crossings not used in the development step.

Developing the Discriminant Function

Each of the 114 crossings with and the 128 crossings without CWT capabilities used to develop the discriminant function was individually verified as having the indicated train-detection capabilities. Therefore, the function was developed from groups of crossings that had known types of train-detection systems. Other data items, such as maximum and minimum train speeds, crossing angle, number of trains, and so on, were obtained from the crossing inventory and not verified on a crossing-by-crossing basis.

Discriminant functions were constructed for three distinct groups on the basis of the highest-priority warning device at the crossing. Separate functions were developed for crossings with (a) flashing lights only, (b) gates with flashing lights and gates with highway signals, and (c) combined categories of flashing lights only plus gates with flashing lights and gates with highway signals. The rationale used in developing separate functions based on the highest type of warning device was that the inherent differences in the reasons for the need for gates, such as high AADTs and train movements, could result in large differences in the discriminant functions for each individual group. Constructing separate functions permitted each group to be inspected separately. This was done to determine whether greater accuracy would be achieved by analyzing crossing groups separately by warning-device type or as combined groups.

The resultant discriminant functions were used to classify the randomly selected 40 percent of the crossings not used in the function development step. The percentage of correct classifications is one measure that is used to determine the accuracy of the discriminant function. Results of the discriminant analysis are summarized in Table 2 and reveal the following:

1. Flashing lights only: The final discriminant function contains the independent variables maximum speed, total trains, switching ratio, and crossing angle. The only independent variable that can be logically related to CWT need is switching ratio. Provisions for maximum speed, if speeds are relatively consistent, can be made with fixed-distance train-detection systems. Crossing angle and total trains have an impact on sight distance and total delay, respectively, not warning-time variations. The distance between the centroids of the respective groups (i.e., crossings with CWT and crossings without CWT) exceeds 1 (0.82798 + 0.26788), which increases the probability that the function will be able to distinguish between the crossings and correctly assign the crossings to the proper group.

Inspecting the classification results reveals that the function is capable 81 percent of the time of correctly identifying crossings that have CWT

TABLE 2 Summary of Discriminant Analysis

	Function Development						Classification		
	No. of Cases								
Highest-Priority Warning Device	With CWT	Without CWT	Variable	Discriminant Coefficient	Group	Centroid	No. of Cases	Correct Classification (%)	Correct Combined Classification (%)
Flashing lights only	47	104	Maximum speed	0.41958	CWT	0.82798	21	81.0	72.4
			Total trains	0.57817	No CWT	−0.26788	66	69.7	
			Switching ratio	0.27737					
			Crossing angle	0.37096					
Gates with flashing lights and gates with highway signals	78	28	Switching ratio	0.35542	CWT	−0.19364	45	62.2	57.9
			Minimum speed	0.39028	No CWT	0.58900	12	41.7	
			AADT	0.75487					
			Speed ratio	−0.65324					
Flashing lights only plus gates with flashing lights and gates with highway signals	114	128	Maximum speed	0.45877	CWT	0.62546	78	78.2	71.9
			Total trains	0.54032	No CWT	−0.55705	82	65.9	
			No. of tracks	0.23516					
			Switching ratio	0.22637					

devices installed. Correct classification of crossings without CWT devices occurred 69.7 percent of the time for an overall accuracy rate of 72.4 percent.

2. Gates with flashing lights and gates with highway signals: Switching ratio, minimum speed, AADT, and speed ratio were the final discriminating variables. These variables can all be logically related to the prime purpose of CWT devices--to provide uniform warning time. Inspection of the discriminant coefficients, however, reveals that the major variable is AADT, with a positive coefficient almost twice as large as the positive coefficients for minimum speed and switching ratio. Because the group centroid for determining CWT need for this function is negative, only speed ratio is a contributing variable. The AADT, minimum speed, and switching-ratio variables reduced the number of crossings that need CWT devices. It is difficult to rationalize the discriminant coefficients for this function, especially when it is realized that gates are often installed in response to high AADT.

The group centroids are separated by only 0.78 (0.58900 + 0.19364), which indicates that the discriminant function has a smaller range around each group centroid in which to determine the classification group for each crossing. This tends to decrease the dependability of the discriminant classifications and could be one of the reasons why the function could only correctly classify crossings as needing and not needing CWT devices 62.2 and 41.7 percent of the time, respectively. The result was an overall correct classification rate of 57.9 percent.

3. Combined categories (flashing lights only plus gates with flashing lights and gates with highway signals): This function included maximum speed, total trains, number of tracks, and switching ratio. All of these variables had positive coefficients and, because the with-CWT group centroid is positive, each variable contributes to predicting the presence of CWT devices. The group centroids are separated by a distance greater than 1 (0.62546 + 0.55705). The function was able to correctly predict locations with CWT installations 78.2 percent of the time with an overall accuracy of 71.9 percent.

It should be noted that because of the combined warning-device categories of flashing lights only plus gates with flashing lights and gates with highway signals, the sample size was larger than the individual categories. The larger sample size in conjunction with the discriminant functions resulted in selection of the combined-categories discriminant function as the best description of CWT need.

Estimate of Total Crossings That May Require CWT Installations

The discriminant function for the combined warning devices was applied to a 50 percent sample of the total public crossings nationwide with active warning devices. The sample crossings were randomly selected from the DOT/AAR inventory of current crossings by a computer program. The only restriction on the random selection process was that the crossing be public and equipped with active warning devices. The result was a sample file that contained a proportional representation of crossings equipped with flashing lights, gates, and highway signals.

The results of the discriminant analysis indicate that 9,877 (34.5 percent) of the sampled crossings have the same prevalent physical and operational characteristics as those crossings that have CWT systems. Extending this percentage to the total number of crossings nationwide (56,211) implies that approximately 19,400 crossings may require but do not have CWT capabilities.

Reliability of CWT Need Estimate

It should be noted that discriminant analysis is used on the national inventory to estimate the number of crossings where CWT systems may be required by making the following assumptions:

- The discriminant function is completely accurate. The discriminant function was determined, as shown in Table 2, to correctly classify crossings with known CWT installations 78.2 percent of the time. The actual number of crossings that may require CWT systems could therefore be higher or lower than the obtained estimate.
- The national inventory is accurate. The accuracy of the national inventory on operational data items is questionable. The railroads and agencies responsible for roadway maintenance do not, in the majority of cases, update the inventory for changes in AADT, number of trains, switching activity, and train speeds.
- Physical and operational conditions are continuous. The discriminant analysis was performed by using the current physical and operational conditions present at the crossing. The conditions that existed when the decision was made to install the CWT systems, however, may not be the same as those that are currently contained in the national inventory. The discriminant function may therefore have been developed from physical and operational conditions that have evolved since CWT installation, not those on which the need was predicated.
- Crossings with passive warning devices do not need CWT systems. There may be crossings that currently have passive warning devices that are in need of both active devices and CWT systems. However, only crossings with active warning devices were included in the discriminant analysis.
- CWT systems are compatible and alternative solutions are absent. The estimated number of crossings that, because of the proximity of adjacent crossings and other inhibiting factors, would not be eligible for CWT installations is unknown. In addition to those crossings incompatible with CWT installations, there may also be crossings where alternative devices such as motion sensors can provide warning-time uniformity.
- CWT systems are installed for correct and similar reasons. The discriminant function was developed from two groups of crossings. One group was verified as having CWT devices and the other as not having CWT devices. The commonality within each group was therefore the presence or absence of CWT devices. Because the crossings used in building the discriminant function were partially obtained from the crossings being investigated for accident analysis, AADT and train movements were relatively high. The two mutually exclusive groups were therefore similar with regard to AADT and train movements, but no other controls on operational or physical features were exerted in selecting crossings for analysis. It is assumed, therefore, that inherent differences exist between the two groups on which the need for CWT devices is predicated. For example, it is expected that, on the average, crossings with CWT devices will have higher train speed ratios than crossings that do not have CWT devices. Ancillary assumptions, therefore, are that railroads are inherently using guidelines on which the need for CWT devices is predicated and that these guidelines are similar among railroads (even though the surveys indicated that no established guidelines existed).

The independent variables selected for the combined discriminant function were analyzed to determine whether differences exist between the group with and that without CWT devices. The Kolmogorov-Smirnov two-sample test was used to determine whether significant differences exist in the cumulative distributions of the variable categories between two groups.

The results of this analysis for maximum speed, total trains, number of tracks, and switching ratio are presented in Tables 3 through 6, respectively, in which it is revealed that in all instances, for crossings without CWT devices, a larger proportion of the total is found at the lower end of the variable grouping. This difference is large enough to be significant and indicates that, with regard to the operational variables analyzed, the two groups exhibit different distributions. Not only are significant differences exhibited, but the manner in which the differences occur is in accord with what could be expected. Crossings with CWT devices have a higher incidence of occurrence when the maximum speed, total trains, number of tracks, and switching activity are maximized.

TABLE 3 Kolmogorov-Smirnov Test: Maximum Speed

Maximum Speed (mph)	Frequency		Cumulative Frequency		
	With CWT	Without CWT	With CWT	Without CWT	Difference
0-10	7	44	0.0365	0.2095	-0.1730
11-20	15	30	0.1146	0.3524	-0.2378
21-30	41	78	0.3281	0.7238	-0.3957
31-40	35	11	0.5104	0.7762	-0.2658
41-50	38	24	0.7083	0.8905	-0.1822
51-60	19	9	0.8073	0.9333	-0.1260
>60	37	14	1	1	0

Note: |Maximum difference| = 0.3957; K-S critical value (95 percent level of confidence) = 0.1358.

TABLE 4 Kolmogorov-Smirnov Test: Total Trains

No. of Trains	Frequency		Cumulative Frequency		
	With CWT	Without CWT	With CWT	Without CWT	Difference
0	1	8	0.0052	0.0381	-0.0329
1-2	6	46	0.0365	0.2571	-0.2206
3-5	11	50	0.0938	0.4952	-0.4014
6-10	16	20	0.1771	0.5905	-0.4134
11-15	19	12	0.2761	0.6476	-0.3715
16-20	52	23	0.5469	0.7571	-0.2102
21-25	24	18	0.6719	0.8429	-0.1710
>25	63	33	1	1	0

Note: |Maximum difference| = 0.4134; K-S critical value (95 percent level of confidence) = 0.1358.

TABLE 5 Kolmogorov-Smirnov Test: Number of Tracks

No. of Tracks	Frequency		Cumulative Frequency		
	With CWT	Without CWT	With CWT	Without CWT	Difference
1	56	120	0.2917	0.5714	-0.2797
2	74	60	0.6771	0.8571	-0.1800
≥3	62	30	1.0000	1.0000	0

Note: |Maximum difference| = 0.2797; K-S critical value (95 percent level of confidence) = 0.1358.

TABLE 6 Kolmogorov-Smirnov Test: Switching Ratio

Switching Ratio	Frequency		Cumulative Frequency		
	With CWT	Without CWT	With CWT	Without CWT	Difference
0	63	87	0.3281	0.4143	-0.0862
0-0.3	11	43	0.3854	0.6190	-0.2336
0.31-0.49	-	3	0.3854	0.6333	-0.2479
0.50-0.74	4	8	0.4063	0.6714	-0.2651
0.75-0.99	6	2	0.4375	0.6810	-0.2435
1.0-1.9	15	33	0.5156	0.8381	-0.3225
2.0-2.9	16	8	0.5990	0.8762	-0.2772
3.0-3.9	12	6	0.6615	0.9048	-0.2433
4.0-4.9	19	3	0.7604	0.9190	-0.1586
5.0-5.9	4	8	0.7813	0.9571	-0.1758
6.0-6.9	10	2	0.8333	0.9667	-0.1334
≥7	32	7	1.000	1.000	0

Note: |Maximum difference| = 0.3225; K-S critical value (95 percent level of confidence) = 0.1358.

CONCLUSIONS

1. No quantitative guidelines established by either the state or the railroads could be identified that would help prescribe where CWT devices should be installed. Considerations that are involved in determining the need for CWT installations include switching activity, AADT, maximum speed, and train speed variation. What limits are necessary on each variable or on any combination of them to justify installation is apparently judgmental and performed on a crossing-by-crossing basis.

2. The verification process indicated that the national inventory was not accurate in identifying locations with CWT installations. The primary reasons for this inaccuracy are seen to be the inherent problems in distinguishing between motion sensors and CWT devices and upgrades to the crossing equipment that were not posted to the inventory.

3. Some of the factors inhibiting the installation of CWT systems are based on perceptions of cost, dependability, and compatibility formed from problems with early CWT models. Many of these problems have been resolved and are not more prevalent in current CWT models than in other train-detection and control logic systems.

4. The results of the discriminant analysis indicated that the best predictive function was obtained by combining crossings with different types of warning devices. This could be partially the result of sample size. Sample sizes were restricted by the procedures used to develop both the groups and the discriminant function. For example, as a result of the verification process and sample partitioning for function development and classification, only 47 crossings with flashing lights and CWT devices were used for function development. This sample size is too small to achieve a strong function for CWT capabilities.

5. Results of the discriminant analysis indicate that 19,400 crossings nationwide may require CWT capabilities. Applying this estimate in conjunction with the estimated 6,300 crossings already having the capability indicates that an additional 13,100 crossings may require CWT systems. This estimate is based on the primary assumptions that (a) the national inventory is accurate with regard to physical and operational characteristics, (b) CWT devices are compatible with the environment at each crossing and alternative countermeasures are not feasible, (c) the physical and operational conditions currently represented in the national inventory were present when the CWT systems were installed, and (d) there are no crossings currently with passive warning de-

vices that require active devices to be installed in conjunction with CWT systems.

6. The characteristics of the independent variables used in the discriminant function reveal that there are significant operational differences between the group of crossings with CWT and that without CWT devices. This indicates that although specific installation criteria in use by the railroads could not be identified, operational abnormalities do exist that prompt the use of CWT systems.

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The Safety, Economic, and Environmental Consequences of Requiring Stops at Railroad-Highway Crossings

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ABSTRACT

The purpose of this study was to determine the safety, economic, operational, and environmental consequences of requiring hazardous materials transporters, school buses, and passenger buses to stop at railroad crossings with active warning devices when the devices are not activated. The study included an assessment of the positive and negative impacts on accidents involving trains and those in which trains are not involved, traffic operations, fuel consumption, delay, pullout-lane construction and maintenance costs, and environmental degradation. Results indicate that not mandating stops at railroad crossings with active devices when the devices are not activated would reduce both train and nontrain accidents annually for all three classes of vehicles; the net annual decrease in train-involved accidents would be 2.6, 10.8, and 17.4 percent for hazardous materials transporters, school buses, and passenger buses, respectively. The annual economic savings resulting from not requiring stops were estimated as $328,000 in accident costs; $1,241,000 in pullout-lane construction and maintenance costs; $12,267,000 in excess fuel consumption; and $1,510,000 in delay.

The actions of drivers of hazardous materials haulers, school buses, and passenger buses at railroad-highway grade crossings are governed by regulations of the Bureau of Motor Carrier Safety (BMCS) through the Federal Motor Carrier Safety Regulations (FMCSR) and by individual state and local regulations. The state and local regulations are adapted, either entirely or partially, from the FMCSR or from recommendations of the National Committee on Uniform Traffic Laws and Ordinances (NCUTLO) contained in the Uniform Vehicle Code (UVC).

Principal differences exist between the FMCSR and the recommendations of the UVC regarding mandatory stops at railroad-highway grade crossings. These differences include no exemptions in the UVC for mandatory stops at streetcar crossings, tracks used exclusively for industrial switching purposes, and abandoned tracks. In addition, stops are not required in the UVC at crossings with train-activated gates

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