CONSTANT WARNING TIME DEVICES FOR RAILROAD-HIGHWAY CROSSINGS

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Research, Development, and Technology

Turner-Fairbank Highway Research Center
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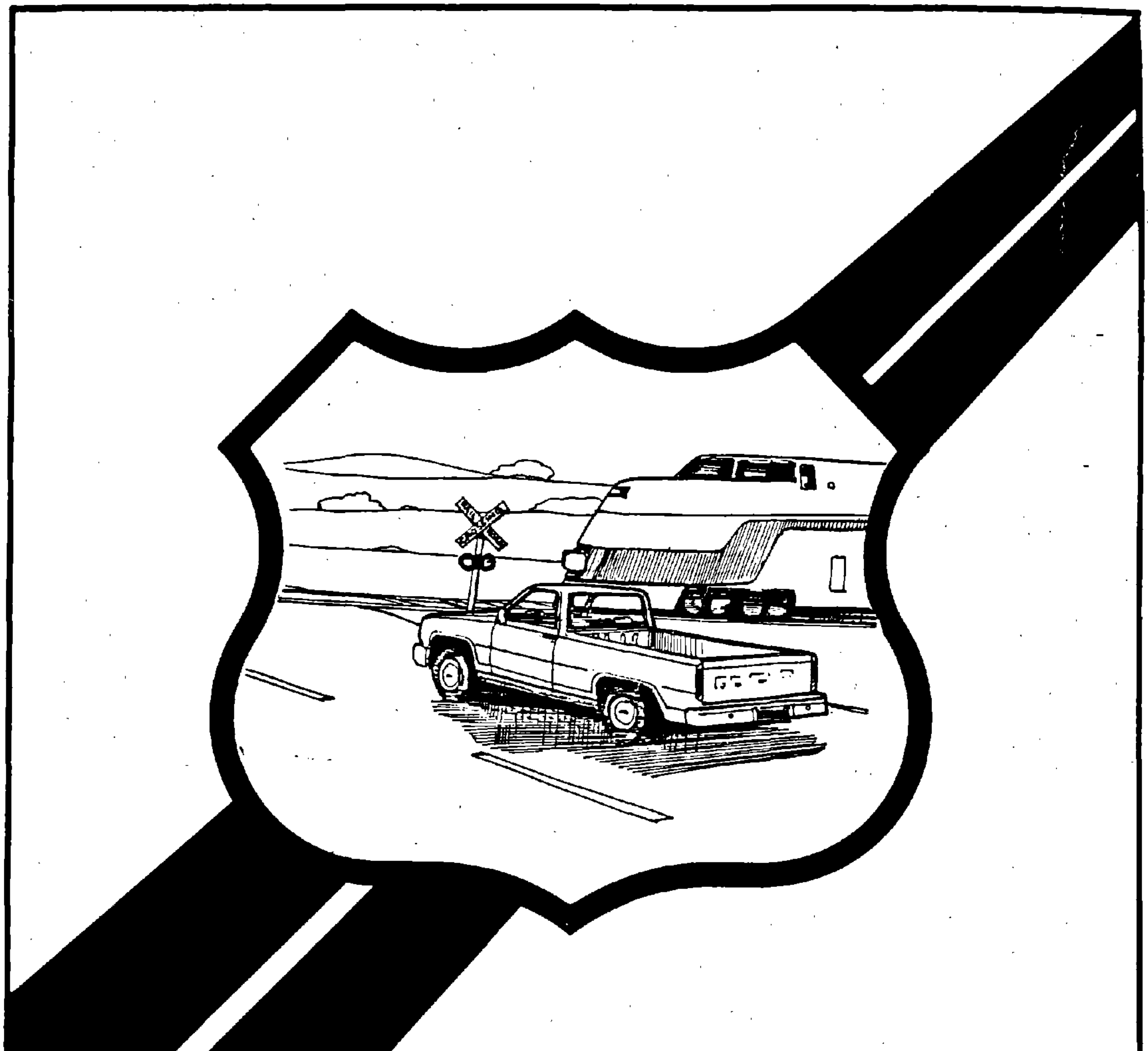

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16. Abstract

The primary purposes of this study were to determine the extent of use, reasons for nonuse, and the effectiveness of constant warning time (CWT) systems. CWT systems consist of track circuitry and control logic capable of determining train speed, motion, and distance from the crossing. These parameters are used by the logic system to estimate train arrival time and to provide a uniform amount of advance warning at the railroad-highway crossings. The result is that motorists are not subjected to unnecessarily long delays before train arrival.

Analysis of operational data indicated that CWT systems are effective in both providing 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 crossings with CWT systems, in the majority of cases, 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.

The study disclosed that 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 sytems. Many of these problems have been resolved and are no longer prevalent in current models.

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METRIC CONVERSION FACTORS

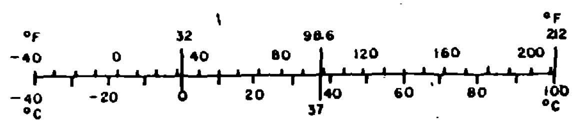
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

Introduction

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 due to 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 inititally developed approximately 100 years ago. These systems, unless configured with overriding capabilities, provide continuous operation of the crossing warning system while a train is on the approach. Trains travelling slower than the design speed or stopping on the approach length result in prolonged activation of the railroad-highway warning system.

When the inappropriate activation becomes a common occurrence, motorists tend to disregard the warning and drive through or around the protective devices, thereby increasing the probability of vehicle-train collisions.[1] The potential consequences associated with excessively long warning times resulted in the development of a constant warning time track circuit and control logic system.

The constant warning time (CWT) system, developed during the 1960's, differs from other systems in that it is capable of detecting train speed in addition to train presence, 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 seconds, 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 due to 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.

Where the speed of different trains on a given track vary considerably under normal operating conditions, the Manual on Uniform Traffic Control Devices (MUTCD) recommends that special devices or circuits be installed to provide reasonably uniform notice in advance of all train movements over the crossing.[3] CWT systems are currently the most desirable type of train detection track circuitry for locations where fluctuations in train speeds result in warning time variation.

Study Scope and Objectives

The specific objectives of the study were:

- To determine the use and effectiveness of CWT systems by examining available accident and inventory data.
- To determine the economic, operational and maintenance reasons which limit the use of CWT systems.
- To determine the effectiveness of CWT systems by examining driver behavior at similar crossings with and without CWT devices.
- To identify and evaluate alternative nonhardware solutions to provide a uniform advance warning time at crossings.

Research Approach

The research approach was structured to use information from the Federal Railroad Administration (FRA), individual States, railroad operating authorities, equipment manufacturers and operational data collected by the project team to perform the following activities:

- Determination of CWT usage: Information from railroads and manufacturers were used to determine the major users of CWT systems and to estimate the number of crossings nationwide with CWT installations. Discriminant analysis techniques were used to determine the primary physical and operational crossing characteristics which are prevalent at locations that have CWT installations. These characteristics were used to estimate the number of crossings, nationwide, whose physical and operational characteristics indicate a need for CWT systems.

- Perceived problems with CWT use: A literature review and surveys forwarded to both users and nonusers of CWT systems were used to determine the perceived problems with CWT deployment and use. These problems were investigated to determine if they were present with current CWT systems or indicative of earlier generation models.

- CWT effectiveness: The effectiveness of CWT systems in reducing accidents and hazardous driving behavior, and in providing a uniform amount of advance warning time, were determined. This involved data extraction and statistical analysis of information obtained from railroads, individual States, FRA, and operational data collected at railroad crossings.

- Alternative solutions to CWT deployment: A meeting was conducted with representatives of the railroads to determine the availability and feasibility of alternative nonhardware solutions to the installations of CWT systems.

Conclusions

Project activities resulted in the following conclusions:

- No quantitative guidelines, established by either the States or railroads, could be identified that would help prescribe when CWT systems 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 or on any combinations of these variables to justify installation is apparently judgmental and exerted on a crossing-by-crossing basis.

- Some States have recommendations on the maximum amount of warning time which is permissible from device activation until train arrival. These maximum time recommendations vary from State to State with noted examples being 35, 40, and 60 seconds. This represents train speed ratios of 1.75:1, 2:1, and 3:1, respectively.

- The verification process and subsequent statistical tests indicated that the FRA inventory was not accurate in identifying locations with CWT installations. The primary reasons for this discrepancy are the difficulty in distinguishing between motion sensors and CWT systems and upgrades to the crossing equipment that were not posted to the inventory.

- 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.

- 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 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.

- Estimates based on information supplied by manufacturers indicate that there are approximately 6,300 crossings, nationwide, currently equipped with CWT systems. The actual number of crossings with CWT capabilities could, however, be higher due to the use of timed circuits by some railroads.

- Results of the discriminant analysis indicates that 19,400 crossings may require CWT capabilities. Applying this estimate in conjunction with an estimated 6,300 crossings already having CWT capability indicates that an additional 13,100 crossings may require CWT systems. Descriminant analysis was performed on groups of crossings with verified train detection and control logic systems. The accuracy of the decriminant function was not, therefore, dependent upon the accuracy of the national inventory in specifying crossings with and without CWT systems. The accuracy of the number of crossings that may require CWT systems is, however, based on the primary assumptions that: 1) the national inventory is accurate with regard to physical and operational characteristics, 2) CWT systems are compatible with the environment at each crossing, 3) alternative countermeasures are not feasible, 4) the physical and operational conditions currently represented in the national inventory were present when the CWT systems were installed, and 5) there are no crossings currently with passive warning devices which require active devices installed in conjunction with CWT systems. The use of discriminant analysis to determine the magnitude of CWT need on a national basis was considered as the most advantageous approach. The relatively large number of necessary assumptions, however, indicates that the resultant estimate should be used with caution.

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

- The modular design and self-diagnostic capabilities of modern CWT systems reduces the maintenance expertise formerly required by purchasers of CWT systems.

- Operational and physical crossing characteristics can combine to complicate the proper installation and operation of CWT systems. Often these factors can become so convoluted that assistance from signal engineers with CWT experience must be obtained. There are virtually no instances, however, where the combination of inhibiting factors cannot be addressed by appropriate countermeasures.

- The reliability of CWT systems and the mean time between failure has increased dramatically with the newer models.

- Some railroads combine a series of fixed-distance and motion sensing systems with time-out circuits to provide a quasi-constant warning time system.

- Railroad personnel indicated that the most prevalent problems with CWT systems are low ballast resistance and component damage due to electrical storms. These problems are, however, common to all track circuit systems.

- The nonhardware alternative to the installation of CWT systems that was most attractive to railroad personnel was the closure or relocation of the crossing.

CHAPTER 1. INTRODUCTION

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 due to 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 inititally 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 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 over 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 1960's, 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 seconds, 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 due to 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.

Statement of the Problem

Where the speed of different trains on a given track vary considerably under normal operating conditions, the Manual on Uniform Traffic Control Devices (MUTCD) recommends that special devices or circuits be installed to provide reasonably uniform notice in advance of all train movements over the crossing.[3] CWT systems are currently the most desirable type of train detection track circuitry where fluctuations in train speed result in warning time variation. The number of crossings equipped with CWT systems is, however, relatively small.

A number of reasons have been postulated for the relatively infrequent use of CWT systems. Included in these reasons are the perceived high associated costs, dependability, compatibility with other track circuit systems, and the absence of definite warranting criteria.[1,4,5] The extent to which these reasons are applicable to, and influence the installation of current CWT models was unknown. In addition, it was also unknown if CWT systems were effective in reducing train-involved accidents.

Study Scope and Objectives

The activites of this study necessitated the use of information available from the Federal Railroad Administration (FRA), individual States, railroad operating authorities, equipment manufacturers, and the collection of field data. The specific objectives of the study were:

- To determine the use and effectiveness of CWT systems by examining available accident and inventory data.
- To determine the economic, operational, and maintenance reasons for the limited use of CWT systems.
- To determine the effectiveness of CWT systems by examining driver behavior at similar crossings with and without CWT systems.
- To identify and evaluate alternative nonhardware solutions to provide a uniform advance warning time at crossings.

The individual tasks performed and their sequence of performance are presented in figure 1.

Grade Crossing Warning Systems

The grade crossing warning system consists of two basic parts: 1) the warning equipment, and 2) the control equipment. The warning equipment consists of those items that provide the visual and audible warning to the roadway traffic. These items include flashing lights, gates, highway signals, bells, and cantilevered lights. The control equipment are those components which control the operation of the visible and audible devices.

The control equipment consists of two primary subsystems: 1) train detection, and 2) control logic. The control logic contains all of the equipment to interpret the train detection information and operate the warning system. This includes the capability to recognize when the system should revert to the fail-safe mode; the presence of a train; and in some instances, its motion, direction, and speed.

All train detection systems currently in use use the track circuit to provide the control logic with information pertaining to the presence of a train. There are five basic types of track circuits which are used for train detection at rail-highway intersections.

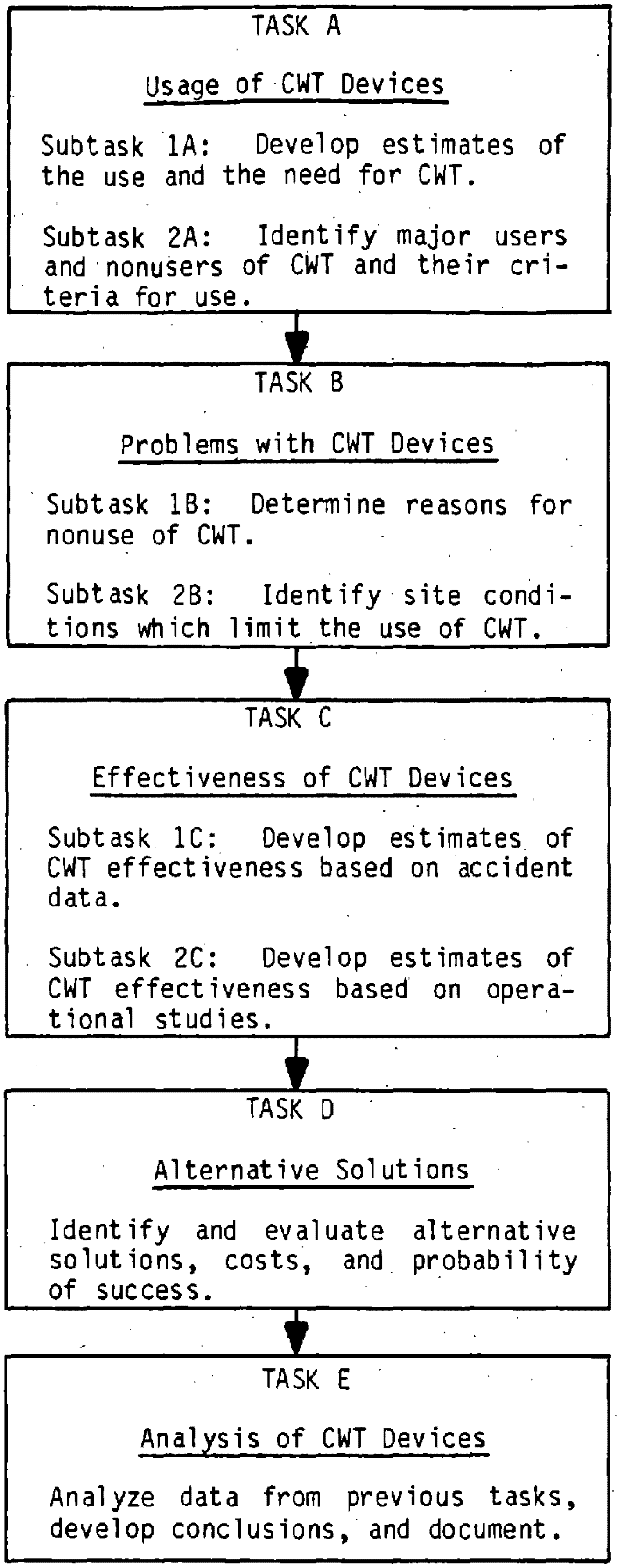

Figure 1. Flowchart of project tasks.

Direct Current (DC) Track Circuits

The DC track circuit, presented in figure 2, is basically the same method developed approximately 100 years ago for automatic train detection. It is a relatively simple circuit that is still used in many crossing warning systems. The rails are used to complete a simple series circuit. Energy is supplied by a battery, through a limiting resistor, to one rail, then through another limiting resistor to a DC relay and back over the other rail to the battery. The relay is constantly energized as long as the circuit is intact and no train is present between the battery and the relay. The presence of a train acts as a shunt, shorting out the current to the relay, causing it to de-energize and activate the warning devices. The length of the circuit is determined by placing insulated joints between rail sections to electrically separate them.

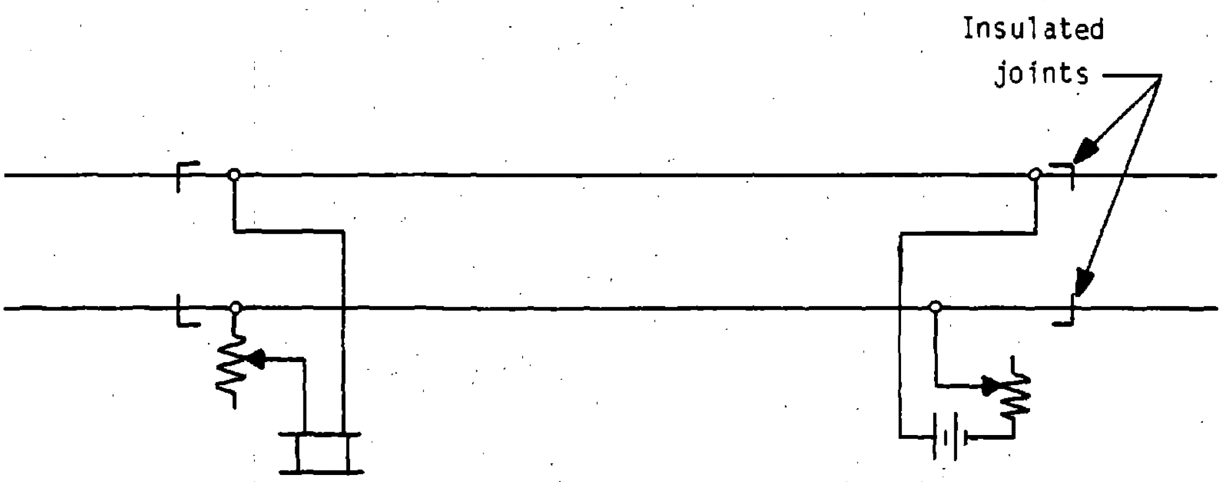

Figure 2. DC track circuit.[6]

Three-track circuits, as presented in figure 3, and associated logic elements can be used to stop the operation of the warning system as soon as a train clears the crossing. This prevents the need to wait until the rear of the train completely clears the circuit and reduces roadway vehicle delay.

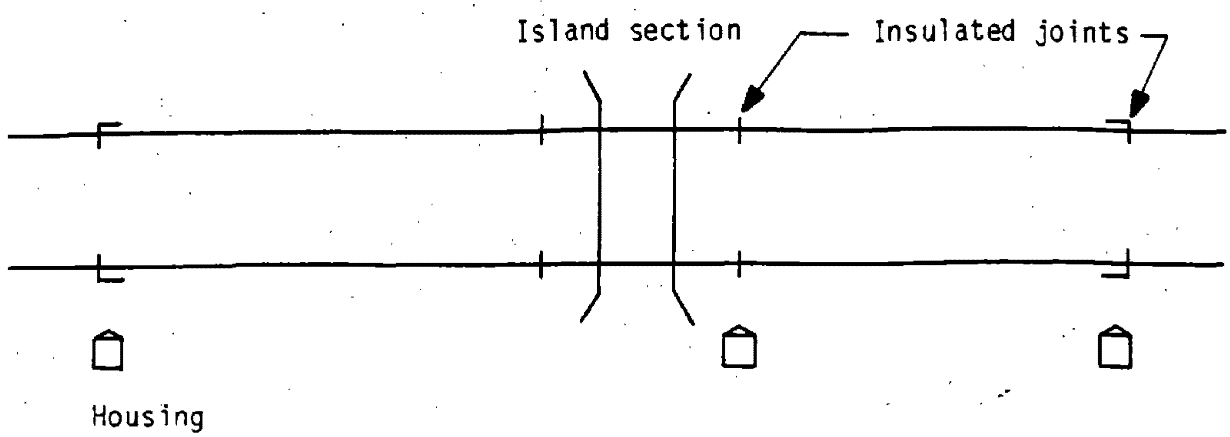

Figure 3. Three-track circuit system.[6]

The warning system is activated as soon as trains enter an approach track circuit. To insure that a minimum warning time is available, it is necessary to design the system on the speed of the fastest train. Consequently, trains that travel at a slower speed than the design speed or that change speed or stop within the approach circuit will activate the warning system for a longer period of time.

This problem can be alleviated by dividing the approach circuit into several smaller circuits and incorporating timers as presented in figure 4. The system is configured so that the first approach circuit is a pretimed circuit. Faster trains start the warning system when the second track circuit is occupied and slower trains initiate operation in the third circuit. A time-out feature is used to clear the crossing for highway traffic if a train stops on the approach.

AC-DC Track Circuits (Type C)

The AC-DC track circuit, commonly referred to as "type C", is used extensively where rails are rusty and where approach distances are less than 1,500 feet (450 m). This circuit, presented in figure 5, is a half-wave rectified circuit. Insulated joints define the circuit length with a rectifier connected across the rails at the far end of the track circuit. This circuit has the advantage of permitting the location of all of the operating equipment at the crossing.

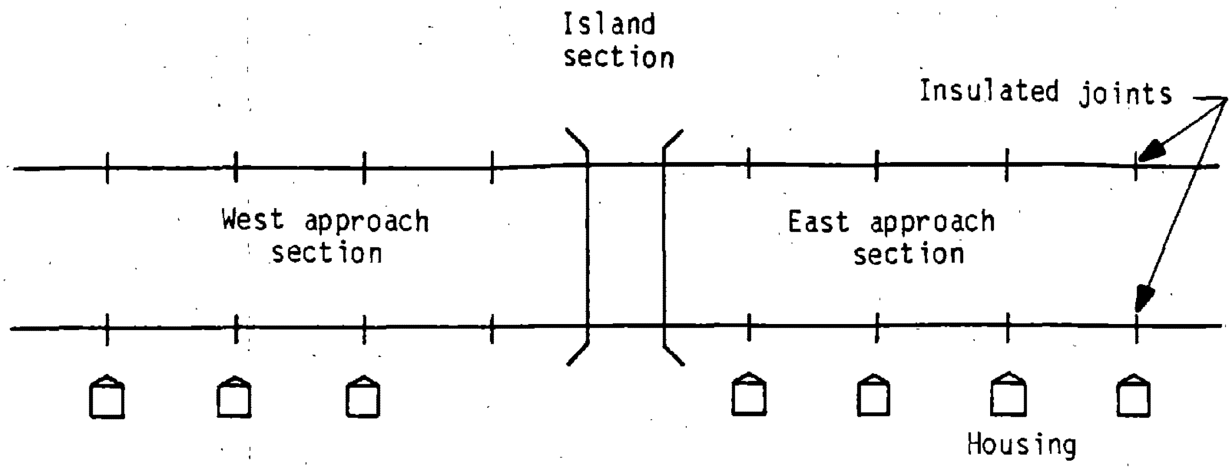

Figure 4. Track circuits with timing sections.[6]

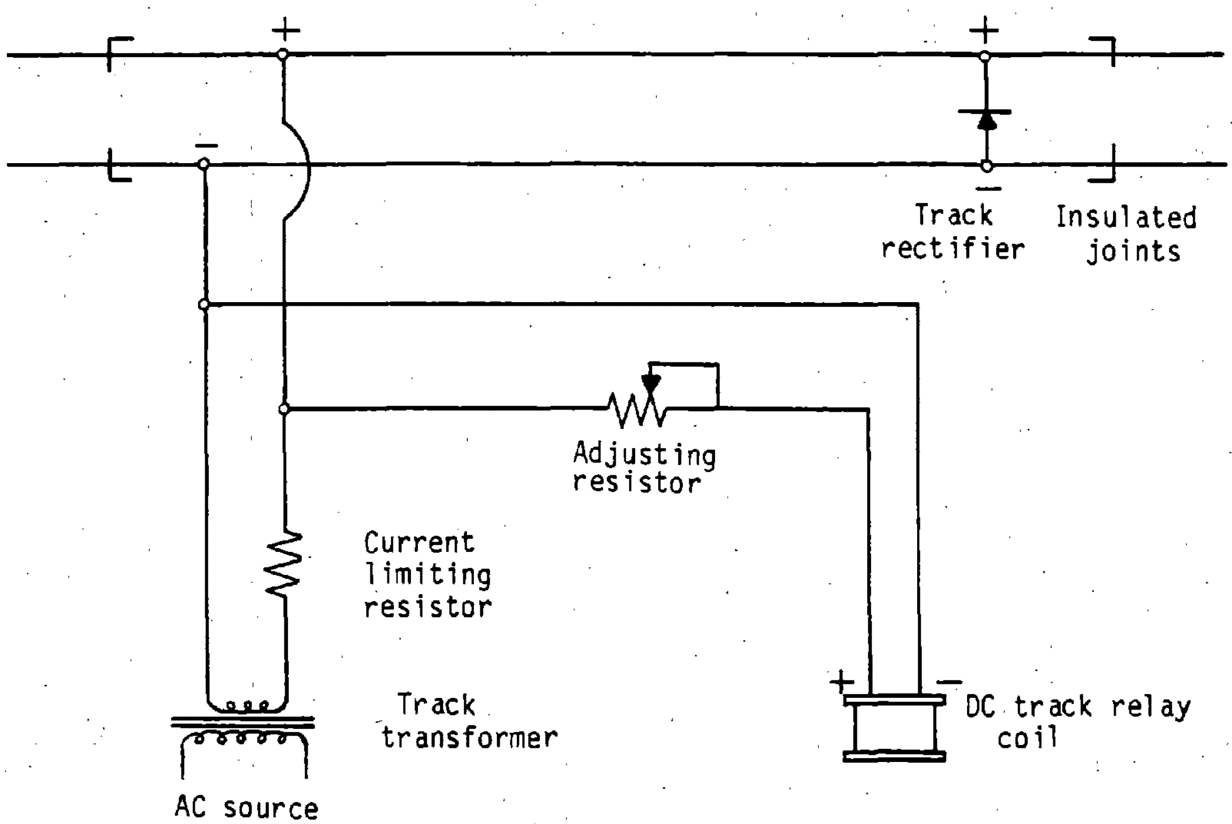

Figure 5. AC-DC track circuit (type C).[6]

The AC-DC track circuit operates by passing a major portion of the transformer secondary current flow through the rectifier during one-half-cycle. The remaining half-cycle current creates a net DC component in the track circuit relay. A train present on the rails reduces the rail voltage and prevents the AC current from being rectified. A low DC voltage is, therefore, present at the DC track relay causing it to release.

Audio Frequency Overlay Track Circuits (AFO)

The AFO track circuit can be superimposed over other track circuits and is similar in operation to the DC track circuits. The AFO circuit, presented in figure 6, uses a transmitter and receiver of the same frequency instead of the battery and relay used in the DC circuit.

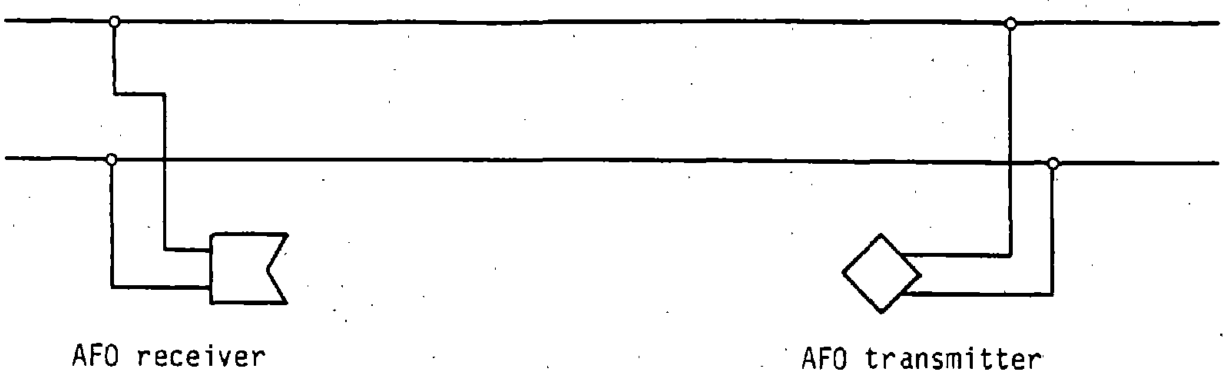

Figure 6. Audio frequency overlay track circuit.[6]

The AFO track circuit transmits an AC sinewave via the rails to a receiver at the opposite end of the track approach. The receiver changes the AC current to DC to operate a relay which operates the warning devices using control logic which is similar to the DC track circuit. No insulated joints are required for the AFO circuit.

Motion Sensitive Track Circuits

This type of circuit, presented in figure 7, uses audio frequencies similar to the AFO equipment. The motion sensitive circuit can, however, detect the motion and direction of, trains on the approach. This is accomplished by continuously monitoring the track circuit impedance to the flow of current. The impedance of the circuit remains relatively constant when no train is within the approach. As a train is moving toward the crossing, the track circuit impedance decreases. If a train stops on the approach, the impedance will remain relatively constant. When a train is departing from the crossing, the impedance will increase. The control logic recognizes when a train is stopped (not blocking the crossing), or moving away. This causes the warning system to be deactivated, reducing the delay to roadway vehicles. This type of circuit is advantageous, therefore, where trains either stop frequently, or perform switching operations within the normal approach limits of a crossing.

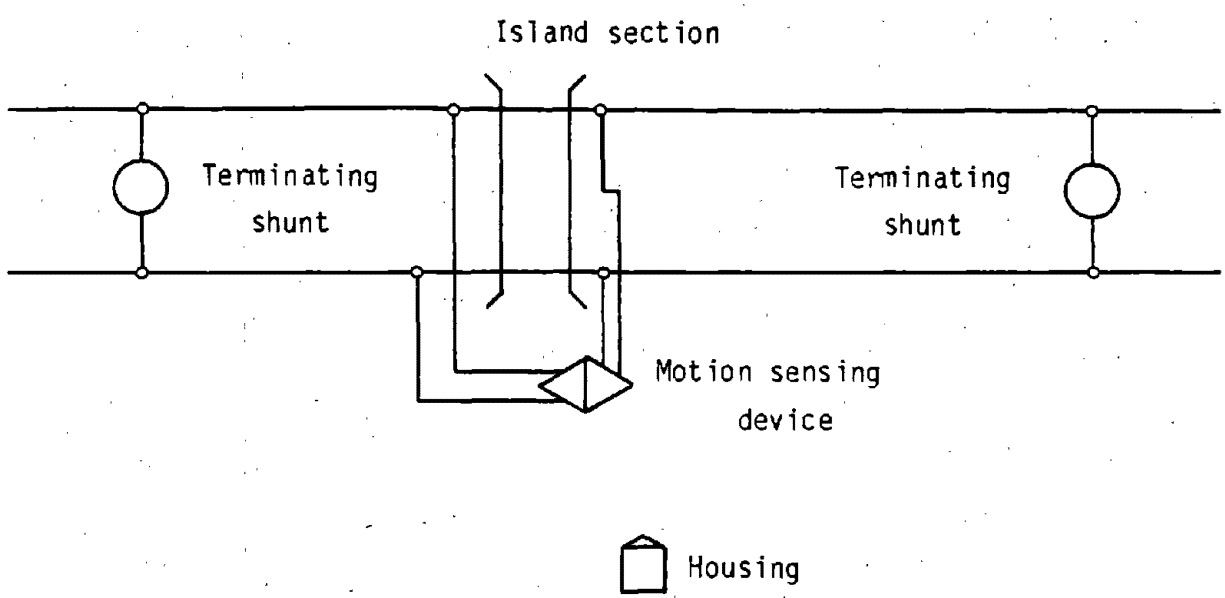

Figure 7. Motion sensitive track circuit (bidirectional application).[6]

The motion sensitive track circuit has the advantage of locating all of the power equipment at the crossing and not requiring the use of insulated joints in a bidirectional application. Tuned electrical shunts are required to define the circuit limits. Circuits of adjacent crossings can be overlaid and overlapped with other train detection circuits.

A unidirectional application can be used if ballast or track conditions preclude a bidirectional application. The unidirectional application, presented in figure 8, requires a separate device for each approach zone with activated rail joints separating the two systems.

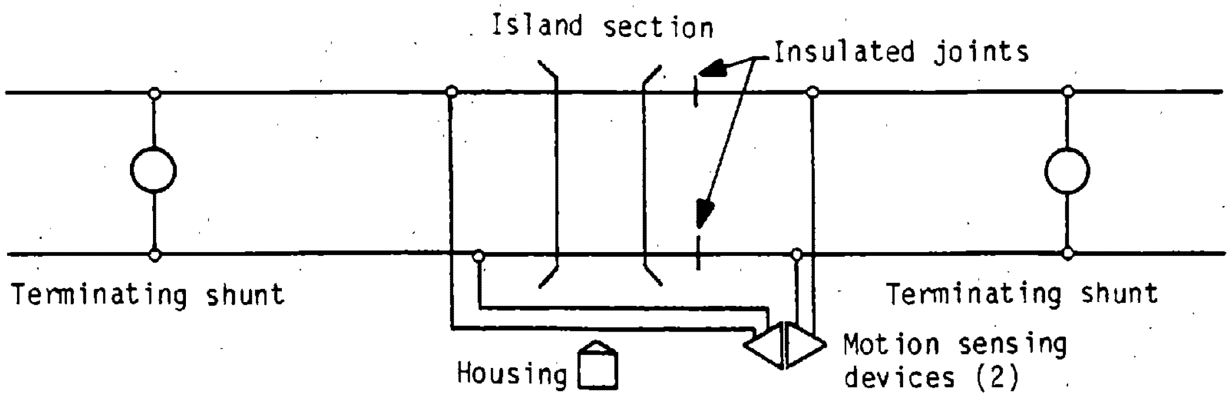

Figure 8. Unidirectional application of motion sensitive track circuit.[6]

Constant Warning Time Track Circuits

Constant warning time track circuits have the capability of detecting train presence and measuring its speed and distance from the crossing. The control logic uses this information to provide a preset and uniform amount of warning time prior to train arrival. Constant warning time systems permit trains to move or switch on the approaches, and depending upon their speed, do not cause the warning system to be activated if the train never reaches the crossing. The uniform warning time reduces vehicular delay and provides drivers with a consistent expectation of train arrival time.

Constant warning time systems can be installed in either a unidirectional or bidirectional mode. The unidirectional application, presented in figure 9, requires a separate device to monitor each approach. The approach zones are separated by insulated rail joints with a terminating shunt placed at the outermost end of each zone. The unidirectional application is advantageous where there are closely following train moves or where a number of competing frequencies exist. Unidirectional applications are also appropriate where it is not possible, due to other rail uses, to bypass the insulated joints.

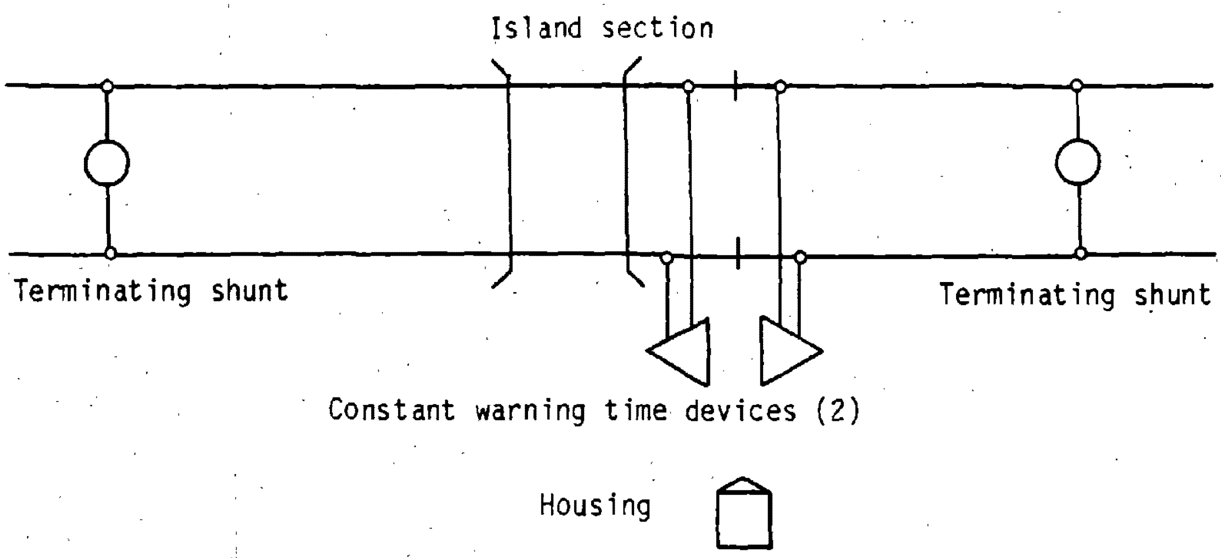

Figure 9. Unidirectional application of constant warning time track circuit.[6]

A bidirectional application of the constant warning time devices is presented in figure 10. This application permits one unit to monitor both approach zones and does not require insulated rail joints. The end of the approach zones is established by the placement of terminating shunts.

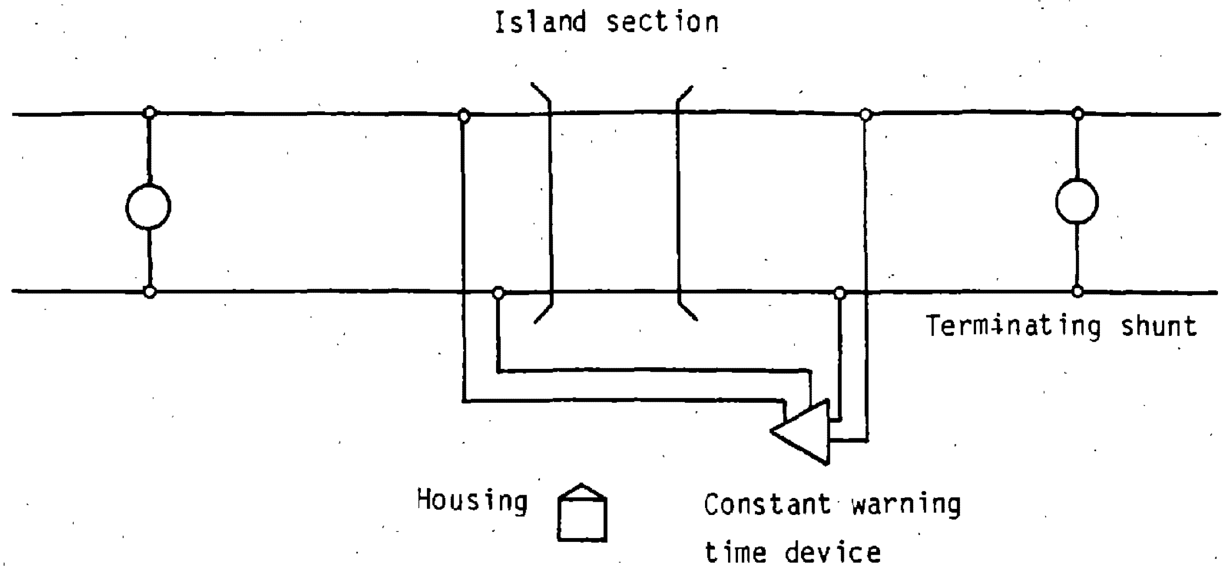

Figure 10. Bidirectional application of constant warning time track circuit.[6]

CHAPTER 2. USAGE OF CONSTANT WARNING TIME SYSTEMS

Estimate of CWT Usage

An estimate of the extent of CWT usage was required to enable: 1) an identification of railroads which are both major users and nonusers, 2) to determine the existence of CWT installation criteria, and 3) to estimate the number of crossings nationwide that should have CWT systems. Determining the major users of CWT devices was accomplished by analyzing the FRA national inventory and by obtaining information from manufacturers.

Analysis of FRA National Inventory

The FRA national inventory contains an entry regarding the presence of CWT systems. This entry asks the question, "Do crossing signals provide speed selection for trains?" A "yes" response indicates that CWT systems are present at the crossing. The national inventory was searched to ascertain: 1) the number of nationwide crossings with CWT systems, 2) the physical and operational characteristics of each crossing; and 3) the major users.

This search resulted in a number of crossings that were coded as having both CWT capabilities and passive warning devices. These entries are a contradiction. If train detection circuitry is present at a crossing, then there must be active devices present. This contradiction was resolved by searching the inventory to locate only those crossings which were public and noted as having constant warning time capabilities in conjunction with active warning devices.

This process indicated that there were 6,337 crossings equipped with CWT systems stratified as shown in table 1. Information pertaining to the crossing inventory number, operating railroad, intersecting roadway, State, city, county, and nearest timetable station were then obtained from a random sample of these crossings. Telephone contacts were established with the operating railroads to verify that the crossings were actually equipped with CWT systems.

Table 1. Crossings identified from the national inventory as being equipped with CWT.

Highest Protection Class	Frequency	Percent of Total
Flashing Lights	2,473	39.0
Gates	3,781	59.7
Highway Signals	83	1.3
Total	6,337	100.0

Results of the verification process on the random sample indicated that a large proportion of crossings identified as having CWT devices by the national inventory actually did not have such devices. Conversations with railroad representatives revealed that they were aware of these inaccuracies. The railroad representatives indicated that the inaccuracies resulted from the inherent difficulty in discerning the difference between motion-sensing devices and devices equipped with constant warning time capability. In addition, upgrades to CWT devices were not always posted to the national inventory.

As part of the verification process, which was required for the accident analysis, information was requested on 201 crossings from 20 different railroads. Since the primary purpose of obtaining this information was to analyze accidents, both crossings with and without CWT devices were used. The railroads were requested to verify in a survey the presence of CWT devices, the date of installation, and train volumes. Results of the returned surveys are presented in table 2. This table indicates that 42 percent (20/48*100) of the crossings coded as having CWT capabilities were coded incorrectly.

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 manufacturers currently engaged in the manufacture of CWT systems. These manufacturers were contacted and

Table 2. Summary of the verification results for type of train detection device.

Responding Railroad	Total Crossings Requested	Coded No Actual No	Coded No Actual CWT	Coded CWT Actual CWT	Coded CWT Actual No
1	15	9	-	-	3
2	5	3	-	-	1
3	1	-	-	1	-
4	22	7	-	7	5
5	24	8	-	3	5
6	16	6	-	9	1
7	19	3	3	7	5
8	4	4	-	-	-
9	5	3	1	1	-
Total	111	43	4	28	20

requested to provide information on the number and model of the devices sold, the year purchased and, if possible, the purchaser and location of the installation.

Safetran Systems agreed to provide information. Representatives from Safetran forwarded the requested information but stated that identifying the individual locations for which the systems were purchased was difficult since the railroads often purchase the units in quantity, either providing just one or no location of installation. It was not possible, therefore, for Safetran to positively identify all locations of CWT installation. In addition, providing information on the possible installation locations required a time-consuming, manual file search. The large amount of time required, plus the questionable accuracy of the information, resulted in locational information being provided for only the States of Michigan, Ohio, Illinois, and Indiana. Locational information was obtained for these States since it was planned that crossings from this area would be used in the collection of traffic conflict and operational data.

According to the Safetran files (summarized in table 3), a total of 12,113 CWT units were sold in the United States. All of these units were believed to be purchased as Grade Crossing Protectors (GCP), which is Safetran's product name for constant warning time devices. The possibility does exist, however, that some of the Model 600 devices were purchased as motion sensors only. This is especially true with one railroad which purchased the Model 600 unit both with and without constant warning time capabilities. This railroad purchased 2,307 Model 600 units, of which 75 percent (1,730) were estimated by Safetran as having CWT capabilities. Estimating the number of crossings with CWT from sales data, required consideration of the following: 1) unidirectional or bidirectional deployment, 2) the number of units sold as replacements or for future installation, 3) units sold by manufacturers other than Safetran, and 4) 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 constant warning time capabilities. Information was not available on the number of units that were purchased with bidirectional capabilities. Attempts to estimate the number of units with bidirectional capabilities required 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 crossings within the approach circuitry of each other. The overlapping approaches require that a different frequency be used for each crossing. However, in heavily congested areas where several streets are close together, bidirectional applications must occasionally be broken up with a unidirectional installation. The proper choice of either a bidirectional or unidirectional CWT device is, therefore, site specific and cannot be estimated by information from the national inventory or the individual manufacturer.

Table 3. Purchase of constant warning time devices from one manufacturer.

Railroad Designation	CWT Purchases	Percent of Total
1	634	5.23
2	21	0.17
3	3	0.02
4	5	0.04
5	3,085	25.47
6	74	0.61
7	2	0.02
8	69	0.57
9	64	0.53
10	85	0.70
11	375	3.10
12	12	0.10
13	25	0.21
14	6	0.05
15	4	0.03
16	41	0.34
17	2	0.02
18	14	0.12
19	49	0.40
20	34	0.28
21	9	0.07
22	33	0.27
23	2	0.02
24	5	0.04
25	263	2.17
26	99	0.82
27	40	0.33
28	8*	0.07
29	2	0.02
30	67	0.55
31	5	0.04
32	16	0.13
33	66	0.54
34	8	0.07
35	227	1.87
36	4	0.03
37	16	0.13
38	17	0.14
39	134	1.11
40	57	0.47
41	1	0.01
42	4	0.03
43	5,544	45.77
44	4	0.03
45	2	0.02
46	2	0.02
47	9	0.07
48	2	0.02
49	862	7.12
50	1	0.01

* Known as currently out of service.

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

Since only Safetran was willing to provide information on the number of units purchased, the number of systems supplied by other manufacturers was estimated. Since Safetran was the only major supplier of CWT systems until approximately 1981, it was estimated that only 500 units were supplied by other manufacturers.

The number of crossings equipped with CWT systems was assumed to be 50 percent of the total units purchased. This was assumed because:

- The availability of bidirectional CWT units is relatively recent. Due to 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 over estimating the number of crossings with CWT capabilities. A number of the units purchased may have been replacement units for existing installations. There is, however, no way to accurately estimate the number of replacement installations.

- A number of crossings consist of multiple tracks where more than one track requires CWT capabilities. Assuming that every CWT purchase equipped a total crossing with CWT capabilities would result in not compensating for the multiple track crossings.

- Information was not available on the number of bidirectional units purchased. A majority of CWT units currently available have the capability of either unidirectional or bidirectional applications. Information was only available on the number of units sold, not on their application capability.

The 50 percent assumption compensates for units purchased for replacement and for multiple track crossings. For example, the purchase of 1,000 bidirectional units has the potential of providing 1,000 single track crossings with CWT capabilities. Applying the 50 percent assumption results, however, in only crediting 500 crossings with CWT capabilities.

The remaining 500 units that have not been assigned to crossings are inherently compensating for units purchased for replacement and for installations at more than one track per crossing. The results of this estimating procedure are presented in table 4.

Table 4. Estimates of CWT units purchased and estimated crossings equipped with CWT devices.

Manufacturer	CWT Units Sold	Crossings Equipped with CWT
Safetran	12,113	6,057
Others	500	250
Known as out of service	-8	-4
Total	12,605	6,303

It should be noted that the number of crossings estimated as being equipped with CWT devices obtained by considering manufacturer's sales (6,303) is close to that obtained from the national inventory (6,337). Replies from the railroads, however, indicated that there was an error rate of 42 percent in identifying the actual crossings with CWT devices. It was expected, therefore, that the similarity in the number of crossings equipped with CWT devices, exhibited by the national inventory and manufacturer sales, is a coincidence.

To confirm this suspicion, a Chi-square test of independence was performed on pertinent physical and operational characteristics between locations identified from information provided by Safetran and from the national inventory. Safetran had provided, as accurately as possible, the locations of installations for Michigan, Ohio, Illinois and Indiana. This information, summarized in table 5, included the State, city, roadway and purchasing railroad. These data items were used to obtain the crossing inventory number from the national inventory file. If the inventory indicated that the crossing identified by Safetran had CWT capabilities then it was assumed that CWT devices were actually present.

Difficulties encountered in identifying the crossing number resulted in only 177 crossings being verified as having CWT installation from the total of 1,483 units sold in the four States. Of the 177 verified crossings 54, 105, and 18 were installed in conjunction with flashing lights, gates with flashing lights, and traffic signals, respectively.

Table 5. Estimates of CWT units sold and verified CWT crossings in Michigan, Ohio, Indiana, and Illinois.

	IL	IN	MI	OH	Total
Units purchased by railroads for use within the respective State.	818	180	333	152	1,483
Crossings verified as having CWT devices.	107	20	39	11	177

The Chi-square test, presented in table 6, consisted of comparisons between type of warning device, speed ratio, AADT, number of trains, and number of tracks. This information was obtained from the inventory file for both those locations identified from the Safetran sales information and the national inventory. The rationale behind the test of these variables was that the installation of CWT devices are predicated by physical and operational characteristics of the crossing. If the national inventory file , by itself, was dependable for identifying crossings with CWT devices, then the characteristics of the inventory crossings would be similar to the characteristics of the verified Safetran crossings. The results of the test indicate that there is a significant difference, at a 99 percent level of confidence, in the tested physical and operational characteristics of the crossings identified from the manufacturer's and the national inventory. It can be concluded, therefore, that the similarity in the total number of crossings identified by the manufacturer's sales information and that identified from the national inventory was a coincidence. The national inventory cannot, therefore, be used to identify crossings equipped with CWT devices.

Table 6. Chi-square test of independence for physical and operational characteristics between CWT crossings identified by manufacturers' list and national inventory.

Method of Crossing Identification	Highest Protection Class		Speed Ratio				AADT						Number of Trains		Number of Tracks			Total
	Flashing Lights	Gates	≤2:1	2:1	3:1	≥3:1	≤250	251-500	500-1,000	1,001-5,000	5,000-10,000	≥10,000	0-5	≥5	1	2	≥3	
Manufacturer Sales	54	105	52	25	10	72	19	11	16	51	27	35	18	141	39	64	58	797
National Inventory	2,473	3,781	1,640	806	329	3,477	763	656	782	2,387	1,588	708	1,590	4,664	2,904	1,827	1,529	31,904
Totals	2,527	3,886	1,692	831	339	3,549	782	667	798	2,438	1,615	743	1,608	4,805	2,943	1,891	1,587	32,701

Chi-square = 81.8
df = 16
Critical Value (99% L.C.) = 32.0

Survey Results from Railroads and States

The information provided by Safetran, previously presented as table 3, was used to identify the major users and nonusers of CWT systems. Surveys were developed and administered to each group of railroads, in addition to States, to determine the reasons for use or nonuse, encountered problems with CWT systems, and the existence of any installation criteria.

Surveys of CWT Users

The list provided by Safetran revealed that 15 railroads had purchased at least 60 CWT units. Nine railroads designated as CWT users were randomly selected from this list, and forwarded a survey. The questions were orientated toward determining the existence of installation criteria, number of units purchased, mean time between failure (MTBF), prevalent causes of failure, alternatives to the installation of CWT devices, and physical conditions at the crossing that limit deployment. The complete survey elements and received responses are presented in Volume II.

A summary of the survey responses pertaining to installation criteria and number of units purchased are contained in figure 11. Inspection of this figure reveals that none of the surveyed railroads have any formal criteria for CWT installation. Primary concerns for determining the need for CWT systems were 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 variations and through train to switching train ratio 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 a concern that must be addressed in the design of a CWT system for a particular crossing environment.

Question Summary	Response Summary	Number of Responses 1/
Is the selection of locations for the installation of CWT devices based on established warrants?	a) Based on unusual and numerous train movements. b) No warrants, but some States have guidelines. c) No.	1 1 2
Please provide a copy or describe any warrants.	a) No response. b) No formal warrants.	1 4
If no formal warrants exist, what factors are taken into consideration for CWT installation?	a) Variation in train speed. b) Proximity of signalized control points. c) Switching operations. d) Train traffic. e) Vehicle traffic. f) Traffic signal preemption.	4 2 3 2 2 1
CWT devices are primarily installed as:	a) Sole corrective countermeasures. b) One part of a crossing upgrading project. c) No response.	2 3 1
Approximately how many CWT devices have been purchased from manufacturers other than Safetran?	a) SAB Harmon. b) Others.	503

1/ The total responses for each question vary due to multiple responses.

Figure 11. Summary of survey responses from railroads identified as users of constant warning time systems.

Surveys of CWT Nonusers

Nonusers were identified by randomly selecting nine of the largest railroads that were either not included on the Safetran list or had purchased a small quantity of CWT systems. The survey forwarded to the nonusers consisted of questions pertaining 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 for CWT systems to be more attractive. The complete survey elements and responses are presented in Volume II.

A summary of the survey responses are contained in figure 12. This figure 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 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 predicate the need for CWT systems. There were no formal criteria for installation, but five of the eight respondents stated that they consider the installation of CWT systems to address specific crossing problems. Alternatives to the installation of CWT devices included the installation of timing circuits and changing the time of switching operations.

Cost was identified as the most important factor in increasing the attractiveness of CWT systems. Responses pertaining to cost included smaller 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.

Surveys of States

Surveys were also forwarded to nine States to determine if any criteria existed for the installation of CWT systems. Included in this survey were queries pertaining to activities performed during grade crossing inspections and recommendations given to the railroads. These surveys were forwarded to a contact within the Federal Highway Administration and conducted by telephone. This process did not result in the identification of any States that had criteria for the installation of, or procedures

Question Summary	Response Summary	Number of Responses[1/]
What are the reasons for not using CWT devices mere extensively?	a) No new installations. b) CWT devices do not always fail in restrictive mode. c) High initial cost. d) High maintenance cost. e) Not needed. f) Too complicated for railroad personnel to install and maintain. g) Recently started using CWT devices. h) Considered as undependable.	1 1 2 1 4 1 2 2
What guidelines or warrants are used to determine where CWT devices should be installed?	a) None. b) Inspection of crossing. c) Wide variations in train speeds. d) Excessive switching.	4 1 2 1
Is the installation of CWT devices considered as a possible countermeasure?	a) Not considered necessary. b) Yes. c) No.	2 5 1
What operational characteristics and identified problems prompt the consideration of CWT devices?	a) Variation in train speeds. b) Switching activity. c) Maximum train speed. d) Roadway volume. e) Ballast condition.	6 6 1 2 1
What changes would need to be accomplished to make CWT devices more attractive?	a) Greater dependability. b) Smaller purchase price. c) Less maintenance and maintenance cost. d) Government participation in maintenance cost. e) Simplified installation, maintenance, and testing. f) No response. g) Present day units are adequate.	2 3 2 1 1 2 1

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

Figure 12. Summary of survey responses from railroads identified as nonusers of constant warning time systems.

Question Summary	Response Summary	Number of Responses[1/]
Additional comments, observations or suggestions.	a) Need to improve system dependability.	1
	b) Need a frequency compatability chart.	1
	c) Would use CWT devices if needed.	1
	d) No response.	3
	e) Primary cause of failure is not due to problems with CWT devices.	1

(1) The total responses for each question vary due to multiple responses.

Figure 12. Summary of survey responses from railroads identified as nonusers of contant warning time systems (continued).

for, identifying the need for CWT devices. Therefore, no completed surveys were obtained from the States. A sample of the survey designed for the States is included in Volume II.

Estimating Total Crossings That May Require CWT Capabilities

One requirement of this project was to determine the number of crossings that should have CWT installations, but do not. To fulfill this requirement, it was necessary to develop project installation criteria which would define the physical and operational characteristics that are prevalent at crossings equipped with CWT systems. Two different approaches were tried in an effort to develop the installation criteria, consisting of: 1) requesting criteria on the surveys forwarded to the railroads and States, and 2) discriminant analysis.

<u>Installation Criteria from Survey Results</u>

The survey results did not reveal any established quantifiable criteria that were used by either railroads or States to identify crossings in need of CWT installations. Considerations that were mentioned as influencing factors in CWT determinations included speed variability, switching activity, maximum train speed, large train and vehicle volumes, and in the case of State responses, minimum and maximum warning time until train arrival. The railroads, which mentioned considerations for installation, did not describe what limits to speed variability or maximum number of switching moves triggered the decision to install CWT devices. The absence of quantitative values resulted in the railroad responses not being a direct benefit in establishing project installation criteria.

The minimum and maximum warning time established by various States could have been used to establish installation guidelines for use within each State. The wide variations in the maximum permissible warning time recommended by the States, however, precludes the extension of this criteria to nationwide estimates. For example, each State that responded to the survey was in agreement on a minimum warning time of 20 seconds, but had maximum recommended times of 35, 40, and 60 seconds from first activation until train arrival. This represents a maximum to minimum warning time ratio of 1.75:1, 2:1 and 3:1, respectively, for 35, 40, and 60 second maximum warning times. Considering a fixed distance approach length, and a track circuitry without CWT capabilities, then the warning time ratio also represents the permissible train speed ratio. The limited number of State responses and the variations in permissible warning time, resulted in the responses being considered inadequate for establishing nationwide installation criteria.

Discriminant Analysis

Discriminant analysis is a statistical technique for studying the differences between two or more groups 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: 1) crossings with, and 2) crossings without CWT capabilities. Discriminant analysis compares common variables (maximum speed, number of tracks, AADT, etc.) between those two groups. Those variables which 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, since no quantitative criteria were obtained from either the railroads or States. The considerations used by the railroads and 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).
- 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 with, and the 128 crossings without, CWT capabilities used to develop the discriminant function were individually verified as having the indicated train detection capabilities. This verification occurred by combining the verified locations from the Safetran list with crossings verified by the individual railroads. Therefore, the function was developed from groups of crossings with known types of track circuitry and control logic systems. Other data items, such as maximum and minimum train speeds, crossing angle, number of trains, etc. were obtained from the crossing inventory and not verified on a crossing-by-crossing basis.

The discriminant analysis was performed using the stepwise method. The stepwise procedure automatically selects the independent variables on the basis of their discriminating power. Those variables which maximize the differences between the centroids of each group are included in the analysis. As variables are selected for inclusion, some variables previously selected may lose their discriminating power. This can occur because the information contained by variables in the function can also be contained in some combination of the entering variables. The result is redundancy which does not improve the power of the discriminant function. However, a variable that had been removed may reenter at a later step if it satisfies the selection criteria at that time. The result of the stepwise discriminant analysis is a function that is built by inspecting all of the input variables and selecting only those variables which contribute to differences between the two groups.

Discriminant functions were constructed for three distinct types of groups, based on the highest priority warning device at the crossings. Separate functions were developed for crossings with 1) flashing lights only, 2) gates with flashing lights and gates with highway signals, and 3) 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 type, was that the inherent differences in predicating the need for gates, such as high AADT's and train movements, could result in large differences in the discriminant functions for each individual group. Constructing separate functions permitted each function to be inspected separately. This was done to determine if greater accuracy would be achieved by analyzing crossing groups separately by warning device type, as opposed to a combined group.

Results of Discriminant Analysis

The resultant discriminant functions were used to classify the 40 percent of the crossings that were not used to develop the function. The percentage of correct classifications was one measure used to determine the accuracy of the discriminant function. Results of the discriminant analysis are summarized in table 7 and reveal the following:

- Flashing Lights Only: The final discriminant function contains the independent variables of maximum speed, total trains, switching ratio and crossing angle. The only independent variable that can logically be related to CWT need is switching ratio. Provisions for maximum speed, if speeds are relatively consistent, can be made with conventional 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 respective group (i.e., crossings with CWT and crossing without CWT) centroids exceeds one (0.82798 + 0.26788), which increases the probability that the function will be able to distinguish between the crossings and, hence, correctly assign the crossings to their respective group.

  Inspecting the classification step results reveals that the function is capable of correctly identifying crossings that have CWT devices installed 81 percent of the time. Correct classification of crossings without CWT devices occurred 69.7 percent of the time for an overall accuracy rate of 72.4 percent.

- 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. Since 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 which 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.

Table 7. Summary of discriminant analysis.

	Function Development Step						Classification Step			
	Number of Cases		Discriminant Function		Group Centroids					
Highest Priority Warning Device	CWT	No CWT	Variable	Discriminant Coefficient	Group	Centroid	Group	Number of Cases	Percent Correct Classification	Correct Combined Classification
Flashing Lights Only	47	104	Maximum Speed	0.41958	CWT	0.82798	CWT	21	81.0	72.4
			Total Trains	0.57817						
			Switching Ratio	0.27737	NO CWT	-0.26788	NO CWT	66	69.7	
			Crossing Angle	0.37096						
Gates with Flashing Lights and Gates with Highway Signals	78	28	Switching Ratio	0.35542	CWT	-0.19364	CWT	45	62.2	57.9
			Minimum Speed	0.39028						
			AADT	0.75487	NO CWT	0.58900	NO CWT	12	41.7	
			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	CWT	78	78.2	71.9
			Total Trains	0.54032						
			Number of Tracks	0.23516	NO CWT	-0.55705	NO CWT	82	65.9	
			Switching Ratio	0.22637						

The group centroids are only separated by 0.78 (0.58900 + 0.19364), which indicates that the discriminant function has a smaller range around each group centroid in which to determine which group each crossing should be classified under. This tends to decrease the dependability of the discriminant classifications. This 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.

- Combined Categories of Flashing Lights Only and Gates with Flashing Lights and Gates with Highway Signals: This function included maximum speed, total trains, number of tracks, and switching ratio in the function. All of these variables had positive coefficients and, since 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 one (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 due to the combined warning device types of flashing lights only and gates with flashing lights and gates with highway signals, the sample size was larger for the combined category than for the individual categories. The larger sample size, in conjunction with the discriminant functions, resulted in the decision to use the combined discriminant function.

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 nationwide crossings with active warning devices. The sample crossings were randomly picked from the FRA inventory of current crossings by a computer program. The only restrictions on the random selection process were 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 applying the discriminant analysis to the national inventory are presented in table 8. This table indicates that 9,877 (34.5 percent) of the sampled crossings have the same relevant physical and operational characteristics as those crossings which had CWT systems. Extending this percentage to the total number of nationwide crossings implies that approximately 19,400 crossings, nationwide, should be equipped with CWT systems. Since it was previously estimated that approximately 6,300 crossings currently have CWT capabilities, there are 13,100 crossings (19,400 - 6,300) that may require, but do not have CWT capabilities.

Table 8. Results of discriminant analysis on public crossings with active warning devices.

Number of Crossings Sampled	Predicted Need for CWT	Percent of Sample Needing CWT	Total Nationwide Crossings	Nationwide Crossings That May Require CWT
28,607	9,877	34.5	56,211	19,400

Reliability of Discriminant Analysis Results

It should be noted that the use of discriminant analysis on the FRA inventory to estimate the number of crossings where CWT systems may be required is inherently making the assumptions discussed below:

- The discriminant function is completely accurate. The discriminant function was determined, as shown in table 7, to correctly classify crossings with known CWT installations 78.2 percent of the time. The actual number of crossings that may require CWT devices could, therefore, be higher or lower than the obtained estimate.
- The FRA inventory is accurate. The accuracy of the FRA 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.
- Continuity of physical and operational conditions. 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 conditions that are currently contained in the national inventory. The discriminant function, therefore, may have been developed from physical and operational conditions that have evolved since, and not predicated the need for, CWT installation.

- 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. Since only crossings with active warning devices were included in the discriminant analysis the passive crossings requiring CWT systems were not included.

- CWT compatability and absence of alternative solutions. The number of the estimated crossings which, due to competing use of the rails for signaling purposes and other inhibiting factors, would not be eligible for CWT installations is unknown. In addition there are a number of crossings that provide a uniform amount of advance warning by using a series of track circuits with time-out relays in lieu of CWT systems.

- 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 systems and the other group verified as not having CWT systems. The commonality within each group was, therefore, the presence or absence of CWT systems. Since, 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 on selecting crossings for analysis. It was assumed, therefore, that inherent differences existed between the two groups that predicate the need for CWT systems. For example, it was expected that, on the average, crossings with CWT systems would have higher train speed ratios than crossings that do not have CWT systems. Ancillary assumptions, therefore, are that railroads are inherently using guidelines to predicate the need for CWT systems 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 if differences exist between the groups with and without CWT systems. This analysis consisted of applying the Kolmogorov-Smirnov two-sample test at a 95 percent level of confidence. This test was used to determine if significant differences existed in the cumulative distributions of the variable categories between the two groups.

The results of this analysis for maximum speed, total trains, number of tracks, and switching ratio are presented in tables 9 through 12, res-

Table 9. Kolmogonov-Smirnov test on maximum speed between verified crossings with and without CWT devices.

Maximum Speed	Frequency		Cumulative Frequency		Difference
	CWT	No CWT	CWT	No CWT	
0-10	7	44	.0365	.2095	-.1730
11-20	15	30	.1146	.3524	-.2378
21-30	41	78	.3281	.7238	-.3957
31-40	35	11	.5104	.7762	-.2658
41-50	38	24	.7083	.8905	-.1822
51-60	19	9	.8073	.9333	-.1260
>60	37	14	1	1	0

|maximum difference| = 0.3957
95 percent critical K-S value = 0.1358

Table 10. Kolmogonov-Smirnov test on total trains between verified crossings with and without CWT devices.

Total Trains	Frequency		Cumulative Frequency		Difference
	CWT	No CWT	CWT	No CWT	
0	1	8	.0052	.0381	-.0329
1-2	6	46	.0365	.2571	-.2206
3-5	11	50	.0938	.4952	-.4014
6-10	16	20	.1771	.5905	-.4134
11-15	19	12	.2761	.6476	-.3715
16-20	52	23	.5469	.7571	-.2102
21-25	24	18	.6719	.8429	-.1710
>25	63	33	1	1	0

|maximum difference| = 0.4134
95 percent critical K-S Value = 0.1358

Table 11. Kolmogonov-Smirnov test on number of tracks between verified crossings with and without CWT devices.

Number of Tracks	Frequency		Cumulative Frequency		Difference
	CWT	No CWT	CWT	No CWT	
1	56	120	.2917	.5714	-.2797
2	74	60	.6771	.8571	-.1800
≥3	62	30	1.000	1.000	0

\|maximum difference\| = 0.2797
95 percent critical K-S value = 0.1358

Table 12. Kolmogonov-Smirnov test on switching ratio between verified crossings with and without CWT devices.

Switching Ratio	Frequency		Cumulative Frequency		Difference
	CWT	No CWT	CWT	No CWT	
0	63	87	.3281	.4143	-.0862
0-.3	11	43	.3854	.6190	-.2336
.31-.49	-	3	.3854	.6333	-.2479
.50-.74	4	8	.4063	.6714	-.2651
.75-.99	6	2	.4375	.6810	-.2435
1.0-1.9	15	33	.5156	.8381	-.3225
2.0-2.9	16	8	.5990	.8762	-.2772
3.0-3.9	12	6	.6615	.9048	-.2433
4.0-4.9	19	3	.7604	.9190	-.1586
5.0-5.9	4	8	.7813	.9571	-.1758
6.0-6.9	10	2	.8333	.9667	-.1334
≥7	32	7	1.000	1.000	0

\|maximum difference\| = 0.3225
95 percent critical K-S value = 0.1358

pectively. These tables reveal that in all instances crossings without CWT systems have a larger proportion of the total occurring in the lower variable groupings. This difference is large enough to be significant and indicates that, with regard to the analyzed variables, 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 systems have a higher incidence of occurrence when the maximum speeds, total trains, number of tracks, and switching activity are maximized.

CHAPTER 3. PERCEIVED PROBLEMS WITH CONSTANT WARNING TIME SYSTEMS

One of the postulated reasons why CWT systems have not had a wider acceptance among the railroad community are perceived problems with regard to reliability, compatibility, and cost. Many of the problems that are identified in the literature are problems that existed with the early CWT models. The majority of these problems have been eliminated and are not more prevalent in the current CWT models than in any other type of track circuitry. All track circuits, for example, are prone to revert to the fail-safe mode when the rails are subjected to lightning strikes during an electrical storm. Statements that the CWT circuits will be damaged by electrical surges caused by lightning strikes are true. These statements must, however, be tempered with the realization that all other track circuits will be damaged also.

The literature review conducted as part of this study, and the surveys forwarded to the railroads, identified a number of the perceived problems with CWT systems. These problems are summarized in this chapter to make known the concerns of both CWT users and potential users. It has been noted where these problems are not more prevalent with CWT systems and which countermeasures and improvements in newer CWT models are available to decrease the adverse impacts.

It should also be noted that with at least one manufacturer, the purchase of a CWT unit includes the cost of engineering consultant services. Problems in adapting the devices to specific physical or operational environments can be resolved, therefore, at no additional cost to the purchaser. Hence, the purchaser is not required to have personnel with the technical expertise to resolve specific installation or device calibration tasks.

Summary of Perceived Problems

Effect of Ballast Resistance

All train detection devices currently in standard use utilize the rails of the track as part of the circuit. The rails of the track form comparatively low impedance feed and return paths for electrical current flow. Since the rails are not insulated from each other, the electrical current tends to leak from rail to rail during wet weather. If this leakage becomes large enough to de-energize the track circuit relay, the warning circuit will then be activated. The control logic of the track circuits are, therefore, intentionally designed to recognize incidents of high current leakage as an inoperative condition and automatically revert to the fail-safe condition.

The paths of current leakage are through the ties, ballast, and accumulated dirt via moisture. The resistance of these paths is variable; high, for example, when the ballast is dry and low when it is wet. The resistance is, therefore, dependent upon the physical condition of the ties and whether the ballast is dry, wet, or frozen. Current leakage is kept low by maintaining as high a resistance as possible. This can be achieved by maintaining ties in a waterproof condition, by keeping dirt and ballast out of contact with the rails, and by using ballast rock that is nonconductive and will provide good drainage. Maximum ballast resistance results in greater system dependability, less energy loss, and reduced costs of operation and maintenance.

Extremely low ballast resistance can not only result in false signal activation, but also in a difficult determination of train distance from the crossing. Constant warning time devices use a constant current feed to develop a track voltage. The rails present an impedance to current flow with accompanying variations in voltage, depending upon the distance of the track shunt from the feed point. The variations of this track voltage is converted by a computer to estimate the anticipated arrival time of a train at the crossing. Since: 1) the voltage drop across an impedance is equal to the current flow times the impedance, and 2) the applied current remains constant, the track voltage is directly proportional to the track impedance. The track voltage should, ideally, vary linearly with distance and provide a direct measure of train distance from the crossing. Measuring the rate of voltage change should, likewise, determine the train speed.

In reality, an ideal linear relationship does not occur due to variations in ballast resistance. Therefore, the relationship between current, voltage, and impedance becomes a nonlinear function. Figure 13 displays how the difference in the ideal and actual relationships affects the accuracy of measurement. For example, if an ideal relationship (e.g., infinite ballast resistance) did exist, then a recorded voltage could be interpreted as representing a train at a distance of D_1 from the feed point. The train could, however, be at a further distance, D_2, due to varying ballast resistance.[1]

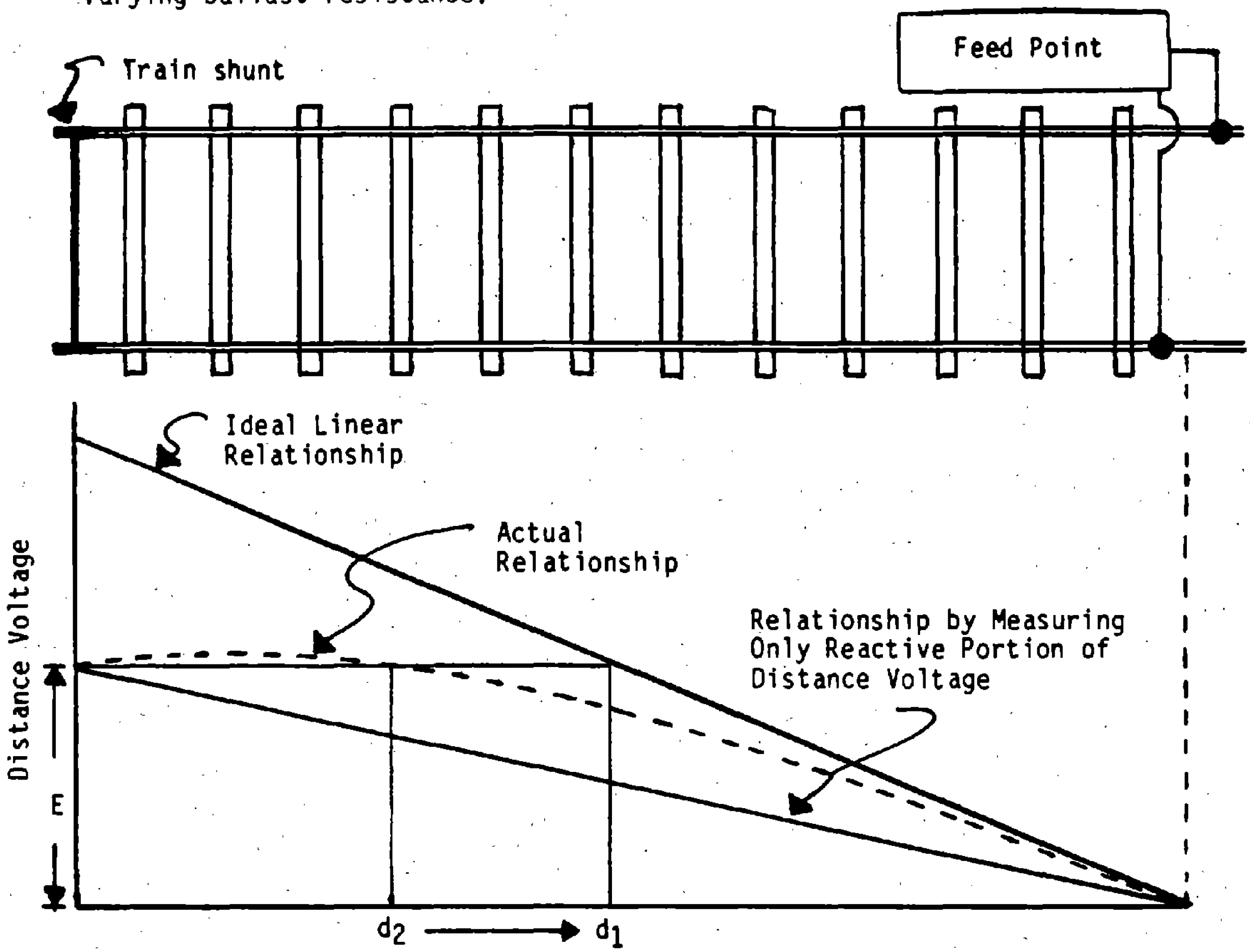

Figure 13. Representation of perceived to actual train distance.[1]

The effect of varying ballast resistance has been mitigated since the first CWT concepts. Initially this was accomplished by measuring the reactive portion of the track impedance. This concept resulted in an improved relationship of voltage to distance. Subsequently, linearity has been further improved under extremely adverse ballast conditions by the mathematical treatment of summing both the reactive and impedance components. An ideal case is presented by the lower curve in figure 13 and provides a more accurate measurement of distance in conditions of varying ballast resistance.

Component Reliability

Grade crossing warning and railroad signalling hardware, by necessity, operate in an extremely harsh environment. The equipment is mounted in trackside relay cases that have no ambient temperature control. Depending upon the location of the relay box, the equipment can be subjected to temperatures as low as 40 degrees Fahrenheit below zero (-40 degrees Celsius) to over 160 degrees Fahrenheit (71 degrees Celsius) inside the case, due to direct sun exposure. Humidity also varies, from extremely dry conditions to conditions where everything is dripping wet. These conditions are compounded by severe vibration from passing trains, and damage from hunters, vandals, and out-of-control automobiles.[4]

Electrical surges from lightning and transient currents from man-made sources also pose problems to wayside electrical components. The rails extend for long distances and form highly inductive and good conductors. The result is a situation in which lightning can create high electrical potential which can propagate for long distances. Railroad signal hardware is, however, normally designed to withstand a 3,000 volt breakdown test. The ability to withstand high voltages coupled with the use of surge arrestors and equalizers which are able to prevent transients of over 1,000 volts, unless the lightning strikes closeby, decreases the potential for electrical surge damage.[4]

The realization of CWT systems is made possible through the use of solid state components. Solid state components are, however, very susceptible to electrical surges and, therefore, require additional surge protection to be designed into the system. Thus, providing protection against electrical surges when using solid state components is a critical factor in device longevity. Improvements in surge and transient suppression have been incorporated into CWT systems which have further improved reliability. This improvement in reliability has occurred in conjunction with the introduction of integrated circuits which have reduced component count while affording improved capabilities.

Maintenance Activity and Cost

The mean time between failure (MTBF) rates for CWT systems are not generally available to the public. Studies performed on some of the earlier models of CWT systems, however, revealed a MTBF rate of 2 1/2 to 3 years.[1] According to the standards established by the railroad, this was close to the maximum failure rate of 2 years. When compared to the MTBF rate of conventional DC circuits of 10 years, the failure rate of early CWT models appeared very high. The MTBF rate has increased dramatically with the newer CWT models. One manufacturer claims that the failure rate of all their current models is from 5 1/2 to 7 1/2 years.

There are a number of reasons why CWT systems do not have the reliability of conventional DC track circuits. One of these reasons is related to device complexity and the interaction of environmental factors. Based on complexity alone, a higher failure rate, due to component damage and malfunction, can be expected. The fail-safe requirement also adds complexity to CWT systems. While the fail-safe feature is a requirement of all systems, it has a greater impact on complicated systems. This is because the fail-safe requirement places added complexity to an already complex device.

Inability to provide broken rail protection and, to some extent, prediction accuracy occur in CWT systems when the ballast resistance is reduced to below 2 to 3 ohms per 1,000 feet of track. Ballast resistance in this neighborhood is not quite low enough to cause failure with conventional DC track circuits or power line frequency AC detection circuits. However, ballast resistance this low causes problems with some of the higher AC frequencies employed by CWT systems. An ideal situation would be a minimum ballast resistance of 3 to 4 ohms per 1,000 feet of track.

Some U.S. railroads, however, have a minimum ballast resistance of 2 to 3 ohms per 1,000 feet or less.[7] There are, therefore, some situations where CWT systems cannot be used unless initial track maintenance is performed especially at crossings where a buildup of conductive materials including deicing salt has occurred over the years.

The electronic equipment and physical track structure for CWT systems may require more maintenance to achieve acceptable operation levels. In the past, although all railroads had the expertise to maintain the track structure, some did not have the expertise to maintain the CWT systems themselves. This is not a problem with the newer models, many of which have status lights and all have modular construction. The status lights indicate faulty modules which can be replaced in their entirety and forwarded to the manufacturer for repair.

Increased Installation Cost

Although total installation costs are a one-time outlay, they can vary drastically from one crossing to another. In addition, to the initial cost of equipment, the installation cost is affected by site characteristics. These characteristics often demand individual planning by a team of railroad and city or state engineers. Insulated joints required by nearby DC track circuits, close proximity of nearby crossings, low ballast resistance and overlay track frequencies are a few examples of peculiarities which require measures and equipment adjustments indigenous to the specific crossing.

Heisler and Morrissey determined that the average installation costs of CWT systems exceeds those of other train track circuitry and control logic systems.[8] The average installation costs (based on 1977 prices) categorized by warning device type, train detection system, and number of tracks are presented in table 13. Although these costs are dated, and the costs of constant warning time systems have been reduced, the table serves to demonstrate the disparity between the various train detection systems at the date of the survey.

Estimates obtained from manufacturers, as part of the study for this report, indicate that 1985 costs for a CWT unit is approximately three thousand dollars higher than required for an audio frequency unit. Since the CWT systems perform functions that cannot be perfomed by the audio circuits, it is not valid to directly compare the costs of the different systems.

Table 13. Average installation costs for motorist warning devices by train detection system and number of tracks, in $1,000. (source: reference 8)

Motorist Warning Device	No. Tracks	Train Detection System[1/]			
		Grade Crossing Predictors	Audio Frequency	Alternating/ Direct Current	Motion Sensors
Flashing Lights	1	---	25.9	22.6	22.3
Cantilevered Flashing Lights	1	---	33.3	46.2	44.2
Flashing Lights with Gates	2	54.3	46.2	43.6	39.0

1/ Sample size for Direct Current System too small for meaningful calculations.

Compatibility with Electrified Railroads

Electrified railroads, which use the rails to provide a return path for traction currents, require the use of impedance bonds which make the use of CWT systems very difficult. It is currently unknown to what extent CWT systems will ever be compatible with electrified systems.[9] The number of miles of electrified railroad is, however, very small.

Bidirectional Versus Unidirectional Deployment

Early CWT models only had unidirectional capabilities. Therefore, if a crossing required a measurement of train speed on both approaches, two unidirectional CWT units were necessary. Current CWT models have bidirectional capabilities enabling the detection of train presence and speed on both approaches. While bidirectional deployments result in greater simplicity and ease of installation, several factors must be considered before selecting bidirectional or unidirectional models.

The simplicity of a bidirectional system is beneficial at locations with overlapping approaches. In overlapping approaches the frequency of each approach passes freely through the adjacent approach to its termination shunt which is located at a full approach distance from the crossing. However, in 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.

Considerations of ballast resistance and frequency are necessary in determining the maximum and minimum operating distances. These are especially important factors when the devices are used with multiple frequencies for train detection on a number of adjacent crossings. The maximum permissible approach length for any operating frequency depends upon the minimum ballast resistance with the distance increasing with higher resistance. The minimum permissible distances reflect the effect of potential loss in the rails and ballast leakage and are inversely proportional to frequency. Higher frequencies are susceptible to degeneration under low ballast resistance conditions. Frequency "bleeding" may be minimized by electrically simulating additional track length through the use of a tunable narrow band shunt.[10]

Determination of the proper track circuit distance or approach length depends upon the maximum train speed, crossing signal operating time, and system response time. The maximum speed is converted to feet per second and is then multiplied by the total time in seconds. For example, a crossing with a maximum train speed of 50 mi/h (80 km/h) (73.3 fps), a signal operating time of 20 seconds, and a system response time of 5 seconds would require an approach distance of 1,833.3 feet.

At the present time, some CWT systems are generally not compatible with 60 and 100 hz AC coded track or coded CAB signal circuits. Existing track circuitry must, therefore, be carefully evaluated when selecting a suitable operating frequency. Prior to the selection of any operating frequency, the frequencies already in use must be surveyed. As a general rule, existing frequencies will be compatible if they do not fail within 24 percent of the CWT operating frequency. If high levels of 60 hz exist, an operating frequency of 114 hz should be avoided.

Survey Results from Railroads

The surveys forwarded to the railroads, discussed in Chapter 2, contained queries pertaining to the perceived problems with CWT systems. Inspecting the response to these questions, summarized in figures 14 and 15, for users and nonusers respectively, indicate that the primary causes of CWT failure are electrical storms, component failure, track circuitry failure, temperature changes, and varying ballast resistance. Ballast resistance was also identified as the most prevalent criteria limiting the installation of CWT systems. Perceived high cost, both maintenance and purchase, in addition to perceived undependability, were factors impeding the use of CWT systems by some railroads.

The railroad survey responses reveal that the perceived problems with regard to dependability, cost, and maintenance, are based on the older CWT models. The newer models have eliminated most of these problems. Other problems still persist, such as system damage due to electrical storms, but these problems are common to all current track circuitry and control logic systems. In addition, the cost difference between CWT and audio frequency track circuits is approximately three thousand dollars. This monetary difference represents a comparison between two totally different systems with different capabilities. When CWT capabilities are required, the

Question Summary	Response Summary	Responses[1/]
What are the most prevalent causes of CWT failures?	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
What limiting criteria have been encountered which is adverse to installation?	a) Electronically coded tracks.	1
	b) Low ballast resistance.	4
	c) Tuned joint couplers.	1
	d) Rusty rail.	1
	e) Availability of usable frequencies in older CWT models.	1
	f) Track circuit type and length.	1
	g) Powerline ground current and its harmonics.	1
What inspections are performed to ensure CWT compatibility?	a) Field surveys.	4
	b) Type and number of train movements.	1
	c) Experience of local signal supervisors.	3
	d) Condition of rail and ballast.	1
	e) Location of adjacent powerlines.	1
	f) Track layout.	
	g) Location of adjacent crossings and other signal facilities.	1
Additional comments.	a) Do not use in poor ballast.	1
	b) Limit use of joint couplers.	1
	c) Susceptible to interference-type problems.	1
	d) CWT's increased maintenance and installation costs.	1
	e) No response.	3

1/ The total responses for each question vary due to multiple responses.

Figure 14. Summary of survey responses pertaining to perceived problems received from railroads identified as users of constant warning time systems.

Question Summary	Response Summary	Number of Responses[1/]
What are reasons for not using CWT devices more extensively?	a) No new installations. b) CWT devices do not always fail in restrictive mode. c) High initial cost. d) High maintenance cost. e) Not needed. f) Too complicated for railroad personnel to install and maintain. g) Recently started using CWT devices. h) Considered as undependable.	1 1 2 1 4 1 2 2
Additional comments, observations, or suggestions.	a) Need to improve system dependability. b) Need a frequency compatability chart. c) Would use CWT devices if needed. d) No response. e) Primary cause of failure is not due to problems with CWT devices.	1 1 1 3 1

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

Figure 15. Summary of survey responses pertaining to perceived problems received from railroads identified as nonusers of constant warning time systems.

only hardware alternative presently available is a series of time-out relays. This circuit system does not provide a continuous measure of train distance and speed as does the CWT system. The number of measures of train distance and speed estimates is dependent upon the number of circuits used in the timed circuit system. These additional circuits represent additional costs that can easily exceed the cost of a CWT system. The cost of currently available CWT systems is not, therefore, more expensive than alternative track circuit and control logic systems that provide the same capabilities.

Countermeasures to Increase CWT Applicability and Reliability

Special circuits and safeguards are available to address the physical constraints that initially limit the effectiveness or preclude the installation of CWT systems. The applicability of these countermeasures are site specific and dependent upon the physical and operational characteristics of each crossing. The railroads, after identifying the need for CWT systems, must determine the applicability and system design. This is often no problem, especially for railroads that are experienced with CWT systems, or that have a diverse signal engineering staff. Problems can occur in system design, however, if the railroads have neither the staff nor the experience or if adverse environmental conditions are convoluted.

It should be noted that conversations with both railroad and manufacturing personnel indicate that CWT systems can be installed at the majority of crossings. Crossings with convoluted inhibiting factors require the expertise of signal engineers thoroughly familiar with the installation of CWT systems. This expertise, if not available within the railroad staff can be obtained, often at no extra cost, from the CWT manufacturer.

Modifications for Improved CWT Device Performance

Circuit modifications are available to meet a variety of applicational needs. Several of these modifications are summarized below:

- Automatic Transfer: The deployment of two units ensures the transfer of control to a standby unit if the primary system fails. Control is transferred through an electronic timing circuit.

- Switch Circuit Controller: While less prevalent in CWT applications, false signal activation may occur in motion sensing deployments when switching occurs within the approach distance with other variable factors present. These factors include the location of the switching activity within the track circuit, length of approach track circuit, speed of train, etc. These factors tend to cause slight voltage variations when the train proceeds out of the switch circuit, and onto the main line.[10] A switch circuit controller, which applies a track shunt to prevent false signal activations, can reduce these fluctuations.

- High Current Track Drive: A high current transmitter coupler will provide additional filtering and prevent track circuit loading. These factors are of particular concern when CWT systems are used in areas of significant electrical interference. This interference is generated, for the most part, by railway sources (i.e., coded DC track circuits, noncoded AC track circuits, 60 hz AC).[10]

- Tuned External Filter: A tuned external filter may be used when AC interference is excessive. If a series notch filter is selected, the operating frequency must be tuned to the CWT system.

- Additional Filters: In DC track circuits where battery chargers are employed, 120 hz ripple and other forms of electrical interference may require additional filtering. Normally the series battery choke will do this but CWT system application guidelines provide specific information on effective filtering techniques and the installation of special isolation units, where required.

Guidelines for Atypical CWT Device Deployments

In some instances, special safeguards must be taken to ensure proper CWT system operation. Some atypical deployment characteristics are discussed below:

- Unequal Bidirectional Approach Distances - Where bidirectional approach distances vary in excess of 30 percent, insulated joints are located at the termination point of the shorter approach. In addition, simulated track length must be added to compensate for the difference in distance, so both approaches appear equal in length.[10]

- Bypass of Insulated Joints - When a CWT system is used in conjunction with existing track circuits, the user may wish to bypass frequencies beyond the insulated joints. This practice is generally acceptable if the user adheres to recommended safeguards contained in the application guidelines.[10] These guidelines include information on bypass feasibility, device selection, compatible operating frequencies, and surge protection.

- Multiple Track Crossings - Frequency conservation may be attained in high density areas by using the same frequency on all tracks of a multiple track crossing. Frequency beating is prevented with frequency synchronization provided in a master-slave operation. Since approach lengths may vary, the operating frequency must operate over all the distance variations in the multiple track crossing. In the selection of island frequencies, it is important that frequencies not be duplicated on the same track within 5,000 feet of the crossings, or within 3,000 feet of the crossing, in the case of adjacent tracks.[10]

- Narrow Band Termination Shunts - In instances where several crossings cause approaches to overlap, wide band termination shunts are replaced with narrow band shunts or tunable narrow band shunts. Adjacent frequencies are generally not used together on the track or a loading effect may result. The severity of the loading effect depends upon the closeness of each frequency, with adjacent frequencies most commonly affected.

  Adjacent channel loading is less severe in bidirectional applications. Narrow band shunts of adjacent frequencies must not be used in a specific zone centered on the crossing. In a unidirectional application, the basic guideline is to avoid overlapping of the next two adjacent channels. Through a technique called "bidirectional simulation," channel separation requirements may be eased. An adjustable inductor and wide band shunt can be added in series across the feed points, resulting in the addition of electrically-simulated track length, which is equal in distance to the approach of the rail being covered unidirectionally. In such cases, some CWT units behave similar to a bidirectional unit, allowing bidirectional adjacent channel guidelines to be used.

A summary of factors inhibiting the installation and proper operation of CWT systems are provided in table 14. Further clarification of countermeasures contained in this table and additional inhibiting factors can be obtained from CWT manufacturers.

Table 14. Summary of inhibiting factors and applicable countermeasures to the use of constant warning time systems.

Inhibiting Factor	Symptoms	Contributing Characteristics	Recommendations for Improved Performance (Including New Technology Where Applicable)
Rusty Rail Conditions	Inhibition or elimination of effective track shunt.	Sporadic track usage, environmental conditions.	Operate with 60 Hz Style C or 12VDC track circuit for improved performance.
Electrical Interference	Unreliable system performance.	Existing track circuitry (coded DC track circuits, non coded AC track circuits, 60 Hz, etc.) Track circuits which employ battery chokes.	Tuned receiver filters, isolation transformers, high current track drive.
Loss of Bidirectional Sensitivity	Impaired sensitivity to approaching train.	An infrequent occurance which may be precipitated by critical relationships involving moving and standing shunts. May occur with greater frequency in areas where closely following train movements are anticipated.	Installation of unidirectional CWT where required by unique site characteristics.
Transmission of Audio Frequency Beyond Termination Shunt	Premature and/or unwanted crossing signal operation.	Low operating frequency in conjunction with short approach distance.	Careful evaluation of site characteristics in selection of operating frequency. Addition of simulated track length through use of tunable inductive shunt.
Variations in Detection Voltage	Unwanted crossing signal activation.	Location of switch within CWT approach, approach length, speed of train. Movement of train out of switch and onto main within CWT approach.	Use of switch circuit controller to place shunt across rails upon switch reversal.

Table 14. Summary of inhibiting factors and applicable countermeasures to the use of constant warning time systems (continued).

Inhibiting Factor	Symptoms	Contributing Characteristics	Recommendations for Improved Performance (Including New Technology Where Applicable)
Loading of Adjacent Channel Frequencies	Degeneration in frequency propagation of adjacent channels.	Overlapping approaches which mandate use of narrow band shunt terminations.	Use of bidirectional CWT reduces likelihood of problem. Avoid overlap of adjacent channels. Adhere to placement restriction of narrow band shunts. Bidirectional simulation of undirectional application.
Incompatibility With Exisiting Track Circuitry	Precludes use of CWT.	60 and 100 Hz AC coded track or coded cab signal circuits.	
Component Failure	Disruption of constant warning functions, activation of crossing lights.		Automatic transfer of control to secondary unit in the event of primary system failure.
Frequency Limitations in Congested Areas	Inability to utilize adequate number of bidirectional operating frequencies.	Congested areas in which multiple crossings exist within approach distance.	Periodic use of unidirectional unit to isolate sections of track, allowing for duplication of frequencies.

CHAPTER 4. 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 where the vehicle struck the first unit of the train were further stratified into the following categories:

- Characteristics of the accident.
- 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 device and track circuit-control logic systems. The combinations of crossing types that were used in the analysis were:

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

The site selection process was initiated by stratifying the Federal Railroad Administration's national inventory, by crossing type, into categories of 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 then it was eliminated from further analysis. A flowchart of the site selection and verification process is presented as figure 16.

The number of crossings that were verified for each crossing type, and subsequently used in the accident analysis, is summarized in table 15. The smallest number of crossings occurs in the flashing light with CWT category. This occurs because there are a relatively small number of crossings that have flashing lights with CWT capabilities. The majority of CWT installations occur in conjunction with gates. Many of the replies returned for flashing lights with CWT indicated that either CWT systems were not in place or that gates had been installed.

Table 15. 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

Measure of Exposure

Comparative accident analysis between independent groups requires the use of exposure rates since the probability of an accident occurring is

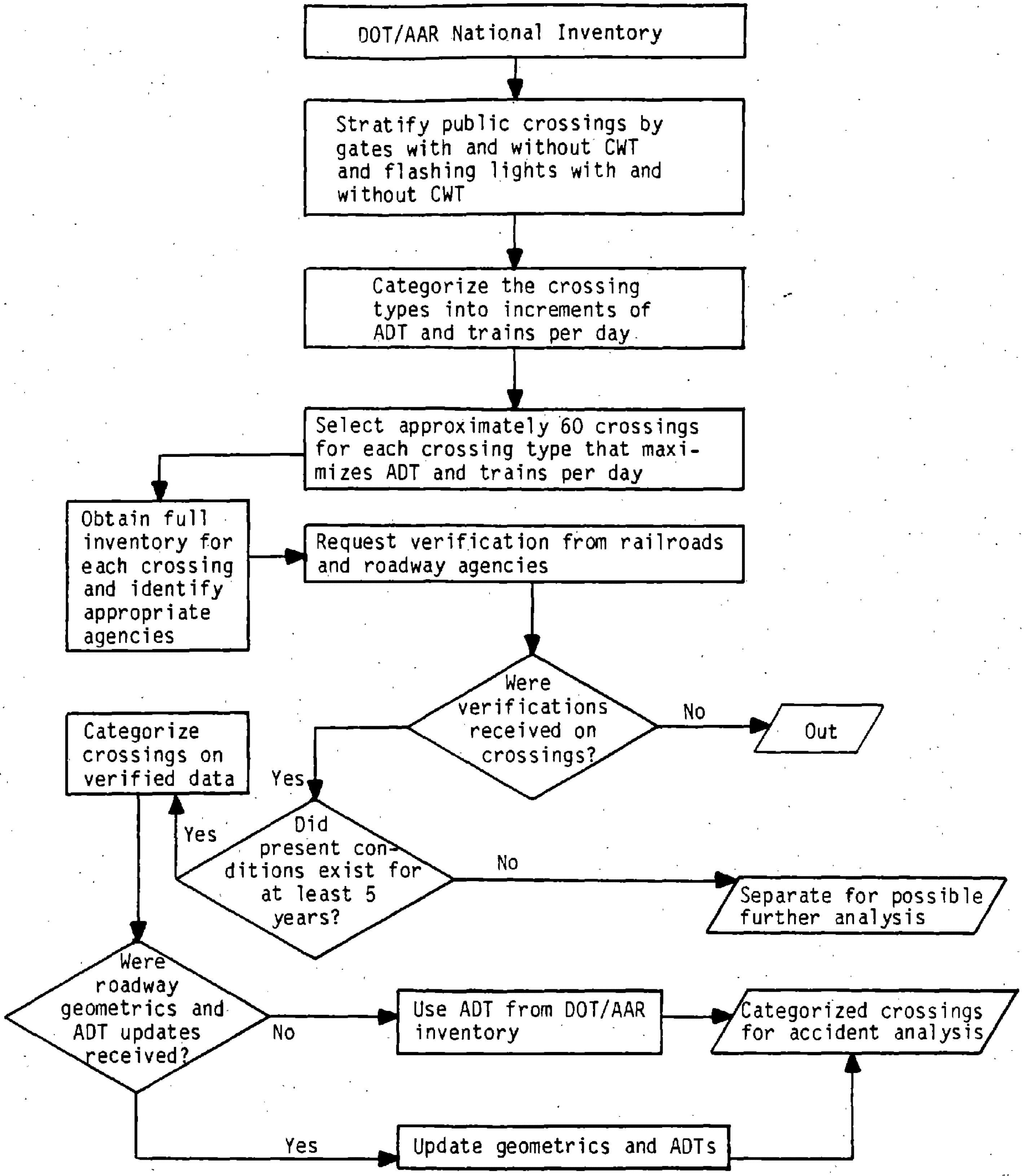

Figure 16. Flowchart of site selection and verification process used for accident analysis.

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 due to the fact that 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 below:

$$\text{Accident rate} = \frac{(\text{number of accidents})\ (1 \times 10^9)}{(\text{ADT})\ (\text{trains per day})\ (365)\ (5\ \text{years})}$$

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 occuring from 1980 through 1984.

Summaries of accident frequency catagorized by accident characteristics and physical-operational characteristics are presented in tables 16 through 18, respectively. Since a different number of crossings with indigenous ADT and train volumes comprise the population of each crossing category it is necessary to normalize the accident frequencies by the five-year exposure. The exposure measure used for accident type and accident characteristics were based on the total five-year exposure for each crossing type as presented in table 19.

Analysis of physical and operational characteristics required the additional consideration of the number of crossings and the indigenous exposure that possessed the attribute being analyzed. It was necessary, for analysis purposes, 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 with 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 are presented in table 20.

Table 16. Summary of accident types for years 1980 to 1984.

Accident Type	Crossing Type: Gates with CWT	Gates without CWT	Flashing lights with CWT	Flashing lights without CWT
Struck by Train	8	16	5	17
Striking 1st unit of train	0	1	2	4
Striking other unit of train	2	1	3	0
Total	10	18	10	21

Table 17. Summary of accident characteristics represented as frequencies.

Accident 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
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 18. 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

Table 19. 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 20. Summary of the number of crossings and the five year exposure (billion vehicle-trains) for selected physical and operational crossing characteristics.

Crossing Characteristics	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

The data was analyzed by performing the Mann-Whitney U-test on the accident rates. The rates were determined by adding accidents where 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 occurrence from the test was equal to or less than five percent, then it was concluded that CWT systems had an impact on accidents.

Inspection of tables 21 through 23 indicate that there were not any significant differences at the 95 percent confidence level in the distribution of accident rates between crossings with and without CWT systems. The accident rate of 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 CWT systems result in lower accident rates.

Table 21. 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 22. 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 proceeded	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 23. 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	

CHAPTER 5. 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 require 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 with using accidents as the sole measure of safety, the accident analysis was complemented by observations of driver behavior. This analysis occurred 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 less violations of the flashing lights and subsequent train accidents. The relationship between the intended purpose of CWT systems, the intermediate objectives and the ultimate objective of reducing accidents is presented in the causal chain of figure 17.

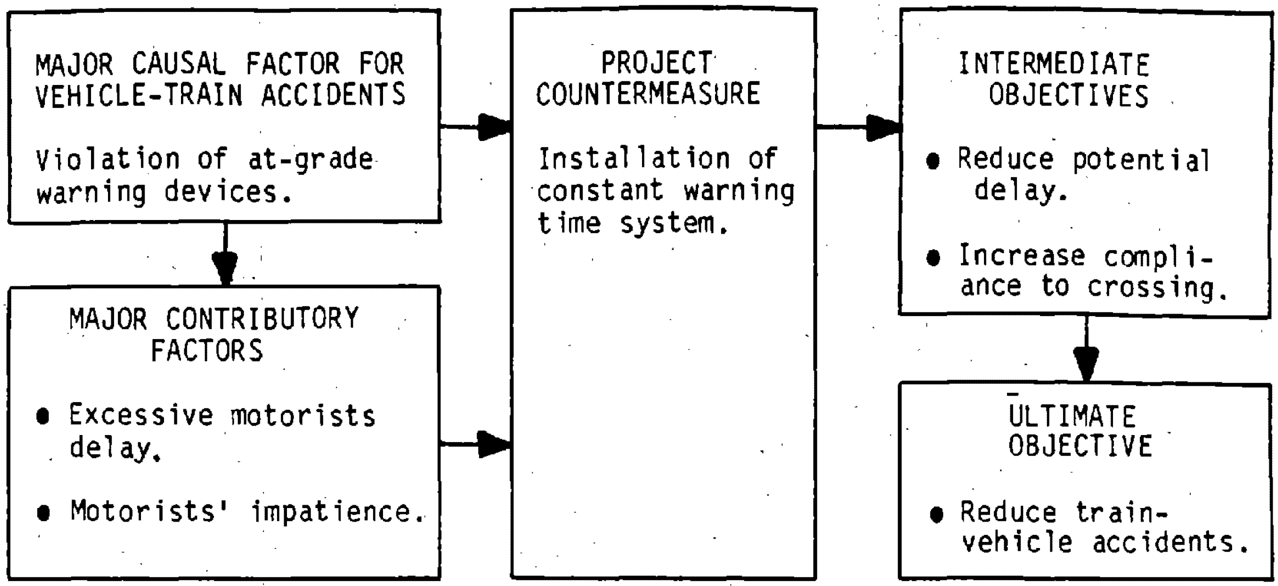

Figure 17. Causal chain for the reduction of vehicle-train accidents by installing CWT systems.

The collection of field data was concentrated on obtaining quantifiable measures of effectiveness that: 1) indicated if CWT systems actually do provide a uniform warning time, and 2) could be directly related to the intermediate objectives. The measures of effectiveness selected for the study are presented in table 24.

Table 24. 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.

Test Site Selection Procedure

The measures of effectiveness determined as being appropriate for the analysis of the operational CWT data required observations on motorist 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 homogenity between analysis sites. This homogenity was necessary to increase the probability that observed differences between the test sites were due to the train detection and type of warning device and not due to 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.
- 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 task. Each prospective site was visited to determine if a suitable observer refuge area, the proper warning device, and the correct locational variables were present. The respective highway agencies and operating railroads were then contacted for those sites that satisfied all of the preliminary selection criteria. These contacts provided information pertaining to hourly roadway counts, daily train volume, train schedule, and additional verification on 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 stop watches were initiated upon first activation of the crossing warning device. 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 represented in table 25 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 seconds was the observed warning time at 40 mi/h (64 km/h) then 240 seconds (8 times 30 seconds) would result for a train traveling 5 mi/h (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 prior to the train entering the crossing. The lower train speeds were the result, therefore, 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

Table 25. Maximum, minimum, and standard deviation of train velocities (mi/h) observed by type of crossing (1 mi/h = 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

two-way analysis of variance presented in table 26 indicate that there is a significant difference at the 95 percent level of confidence between the effect of the different types of crossings on 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 presented in table 27 indicate that there are significant differences, at a 95 percent level of confidence between crossings equipped with and without CWT systems. Crossings equipped with CWT systems, therefore, display different characteristics in their average warning time than crossings not equipped with CWT systems.

Table 26. ANOVA on the mean warning time (seconds) per train velocity group (mi/h) for different crossing types.

Speed Group	Crossing Type			
	Flashing lights without CWT	Flashing lights with CWT1/	Gates without CWT	Gates with CWT1/
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 27. Scheffe contrast test on the effect of crossing type on mean warning time (seconds).

	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.

The values contained in table 22 were plotted and the linear best fit line regression line obtained. An inspection of these plots, presented in figure 18, indicates a negative slope for all crossing types except for gates with CWT. With the 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. Since 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 was collected were 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

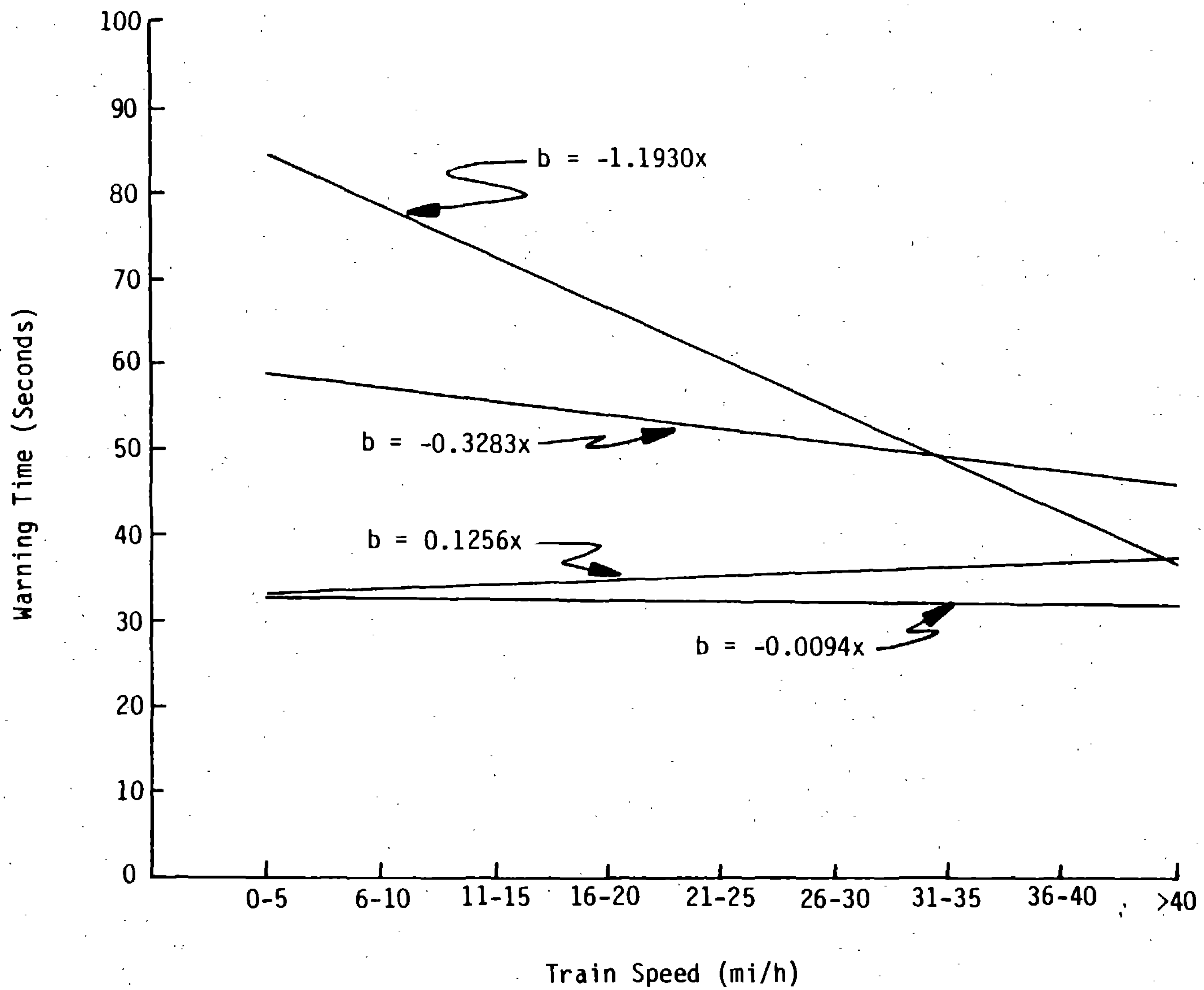

Figure 18. Best fit linear approximations and the resultant slopes for each crossing type on speed groups and mean warning time.

warning devices (violations) to be similar, per unit of time, for each test site. Since 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 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 28 indicates that the majority of these violations occurred when the amount of warning time exceeded 50 seconds. 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 seconds.

Table 28. 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

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 presented in table 29. It is interesting to note that five of these observations included clearance times of less than six seconds.

Table 29. Observed violations of the activated warning device and cumulative proportions categorized by time until 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

The Kolmogorov-Smirnov two-sample test was used to determine if the violations observed at crossings 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 presented in tables 30 and 31. Similar analyses for violations by time before train arrival are presented in tables 32 and 33. Each of these tests indicate, at the 95 percent level of confidence, that there are significant differences between crossings with comparable types of warning devices, equipped 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 crossings without CWT systems. The majority of vehicles that violate the warning devices at crossings equipped with CWT systems are, therefore, exposed to an increased probability of being struck by a train than violators at crossings without CWT systems. The number of violators is, however, much smaller at crossings with CWT systems.

Table 30. Kolmogorov-Smirnov test on the number of violations occurring within categories of advance warning time (seconds) 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

Table 31. Kolmogorov-Smirnov test on the number of violations occurring within categories of advance warning time (seconds) 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 32. Kolmogorov-Smirnov test on the time (seconds) 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 = 0.73   95 percent critical K-S value = 0.318

Table 33. Kolmogorov-Smirnov test on the time (seconds) 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

CHAPTER 6. ALTERNATIVE SOLUTIONS TO THE USE OF CONSTANT WARNING TIME SYSTEMS

Alternative solutions to the use of CWT systems can be categorized into the general formats of hardware and nonhardware solutions. The hardware solutions consist of both ontrack and offtrack train detection refinements and innovative techniques. Research is continually taking place to determine what improvements in hardware components will further reduce the effects of varying ballast resistance, induced voltages, electrical surges, and high power consumption. Innovative techniques to detect train presence by pressure, noise, vibration, deflection, force, frequency, wheel dectectors, sonar, radar, beam interruptions, inductive loops and microwave transmission are examples of hardware based concepts that have been investigated for feasibility and dependability.

Nonhardware solutions consist primarily of operational or physical changes to the crossing, train or roadway environment. The feasibility of the nonhardware alternatives was the emphasis of this study. These alternatives were identified by conducting a literature review and through meeting with railroad personnel.

Nonhardware Alternatives Identified Through a Literature Review

The primary emphasis on nonhardware alternatives in the current literature is on grade separation and motorist education.

Grade Separation

Physically separating the roadway and railroad is an effective, but cost-intensive method of reducing delay and vehicle-train accidents. The reduction in vehicle-train accidents is, however, often offset by an increase in fixed-object accidents.

In a study conducted in Ohio, Wilde determined that twice as many accidents occur at grade separated locations, including train and non-train involved accidents, than occur at grade crossings with a severity index that is approximately equal.[12] Hopkins noted that active warning devices have approximately the same effectiveness as grade separated crossings in reducing accidents when both train and nontrain-involved accidents are taken into consideration.[12] In a subsequent study Hopkins compared the accident reduction capabilities and costs for different grade crossing scenarios, as presented in figure 19.[13]

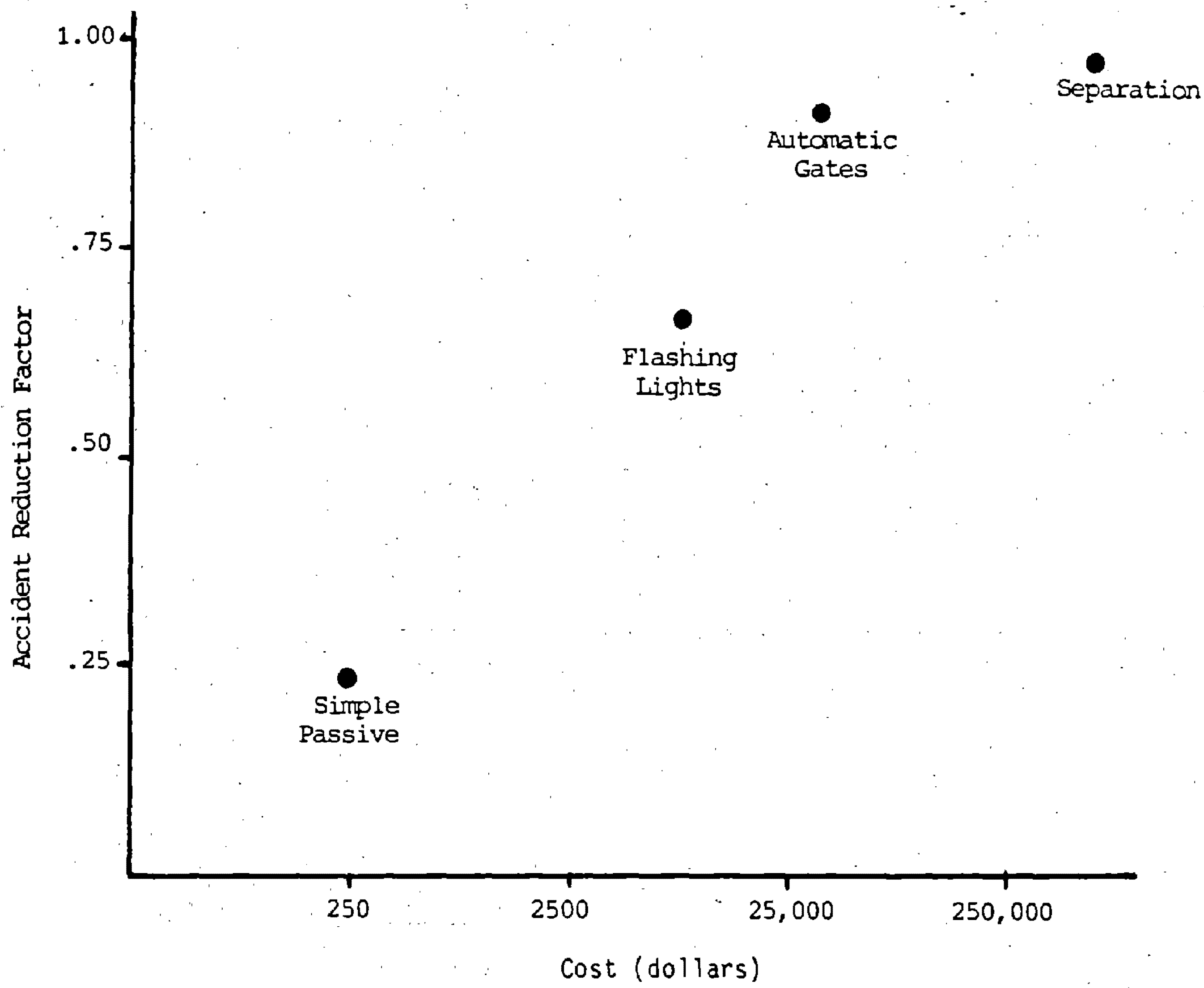

Figure 19. Estimated effectiveness and cost of typical grade crossing warning systems.[13]

Motorist Education

Prior studies indicate that many drivers do not look for trains when approaching a grade crossing. Wigglesworth determined that approximately one-third of observed drivers did not look for trains even at crossings with no active warning devices. His study concluded that the differences observed in speed and head movements between observation times with trains and without trains was small.[14]

Hopkins noted that, in order to decrease fatalities, it is not only necessary that motorists see the warning device, but also understand its meaning and act accordingly.[12] Sonefeld concurs, stating:[15]

Unlike many other highway-safety topics, very little, if any, attention has been given to rail-highway crossings in driver education or driver licensing courses. About two years ago, a national study in driver license manuals showed that some states almost completely avoided the subject and, even worse, some states actually gave misinformation about procedures at grade crossings.

Nonhardware Alternatives Identified Through Meetings With Railroad Personnel

Information was requested from railroad personnel during a meeting of the American Railway Engineering Association (AREA) on March 27, 1985. Time was allocated after a regularly scheduled session to provide participants with a set of nonhardware alternatives to the installation of CWT devices. Each option was explained fully and an open discussion on the advantages, disadvantages, and variations of each alternative was conducted. The participants were then requested to rank each alternative according to their perceived effectiveness and feasibility. The process resulted in the identification and ranking of additional alternatives. The results of the responses are presented in figure 20.

Uniform Train Speeds

The prevalent opinion expressed during the discussion was that variations in train speed exist due to operational necessities. Reducing the

Figure 20. Nonhardware alternatives to the installation of constant warning time devices.

Options	Perceived Feasibility					Perceived Effectiveness					Comments
	1	2	3	4	5	1	2	3	4	5	
Uniform Train Speeds	6	6	3	0	0	3	2	1	6	4	a. In certain areas with a uniform mix of trains, train speed may be easier to adjust. b. The railroad attempts to maintain uniform speed whenever possible. Due to switching operations and sidings, it is not possible in several cases. Also, different types of trains cause speed variations. c. Feasibility, in general, cannot be determined. Could vary from 1 to 5. d. We have agreed, in some instances, that constant warning devices were unneeded since train speeds were relatively constant at the location; however, there will still be some variance. e. Not feasible to slow Amtrak to freight train speed.

1 = Least feasible or effective.
5 = Most feasible or effective.

Figure 20. Nonhardware alternatives to the installation of constant warning time devices (continued).

Options	Perceived Feasibility					Perceived Effectiveness					Comments
	1	2	3	4	5	1	2	3	4	5	
Decrease in Switching	12	1	2	0	0	4	3	5	1	2	a. Have to serve industry/shipper needs. b. Due to "nature of the beast", we need flexibility to switch when needed unless you want to relocate a yard or industry, very expensive. c. Feasibility, in general, cannot be determined, could vary from 1 to 5. d. Relocation of crossing from switching area would be more practical and efficient than decreasing switching operations. e. Relocate crossing location.

1 = Least feasible or effective.
5 = Most feasible or effective.

Figure 20. Nonhardware alternatives to the installation of constant warning time devices (continued).

Options	Perceived Feasibility					Perceived Effectiveness					Comments
	1	2	3	4	5	1	2	3	4	5	
Shifting Time of Switching Operations	7	6	2	1	0	5	4	5	1	1	a. Time of switch often dictated by an industry with little control by railroad. b. Concern for employee safety at night. Conducting switching activities at night would result in railroad employees working under unfavorable visibility conditions. Motorists would also be subjected to trains occupying the crossing during hours of restricted visibility. c. Could help, if possible, if done at times of low ADT. Probably not feasible. d. Might make crossing safer, but could also make switching operations more difficult. e. Could be considered only at selective locations where rush hour vehicle traffic could be involved and switch yard nearby.

1 = Least feasible or effective.
5 = Most feasible or effective.

Figure 20. Nonhardware alternatives to the installation of constant warning time devices (continued).

Options	Perceived Feasibility 1	2	3	4	5	Perceived Effectiveness 1	2	3	4	5	Comments
Cost Intensive Grade Separation	9	5	0	0	1	1	0	0	0	15	a. Also consider closing crossing or relocate roadway. b. May be needed anyway, but this would seldom be primary reason for doing so. c. Ideal, but not practical.
Relocation of Rail-road yards	15	1	0	0	0	2	13	1	0	0	a. Yards were initially placed away from cities. What is to stop the city from coming to the yard again? b. Too costly. c. All approach tracks would need to be relocated. d. Most switching operations that cause traffic problems do not occur at the yard. e. Who is going to supply the land and money?

1 = Least feasible or effective.
5 = Most feasible or effective.

Figure 20. Nonhardware alternatives to the installation of constant warning time devices (continued).

Options	Perceived Feasibility					Perceived Effectiveness					Comments
	1	2	3	4	5	1	2	3	4	5	
Reconfigur-ation of Railroad Yard	13	2	1	0	0	15	1	0	0	0	a. Most switching operations that cause traffic problems do not occur at the yard -- leave the yard alone. b. Not very feasible. c. Would be easier to move the roadway. d. Feasibility, in general, cannot be determined. Could vary from 1 to 5.
Relocation of Switching Operations	16	0	0	0	0	15	1	0	0	0	a. Location of switching operation is largely dependent upon the location of customer facilities. b. Low train speeds not always due to switching. c. Disruptions to traffic should be considered by government people when approving construction plans for manufacturing plants. d. Not very feasible.

1 = Least feasible or effective
5 = Most feasible or effective

Figure 20. Nonhardware alternatives to the installation of constant warning time devices (continued).

Options	Perceived Feasibility					Perceived Effectiveness					Comments
	1	2	3	4	5	1	2	3	4	5	
Close or Relocate Crossing	2	6	6	0	0	2	3	3	6	0	a. May be best alternative of all. b. Railroads should analyze effects of locating sidings near grade crossings c. Feasibility, in general, cannot be determined. Could vary from 1 to 5.

1 = Least feasible or effective
5 = Most feasible or effective

variation in train speeds was not, therefore, considered as being a viable alternative by the majority of participants. This was especially true in those instances where the line was used by both freight and passenger trains. Often, the operating entity for the freight and passenger movements are different companies sharing the line. Any decrease in speed variations would not only be infeasible from the operational aspects, but would require cooperation between the operating entities.

The open discussion revealed that one possible reason for excessive warning time is imposed speed limits. Fixed distance train detection systems are designed to provide a minimum amount of warning based on the fastest train. If the crossings within a certain political jurisdiction were designed to provide 30 seconds of warning for a maximum speed of 60 mi/h (96 km/h) and a speed limit of 30 mi/h (48 km/h) is imposed on the train, then the amount of advance warning increases to 60 seconds. This is analogous to an artifical variation in train speed. Imposition of speed limits should, therefore, be accompanied by adjustments to the train detection circuitry at every crossing affected by the imposed limit. This is, however, often not accomplished due to manpower constraints and the associated cost. The opinion was expressed that if decisions on maximum train speeds are made by public agencies, then those agencies, and not the railroads, should incur any costs associated with requisite circuitry modifications. This was considered as being justified, since the imposed limits already impact the railroad monetarily through increased operating costs.

Decrease in and Shifting Time of Switching Operations

These were presented as two different alternatives to the participants. The opinions expressed for decreasing switching operations and shifting the time of switching operations were similar, however. The prevalent issue of discussion concerned customer needs. Relatively large manufacturing plants, for example, request service at specific times to coincide with the scheduling of personnel and production needs. The railroads do not, therefore, have total control over the train schedules. A couple of examples were given where the manufacturing plant requests train movement during the time of shift change to reduce employee idle time. These plants are located such that the train movements result in large delays to major arterials. Since the train movements coincide with shift changes, the volumes on these arterials are at a maximum. These delays have become so prevalent at these plants that employees reporting for work typically arrive early enough to miss the anticipated congestion.

An expressed concern with regard to shifting the time of switching operations was the possible adverse safety impact on the railroad employees. The majority of the railroad personnel believed that shifting the time indicated more nighttime work which is inherently more dangerous. It was also expressed that shifting the time of switching operations in the yards would be operationally impractical. Many of the freight trains are scheduled to run at night which, due to decreased roadway volumes, results in less overall delay. Running the trains at night, however, requires that the units of the train be coupled during the day.

Grade Separation

The majority of participants believed that while this alternative would be very effective, it was not very feasible. The problem with feasibility was primarily centered around the costs of construction and maintenance. It was expressed that the high associated costs were not warranted by merely providing a uniform warning time. Providing a uniform warning time was stated as one concern that was evaluated in conjunction with other factors in determining the need for a grade separation. Providing a uniform warning time would not, however, be the sole criterion to justify the large expenditures required.

Relocation and Reconfiguration of Railroad Yards

The opinion was expressed by the participants that most of the problems to roadway traffic caused by switching operations are not at the location of the switching yards. The primary points of conflict occur when material is being loaded and unloaded at the consignment points. The main fault, contended the participants, was that inadequate planning was being performed in the design of customer facilities. It was suggested that governmental authorities, responsible for approving site plans, pay greater attention to the possibilities of traffic disruptions caused by switching operations.

It was also expressed that any yards or customer facilities that are currently experiencing problems are most likely the result of urban expansion. Switching yards are usually constructed in rural or urban fringe locations to decrease costs and minimize community disruptions. In some instances, urban growth has resulted in previously rural yards being completely surrounded by the urban community. If the railroad has to pay the cost of relocating, they are essentially being penalized for helping to foster the communities' economic success. In some instances, communities have contributed land and tax incentives in exchange for yard relocation. This was the only way in which some of the participants could envision the feasibility of relocating the switching yards.

If the yards are relocated, the tracks approaching the yard must also be relocated. If the new yard is not positioned along the current right-of-way, then new track alignment and accompanying right-of-way must be acquired. Relocating yards is, therefore, not only very expensive, but require extensive planning to minimize the impact on other parts of the community.

Close or Relocate the Crossing

This alternative was the most acceptable in terms of both perceived feasibility and effectiveness. This is understandable, since it places the primary responsibility for remedial action on the roadway authorities. The feasibility probably would not have been rated as high if the evaluation had been performed by individuals with the primary responsibility of maintaining the roadway network.

Alternatives Identified Through Railroad Surveys

The surveys forwarded to the railroads described in chapter 2, contained queries pertaining to CWT alternatives that had been used by the railroads. These responses summarized in figures 21 and 22 indicate that the installation of timing circuits was performed in addition to changing the time of switching operations. The majority of the responses, however, indicated that no action was taken.

Question Summary	Response Summary	Number of Responses
What alternatives to the installation of CWT devices have been tried?	a) None.	3
	b) No response.	1
	c) Timing sections.	1
	d) Style "C" track circuits with time out circuits.	1

Figure 21. Summary of survey responses pertaining to constant warning time alternatives from railroads identified as users of constant warning time systems.

Question Summary	Response Summary	Number of Responses
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 2
	d) None.	4

Figure 22. Summary of survey responses pertaining to constant warning time alternatives from railroads identified as nonusers of constant warning time systems.

CHAPTER 7: CONCLUSIONS

The conclusions presented below are based on the results of the project analysis, observations made during the study, and the literature review:

- No quantitative guidelines, established by either the States or railroads, could be identified that would help prescribe when CWT systems 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 or on any combinations of these variables to justify installation is apparently judgmental and exerted on a crossing-by-crossing basis.

- Some States have recommendations on the maximum amount of warning time which is permissible from device activation until train arrival. These maximum time recommendations vary from State to State with noted examples being 35, 40, and 60 seconds. This represents train speed ratios of 1.75:1, 2:1, and 3:1, respectively.

- The verification process and subsequent statistical tests indicated that the FRA inventory was not accurate in identifying locations with CWT installations. The primary reasons for this discrepancy are envisioned as the inherent problem in distinguishing between motion sensors and CWT devices and upgrades to the crossing equipment that were not posted to the inventory.

- 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.

- 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 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.

- Estimates based on information supplied by manufacturers indicate that there are approximately 6,300 crossings, nationwide, currently equipped with CWT systems. The actual number of crossings with CWT capabilities could, however, be higher due to the use of timed circuits by some railroads.

- Results of the discriminant analysis indicates that 19,400 crossings may require CWT capabilities. Applying this estimate in conjunction with an estimated 6,300 crossings already having CWT capability indicates that an additional 13,100 crossings may require CWT systems. Descriminant analysis was performed on groups of crossings with verified train detection and control logic systems. The accuracy of the decriminant function was not, therefore, dependent upon the accuracy of the national inventory in specifying crossings with and without CWT systems. The accuracy of the number of crossings that may require CWT systems is, however, based on the primary assumptions that: 1) the national inventory is accurate with regard to physical and operational characteristics, 2) CWT systems are compatible with the environment at each crossing, 3) alternative countermeasures are not feasible, 4) the physical and operational conditions currently represented in the national inventory were present when the CWT systems were installed, and 5) there are no crossings currently with passive warning devices which require active devices installed in conjunction with CWT systems. The use of discriminant analysis to determine the magnitude of CWT need on a national basis was considered as the most advantageous approach. The relatively large number of necessary assumptions, however, indicates that the resultant estimate should be used with caution.

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

- The modular design and self-diagnostic capabilities of modern CWT systems reduces the maintainance expertise formerly required by purchasers of CWT systems.

- Operational and physical crossing characteristics can combine to complicate the proper installation and operation of CWT systems. Often these factors can become so convoluted that assistance from signal engineers with CWT experience must be obtained. There are virtually no instances, however, where the combination of inhibiting factors cannot be addressed by appropriate countermeasures.

- The reliability of CWT systems and the mean time between failure has increased dramatically with the newer models.

- Some railroads combine a series of fixed-distance and motion sensing systems with time-out circuits to provide a quasi-constant warning time system.

- Railroad personnel indicated that the most prevalent problems with CWT systems are low ballast resistance and component damage due to electrical storms. These problems are, however, common to all track circuit systems.

- The nonhardware alternative to the installation of CWT systems that was most attractive to railroad personnel was the closure or relocation of the crossing.

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