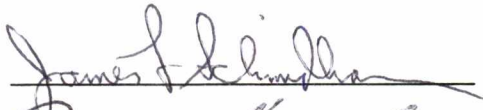
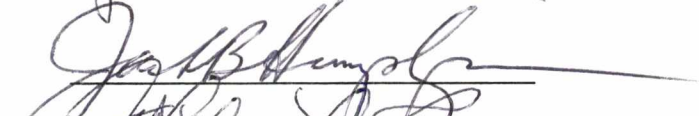
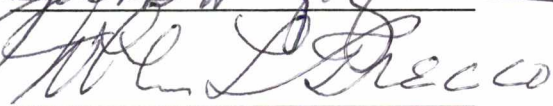
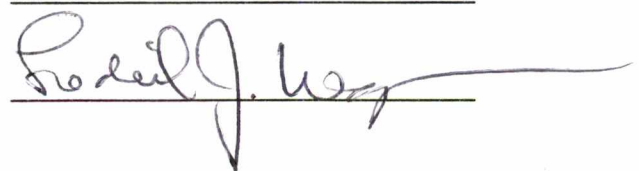


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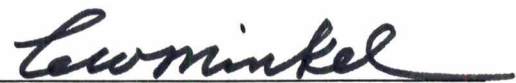
I am submitting herewith a dissertation written by Stephen Harold Richards entitled "An Evaluation of Undesirable Driver Actions at Railroad-Highway Grade Crossings With Active Traffic Control." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.


Major Professor
Kenneth W. Heathington, Ph.D., P.E.

We have read this dissertation
and recommend its acceptance

Accepted for the Council:


Vice Provost
and Dean of The Graduate School

AN EVALUATION OF UNDESIRABLE DRIVER ACTIONS
AT RAILROAD-HIGHWAY GRADE CROSSINGS
WITH ACTIVE TRAFFIC CONTROL

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Stephen Harold Richards

December 1989

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DEDICATION

To my mother and the memory of my father, who together gave me the will and discipline to accomplish this dream.

ACKNOWLEDGMENTS

The author expresses his gratitude to the many individuals who assisted in completion of this research. The overall guidance and direction provided by Dr. Kenneth W. Heathington, the major professor for the research, is especially acknowledged, along with the guidance and contributions of the other members of the graduate committee. They include Drs. William L. Grecco, Jack B. Humphreys and Frederick J. Wegmann of the Civil Engineering Department, and Dr. James L. Schmidhammer of the Statistics Department.

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ABSTRACT

As of 1987, over 54,000 of the nation's 192,454 railroad-highway crossings were equipped with active traffic control devices, i.e., flashing light signals with or without automatic gates. Although these active devices have enhanced crossing safety, there is evidence that they are not performing as intended. Research indicates that serious safety problems result when drivers intentionally elect to drive around or through functioning active devices. In fact, over one-half of all grade crossing fatalities occur at crossings with active traffic control even though these crossings account for less than 30 percent of the total crossings. One out of ten grade crossing accidents involves a vehicle driving around a lowered gate arm.

The purpose of this research was to: (1) determine the extent and nature of undesirable driver actions at grade crossings with active traffic control; and (2) identify driver-related factors which influence this undesirable driver behavior. A multi-faceted research approach was used. Field studies were conducted at three grade crossings. The results of these studies documented the extent of undesirable driver actions at typical active crossings, and they provided data for an in-depth assessment of the effects of warning time on driver behavior. A laboratory study was conducted to further evaluate drivers' expectancies and tolerances with respect to warning times.

To identify driver-related factors which, together with warning time, influence driver crossing behavior, a driver survey was developed and administered nationwide to 662 drivers. In the survey, drivers

reported their comprehension of the active devices and pertinent traffic laws, recognition of the grade crossing hazard, tendencies for risk-taking, respect for active crossing devices, exposure to active systems, and general demographic characteristics. The effects of these driver-related factors on the drivers' self-reported behavior were then evaluated using multivariate analysis of variance (MANOVA) and discriminant analysis techniques.

The results of the research indicate that undesirable driver behavior at active crossings is a wide-spread problem. (Undesirable driver behavior refers to drivers intentionally going around or through functioning active traffic control devices.) Such behavior has a very negative effect on overall crossing safety.

Several factors were found to significantly influence driver behavior at active crossings. They include: (1) the driver's perception of the crossing hazard; (2) the driver's comprehension of his/her duties; (3) the driver's perceptions regarding system reliability; and (4) the driver's age, gender, and driving experience. Drivers who "normally" engage in undesirable behavior tend not to accept that their actions are hazardous, and they believe that their actions are legal. Also, they have been exposed to false activations and believe that false activations are common. They typically are male, relatively young, and frequent drivers.

The length of the warning period also has a significant influence on driver behavior at active crossings. Warning times between 20 and 35 seconds minimize the number of undesirable driver actions at crossings with flashing light signals and at gated crossings. Warning times in excess of 40 seconds at crossing with flashing signals, and in excess of

60 seconds at gated crossings, erode drivers' credibility in the active warning, and greatly increase the number of undesirable driver actions. Excessive warning times also promote aggressive and very risky crossing behavior.

Based on the research findings, recommendations are presented for mitigating undesirable driver actions at grade crossings with active traffic control. These include recommendations for minimum, maximum, and desirable warning times. General recommendations are also presented relative to the major driver factors which influence undesirable driver behavior at active crossings.

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CHAPTER 1

INTRODUCTION

Since 1974, over \$2.0 billion in Federal-aid highway funds have been spent to eliminate safety hazards at railroad-highway grade crossings.⁽¹⁾ The majority of these funds have been used to install or upgrade active warning devices, i.e., flashing light signals with or without automatic gates. Likewise, the railroads and states have annually invested millions of dollars on active warning devices. As of 1986, 32,778 of the nation's 192,454 public crossings were equipped with standard flashing light signals, and 22,066 crossings had flashing light signals with automatic gates.⁽²⁾ These numbers represent 17.0 and 11.5 percent, respectively, of the total public crossings in the country.

The substantial investment in active traffic control systems has undoubtedly enhanced grade crossing safety. As shown in Table 1, there has been a significant decline in grade crossing accidents and casualties since 1974.⁽³⁾ In 1987, there were only 589 total deaths resulting from grade crossing accidents, compared to 1,270 total deaths in 1974. Injuries have also declined dramatically. There were 2,295 total injuries resulting from grade crossing accidents in 1987, compared to 3,199 total injuries in 1974.

Despite the obvious safety gains, there is still concern that active warning devices are not performing as well as they could or should. The apparent deficiencies in the standard active traffic control systems are evident in undesirable driver behavior observed at

Table 1. Railroad-highway grade crossing accidents (1974-1987).

Year	Deaths ¹				Nonfatal Injuries ¹			
	Motor Vehicle	Pedes-trian	Other	Total	Motor Vehicle	Pedes-train	Other	Total
1974	1,140	72	58	1,270	3,061	32	106	3,199
1975	778	63	127	978	3,600	39	529	4,168
1976	1,028	52	88	1,168	4,414	37	436	4,887
1977	846	70	28	944	4,455	44	150	4,649
1978	926	68	24	1,018	4,124	31	106	4,260
1979	727	71	36	834	4,019	37	116	4,172
1980	708	54	26	788	3,534	31	97	3,662
1981	623	47	27	697	3,020	30	71	3,121
1982	526	36	18	580	2,417	22	69	2,508
1983	483	37	22	542	2,372	29	66	2,467
1984	543	40	27	610	2,597	25	101	2,723
1985	480	31	26	537	2,395	21	92	2,508
1986	507	44	27	578	2,227	36	65	2,328
1987	526	42	21	589	2,221	27	47	2,295

¹Preliminary figures.

Source: Accident Facts (1988 Edition), National Safety Council, Chicago, Illinois, 1989.

crossings with active traffic control, and in grade crossing accident statistics.

Problem Description

Studies of driver behavior at active crossings demonstrate the shortcomings of standard flashing light signals with or without automatic gates. Research conducted by Heathington, Fambro, and Richards⁽⁴⁾ found that gate violations were very common at a typical urban crossing. In fact, an average of 2.5 vehicles per train event were observed driving around the lowered gates at the study crossing, and 8.0 percent of these violations occurred within 10 seconds of train arrival. In another study, Berg⁽⁵⁾ found that approximately 10 percent of motorists drove around lowered gate arms at a group of crossings with standard gates and flashing light signals.

The research by Heathington, Fambro, and Richards⁽⁴⁾ also documented undesirable motorist behavior at crossings with standard flashing light signals. At one suburban crossing, an average of 10 vehicles went through the activated signals per train event, and at least one vehicle was observed crossing within 10 seconds of the train during 29 percent of the train events. In other research, Berg⁽⁵⁾ observed that 54 percent of motorists drove through activated flashing light signals while a train was approaching. Sanders⁽⁶⁾ found that 15 percent of motorists arriving at a crossing with the signals activated and within one minute of train arrival, drove through the flashing signals in front of the approaching train.

With regard to grade crossing accidents, it is significant to note that 28.5 percent of the public crossings in the country have active warning devices; however, these crossings account for over 53 percent of all crossing accidents.^(1,7) The 17.0 percent of the crossings with flashing light signals account for over 35 percent of all crossing accidents, and the 11.5 percent of the crossings with automatic gates and flashing light signals account for 17 percent of the total crossing accidents. The majority of grade crossing accidents occur at crossings with active control, and it follows that improved safety at these crossings, if it is possible, would have the greatest impact on overall crossing safety.

Furthermore, a recent study by the National Transportation Safety Board⁽⁸⁾ concluded that three-fourths of the accidents at active crossings occurred because drivers drove around or through functioning gates and/or flashing light signals. In fact, 10 percent of all grade crossing accidents in 1987 occurred when motorists drove around lowered gates.⁽¹⁾ These data indicate that a significant portion of the accidents at crossings with active traffic control is a direct result of deliberate driver actions which are contrary to the intent of the traffic control. These actions are certainly undesirable, but they may or may not be illegal depending on the circumstances. Also, even if the actions are technically illegal, they may not be perceived as such by the motorists.

Research Needs

Based on observed driver behavior and the resulting accident experience, the standard active traffic control devices clearly are not

performing as intended. Since the data indicate that much of the problem involves motorists intentionally driving around or through a functioning active warning device, there is a need to identify those factors which influence the undesirable behavior, and recommend measures to alleviate the undesirable behavior.

To date, most of the grade crossing research involving active traffic control devices has focused on the visibility and conspicuity of the devices, and on initial driver response to active systems.⁽⁹⁾ Initial driver response includes approach speed, deceleration, and looking behavior. There has been very little research directed toward evaluating those factors which influence driver behavior after the driver has reached the crossing.

Intuitively, a number of factors may influence driver behavior at active crossings once the driver is at the crossing and has seen the active devices. These include the driver's: (1) comprehension of the devices and associated laws, (2) perception of the grade crossing hazard, (3) psychological and physical attributes, (4) trust in the active devices to provide credible and reliable information, and (5) previous exposure to active systems. These factors, along with others which may be identified, need to be fully evaluated. In particular, the effects of warning time on driver behavior at active crossings need to be fully evaluated. There is already evidence that excessive warning times encourage undesirable driver behavior at active crossings.^(4,6,10) Long warning times are experienced at many active crossings due to the type

of train detection equipment and the presence of variable speed trains and/or switching operations.

Research Purpose and Scope

The overall purpose of the research was to identify and evaluate factors which influence driver behavior at grade crossings with active traffic control systems, i.e., flashing light signals with and without automatic gates. The research focused on the problem of drivers intentionally driving around or through functioning active traffic control devices, rather than the issues of device visibility or driver inattentiveness. As noted previously, such undesirable driver behavior accounts for a large portion of the safety problem at active crossings, and this problem has not been addressed to a great extent. To accomplish the overall purpose of the research, five specific objectives were defined as follows:

1. Determine the extent and nature of undesirable driver behavior at grade crossings with active traffic control devices.
2. Evaluate the effects of warning time on driver behavior and safety at active crossings.
3. Assess drivers' expectancies and tolerances with respect to warning times at active crossings.
4. Identify driver-related factors which significantly influence drivers to intentionally drive around or through functioning active crossing devices.

5. Recommend measures to minimize drivers' undesirable behavior at grade crossings with active traffic control devices.

Research Methodology Overview

A multi-faceted research approach was developed to accomplish the objectives of the research. First, an in-depth study of undesirable driver actions was conducted at three grade crossings with active traffic control. (Two of the study crossings had flashing light signals, while the third was equipped with gates and flashing light signals.) The field study results provided evidence of the extent of driver behavior deficiencies at active crossings, and provided insight into the factors which influence this undesirable behavior.

Using the data collected in the field studies, a detailed assessment of warning time effects on driver behavior was also conducted. The effects of warning time length on crossing violations, clearance times, and exposure times were evaluated. Based on empirical data from the field studies, a computer simulation model was developed to demonstrate the aggregate impacts of excessive warning times on total crossing violations and motorist delay. In addition, a laboratory study was conducted to further evaluate drivers' expectancies and tolerances with respect to warning times.

To identify and evaluate factors which, together with warning time, influence driver behavior at active crossings, a driver survey was developed and administered nationwide. The survey focused on drivers' behavior at crossings with gates and flashing light signals. Survey participants were asked a series of questions to ascertain their

comprehension of the devices and pertinent traffic laws, perception (and acceptance) of the grade crossing hazard, tendencies for risk-taking, respect for active crossing devices, exposure to active systems, and general demographic characteristics. The effects of these factors on the drivers' self-reported crossing behavior were then evaluated. A multivariate analysis of variance (MANOVA) approach was used to determine the general effects of the various factors. A discriminate analysis approach was used to identify the combination of factors which have the greatest influence on crossing behavior. The discriminate analysis also yielded "linear discriminate functions" for classifying individual drivers as either potential violators or non-violators.

Based on the results of the field and laboratory studies and the driver survey, measures for improving driver response at grade crossings with active traffic control are recommended. These include guidelines for minimum, maximum, and desirable warning times at active crossings.

Report Organization

This report is organized into eleven chapters. Following this introductory chapter (Chapter 1), a review of pertinent literature is presented in Chapter 2. The literature review describes the two predominate types of active traffic control systems used at grade crossings; drivers' duties with respect to these systems are also discussed. The significant past research on factors affecting undesirable driver behavior in general, and in particular at grade crossings with active traffic control, is then summarized.

Chapter 3 describes the field studies conducted to assess the extent and nature of drivers' undesirable behavior at crossings with active traffic control, and Chapter 4 presents the results of these studies. The extent of undesirable driver actions at active crossings is documented in the first part of the chapter, then the specific effects of warning time on driver behavior are analyzed in the second part.

Chapters 5 and 6 continue the in-depth assessment of warning time effects. Chapter 5 describes a computer simulation model developed as part of the research to demonstrate the overall negative impacts of excessive warning times on crossing safety and motorist delay; the results of the application of this model are summarized and discussed. Chapter 6 presents the results of a laboratory study conducted to assess drivers' expectancies and tolerances with respect to warning times at active crossings.

The research into warning time effects is culminated in Chapter 7. This chapter presents guidelines for minimum, maximum, and desirable warning times based on the results of the field and laboratory studies and the literature review.

Chapters 8, 9, and 10 document the work performed to identify and evaluate those driver-related factors which, together with warning time, influence driver behavior at active crossings. Chapter 8 describes the national survey undertaken to gather data for the evaluation; Chapters 9 and 10 present the survey results. Specifically, Chapter 9 reports the results of the multivariate analysis of variance (MANOVA) of driver behavior at active crossings, and Chapter 10 presents the results of the

discriminant analysis performed to identify the "most significant" factors influencing driver behavior.

Chapter 11 presents the major conclusions and recommendations based on the research results. Conclusions concerning the effects of warning time, driver attributes, system reliability, and traffic law enforcement are presented. Measures for improving driver performance at active crossings are recommended.

CHAPTER 2

LITERATURE REVIEW

This chapter describes the two types of active traffic control devices in common use at railroad-highway grade crossings in this country, and reviews the standards and laws which govern their use and meaning. A review of the pertinent literature on factors which can influence driver behavior in general, and at grade crossings in particular, is presented. Also presented is a review of the literature on warning time issues, including the effects of warning time on driver behavior and crossing safety.

Active Warning Devices

There are two basic types of traffic control systems used at railroad-highway grade crossings: passive systems and active systems. Passive systems employ signing and pavement markings to indicate the presence of a crossing. A typical passive traffic control system, consisting of a railroad advance warning sign, a crossbuck sign, and appropriate pavement markings, is shown in Figure 1. Active warning systems incorporate these same signs and pavement markings, and they employ an "active" device to warn motorists of the approach or presence of a train. The two types of active devices in common use are: (1) flashing light signals and (2) automatic gates with flashing light signals.

Flashing Light Signals. Flashing light signals, originally designed to simulate the appearance of a signalman waving a red lantern,

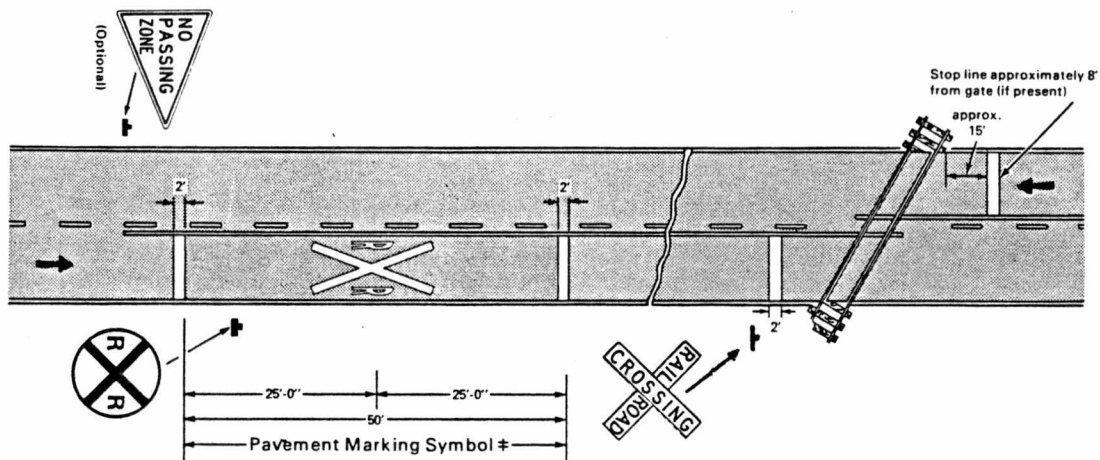


Figure 1. Typical placement of warning signs and pavement markings.

Source: Manual on Uniform Traffic Control Devices for Streets and Highways, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1989.

have been in use at grade crossings since 1923.⁽¹¹⁾ The current configuration was adopted into standard practice in 1930, and present day standards for the design and operation of flashing light signals are contained in the Manual on Uniform Traffic Control Devices (MUTCD).⁽¹²⁾

A typical post-mounted flashing light signal assembly is shown in the left-hand side of Figure 2. As illustrated in Figure 2, the standard assembly consists of two light units that flash alternately at a rate of 35 to 55 times per minute.⁽¹³⁾ The flashing light signals are connected to a train detection device so that the lights are "activated" when a train is approaching or occupying the crossing. A bell may also be included in the assembly and operated in conjunction with the flashing light signals primarily to warn pedestrians and bicyclists. A crossbuck sign is always used in conjunction with flashing light signals, and it is normally mounted above the light units on the same post with the flashing light signals. Other supplementary signs may also be mounted on the post.

The pair of flashing lights is attached to a horizontal crossbar with a 30-inch spacing between lights. Each light has either an 8-3/8 or 12-inch red lens (or roundel), surrounded by a 20-inch black circular backplate. The lights use low power lamps, typically ranging from 18 to 25 watts. The use of low-wattage lamps is necessary since flashing light signal installations are powered by a 12-volt battery power system. An internal reflector and the roundel are designed to focus the light intensity toward approaching motorists. As might be expected, proper alignment of the light unit is critical for visibility. Post-mounted

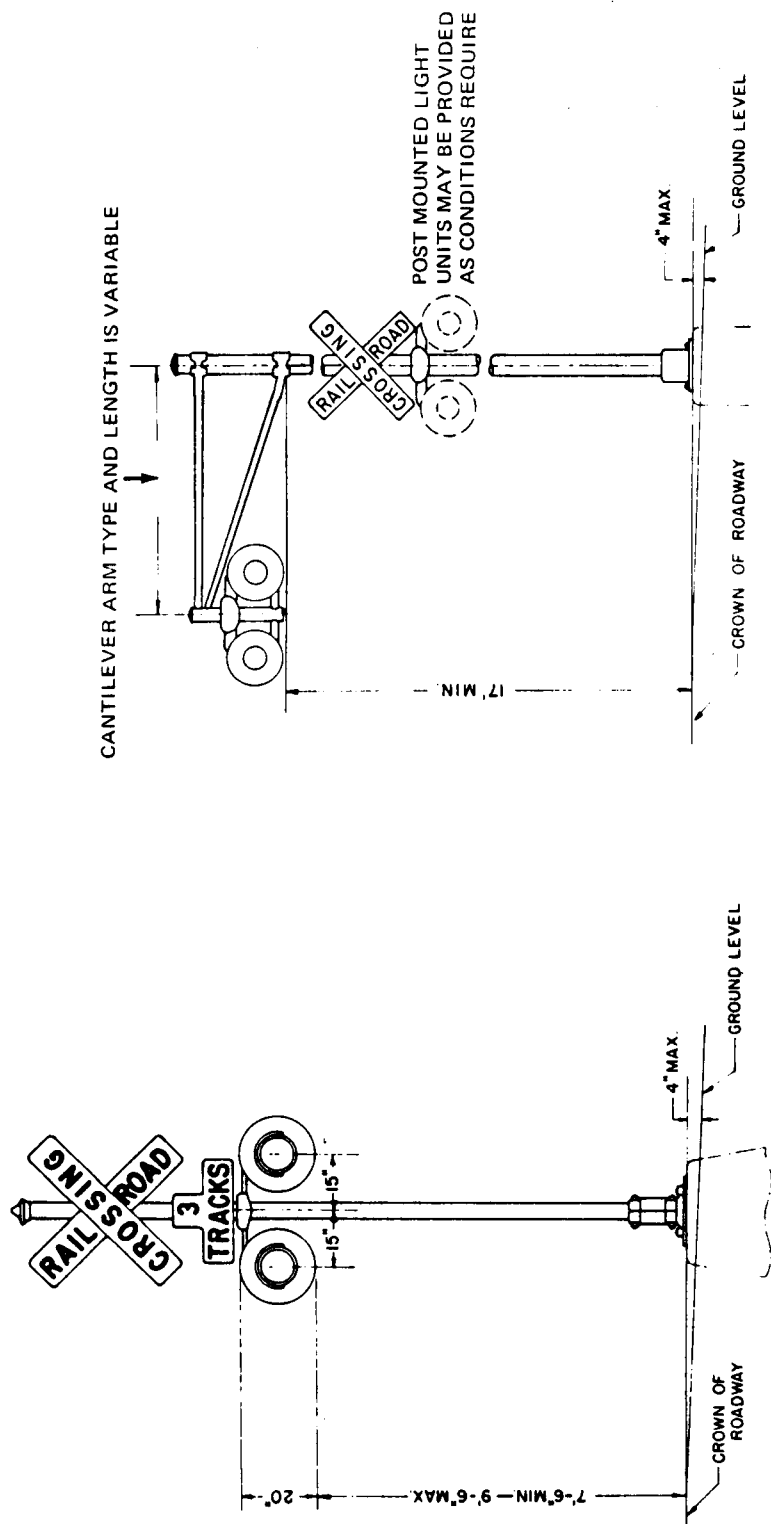


Figure 2. Typical flashing light signal assemblies.

Source: Manual on Uniform Traffic Control Devices for Streets and Highways, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1989.

flashing light signals are generally placed on the right side of the roadway, on both approaches to a crossing.

Back-to-back pairs of lights, aimed in opposite directions, are often used. Also, additional pairs of lights may be mounted on a pole and directed toward traffic approaching the crossing from nearby side roads, driveways, etc. For better visibility and particularly on multi-lane highways, flashing light signals may be cantilevered as illustrated in the right-hand side of Figure 2.

Automatic Gates. Manual gates, operated by a railroad signalman, date back to horse-and-buggy days; however, automatic gates with flashing light signals were first installed in this country in 1936.⁽¹⁴⁾ Current standards for the design and operation of automatic gates with flashing light signals are presented in the MUTCD.

A typical automatic gate installation is shown in Figure 3. The installation consists of a post-mounted flashing light signal assembly with an added drive mechanism which raises and lowers a "short-arm" gate. This gate arm, typically made of aluminum, fiberglass, or wood, is fully reflectorized with 16-inch long, alternating red and white stripes. The stripes slope downward at a 45-degree angle toward the center of the roadway. There are three red lights attached to the gate arm at even intervals. These lights, along with the flashing light signals, flash during the entire activation sequence.

As a train approaches the crossing, the flashing light signals and gate lights are first activated, then the gate arm is lowered from the vertical ("up") position to a horizontal ("down") position, approximately 4 feet above the pavement. The gate remains down until the train is

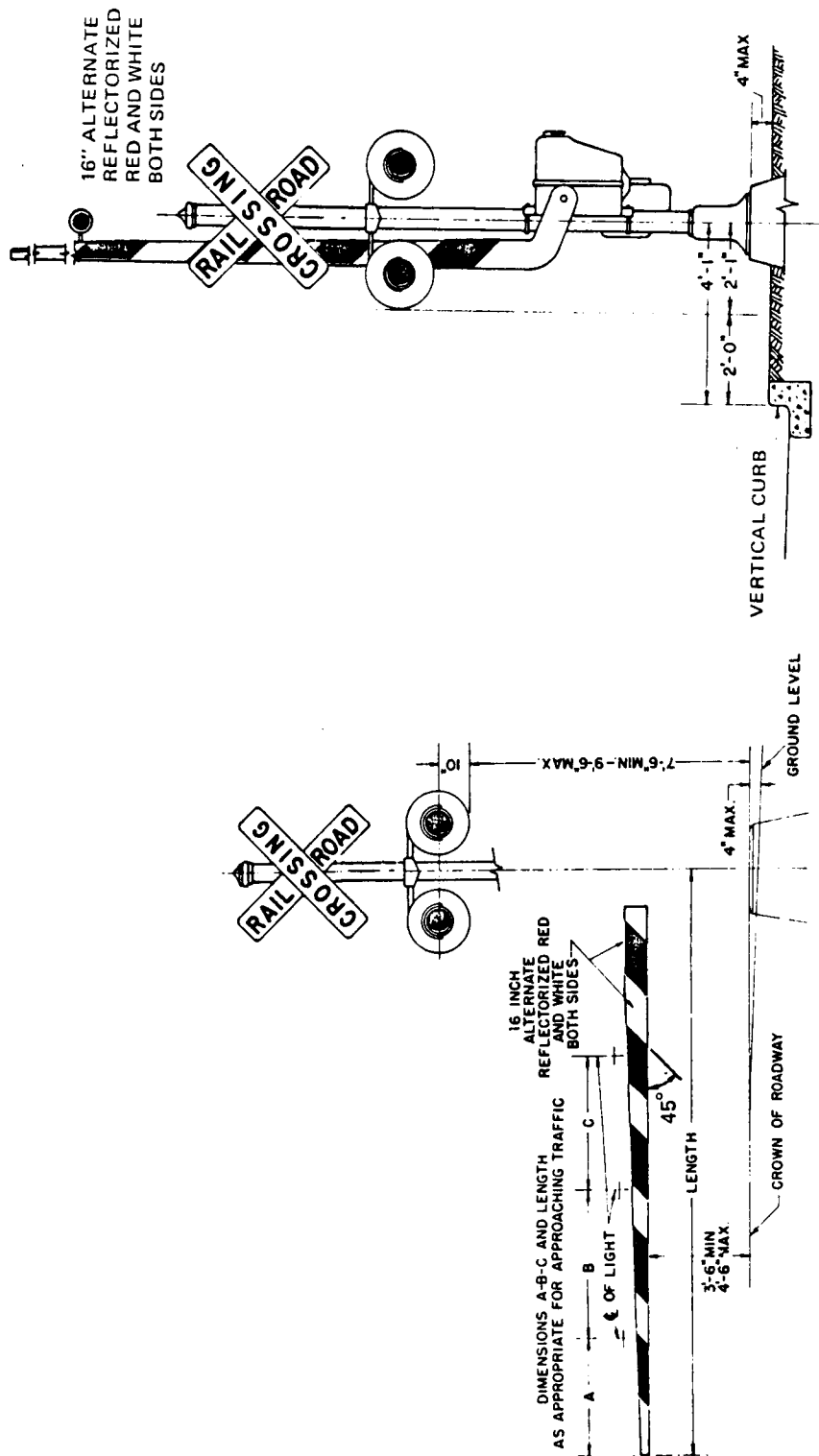


Figure 3. Typical automatic short-arm gate installation.

Source: Manual on Uniform Traffic Control Devices for Streets and Highways, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1989.

clear of the crossing. While in the "down" position, the gate arm physically blocks the approach lanes at the crossing. However, the "short-arm" gates are designed to only block one-half of the roadway. There is generally room for a motorist to go around a lowered gate arm by driving into the opposing traffic lanes if he/she elects to do so.

Warning Time Requirements. Warning time requirements for flashing light signals with and without automatic gates are specified in the MUTCD. Warning time refers to the length of time between device activation and arrival of the train at the crossing. The MUTCD states:

On tracks where trains operate at speeds of 20 mph or higher, circuits controlling automatic flashing light signals shall provide for a minimum operation of 20 seconds before arrival of any train on such track. . . .

Where the speeds of different trains on a given track vary considerably under normal operation, special devices or circuits should be installed to provide reasonably uniform notice in advance of all train movements over the crossing. Special control features should be used to eliminate the effects of station stops and switching operations within approach control circuits. (p. 8C-7)

From the above passages, the MUTCD requires a minimum warning time of 20 seconds at crossings with flashing light signals where train speeds are 20 mph or higher. Since all gated crossings also have flashing light signals, the 20-second minimum warning time also applies to gated crossings. It should be noted that the MUTCD does not establish maximum or desirable warning times for crossings with active traffic control.

The MUTCD does address the issue of variable warning times, but only in a general fashion. Determination of train speed variance and

"reasonably uniform notice" mentioned in the passages are left for the responsible railroad to decide on a case-by-case basis.

With regard to the operation of automatic gates, the MUTCD states the following:

In a normal sequence of operation the flashing light signals and the lights on the gate arm in its normal upright position are activated immediately upon detection of the approach of a train. The gate arm shall start its downward motion not less than 3 seconds after the signal lights start to operate, shall reach its horizontal position before the arrival of any train, and shall remain at that position as long as the train occupies the crossing. . . . In the designing of individual installations, consideration should be given to timing the operation of the gate arm to accommodate slow moving trucks.
(p. 8C-4)

The above passage provides specific information about the gate operation sequence, however, it does not provide specific guidelines on maximum or desirable warning times for gated crossings. The passage suggests that consideration should be given to slow moving trucks without indicating what this consideration should be, and it is mute on the issue of gate descent times. Gate descent time is the time involved in lowering the gate arm from the vertical ("up") position to the horizontal ("down") position.

Use of Active Devices

As of 1986, there were 192,454 public grade crossings in the United States. A total of 22,066 of these crossings (11.5 percent) were equipped with automatic gates and flashing light signals, while 32,778 crossings (17.0 percent) had flashing light signals.⁽²⁾ Combining these numbers, there were a total of 54,844 crossings with standard active

devices, or 28.5 percent of the total public crossings. In addition, there were over 9,000 public crossings with "non-conventional" active traffic control devices such as "wig-wags" or highway traffic signals, bringing the total number of active crossings to over 60,000.⁽⁷⁾

The criteria for installing active devices vary, and most organizations do not have a single set of criteria which are uniformly applied. In fact, the MUTCD encourages flexibility in the use of active devices as follows:

Due to the large number of significant variables which must be considered there is no single standard system of active traffic control devices universally applicable for grade crossings. Based on an engineering and traffic investigation, a determination is made whether any active traffic control system is required at a crossing and, if so, what type is appropriate. (p. 8D-1)

The Railroad-Highway Grade Crossing Handbook⁽⁷⁾ and the Traffic Control Devices Handbook⁽¹⁵⁾ identify conditions under which flashing light signals and automatic gates with flashing light signals should be considered. These guidelines, compiled in Figure 4, represent a synthesis of practices throughout the country. In fact, a survey by Wunderlich revealed that 89 percent of 287 study crossings in 44 states were in compliance with the guidelines presented in Figure 4.⁽¹⁶⁾ It should be emphasized that no legal requirement is implied by the guidelines.

Driver Duties

In a recent report to Congress, the Secretary of Transportation acknowledged that "Traffic laws place the burden for most actions to

Guidelines for Active Traffic Control

- Vehicular traffic volume--an ADT of less than 1,000 would require other significant warrants;
- Railroad traffic volume--less than 6 trains per day would normally represent light exposure except where passenger train operations exist;
- Maximum train speeds--speeds greater than 50 miles per hour in rural areas or 35 miles per hour in urban areas deserve careful consideration;
- Maximum permissible vehicular speeds--speeds in excess of 35 miles per hour in rural areas or 25 miles per hour in urban areas deserve careful consideration;
- Pedestrian volumes--pedestrian volumes of 150 or more per hour may be a significant determinant;
- Accident record--occurrence of a train-involved accident within a three year period indicates a need for careful analysis;
- Reduced sight distance--limited view of tracks should be checked for limited driver reaction; and
- Elimination potential--closing lightly used crossings and installing active devices at more heavily used crossings should be considered.

Additional Criteria for Automatic Gate Control

- Multiple main line railroad tracks;
- Multiple tracks where a train on or near the crossing can obscure the movement of another train approaching the crossing;
- High-speed train operations combined with limited sight distance;
- Combination of high speed and moderately high volume highway and railroad traffic;
- Presence of school buses, transit buses, or farm worker vehicles in the traffic flow;
- Presence of trucks carrying hazardous materials, particularly when the view down the track from a stopped vehicle is obstructed;
- Presence of passenger trains; and
- Continuance of accidents after installation of flashing lights.

Figure 4. Factors used in determining the need for active traffic control devices at railroad-highway grade crossings.

Source: Heathington, Fambro, and Richards, Field Evaluation of Innovative Active Warning Devices for Use at Railroad-Highway Grade Crossings, Report No. FHWA-RD-88-135. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., January 1988.

avoid accidents at crossings on the roadway user."⁽¹⁾ This statement emphasizes the importance of driver duties at active grade crossings.

Section 11-701 of the Uniform Vehicle Code (UVC)⁽¹⁷⁾ defines drivers' legal responsibilities at railroad-highway grade crossings with active traffic control. Although adoption of the UVC by states is not mandatory, most states have incorporated its provisions relative to grade crossing traffic control into their state traffic regulations, either verbatim or in general principle. Following are the key passages from Section 11-701 of the UVC which define driver duties at active crossings:

- (a) Whenever any person driving a vehicle approaches a railroad grade crossing under any of the circumstances stated in this section, the driver of such vehicle shall stop within 50 feet but not less than 15 feet from the nearest rail of such railroad, and shall not proceed until he can do so safely. The foregoing requirements shall apply when:
 - 1. A clearly visible electric or mechanical signal device gives warning of the immediate approach of a railroad train;
 - 2. A crossing gate is lowered or when a human flagman gives or continues to give a signal of the approach or passage of a railroad train;
 - 3. A railroad train approaching within approximately 1,500 feet of the highway crossing emits a signal audible from such distance and such railroad train, by reason of its speed or nearness to such crossing, is an immediate hazard;
 - 4. An approaching railroad train is plainly visible and is in hazardous proximity to such crossing.
- (b) No person shall drive any vehicle through, around or under any crossing gate or barrier at a railroad crossing while such gate or barrier is closed or is being opened or closed.

The meaning and intent of these passages are discussed in detail in the following sections. State compliance with these provisions is also summarized.

Flashing Light Signals. As stated in the UVC, all drivers must stop at crossings with flashing light signals whenever the signals are activated, i.e., warning of the "immediate approach of a railroad train." After stopping, drivers must remain stopped until they can safely proceed. If no train is in hazardous proximity, a motorist can legally cross, even if the signals are flashing, provided the driver has first stopped.

It should also be mentioned that drivers (with some exceptions) are not explicitly required under the UVC provisions to stop, slow down, or even look for a train at crossings with flashing light signals when the signals are not activated. The exceptions are drivers of school buses, public transportation buses, and vehicles transporting hazardous materials. Most states have laws requiring these drivers to stop at all crossings at all times before proceeding.⁽¹⁸⁾

The large majority of states have adopted the UVC provisions relative to flashing light signals verbatim, or have adopted them in principle with minor changes. A 1979 compilation of states' traffic laws by Russell et al.⁽¹⁹⁾ revealed that 45 of the 50 states have adopted the UVC or consistent provisions relative to flashing light signals. Of the five non-complying states in 1979, two (Connecticut and Wisconsin) required motorists to remain stopped for an activated signal, even if no train is in hazardous proximity. The other three states (Kentucky, South Carolina, and Virginia) did not explicitly require motorists to stop for

activated signals under all circumstances. The 1979 compilation is the most recent national survey. Occasionally, a state will change its laws relative to active crossings; however, the large majority of states still are in compliance with the basic provisions of the UVC.

Gates with Flashing Light Signals. Under the UVC provisions, all drivers must stop at crossings equipped with gates and flashing light signals whenever the gates and/or flashing light signals are activated. They must remain stopped for the entire time that the gate is down or is being lowered or opened, regardless of whether a train is visible or in hazardous proximity. As was the case for crossings with flashing light signals, drivers (with exceptions) are not required to stop, slow down, or even look for a train at gated crossings when the gates and signals are not activated. The exceptions are drivers of school buses, public transportation buses, and vehicles transporting hazardous materials, who are required in most states to stop at all crossings at all times before proceeding.

The compilation of states' traffic laws by Russell, et al.,⁽¹⁹⁾ found that 40 of the 50 states had traffic laws which comply with the UVC provisions relative to drivers' duties at gated crossings. This is a substantial number, but is lower than the number of states in compliance with UVC provisions pertaining to flashing light signals. Of the 10 non-complying states in 1979, four had laws which did not explicitly require drivers to stop at gated crossings, nor did their laws explicitly forbid driving around a lowered gate arm. Four more states allowed drivers to drive around lowered gate arms after stopping, if no train was visible or in hazardous proximity. One state had no laws specifically relating

to gates; however, there was a general provision requiring motorists to obey all "official traffic control devices" in another section of this state's traffic code. The final non-complying state had adopted the UVC wording relative to gated crossings, but excluded urban crossings from the provisions.

Mandatory Stop Laws. Based on a survey by Bowman and McCarthy,⁽¹⁸⁾ 48 of the 50 states, and the District of Columbia, have laws which require certain vehicles to stop at grade crossings regardless of the presence of a train. At least 36 states comply with Federal Motor Carrier Safety Regulations which require school buses, public transportation buses, and vehicles carrying hazardous cargo to stop at crossings with active traffic control devices even when the devices are not activated.

Bowman and McCarthy⁽¹⁸⁾ evaluated the level of compliance with mandatory stop laws in several states. They found the violation rate for large trucks to be high -- 97.5 percent for all affected trucks and 70.1 percent for tank trucks. Bus violation rates were lower but still approached 40 percent. Bowman and McCarthy's research is significant because it further illustrates the extreme level of non-compliance with active traffic control devices and associated laws. In addition, the research showed that some large vehicles, albeit a small number, stop at active crossings when the devices are not activated. These vehicles must be given adequate time to clear the crossing when starting from a stopped position, and this clearance requirement may impact minimum warning times.

Components of Driver Response

It is hypothesized that several factors work in combination to influence undesirable driver behavior at grade crossings. In support of this contention, Sanders states that:

The driver at the grade crossing represents a highly complex situation. His or her behavior is a product of a large number of interacting factors. Some of these are physical and objectively measurable such a characteristics of the site itself, nature and status of signs and warning devices, conditions of visibility and weather, and presence or absence of a train. Many others, however, are far less tangible. They include factors such as driver knowledge, driving experience, attitude, and perception-motor capabilities. Collectively, these intangibles may be designated as the human factors of grade-crossing behavior.⁽²⁰⁾

Sanders developed a conceptual model of the components of driver response at grade crossings. This model is presented in Figure 5. As illustrated in Figure 5, Sanders purported that crossing behavior is a result of a motorist's "inherent driver safety potential" interacting with the "situational context" of the crossing. A driver's inherent safety potential is a product of four elements: (1) on-road experience; (2) educational domain; (3) affective domain; and (4) psychomotor domain.

Sanders also identified six elements which contribute to safe driving performance. These six elements, listed below, are potential areas of countermeasures for undesirable crossing behavior:

1. Driver education;
2. State licensing procedures;
3. Safety programs;
4. Law enforcement;
5. Attitude and habit components of railroad-highway safety; and

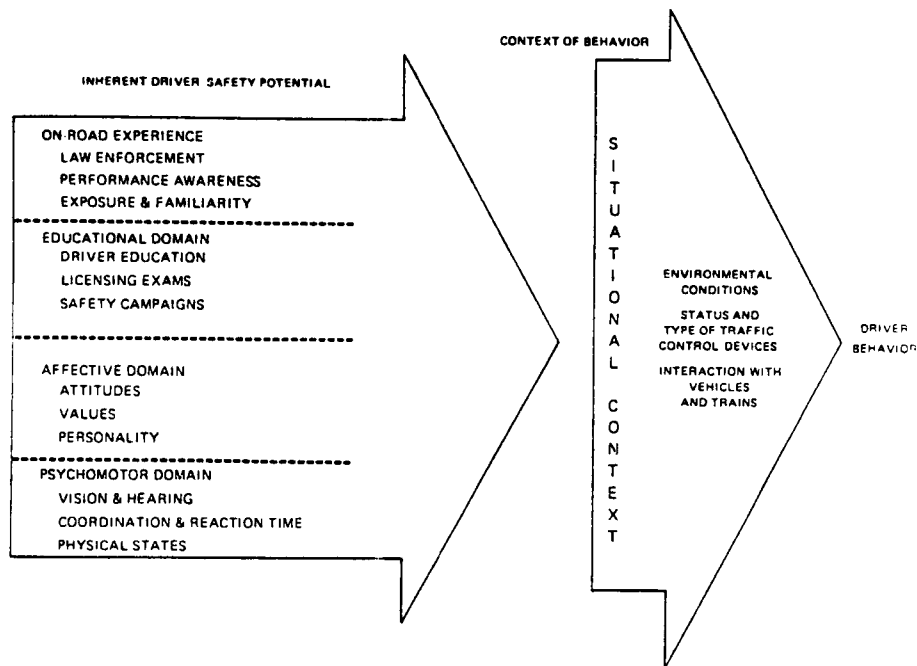


Figure 5. Components of driver response at railroad-highway grade crossings.

Source: Sanders, J.H., Jr., "Driver Performance in Countermeasure Development at Railroad-Highway Grade Crossings," Transportation Research Record 562, Transportation Research Board, Washington, D.C., 1976, pp. 28-37.

6. Physiological capabilities and limitations.

Sanders' research was directed toward both passive and active crossings, and toward driver behavior on the approaches as well as at the crossing. Therefore, some of the factors identified may not have much influence on drivers' intentional crossing actions at grade crossings with active traffic control devices. Those factors which most likely would influence undesirable crossing behavior at active crossings include: (1) driver comprehension and knowledge of the devices and laws; (2) personality characteristics with respect to risk-taking; (3) perceptions about the level of hazard; (4) perceptions about law enforcement; and (5) attitudes and device credibility resulting from previous exposure and familiarity. These factors and others are discussed in detail in the following sections.

Driver Comprehension and Knowledge

Even though the intent of active traffic control devices and associated driver duties is clearly stated in traffic codes and agency standards, drivers may not comprehend the intended meanings or fully understand their responsibilities. This lack of comprehension and understanding, in turn, may lead motorists to act inappropriately in response to active systems. Thus, the issue of driver comprehension and knowledge is an important one.

Considerable research has been conducted into driver comprehension and knowledge of general traffic control devices. There has also been significant research into driver understanding and knowledge of grade

crossing traffic control devices in particular, including flashing light signals and automatic gates.

Comprehension of General Traffic Control Devices. Hulbert, Beers, and Fowler⁽²¹⁾ evaluated motorist understanding of 16 common traffic control devices and situations by surveying over 3,100 drivers in three regions of the country. Although the 1978 study did not specifically evaluate motorists' understanding of active grade crossing devices, it did reveal some important trends regarding the effects of driver demographics on motorists' understanding and recognition of traffic control devices. First of all, the studies found no significant difference in overall comprehension level by gender or region of the country. However, there were regional and gender differences for a few of the devices studied. Secondly, there were significant differences in device understanding and recognition by age. Older drivers (over 49) and very young drivers (18 and below) consistently had more problems with device recognition and understanding.

In a follow-up to the 1978 study, Hulbert and Fowler⁽²²⁾ evaluated motorist understanding of 19 additional traffic control devices, including the railroad crossbuck sign. In this second study, over 1,700 drivers were surveyed, again from all parts of the country. Combining the results of the two surveys the researchers concluded that there is wide variance in motorist understanding of traffic control devices, and that driver education and improvement programs need to give more attention to the proper understanding and interpretation of traffic control devices. Again in the second survey, no significant differences were found in overall comprehension level by gender or region, but there

were gender and regional differences noted for a few of the individual devices. With regard to the crossbuck sign, driver recognition and comprehension were excellent. This sign was correctly understood by 97 percent of the survey participants, which was the highest comprehension level for any of the 35 (16 + 19) traffic control devices tested. There were no significant differences in comprehension of the crossbuck sign by region, gender, or age.

Reilly and Woods⁽²³⁾ surveyed 280 Arizona drivers to assess the degree of driver comprehension of 25 standard and non-standard traffic signs and pavement markings. Based on the survey results, the researchers concluded that drivers in general have a "very limited knowledge" of common traffic control devices and principles. They also concluded that additional research into driver understanding of traffic control devices is needed, and that driver education programs should include substantial amounts of information on the meaning and intent of traffic control systems. In their survey, Reilly and Woods found no significant effects of driver age or annual mileage; however, male drivers tended to have a higher comprehension level for traffic control devices than female drivers.

Comprehension of Grade Crossing Devices. Several studies have been conducted to investigate driver comprehension and knowledge of grade crossing traffic control devices and associated traffic laws. These studies have revealed that many drivers do not fully comprehend the meaning and intent of the devices and laws, nor do they understand exactly what is expected of them under various situations. In addition,

some motorists have misconceptions about the capabilities of trains and the accident avoidance options available to train operators.

Tidwell⁽²⁴⁾ conducted research to: (1) estimate the proportion of drivers with insufficient knowledge of grade crossing devices and driver duties at grade crossings, and (2) determine which knowledge deficiencies, if any, contribute to unsafe behavior. In a survey of 1,011 Tennessee drivers, he found that 51 percent of the drivers incorrectly answered at least 4 of 11 questions related to basic knowledge of grade crossing traffic control; 31 percent did not recognize standard grade crossing signs and pavement markings. Tidwell also conducted field studies at two passive crossings to determine if knowledge of grade crossing traffic control devices influences drivers' speeds, looking behavior, and stopping behavior. Based on the study results, he concluded that comprehension of the devices and their intent did not significantly influence the behavior measures studied. Tidwell did not, however, evaluate the possible effects of driver comprehension on drivers' intentional undesirable crossing behavior at crossings with active traffic control.

Richards and Heathington⁽²⁵⁾ conducted a questionnaire survey of 211 Tennessee drivers to assess drivers' comprehension and knowledge of grade crossing traffic control devices and safety issues. The survey was patterned somewhat after the Tidwell survey, with more emphasis on active traffic control devices. Some of the pertinent findings of the survey are enumerated below:

1. Thirty-five percent of the drivers surveyed did not receive any training in a driver's education course on grade crossing

traffic control (it is not known what percentage of these drivers had taken a driver's education course); 11 percent said they had never received any instructions or information on crossing safety/traffic control from any source.

2. Twenty-two percent of the drivers believed that all grade crossings had active warning devices. Sixty-two percent of the very young drivers (age 16-18) thought that all crossings had active warning devices.
3. Three-fourths of the drivers believed they were required by law to stop and wait for a flashing light signal, even though state law allows motorists to proceed after stopping if no train is in hazardous proximity. In addition, in a companion survey of 35 local police officers, over 80 percent of the officers believed that drivers were required by law to stop and wait.
4. Almost 6 percent of the drivers said that it was permissible (legal) to drive around lowered gate arms if a train was not coming, even though Tennessee law prohibits driving around gates under any circumstances.
5. Forty-five percent of the drivers believed that a train could and should slow down or stop to avoid a collision with a motor vehicle.

In other research, Sanders et al.⁽²⁶⁾ found that 15 percent of 1,267 drivers in Texas, Michigan, and California believed that all crossings had some type of active traffic control, when in fact only about one-fourth do. This research also found that 35 percent of interviewed

drivers had received no training or instruction on crossing safety or traffic control. However, the most significant finding from the research was that drivers who had some instruction in the meaning and intent of active devices, were less likely to exhibit improper speed and looking behavior at active crossings.

In a recent in-depth study⁽⁸⁾ of 75 car-commuter train accidents, the National Transportation Safety Board concluded that a major contributory factor in the accidents was that the drivers did not understand that the train could not stop in time to avoid a collision. The researchers also found that the drivers involved in vehicle-train accidents often had misconceptions about train speeds.

From the research cited in this section, it is apparent that there are deficiencies in drivers' comprehension of active devices and associated laws and of traffic control principles in general. There is also some indication that this lack of understanding affects behavior. It should be mentioned that there are continuing efforts to improve the level of driver comprehension and knowledge relative to grade crossings. One program which has attempted to improve driver comprehension and awareness of grade crossing safety issues and devices is "Operation Lifesaver."⁽¹⁾ Operation Lifesaver began in 1972 under the auspices of the Union Pacific Railroad. It has developed into a national program for informing and educating drivers, law enforcement personnel, and the transportation safety community on the extreme hazards of grade crossings. Unfortunately, the program is not reaching the large majority of motorists. A recent study by the National Transportation Safety Board

revealed that just over one percent of the nation's drivers have been directly exposed to Operation Lifesaver programs.⁽⁸⁾

Risk-Taking and Hazard Perception

Undesirable driver behavior has been linked in previous research to a driver's overall risk-taking tendencies. For example, based on field observations and follow-up driver surveys at a group of active crossings, Sanders⁽²⁰⁾ found that, "drivers who perform less safely according to the safety measures tended to score more highly as risk takers." Research has also identified several factors which encourage risk taking or are common to risk taking drivers. Many of these factors, enumerated below, may influence driver behavior in response to active traffic control devices at grade crossings:

1. Unsafe driving patterns have been linked to numerous negative personality traits including: impulsive, immature, and antisocial living habits; anxiety and moodiness; and emotional instability.^(27,28,29) Unsafe drivers tend to be more extroverted and aggressive in nature than safe drivers.^(30,31)
2. At least one study indicated that intelligence is not related to safe driving behavior.⁽³²⁾ However, other research has concluded that unsafe drivers tend to process information slower.^(33,34)
3. Safe drivers tend to be more confident about driving and have a better overall self-image.⁽³⁵⁾
4. Several studies have found seat belt use to be a good indicator of risk-taking potential.^(35,36,37,38)

5. Research suggests that United States drivers tend to be greater risk takers compared to drivers in many other countries; however, there is no evidence that there are significant differences in risk taking in driving by region of the country.⁽³⁰⁾
6. Research suggests that risk taking drivers are not a homogeneous group, and that it may be difficult to categorize (or discriminate) these drivers.^(39,40) Related to this issue, research suggests that there is more variability within one driver's behavior than there is in the behavior among drivers; this variability is due to situational factors.⁽⁴¹⁾ Situational factors which influence an individual's driving behavior at any given time include: a priori driving experience, route familiarity, car familiarity, fatigue, stress, time pressure, activation level, motivation, and health.⁽⁴²⁾
7. Driver attitude and associated risk taking tendencies have been reported to vary by driver experience, gender, and age. Several studies indicate that traffic violators tend to be male, under 20 or 25 years of age, with less than 5 years driving experience.^(43,44,45,46)
8. Drivers tend to think of themselves as more skillful, safer drivers than they really are.^(30,43) They tend to underreport certain unsafe behaviors, although this was not the case in a study of grade crossing behavior.⁽³⁷⁾

9. The presence of passengers in the vehicle discourages drivers from committing some overt forms of risk taking, e.g. running a stop sign.⁽³⁷⁾

Undesirable driver behavior has also been linked to a driver's perceptions of the degree of hazard. Specifically with regard to railroad-highway grade crossings, Heathington and Urbanik⁽⁴⁷⁾ conducted research to evaluate driver attitudes concerning the relative and absolute hazard at crossings. As part of the research, 259 driver subjects were asked to compare the perceived hazard level associated with grade crossings and five other common traffic situations. The five other potential hazards were: signalized intersections, stop-controlled intersections, yield-controlled intersections, crossroads, and horizontal curves. Based on the survey results, the respondents considered railroad grade crossings to be relatively more hazardous than the five other hazards. However, on an absolute basis, the drivers rated the grade crossing hazard as only a "moderate" hazard. The researchers concluded that "this lack of concern for hazardous conditions existing on highways might account for the problems of safety at many of the highway-railway grade crossings."

Level of Enforcement

Risky behavior may be influenced by the perceived threat of enforcement. That is, compliance with traffic control devices and laws may improve if motorists perceive a significant threat of enforcement. In fact, based on his observations of driver performance at railroad-highway grade crossings, Sanders⁽²⁰⁾ concluded that "Driver awareness of

enforcement yields more careful overall behavior (at crossings) and tends to increase awareness in general." He also found indications that "enforcement of required behavior is a factor in (grade crossing) accident reduction."

However, enforcement of traffic laws related to active grade crossing devices has generally been haphazard and infrequent. The reason for this low level of enforcement is evident in a report⁽¹⁾ by the FHWA Administrator wherein the Administrator concluded that "Because accidents at rail-highway crossings are rare events, enforcement of traffic laws at crossings is usually not a high priority for local law enforcement officials." The Administrator went on to recommend that enforcement efforts be expanded through the following measures:

1. There should be increased surveillance at heavily traveled crossings, and grade crossing laws should be more strictly enforced.
2. Local enforcement and railroad personnel should work together to identify problem crossings and "high exposure" points.
3. Operation Lifesaver programs should emphasize to local law enforcement agencies the importance of visible efforts to enforce crossing laws.

Despite the general low level of enforcement, there have been some specific enforcement programs targeted at grade crossings. Recently, railroad and local law enforcement officials in a Midwestern state developed a program which involved placing police officers on trains to observe and report traffic violations to officers on the highway.⁽¹⁾ This "Trooper on the Train" program, as it is called, received much media

attention and local visibility. Although a relatively few citations and warnings were issued, the organizers of the program concluded that it improved overall driver behavior at crossings because it increased the "perceived" level of enforcement and heightened drivers awareness of the crossing safety issue.

Device Credibility

Undesirable driver behavior observed at active crossings may be due in part to drivers' lack of trust or credibility in the devices. Drivers may not consider the devices to be accurate or reliable, leading to eventual violation of their warning. In fact, there have been several studies which suggest that drivers do lack trust in active warning devices. In a Canadian study, Wilde, Cake and McCarthy⁽¹⁰⁾ found that 10 to 60 percent of drivers looked down the tracks when approaching crossings with "unactivated" flashing light signals. Wilde et al. concluded that looking behavior indicated a lack of credibility in the signals. Similarly, Sanders, Kolsrud and Berger⁽²⁶⁾ found that there was no difference in drivers' looking behavior at passive versus active crossings. One conclusion which can be drawn from this result is that drivers do not fully trust active devices to warn of an approaching train.

Warning Time and Credibility. The most significant credibility problem probably results from the excessive warning times which are experienced at many active crossings. In support of this claim, Heathington, Fambro, and Richards⁽⁴⁾ observed warning times ranging from below 30 seconds to almost 2 minutes at a typical urban crossing with

automatic gates. They found that crossing violations observed at this crossing were directly related to the variable and sometimes long warning times. As shown in Figure 6, as warning time increased from 29 seconds to 118 seconds, average gate violations per train event increased from no violations to over 6 violations per train event. Sanders⁽⁶⁾ and Wilde, Cake and McCarthy⁽¹⁰⁾ in similar studies concluded that excessive warning times are one of the main reasons for lack of compliance with active warning devices. Sanders⁽⁶⁾ even reported observing warning times ranging from as low as 2 seconds to almost 5 minutes at a group of active crossings. These findings collectively support the contention that drivers lose respect for active systems if the warning occurs too early prior to train arrival. They also document the fact that relatively long warning times do occur at active crossings.

To expand on the issue of warning time and credibility, other research is noteworthy. Berg, Knoblauch, and Huckle⁽⁴⁸⁾ studied causal factors in grade crossing accidents. They reconstructed 43 accidents which occurred at grade crossings with flashing light signals in North Carolina and Wisconsin, and found that between 53 and 71 percent of these accidents were a result of driver decision errors. Furthermore, 90 percent of the decision errors involved a driver observing the flashing light signals, but intentionally crossing while the signals were activated. The researchers concluded that "Warning times in excess of 30 seconds represented an unnecessarily long advance warning of the approach of a train." They also concluded that traffic control device "credibility is more important than conspicuity" at crossings with flashing light signals.

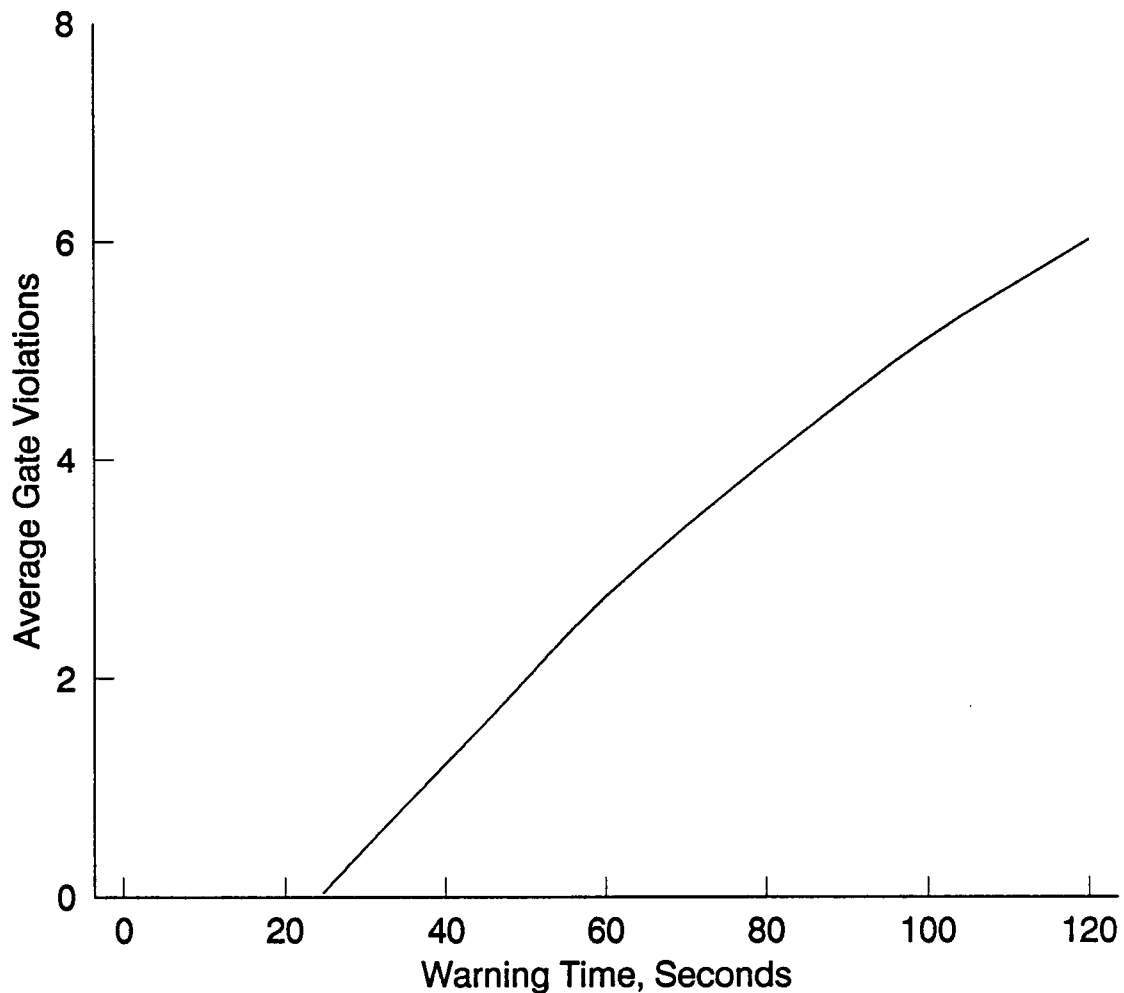


Figure 6. Average number of violations as a function of the warning times at a typical gated crossing.

Source: Adapted from Heathington, Fambro, and Richards, Field Evaluation of Innovative Active Warning Devices for Use at Railroad-Highway Grade Crossings, Report No. FHWA-RD-88-135, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., January 1988.

Wigglesworth⁽⁴⁹⁾ conducted an evaluation of the influence of driver-related factors in grade crossing accidents for the Australian Ministry of Transport. Based on his observation of driver actions at over 20 active crossings, Wigglesworth concluded that,

"Without question, some road users indulge in behavior deemed by other road users to be reprehensible and risk taking. This undesirable behavior possibly was due to driver confusion about what to do in the presence of switching trains, excessive waiting times, the perception that the train was too far away to represent a hazard, and/or the driver was simply in a hurry."

With specific regard to warning time, and after observing crossings with warning times in excess of 3 minutes, Wigglesworth stated that ". . . in the context of an elapsed interval of 3 minutes the assumption that there had been a system malfunction of some sort seems reasonable enough, and the subsequent behavior seems therefore understandable if not readily forgivable." Wigglesworth made case studies of seven incidents which resulted in crossing violations at gated crossings. Three of the incidents involved excessive warning times longer than 145 seconds. One incident involved a train switching operation in which waiting motorists observed a very slow moving train repeatedly cross in front of them during a five minute time period.

Research has also revealed that drivers tend to overestimate their wait time at active crossings. In all likelihood this tendency acts to further degrade device credibility as the warning time increases. For example, Sanders polled drivers at a group of study crossings where the warning times generally ranged from 40 to 60 seconds in length.⁽²⁰⁾ Over 40 percent of the drivers stated that the warning periods were in excess

of 60 seconds, and over 15 percent said that the warning periods were longer than 2 minutes. In addition, 54 percent of the drivers reported that they waited for over 5 minutes when stopped for a train, even though actual delays were much shorter. Sanders found that drivers who reported long delays when stopped at grade crossings tended to display unsafe crossing behavior. Also, Sanders reported that "Drivers who crossed against an activated signal . . . generally were observed to be in a hurry to complete their trip."

Train Detection and Warning Time

Much of the warning time issue at crossings with active traffic control is hardware-related -- that is, certain types of train detection equipment cannot provide uniform and reasonable warning times if there are variable speeds and/or switching activities at the crossing. Therefore, it is appropriate to briefly review train detection in the context of its impact on warning times.

The MUTCD establishes general guidelines related to train detection requirements at active crossings. The MUTCD states:

To serve their purpose of advising motorists and pedestrians of the approach or presence of trains, locomotives, or railroad cars on grade crossings, the devices employed in active traffic control systems shall be actuated by some form of train detection. Generally the method is automatic, requiring no personnel to operate it, although a small number of such installations are still operated under manual control.

The automatic method currently uses the railroad circuit. Railroad circuits insofar as practical shall be designed on the fail safe principle, which uses closed circuits. (p. 8C-5)

The predominate means of train detection in this country is the railroad track circuit, although other means of train detection such as radar are used in a very limited number of systems. The track circuit approach to train detection is straight-forward in concept. An electrical circuit is established on the rail approaches to a crossing by passing a low current through the rails. The rails act as conductors in the circuit. When a train enters the electrified track section, the steel wheels and axles of the locomotive and rail cars "shunt" the circuit, which triggers the activation of the flashing light signals and/or gates.

Detection systems which utilize the track circuit approach are designed to be "fail-safe"; that is, any shunt of the circuit will trigger activation of the traffic control devices. The "fail-safe" feature virtually eliminates the possibility of the traffic control devices not activating when there is a train present. However, it will cause false activations in the event of a damaged rail, vandalism or accidental damage to detection hardware, or even water standing across the rails.

Fixed-distance Systems. There are two basic categories of train detection systems: fixed-distance systems and constant warning time (CWT) systems.⁽⁵⁰⁾ With fixed-distance systems, trains activate the traffic control devices when they arrive at a predetermined, fixed distance from the crossing, and the devices continue to operate as long as the train occupies the space between the pre-set activation point and the crossing. This distance is generally calculated based on the speed of the fastest train and a specified desirable warning time for this fastest train. If

all the trains using the crossing travel at or near the speed of the fastest train, then all the warning times will be fairly consistent and near the desirable warning time specified. However, if slower trains use the crossing, they will have longer warning times, and these times will be inversely proportional to their speed.

There are four different types of train detectors in common use that fall into the "fixed-distance" category: (1) direct current track circuit; (2) AC-DC track circuit; (3) audio frequency overlay track circuit; and (4) motion sensitive track circuit.⁽¹⁾ Collectively, these four types of fixed-distance detectors are installed at over 45,000 crossings nationwide.^(2,51) None of them can accommodate variable speed trains without the resulting variable and long warning times; however, "motion sensors" do have the capability of appropriately "de-activating" the traffic control devices during switching operations and if a train stops before it reaches the crossing.

Constant Warning Time Systems. In contrast, CWT systems have the capability of sensing a train in the approach section, measuring its speed and distance from the crossing, and activating the warning devices at a pre-set time relative to the train's arrival at the crossing. Thus, CWT equipment provides a reasonably uniform warning time regardless of the train speed. The predominate type of CWT system is a track circuit system which utilizes control hardware commonly called a "train predictor."

Research on CWT Systems. Bowman and McCarthy⁽⁵¹⁾ conducted a study to determine the use and installation criteria of CWT systems. Using the 1986 National Crossing Inventory File and data from manufacturers, they

estimated that approximately 6,300 crossings nationwide are equipped with CWT systems. Of this number, 39 percent are installed at crossings with flashing light signals, 60 percent are installed at crossings with gates and flashing light signals, and 1 percent are installed at crossings with highway traffic signals. Bowman and McCarthy also found that there are no quantitative guidelines for installing CWT systems, although train speed, switching activity, and highway traffic volumes are all important qualitative factors used by professionals on a crossing-by-crossing basis. In order to estimate the number of additional crossings that might benefit from CWT systems, a discriminate analysis was performed on a sample of crossings to classify them as CWT/no CWT based on crossing characteristics. The results of the discriminate analysis were applied to the National Crossing Inventory File to estimate the total number of potential CWT crossings at 19,400. Subtracting out those that already have CWT indicates that an additional 13,100 crossing may require CWT systems.

Halkias and Eck⁽⁵⁰⁾ studied the influence of highway classification, angle of crossing, and train speed on the effectiveness of fixed-distance and CWT systems through analysis of the data in the National Crossing Inventory File and the Federal Railroad Administration's Accident/Incident Reporting System. Results showed that upgrades from fixed-distance to CWT systems yielded a 26 percent increase in safety effectiveness, tending to confirm the hypothesis that CWT systems have better credibility with motorists. The benefits of CWT over fixed-distance systems were greatest for crossings with variable speed trains, and at

acute angle crossings (0-29 degrees). Highway classification and maximum train speeds were not significantly related to CWT system effectiveness.

Richards, Heathington, and Fambro⁽⁵²⁾ conducted a before-and-after evaluation of train predictors installed at a suburban crossing with flashing light signals. Train speeds at the crossing were highly variable, and before the CWT system was installed at the crossing, warning times tended to be long and highly variable. The train predictors were found to be operationally reliable, and they reduced the average warning time at the crossing from 75.2 seconds to 41.7 seconds. Driver behavior improved significantly after the predictors were installed. The number of vehicles crossing the tracks while the flashing light signals were activated was reduced from 1,086 crossings per 100 train arrivals to 335. In addition, the CWT system significantly reduced the numbers of vehicles crossing within 20 seconds of train arrival (CL20s) and 10 seconds of train arrival (CL10s). CL20s and CL10s were defined by the researchers as measures of aggressive driver behavior and risky driver behavior, respectively.

Warning Time Needs of Mandatory Stop Vehicles

A special issue pertaining to warning times at active crossings is the impact of mandatory stop vehicles on minimum warning times. As noted previously, most states have laws which require buses and hazardous cargo trucks to stop at passive crossings and at crossings with active traffic control, even when the devices are not activated. As a result, the minimum warning time at a crossing must be sufficient to permit one of

these vehicles to clear the crossing should a train approach just as the vehicle starts-up from a stop.

To address the issue of warning time requirement for mandatory stop vehicles, Bowman and McCarthy⁽¹⁸⁾ performed an evaluation of the clearance times for various tractor-semitrailer configurations as a function of roadway grade and length of the hazard zone. They utilized a simulation method developed by the University of Michigan for predicting truck acceleration performance under a variety of conditions. Table 2 summarizes the findings of the evaluation. As shown in Table 2, clearance times ranged from 11.5 seconds to 33.7 seconds for single trailer trucks, from 11.9 to 34.5 seconds for double trailers, and from 15.8 to 42.2 seconds for triple trailers, depending on the crossing width and grade. The researchers concluded that the current minimum warning time of 20 seconds for active crossings may be inadequate for some crossings, depending on the crossing width and grade, if mandatory stop vehicles are present.

Warning Time Practices in Foreign Countries

A survey of warning time practices in selected foreign countries was conducted as part of the literature review. Six countries -- Australia, United Kingdom, Sweden, West Germany, Canada, and Japan -- responded to the survey. Tables 3 and 4 summarize the findings of the foreign survey relative to flashing light signal systems and gates with flashing light signals, respectively.

Note from Tables 3 and 4 that the minimum warning times are relatively consistent from one country to the next, both for flashing

Table 2. Clearance times for mandatory stop vehicles.

		Length of Hazard Zone (Feet)									
		Grade (%)	35'	45'	55'	65'	75'	85'	95'	105'	115'
Clearance Times (seconds) for 65 Foot Tractor- Semitrailer	0-2		11.5	12.4	13.2	14.1	14.9	15.8	16.6	17.5	18.3
	3-5		14.4	15.5	16.6	17.7	18.9	20.0	21.2	22.3	23.5
	6-10		16.6	18.0	19.4	20.7	22.1	23.5	24.8	26.2	27.5
	11-13		20.0	21.8	23.5	25.2	26.9	28.6	30.3	32.0	33.7
Clearance Times (seconds) for 70 Foot Doubles	0-2		11.9	12.8	13.6	14.5	15.4	16.2	17.1	17.9	18.8
	3-5		14.9	16.1	17.2	18.3	19.5	20.6	21.8	22.9	24.0
	6-10		17.3	18.7	20.0	21.4	22.8	24.1	25.5	26.9	28.2
	11-13		20.9	22.6	24.3	26.0	27.7	29.4	31.1	32.8	34.5
Clearance Times (seconds) for 115 Foot Triples	0-2		15.8	16.6	17.5	18.3	19.2	20.0	20.9	21.8	22.6
	3-5		20.0	21.2	22.3	23.5	24.6	25.7	26.9	28.0	29.1
	6-10		23.5	24.8	26.2	27.5	28.9	30.3	31.6	33.0	34.4
	11-13		28.6	30.3	32.0	33.7	35.4	37.1	38.8	40.5	42.2

Source: Bowman, B. L., and K. P. McCarthy, Consequences of Mandatory Stops at Railroad-Highway Crossings, Report No. FHWA/RD-86/014, Federal Highway Administration, December 1985.

Table 3. Warning time standards for grade crossings with flashing light signals.

Country	Minimum Warning Time	Maximum Warning Time	Comments
Australia	20 sec.	None	Warning time is increased at multi-track crossings.
Canada (current)	20 sec. (Train speeds >10 mph) 7 sec. (Train speeds <10 mph)	None	Warning time is increased if crossing width >35 feet.
Canada (proposed)	20 sec. (Train speeds >10 mph) 15 sec. (Train speeds <10 mph)	33 sec. (Train speeds >10 mph) 28 sec. (Train speeds <10 mph)	Warning time is increased if crossing width >35 feet, and depending on type of train detection equipment.
United Kingdom	27 sec.	95% of warning times must be <75 sec. 50% of warning times must be <50 sec.	Warning time is increased if crossing width >15 meters. U.K. warning systems have a steady amber light which provides a 3-sec. initial warning period. The minimum time of 27 seconds includes this initial warning period.

Table 3 (continued)

Country	Minimum Warning Time	Maximum Warning Time	Comments
Japan	20 sec.	None	A "standard" warning time of 30 sec. is generally used. The warning time <u>cannot</u> be affected by train or vehicle speeds. Flashing light signals can only be used at low volume crossings.
Sweden	20 sec.	40 sec.	
United States	20 sec. (Train speeds >20 mph)	None	Highly variable warning times are discouraged.
West Germany	20 sec.	Variable based on average speed of slowest vehicle and width of crossing (see comments)	For speed = 10 km/hr, max WT = 13 sec. plus .36 x crossing width in meters. For speed = 5 km/hr, max. WT = 19 sec. plus .72 x crossing width in meters.

Table 4. Warning time standards for grade crossings with gates and flashing light signals.

Country	Minimum Warning Time	Maximum Warning Time	Gate Delay Time ¹	Gate Descent Time ²	Comments
Australia	25 sec.	None	6-9 sec.	10-15 sec.	Warning time is increased at multi-track crossings.
Canada (current)	20 sec. (Train speeds >10 mph)	None	3 sec. minimum	None specified ³	Warning time is increased if crossing width >35 feet.
Canada (proposed)	20 sec. (Train speeds >10 mph) 15 sec. (Train speeds <10 mph)	33 sec. (Train speeds >10 mph) 28 sec. (Train speeds <10 mph)	3 sec. minimum	None specified ³	Warning time is increased if crossing width >35 feet, and depending on type of train detection equipment.
United Kingdom	27 sec.	95% of warning times must be <75 sec. 50% of warning times must be <50 sec.	3 sec. (i.e., at the end of the warning period.)	6-8 sec.	Warning time is increased if crossing width >15 meters. U.K. warning systems have a steady amber light which provides a 3-second initial warning period. The minimum time of 27 seconds includes this initial warning period.

Table 4 (continued)

Country	Minimum Warning Time	Maximum Warning Time	Gate Delay Time ¹	Gate Descent Time ²	Comments
Japan	25 sec.	None	None specified	10-15 sec. (includes any gate delay time.)	A "standard" warning time of 35 seconds is generally used The warning time <u>cannot</u> be affected by train or vehicle speeds.
Sweden	Variable based on train speed	60 sec.	None specified	None specified ³	
United States	20 sec. (Train speeds >20 mph)	None	3 sec.	None specified ³	Highly variable warning times are discouraged
West Germany	22 sec.	30 sec.	12 sec.	6-10 sec.	

¹Gate delay time is the time from the initial activation of the signal lights to the beginning of the gate descent.

²Gate descent time is the time in which the gate arms are in downward motion.

³Standards require only that the gate be fully lowered before the train arrives.

light signals and automatic gates. For flashing light signals (Table 3), minimum warning times range from 20 to 27 seconds, except Canada allows short times on low speed lines. For gates with flashing light signals (Table 4), minimum warning times again range from 20 to 27 seconds, except Canada allows shorter times on low speed lines and Sweden has a variable minimum time which increases with increasing train speeds.

Unlike the United States, several of the foreign countries have adopted maximum warning times. For example, Sweden has a 40-second maximum warning time at crossings with flashing light signals (Table 3), and Canada has proposed a 28 to 33 second maximum warning time for both flashing light signals (Table 3) and gates with flashing light signals (Table 4). Other countries, like Japan, have provisions which require CWT train detection. Japan reports that all of their warning times are consistently set at 30 seconds at crossings with flashing light signals, and 35 seconds at gated crossings.

A detailed discussion of the findings of the foreign survey is presented in Appendix A.

Driver Surveys of Deviant Driver Behavior

A major task of the research involved conducting a driver survey in an effort to identify and evaluate factors which influence undesirable driver behavior at active crossings. Therefore, it is appropriate to review the procedures and finding of other similar surveys undertaken to evaluate deviant driver behavior.

Hirsh⁽⁵³⁾ conducted a disaggregate analysis of the speeding behavior of drivers in Israel. He used a questionnaire survey approach to gather

basic information from drivers concerning their age, education, vehicle ownership, trip purpose, driving violation history, and number of passengers. The survey was administered at the roadside downstream of the study area. Hirsh constructed a regression model using the above mentioned independent variables in an effort to explain drivers' self-reported speeding behavior. Based on the regression analysis, he concluded that trip purpose and age of vehicle had the most significant affect on self-reported speed choice. Drivers making social trips and drivers of newer cars tended to drive faster. Surprisingly, Hirsh reported that, "Drivers' characteristics were not found to affect significantly their speed choice." These characteristics included age, education, and gender. Vehicle ownership proved to be significant; that is, drivers driving their own vehicles tended to drive slower than those driving a company-owned vehicle or one owned by a friend or relative. Hirsh also concluded that, "speeding is an outcome of a choosing process that is affected by many factors, among them the speed limit."

In another similar study, Nordstrom⁽⁵⁴⁾ also developed a causal model to explain speeding behavior. Whereas Hirsh had used a roadside survey approach, Nordstrom used a mailed questionnaire to gather input from drivers. Based on his research, Nordstrom concluded that self-reported speeding behavior is affected most by the driver's age, annual driving mileage, and perceived risk of speeding assessment.

Marks et al.⁽³⁷⁾ conducted an investigation of drivers' motivations for selected unsafe driving actions (UDA). Four UDAs were investigated including: (1) speeding; (2) following too closely; (3) running a stop sign; and (4) turning in front of oncoming traffic. A driver question-

naire, administered at the roadside, was used to gather data for the analysis. In fact, a major emphasis of the research was to determine if such a driver survey could effectively be used for investigating UDAs.

Based on the research, Marks et al. concluded that "it is feasible to use roadside survey methods to collect useful data on drivers' motivations for committing the subject UDA. . . . Further, the reasons given by the drivers for their driving behavior were amenable for use in designing countermeasures aimed at preventing future UDAs." It is noteworthy that the researchers used predominately closed-ended questions in the survey to solicit information on driver demographics, attitudes, risk-taking tendencies, and driving exposure. Also, several of the attitudinal questions used a 5-interval rating scale ranging from "Strongly disagree" to "Strongly agree." The researchers observed that drivers, in a few cases, had difficulty responding to these rating questions. They concluded that the wording of some of the questions was unclear.

Marks et al. also discussed several general principles involved in developing driver surveys to assess unsafe driving actions. Several of these principles pertinent to this research are enumerated below:

1. Self-reported unsafe driving behavior is subject to "distortion" by several influences, most notably "social desirability." Social desirability refers to the driver's desire that his/her response not deviate from the perceived norm.
2. Drivers may have difficulty verbalizing their motivations for committing undesirable driving actions. One approach to soliciting the needed input is through the use of indirect

questioning, and an effective approach to indirect questioning is to employ questions with "manifest and latent" content.

3. Open-ended questions are useful when little is known "a priori" about the range of responses that subjects may give. Closed-ended questions are appropriate when there are well-defined responses with definite limits.

Obtaining accurate and reliable input from drivers concerning their illegal driving patterns is difficult; however, the several studies cited in this section demonstrate that survey approaches can be effective. In developing such a survey, Cook and Selltiz⁽⁵⁵⁾ recommend the following approaches to insure success:

1. Assurances of anonymity;
2. Statements emphasizing the importance of honest answers in order to contribute to some desirable outcome;
3. Building up rapport between the questioner and respondent;
4. Inclusion of items to which an unfavorable reply is likely to be considered acceptable; and
5. Use of forced-choice items.

Summary

Active traffic control systems at railroad-highway grade crossings incorporate conventional signing and pavement markings to identify the presence of the crossing, and they employ an "active" device to warn motorists of the approach or presence of a train. The two-types of active devices in common use are: (1) flashing light signals, and (2)

automatic gates with flashing light signals. As of 1986, approximately 28.5 percent of the nation's 192,454 public grade crossings were equipped with active devices; however, the criteria for use of these devices varies considerably from one organization to the next.

The Uniform Vehicle Code defines drivers' duties at grade crossings with active traffic control, and although adoption of the UVC provisions is not mandatory, most state traffic codes are in compliance with the provisions. These provisions require motorists to come to a full stop and wait for the train to clear, when the automatic gates and/or flashing light signals are activated. However, at crossings with flashing light signals only, the motorist may proceed through flashing lights if it is safe to proceed, i.e., if no train is visible or in hazardous proximity. At gated crossings, motorists are not allowed to cross while the gates are down (or being lowered or raised) under any circumstances.

Undesirable (and intentional) crossing behavior accounts for a major portion of the overall grade crossing safety problem at crossings with active traffic control. Several factors work in combination to influence this undesirable behavior. Those factors which appear most influential include: (1) driver comprehension and knowledge of the devices and associated traffic laws; (2) personality characteristics with respect to risk-taking and hazard perception; (3) perceptions about law enforcement; and (4) attitudes on device credibility resulting from previous exposure and familiarity.

There is evidence that many drivers do not fully comprehend the meaning and legal intent of active traffic control devices, and that this lack of understanding encourages these drivers to respond inappropriately

at active crossings. There is also research that suggests that undesirable crossing behavior is closely linked to an individual's overall risk-taking tendencies, as dictated by situational factors, and his/her perceptions of the level of law enforcement. Driver trust in the reliability and credibility of the active traffic control system also appears to be a major factor influencing driver response at active crossings. The most critical credibility issue is length of the warning period.

The Manual on Uniform Traffic Control Devices requires a minimum warning time of 20-seconds at active crossings; no maximum or desirable warning time limits are specified, although research indicates that excessive and/or highly variable warning times can encourage motorist disrespect for active systems.

The issue of warning time is closely related to train detection hardware; that is, most types of detectors cannot provide reasonable, consistent warning times if train speeds at the crossing are variable. However, CWT detection systems are available, and have already been installed at approximately 6,300 crossings nationwide. Research on these CWT systems indicates that they are reliable, and that they can improve driver behavior and overall crossing safety.

There have been previous surveys conducted to evaluate unsafe driver behavior. The success of these surveys indicates that a survey approach is a viable one for identifying and evaluating factors which influence undesirable behavior in response to active grade crossing devices.

CHAPTER 3

FIELD STUDY DESCRIPTION

In order to assess the extent and nature of undesirable driver actions at active crossings, an in-depth analysis of driver behavior was performed using data from three active crossings. A second purpose of these studies was to evaluate the effects of warning time on driver behavior. This chapter discusses the methodology used in collecting and analyzing the field data, and describes the study sites. It also reports the sample sizes (numbers of train events, numbers of vehicles, and warning times) attained for the studies. Chapter 4 presents the results and findings of the field studies.

General Approach

Data for the analyses were taken from videotapes of driver behavior at three active crossings. These videotapes had been collected as part of a recently completed FHWA study⁽⁴⁾ conducted at three crossings in the Knoxville, Tennessee, area. Two of the study crossings had standard flashing light signals, while the third crossing had standard gates with flashing light signals. It should be noted that in the previous study, the videotape data were used to compare the before-and-after effects of certain innovative traffic control devices which subsequently were installed at the three crossings. However, for the purpose of this study the focus was on: (1) documenting the nature and extent of undesirable driver behavior at active crossings with standard active traffic control devices; and (2) assessing warning time issues at crossings with standard

devices, i.e., flashing light signals and gates with flashing light signals.

With regard to the warning time evaluation, the objectives were to quantify the effects of warning time length on key driver response measures and to verify the statistical significance of these effects. The key driver response measures were: (1) vehicles crossing during the warning period; (2) clearance times between crossing vehicles and the train; (3) dwell times, i.e., the amount of time that motorists waited at the crossing; and (4) exposure times, i.e., the time that crossing vehicles occupied the area between the stop lines on either side of the tracks. Each of these measures logically could be affected by the length of the warning period, and each one is related to crossing safety and/or efficient operations.

Several statistical procedures were employed as appropriate to test the significance of the effects. These included the Kruskal-Wallis test, Mann-Whitney U test, and Chi-Square Test of Independence.^(56,57,58) The null hypothesis tested in each case was that warning time had no significant effect on the response measure. The alternative hypothesis was that warning time did have a significant effect.

The Kruskal-Wallis test⁽⁵⁶⁾ is a nonparametric ranking procedure used to determine whether a group of sampled populations have the same "location," that is, if the sampled populations have the same basic characteristics. It is appropriate for two or more populations, assuming that the populations sampled are continuous and identical, except for location. The null hypothesis is that the populations all have the same location. For two sample populations (sample groupings), the Kruskal-

Wallis test is equivalent to the more common Wilcoxon's signed rank test when the sample sizes are equal, or the Mann-Whitney U test when the sample sizes are unequal.⁽⁵⁶⁾

The Chi-Square Test of Independence^(57,58) is used to test whether two methods of classification are statistically independent. For the purpose of this study, it was used to test whether the differences observed in driver response across the various levels of a categorical variable, such as weather condition, were significant. In other words, it was used to determine if driver response was "independent" of the categorical variable under study.

Study Sites

The study sites are described in detail in a report by Heathington, Fambro, and Richards.⁽⁴⁾ General descriptions of the three study crossings are presented in this section.

The three study sites were all Norfolk-Southern crossings in the Knoxville, Tennessee, area. Each of the crossings had relatively high train and traffic volumes, thus affording the opportunity to collect a reasonable amount of driver response data. Also, all three crossings had a history of at least some accidents. Table 5 presents a summary description of each of the crossings, and the crossings are briefly discussed in the following sections.

Cherry Street. The first crossing (Inventory Number 730584K) is located in the eastern part of Knoxville on Cherry Street. This double-track crossing has standard automatic gates, standard railroad flashing light signals, and a bell. In 1985, the crossing was ranked as the 223rd

Table 5. Summary descriptions of three field study locations.

Physical Descriptions	Crossing Location		
	Cherry Street	Cedar Drive	Ebenezer Road
Number of Traffic Lanes	4--2 in each direction	2--1 in each direction	2--1 in each direction
Horizontal Alignment	S--straight N--straight	E--straight W--straight	N--curves S--curve
Vertical Alignment	S--level N--level	E--level W--downhill	N--uphill S--level
Sight Distance Obstructions	N--1 quadrant S--none	E--1 quadrant W--2 quadrant	N--1 quadrant S--2 quadrant
Average Daily Traffic	14,000 vpd	14,000 vpd	10,000 vpd
Posted Speed Limit	30 mph	40 mph	40 mph
Number of Tracks	2	1	1
Thru Train Volume	15 tpd	16 tpd	10 tpd
Train Speeds	20-40 mph	5-40 mph	5-55 mph
Number of Accidents (previous 5 years)	1	3	1
Warning Devices	Flashing Lights, Flashing Lights, Flashing Lights Bell, Automatic Bell, and Pave- and Bell Gates, and Pave- ment Markings. ment Markings		

Note: N, S, E, and W refer to direction of vehicular traffic. Number of accidents refers to previous 5-year period as this was the reporting requirement for the national inventory.

vpd - vehicles per day

mph - miles per hour

tpd - trains per day

Source: Heathington, Fambro, and Richards, Field Evaluation of Innovative Active Warning Devices for Use at Railroad-Highway Grade Crossings, Report No. FHWA-RD-88-135, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., January 1988.

most dangerous crossing in the state. As shown in Figure 7, Cherry Street is a four-lane, undivided urban street in the vicinity of the crossing. The roadway approaches to the crossing are straight and level. There is a building in the southwest quadrant which obstructs a northbound driver's view of eastbound trains. The average daily traffic at the site is approximately 14,000 vehicles per day, and the average through train volume is approximately 15 trains per day. The speed limit on Cherry Street is 30 mph. Typical train speeds at the crossing range from 20 to 40 mph and motion sensors are installed at the crossing.

Cedar Drive. The second crossing (Inventory Number 730643K) is located in the northern part of Knoxville on Cedar Drive. This crossing has standard railroad flashing light signals with 8-3/8 inch roundels and a bell. The crossing was ranked as the 31st most dangerous crossing in Tennessee in 1985. As shown in Figure 8, Cedar Drive in the vicinity of the crossing is two lanes wide and straight on both approaches to the crossing. The vertical alignment on the westbound approach limits a motorist's line of sight to the crossing. In addition, the thick vegetation in the vicinity of the crossing restricts a driver's view of approaching trains. The average daily traffic at this site is approximately 14,000 vehicles per day, and the average through train volume is approximately 16 trains per day. The speed limit on Cedar Drive is 40 mph, and train speeds at the crossing range from 5 to 40 mph. As evidenced by its hazard ranking and the three car-train accidents that occurred at this site in the past five years, this is a hazardous location.



Looking north



Looking south

Figure 7. Cherry Street crossing.



Looking east



Looking west

Figure 8. Cedar Drive crossing.

Initially, the Cedar Drive crossing had fixed-distance train detectors, and because train speeds vary substantially at the crossing, warning times tended to be variable and often very long. Data were first collected under these conditions. Then, train predictors were installed at the crossing resulting in more consistent and generally shorter warning times. Additional data were collected under the new conditions.

It should be noted that there is a siding track located a few hundred feet north of the Cedar Drive crossing. Constant warning time devices were not installed on this siding at the time they were installed on the main track. As a result, a few very long warning times were observed at the crossing even after predictor installation. The trains causing these long times were slow-moving trains coming from the siding track.

Ebenezer Road. The third crossing (Inventory Number 731461C) is located in the western part of Knox County on Ebenezer Road. This single-track crossing has standard railroad flashing light signals with 8-3/8 inch roundels and a bell. It was ranked as the 276th most dangerous crossing in Tennessee. As shown in Figure 9, Ebenezer Road is a two-lane suburban road in the vicinity of the crossing, and the roadway's horizontal and vertical alignments limit the crossing's visibility from both directions. Sight distance obstructions on both approaches also limit the driver's view of approaching trains. The average daily traffic on Ebenezer Road is approximately 10,000 vehicles per day, and the average through train volume is approximately 10 trains per day. The speed limit on Ebenezer Road was 40 mph at the time of the studies. Train speeds at the crossing typically range from 5 to 55 mph,



Looking north



Looking south

Figure 9. Ebenezer Road crossing.

however, the majority of trains travel between 45 and 55 mph. There has been one car-train accident at this location in the past five years.

Data Collection

At each of the study crossings, driver response data were automatically recorded on video tape whenever a train was approaching. A detailed discussion of the data collection system is presented in Reference 4; therefore, only a brief description of the system is presented here.

Three portable video recorder/camera systems were used at each crossing for data collection. The video recorders were battery-powered, and used standard 1/2-inch VHS cassettes. The video cameras used with the recorders were black-and-white closed circuit television cameras that provided high quality video under both day and night light conditions. The cameras operated on 12-volt direct current using the recorder batteries as a power source; therefore, they were only energized when the recorders were activated.

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

It was important to activate the video recorder/camera systems just prior to activation of the traffic control devices so that driver response during the entire warning period could be evaluated. To

accomplish this, a train detector system separate from the regular track circuitry was necessary. The special pole-mounted detection system projected an infrared light beam across the tracks. When a train broke the beam, the detector transmitted an audio (FM radio) signal which activated the recorders and cameras simultaneously. A detector was placed on each approach at each crossing such that the camera activation signal was transmitted at least 10 seconds prior to a train activating the traffic control device at a crossing.

Data Reduction

As noted at the beginning of the chapter, videotapes from a previous FHWA study were used as the primary source of data for the evaluation of warning time effects. Although some data relative to undesirable driver behavior and warning times had been extracted from the tapes for the previous study, these data were not of sufficient detail for this evaluation. Therefore, all of the tapes were reviewed and reduced again. Two data technicians, working together to assure consistency, reduced the data from the tapes.

In reducing the videotape data, the "Data Sheet" shown in Figure 10 was completed for each train event. The following general information was recorded for each event: weather condition, light condition, train direction, warning time, and type of traffic control. At the gated crossing (Cherry Street), the gate delay/descent time was also noted. Then, vehicle and driver response data were recorded for every vehicle which arrived at the crossing during the entire warning period. These data included: vehicle arrival position (1st, 2nd, etc.); vehicle type

and whether the vehicle was pulling a trailer; direction and lane of travel; whether the vehicle stopped and/or crossed; and, as appropriate, the times of stopping, starting up, crossing over the tracks, and clearing the crossing area. All times were measured with a digital stopwatch, and checked against an electronic clock which had been added onto each tape. The use of the stopwatch simplified the data reduction process; the check against the electronic video clock from time to time assured the accuracy of the time data. After the data were reduced from the video tape onto the data forms, they were encoded into a SAS data file.⁽⁵⁸⁾

Sample Size

Data were collected at each site for approximately two months in order to observe a sufficient number of both train events and vehicles arriving during the warning period. It is significant to note that there was a fairly wide range of warning times observed at each of the crossings, thus facilitating the evaluation of warning time effects.

Train Events. Table 6 shows the numbers of train events observed at each of the study crossings and all crossings combined. As seen in Table 6, there were a total of 445 train events at the three crossings combined, and vehicles were present during 407 of these events. Also, 296 (66.5 percent) of the train events were in the daytime, and 149 (33.5 percent) were at night.

At the Cherry Street crossing, 129 train events were observed; 119 of these events had vehicles present. At the Ebenezer Road crossing, 179 train events were observed, and vehicles were present during 159 of these

Table 6. Summary of train event sample sizes.

Train Events	Cherry Street	Cedar Drive (no predictors)	Cedar Drive (predictors)	Ebenezer Road	All Crossings
Total Train Events	129	74	63	179	445
Events with Vehicles	119	70	59	159	407
Events without Vehicles	10	4	4	20	38
Total Daytime Events	87	45	29	135	296 (66.5) ¹
Total Nighttime Events	42	29	34	44	149 (33.5) ¹

¹Percent of total train events.

events. The data for the Cedar Drive crossing are broken down into two groups, i.e. before train predictors were installed at the crossing and after predictors were installed. As shown in Table 6, 74 train events were observed before predictor installation; 70 of these had vehicular traffic present. After predictor installation, 63 train events were observed; 59 of these events had vehicles present.

Vehicles. Table 7 shows the numbers of vehicles observed at each of the study crossings and all crossings combined. A total of 3,555 vehicles was observed at the three crossings combined. At Cherry Street, 1,030 vehicles were observed, and 1,121 vehicles were observed at the Ebenezer Road crossing. At Cedar Drive, 999 vehicles were sampled before predictor installation, and 405 vehicles were sampled after predictor installation.

Table 7 also shows a break down of the sample by vehicle type. Note that the total sample and the samples for each crossing were made up predominately of passenger cars. The total sample only included 67 vehicles which were not passenger cars, pickups, or vans. This represents only 1.9 percent of the total sample size. Furthermore, only 12 heavy trucks and 1 bus were sampled at all crossings combined. The small numbers of other vehicle types made it impossible to evaluate the effects of warning times on these vehicles with any degree of confidence. Nevertheless, some general trends regarding trucks were observed and are discussed in the next chapter.

Warning Times. Table 8 summarizes the warning time conditions observed at each of the study crossings. The top part of Table 8 shows the mean warning times, standard deviations, and ranges of observed times

Table 7. Summary of vehicle sample sizes.

Vehicle Type	Cherry Street	Cedar Drive (no predictors)	Cedar Drive (predictors)	Ebenezer Road	All Crossings
Passenger Cars	1,001	984	403	1,100	3,488
Motorcycles	6	7	0	3	16
Light Trucks	14	6	2	16	38
Heavy Trucks	9	1	0	2	12
Buses	0	1	0	0	1
Total Vehicles	1,030	999	405	1,121	3,535

Table 8. Summary of warning times.

Warning Times	Cherry Street	Cedar Drive (predictors)	Cedar Drive (no predictors)	Ebenezer
Sample Size	129	63	74	179
Mean Warning Time, sec.	57.9	39.8	75.6	40.2
Standard Deviation sec.	15.6	12.8	19.4	11.1
Range, sec.	28-120	26-83	49-139	24-110
Warning Times, sec.				
20-30	2 (1.6%)	5 (7.9%)	0 (0.0%)	14 (7.8%)
30-40	9 (7.0%)	39 (61.9%)	0 (0.0%)	92 (51.4%)
40-50	30 (23.3%)	11 (17.5%)	3 (4.1%)	57 (31.8%)
50-60	39 (30.2%)	2 (3.2%)	12 (16.2%)	5 (2.8%)
60-90	44 (34.1%)	6 (9.5%)	45 (60.8%)	9 (5.0%)
>90	5 (3.9%)	0 (0.0%)	14 (18.9%)	2 (1.1%)
Totals	129 (100.0%)	63 (100.0%)	74 (100.0%)	179 (100.0%)

by crossing. The bottom part of Table 8 shows the distribution of warning times at each crossing by 10 second increments. As noted previously, a range of warning times was observed at each crossing, thus facilitating the evaluation. There was even a relatively wide range of warning times (26-83 seconds) observed at the Cedar Drive crossing after installation of train predictors. This occurred because the predictors were installed on the mainline track, and there was a siding without predictors just a few hundred feet from the crossing.

As shown in Table 8, the mean warning time at the Cherry Street crossing was 57.9 seconds, and observed warning times ranged from 28 to 120 seconds. The Ebenezer Road crossing had a mean warning time of 40.2 seconds, with a range of 24 to 110 seconds. Before predictors were installed, the Cedar Drive crossing had a mean warning time of 75.6 seconds and range in warning times of 49 to 139. After installation of the predictors, the mean warning time dropped to 39.8 seconds with a range of 26 to 83 seconds. Based on a Mann-Whitney U test, the installation of predictors significantly reduced the mean warning times at the Cedar Drive crossing.

Although not shown in Table 8, there was a significant difference in the daytime versus nighttime mean warning times at the Ebenezer Road crossing. The daytime mean warning time was 41.4 seconds, with a range of 24 to 110 seconds. The nighttime mean warning time was 36.7 seconds, with a range of 26 to 60 seconds. Nighttime warning times were generally shorter and less variable due to train operations at the crossing. At the other two study crossings, there were no significant differences in

daytime and nighttime warning times, based on Mann-Whitney U test results.

CHAPTER 4

FIELD STUDY RESULTS

This chapter presents the results of the field studies. In the first part of the chapter, an assessment of driver reaction to the onset of the warning period is presented, along with an evaluation of driver response to the gate delay/descent time at the Cherry Street crossing. Following these general results, a summary of driver behavior observed at the study crossings is presented.

Next, the effects of warning time on key driver response measures (i.e., driver stopping/waiting behavior, dwell times, clearance times, and exposure times) are identified and discussed. At the end of the chapter, miscellaneous results of the field studies are presented, including the influence of vehicle queue size and order of arrival at the crossing.

General Results

At each of the study crossings, the actions of every vehicle arriving during the warning period prior to train arrival were recorded. These actions were classified into three basic types: (1) vehicle crossed without stopping; (2) vehicle stopped first, but then crossed during the warning period; or (3) vehicle stopped and waited for the train to pass. In analyzing the driver behavior data, it was apparent that drivers very close to the crossing when the traffic control activated could not respond to the devices. Thus, a preliminary analysis was performed to assess driver response during the initial onset of the

warning period and to identify those vehicles which should be excluded from the sample. In the case of the Cherry Street crossing, it was also hypothesized that drivers might respond very differently during the gate delay/descent period compared to after the gates were fully lowered. This issued was addressed at the start of the evaluation so that the data from the Cherry Street crossing could be handled appropriately.

Onset of Warning Period. It was recognized that drivers very near a crossing at the onset of the warning period would not be capable of responding to the traffic control. Since it was desirable to exclude these vehicles in certain of the analyses, driver stopping behavior immediately following device activation was evaluated. This evaluation not only served to identify appropriate vehicles to include in the study sample, but also provided insight into drivers' "typical" perception/brake-reaction times at active crossings.

Figure 11 shows the relationship between driver stopping behavior and arrival time for gates with flashing light signals (Cherry Street crossing) and for flashing light signals (Cedar Drive and Ebenezer Road crossings combined). Based on Kruskal-Wallis test results, no differences were found in initial stopping behavior between the Cedar Drive and Ebenezer Road crossings at the .05 confidence level, thus the data from these two crossings were merged. Arrival time in Figure 11 refers to a vehicle's arrival time relative to the start of the warning period. As seen in Figure 11, arrival time influenced the percent of drivers who crossed without first stopping. In addition, there was a distinct difference in stopping behavior for the two types of traffic control,

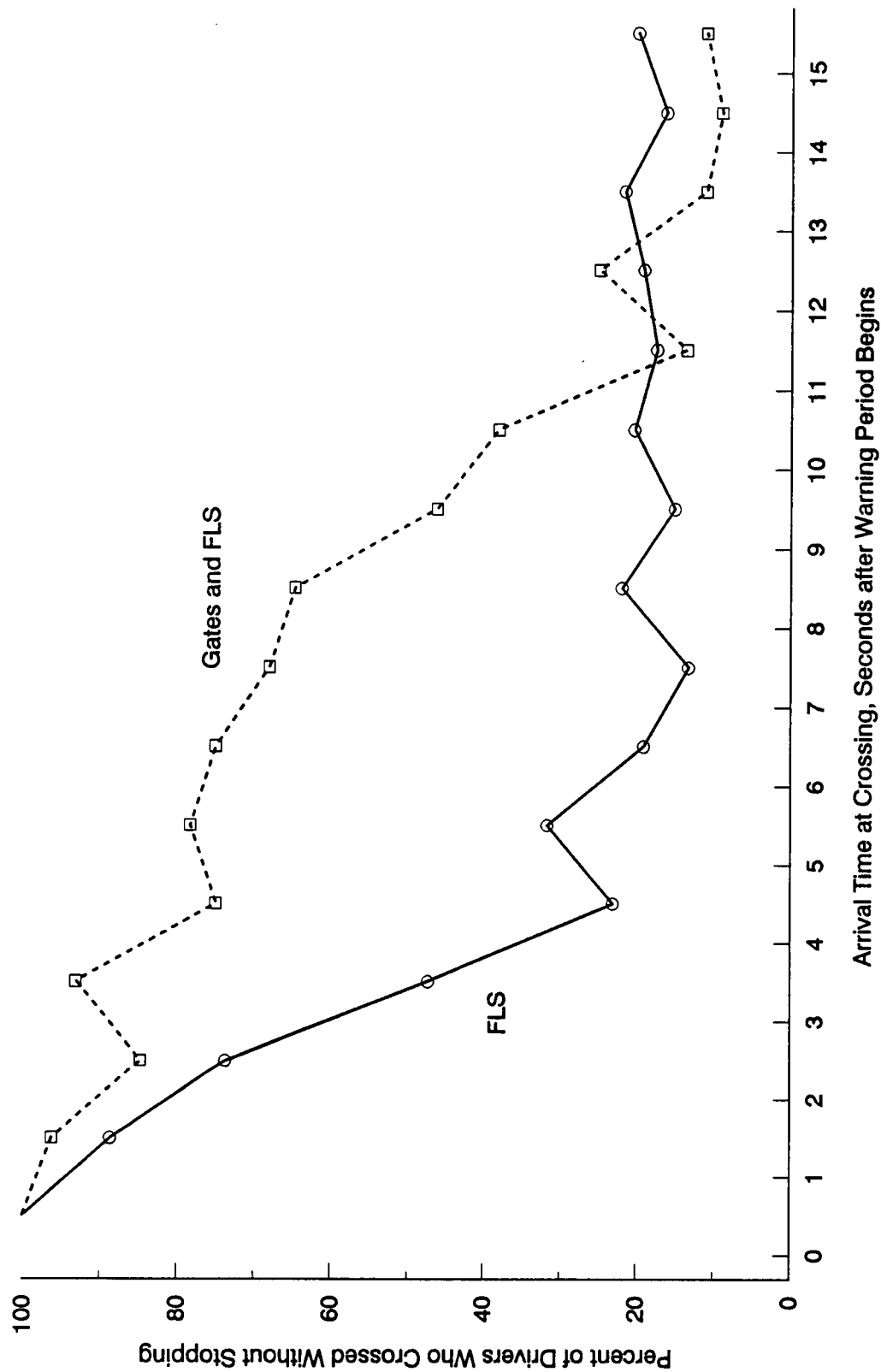


Figure 11. Relationship between arrival time at crossing and stopping behavior.

i.e., flashing light signals (FLS) and gates with flashing light signals (Gates and FLS).

At both crossings with flashing light signals, Figure 11 reveals that all drivers who were within one second of the crossing at the time of flashing light signal activation crossed without stopping. These drivers simply had no chance to respond to the signals. For arrival times between one and approximately four seconds, the percentage of drivers who crossed without stopping declined steadily. At the four-second point, the percentage of drivers who crossed without stopping leveled off to approximately 20 percent. Beyond this point, it is likely that the large majority of drivers could have stopped at the study crossings, but consistently a few did not. The four-second point therefore was selected for sample screening, i.e., vehicles arriving at the crossing less than four seconds into the warning period were excluded from the sample.

It is interesting to note that drivers' perception/brake-reaction times in response to the flashing light signals appear similar to those observed at signalized highway intersections. For example, four seconds is generally recognized as an appropriate warning period for traffic signals.⁽⁵⁹⁾ A major difference between flashing light signals and highway traffic signals, however, is that a significant percentage of drivers do not stop for flashing light signals. Most of these drivers slow down and look, but they do not stop completely.

Figure 11 also shows that driver stopping behavior during the onset of the warning period is much different at crossings with gates compared to crossings with flashing light signals only. From Figure 11, it is

seen that many drivers at the Cherry Street crossing did not respond to the initial device activation. Instead, most drivers continued to cross without stopping well into the gate delay/descent period. As seen in Figure 11, 60 percent or more of the drivers crossed without stopping during the first nine seconds of the warning period. Since the average gate delay/descent time at the Cherry Street crossing was 14.0 seconds, it follows that most drivers responded to the onset of the gate/flashing light signal activation by "driving to beat the gates." They only stopped when they could no longer clear the crossing before the gates were lowered.

Gate Delay/Descent Period. It was theorized that driver behavior during the gate delay/descent period would be different from driver behavior after the gates were fully lowered. This expectation was confirmed by the data for the Cherry Street crossing presented in Figure 11. During the gate descent/delay period, most drivers made no effort to stop but rather attempted to "beat the gates." Given this type of behavior, it was deemed appropriate to separate the driver response data for the Cherry Street crossing into the two time periods--before the gates were fully lowered and after the gates were fully lowered.

It was also observed that the length of the gate delay/descent period apparently had a significant effect on driver stopping behavior. Figure 12 illustrates this influence. It shows the percentage of drivers arriving during the gate delay/descent period who crossed without stopping at the Cherry Street crossing. As seen in Figure 12, the percentage of drivers not stopping rose sharply as the gate delay/descent time increased from around 11 seconds to 15 seconds. For times above 15

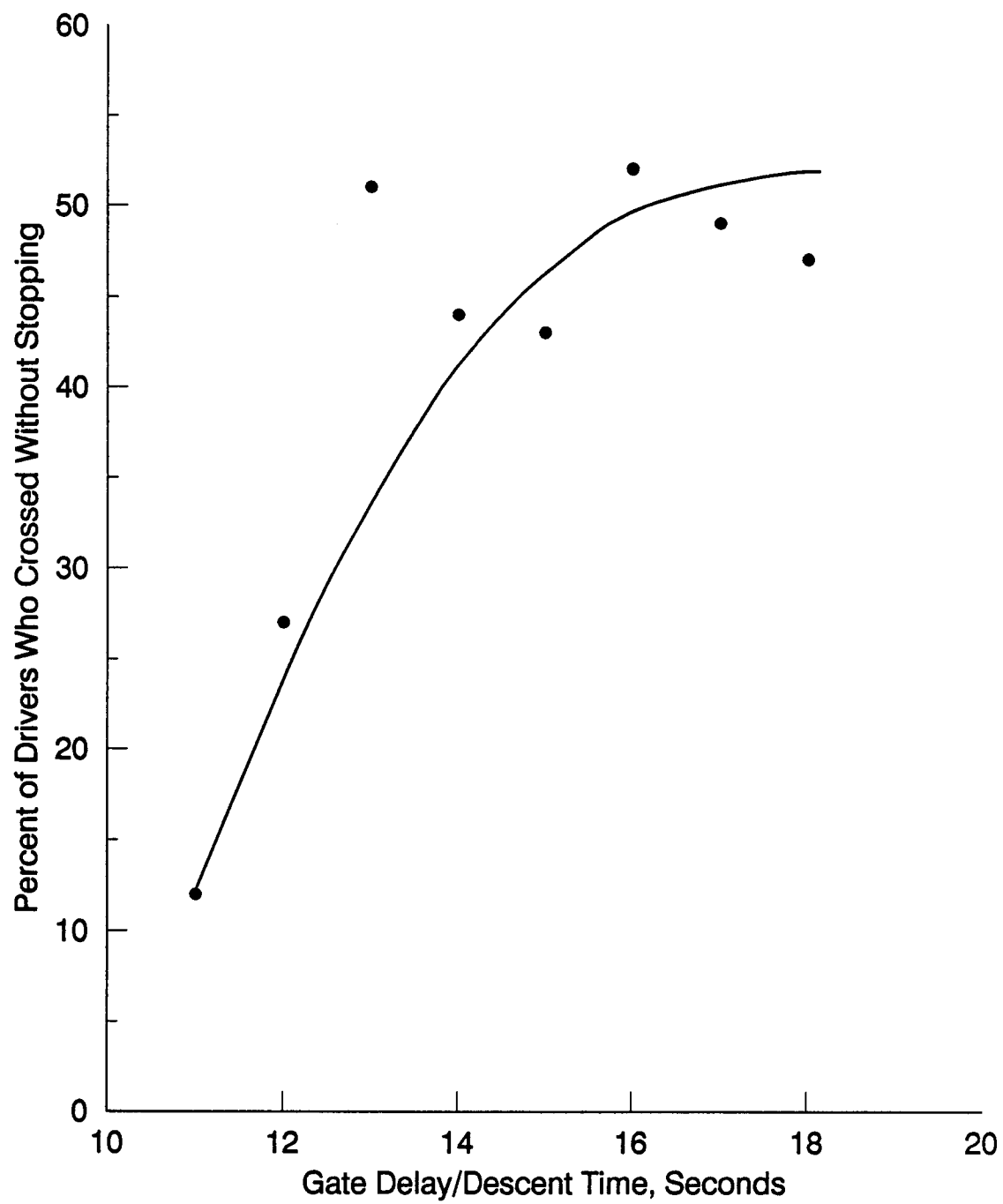


Figure 12. Relationship between gate delay/descent time and stopping behavior.

seconds, the percentage of drivers who crossed without first stopping leveled off at approximately 50 percent. The data in Figure 12 suggest that gate delay/descent times which are too long may encourage drivers to try to beat the gates and discourage them from stopping. If this is the case, reasonably short times should promote overall crossing safety; however, short gate delay/descent times may also increase the frequency of "gate rubs" by long, slow-moving vehicles.

Summary of Driver Behavior

Table 9 presents a summary of driver behavior observed at the three study crossings. The table shows the percentages of drivers who: (1) crossed without stopping; (2) stopped and then crossed during the warning period; and (3) stopped and waited for the train to pass. The data in the table exclude those drivers who were less than four seconds from the crossings when the traffic control was activated.

At the Cherry Street crossing, 60.3 percent of the motorists who arrived while the gates were lowered stopped and waited; only 32.1 percent of drivers who arrived during the gate delay/descent period stopped and waited. These percentages are relatively low, particularly the percentage for the gate delay/descent period. They underscore the fact that there are deficiencies in driver behavior at some crossings with active traffic control.

Note also in Table 9 that 56.2 percent of the motorists who arrived during the gate delay/descent period crossed without stopping. This relatively high percentage further illustrates that many drivers (in this case over one-half) tried to "beat the gates" and did not respond

Table 9. Summary of driver behavior by crossing.

Crossing	Total Vehicles	Percent of Drivers		
		Crossed without Stopping	Stopped and Crossed	Stopped and Waited
Cherry Street (gate delay/descent)	162	56.2	11.7	32.1
Cherry Street (gates lowered)	768	11.7	28.0	60.3
Ebenezer Road	1,036	14.5	31.1	54.4
Cedar Drive (without predictors)	937	19.0	61.4	19.6
Cedar Drive (with predictors)	363	10.5	45.5	44.1

appropriately to the advance warning of the flashing light signals prior to and during gate activation. These motorists who crossed were in violation of UVC provisions and Tennessee state law.

In the case of flashing light signals, 14.5, 19.0, and 10.5 percent of the drivers crossed without stopping at the Ebenezer Road, Cedar Drive (without predictors), and Cedar Drive (with predictors) crossings, respectively. Most of these drivers slowed down considerably and looked for the train, but still their actions violated state law and safe driving behavior. It is significant to note that the percentages of drivers who did not stop were approximately the same at the Ebenezer Road crossing and the Cedar Drive crossing without and with predictors. These percentages were 14.5, 19.0, and 10.5 percent, respectively. Also, approximately the same percentage (11.7 percent) of drivers did not stop at the Cherry Street crossing after the gates were down. Thus, it appears that roughly 10-20 percent of motorists at all the study crossings demonstrated very undesirable behavior.

Table 9 also shows that 54.4, 19.6, and 44.1 percent of drivers stopped and waited at the Ebenezer Road, Cedar Drive (without predictors), and Cedar Drive (with predictors) crossings, respectively. It is interesting to note that the percentage of drivers who did not cross was approximately the same at Ebenezer Road (which had only flashing light signals) as it was at the Cherry Street crossing (which had gates). On the positive side, this indicates that flashing light signals operated efficiently can encourage most drivers to stop and wait. On the negative side, it indicates that driver response to the Cherry Street gates certainly could be improved.

The effectiveness of the train predictors installed at the Cedar Drive crossing are also highlighted by the data in Table 9. Only 19.6 percent of the drivers stopped and waited before predictors were installed and warning times were highly variable and sometimes very long. After predictors were installed, this percentage rose to 44.1. This difference was statistically significant at the .01 confidence level based on a Chi Square Test of Independence.

Light Condition. Table 10 shows the percentages of drivers who stopped and waited at each crossing under day versus nighttime conditions. Chi-square Tests for Independence indicated that light condition effects were significant at the 0.01 confidence level for the Cherry Street crossing during the gate delay/descent period and at Ebenezer Road. At the Cherry Street crossing, 29.9 percent of the motorists arriving during the gate delay/descent stopped and waited in the daytime; 50 percent stopped and waited at night. It is theorized that drivers at night were less inclined to attempt to "beat the gates" because of the reduced visibility and depth perception at night. Once motorists stopped and the gates were lowered, then the physical and legal restriction of the gates encouraged these motorists to remain stopped.

At the Ebenezer Road crossing, 53.4 percent of the drivers stopped and waited in the day; a significantly higher percent of drivers (69.6) stopped and waited at night. Further analysis revealed that the nighttime sample had generally shorter warning times relative to the daytime sample. The nighttime differences in driver behavior were attributed to warning time differences rather than light condition effects.

Table 10. Effects of light conditions on driver behavior
at the study crossings.

Crossing	Percent of Drivers who Stopped and Waited			
	Day		Night	
Cherry Street (gate delay/descent)	29.9	(144) ¹	50.0	(18)
Cherry Street (gates lowered)	60.7	(634)	58.2	(134)
Ebenezer Road	53.4	(967)	69.6	(69)
Cedar Drive (without predictors)	21.0	(738)	19.6	(354)
Cedar Drive (with predictors)	40.4	(208)	49.0	(261)

¹Numbers in parentheses represent total sample sizes of categories.

Weather Conditions. Table 11 shows the percentages of drivers who stopped and waited at each crossing, broken down by weather conditions. The two weather conditions were: (1) clear; and (2) rain or snow. As reported in Table 11, the sample sizes (total vehicles observed) for inclement weather conditions were relatively small. None of the weather effects were statistically significant at the 0.05 confidence level based on the results of Chi Square Tests of Independence.

Warning Time Effects on Stopping/Waiting Behavior

A primary objective of the field studies was to investigate the relationship between warning time and driver actions at active grade crossings. The effects of warning time on stopping/waiting behavior are illustrated in Figure 13. Figure 13 shows the percentage of drivers who stopped and waited at the study crossings by warning time. The data from the Ebenezer Road and Cedar Drive (with predictors) crossings are combined in the figure because of the similarities in the data sets. Additional curves are shown for the Cherry Street crossing and Cedar Drive (without predictors) crossing. The data for the Cherry Street crossing do not include vehicles arriving during the gate delay/descent period.

As shown in Figure 13, warning time had a very significant effect on drivers' stopping/waiting behavior at the Cherry Street crossing and at the Ebenezer Road and Cedar Drive (with predictors) crossings. These effects were confirmed by Chi Square Tests of Independence at the .01 confidence level. Generally, most drivers stopped and waited at these crossings if the warning time was relatively short, i.e., 20-30 seconds.

Table 11. Effects of weather conditions on driver behavior at the study crossings.

Crossing	Percent of Drivers who Stopped and Waited			
	Dry		Rain or Snow	
Cherry Street (gate delay/descent)	55.3	(152) ¹	70.0	(10)
Cherry Street (gates lowered)	11.1	(709)	18.3	(60)
Ebenezer Road	15.2	(987)	0 ²	(49)
Cedar Drive (without predictors)	19.0	(931)	16.7	(6)
Cedar Drive (with predictors)	10.6	(358)	0 ²	(5)

¹Numbers in parentheses represent total sample sizes of categories.

²All of the drivers observed during the warning period crossed the tracks.

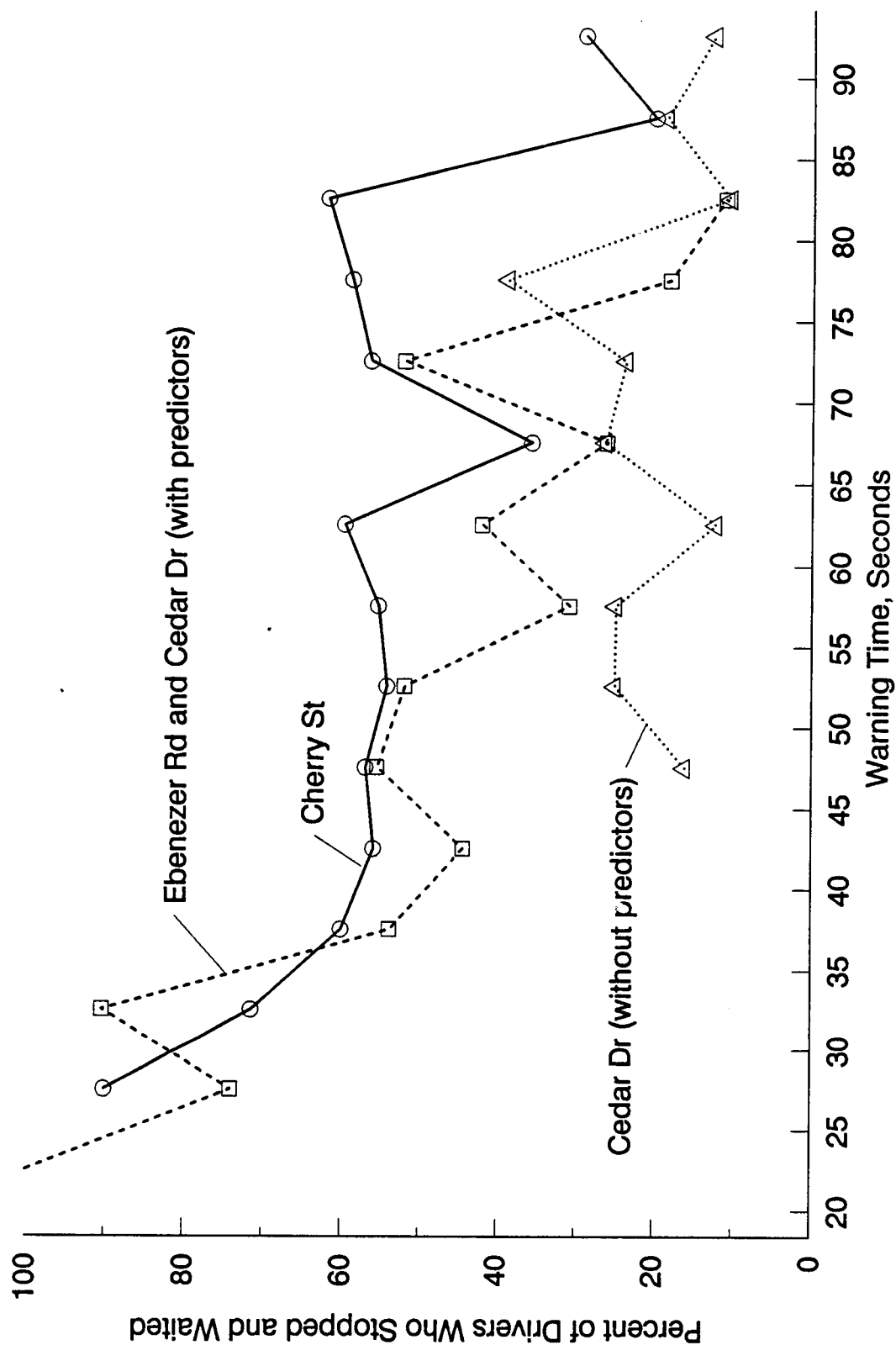


Figure 13. Effects of warning time on driver's stopping/waiting behavior.

As the warning times increased beyond 30 seconds, the percentage of drivers who stopped and waited declined rapidly.

At the Cherry Street crossing, approximately 90 percent of arriving motorists stopped and remained stopped for warning times between 20 and 25 seconds. This percentage declined to about 70 percent for warning times between 25 and 30 seconds and to approximately 60 percent for warning times between 30 and 35 seconds. Then the percentage of drivers who stopped and remained stopped held fairly constant (at around 60 percent) for warning times up to about 80 seconds. After 80 seconds, there was again a sharp drop in driver obedience of the gates to below 30 percent. These data indicate that relatively short warning times (20-35 seconds) are desirable to minimize gate violations. They also suggest that if warning times are greater than about 35 seconds, approximately 40 percent or more of the drivers will violate the gates.

At the Ebenezer Road and Cedar Drive (with predictors) crossings, 98 percent of the drivers stopped and remained stopped for warning times between 20 and 25 seconds. For warning times between 25 and 35 seconds, 73-90 percent of the drivers stopped and remained stopped. For warning times beyond 35 seconds, the percentage of motorists who stopped and remained stopped declined steadily to less than 20 percent for warning times over 80 seconds. As was the case for the gated Cherry Street crossing, these data suggest that relatively short warning times (20-35 seconds) are desirable at crossings with flashing light signals. Driver behavior steadily deteriorates for warning times greater than 35 seconds. It is the researchers' opinion that such frequent undesirable driver

actions degrade general crossing safety because of the lost respect and credibility for the traffic control.

The severe driver behavior deficiencies at the Cedar Drive (without predictors) crossing are also illustrated in Figure 13. Because of the generally long warning times at the crossing (the mean warning time was over 75 seconds), the percentage of drivers who stopped and waited never rose above 30 percent and even dropped to approximately 10-15 percent for warning times greater than 80 seconds. Even at moderately long warning times of 45-60 seconds, the Cedar Drive (without predictors) crossing performed significantly worse than the Ebenezer Road and Cedar Drive (with predictors) crossings, at the same warning times. This indicates the occurrence of some long warning times at a crossing can have negative impacts which affect overall driver behavior at the crossing. This finding supports the need for consistently short warning times, i.e., some long warning times at a crossing may negate the positive influences of reasonably short times at the same crossing.

Train Wait Time. The previous results suggest that drivers who arrive at an active crossing long before the train arrives are unlikely to wait, regardless of the status of the active control devices. Thus, the relative time of arrival which is perceived to be too long by drivers should be considered in establishing maximum warning times. This issue was addressed in the field studies by evaluating driver behavior as a function of arrival time at the crossing relative to the trains' arrival (train wait time). The results are summarized in Figure 14.

Figure 14 shows the percentage of drivers who stopped and waited at the three crossings as a function of train wait time. The data do not

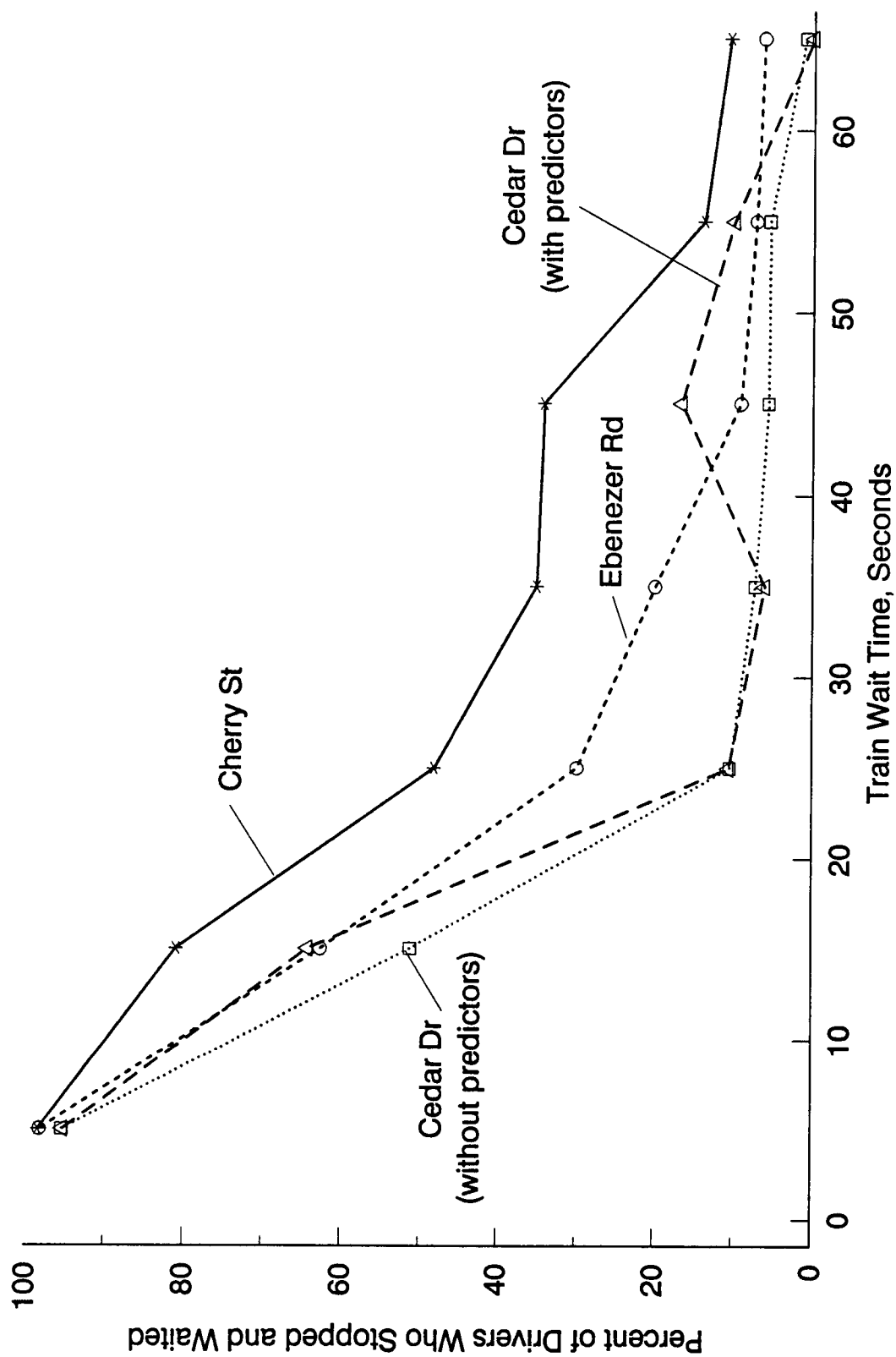


Figure 14. Relationship between train wait time and driver behavior.

include those vehicles which were less than four seconds from the crossing when the traffic control was activated. Also, the data for the Cherry Street crossing include only those arrivals after the gates were fully lowered.

At the Cherry Street crossing, 98.2 percent of the drivers arriving at the crossing 10 seconds or less before train arrival stopped and remained stopped; 80.8 percent arriving 10-20 seconds before the train arrival stopped and remained stopped; and only 43.0 percent arriving 20-30 seconds before the train arrival stopped and remained stopped. After 30 seconds, the percentage continued to decline. These data support the contention that warning times longer than necessary will encourage gate violation.

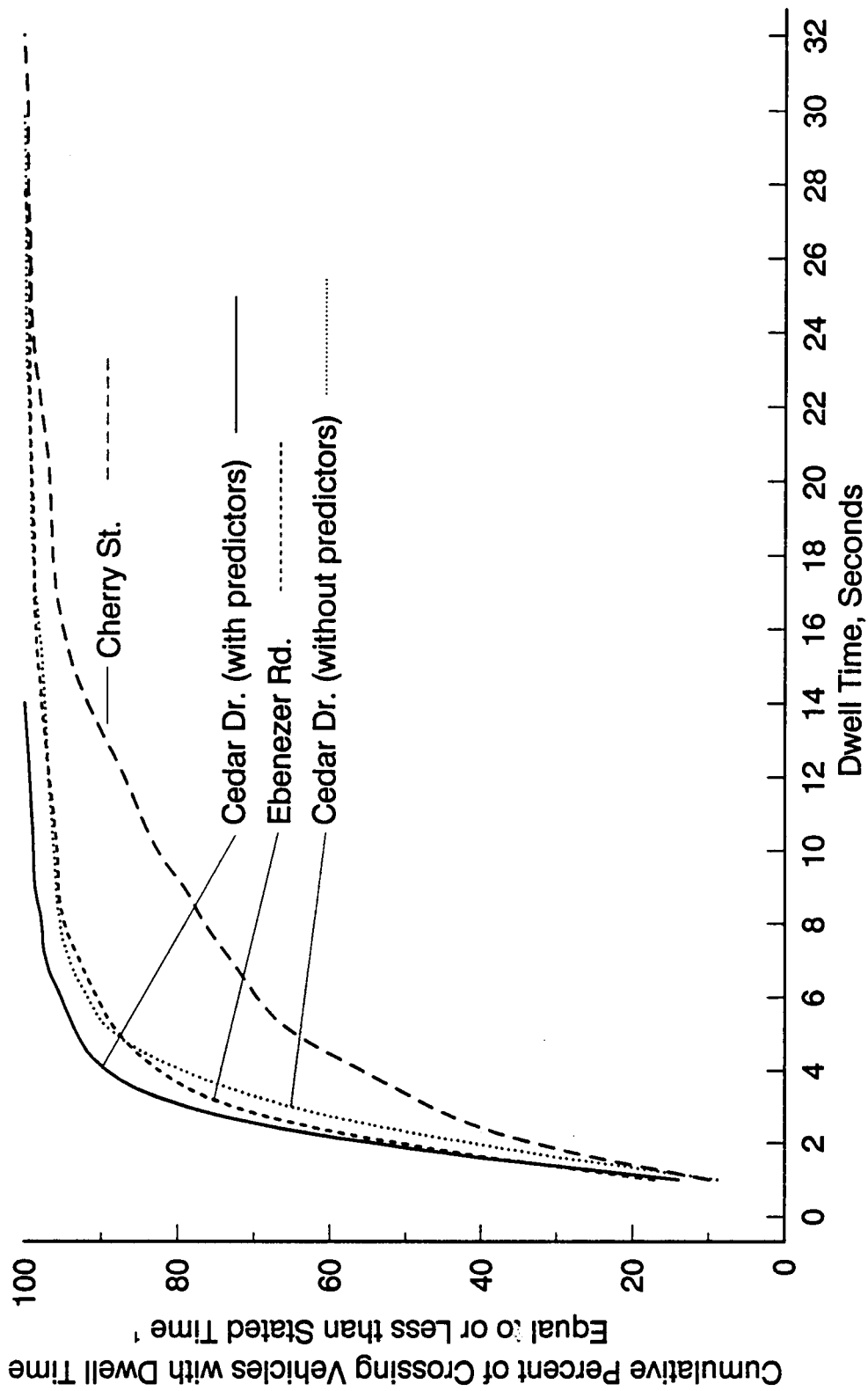
At the crossings with flashing light signals nearly all the drivers arriving at the crossing less than 10 seconds before train arrival stopped and remained stopped. These percentages were 98.0 percent at the Ebenezer Road crossing, 95.2 percent at the Cedar Drive (without predictors) crossing, and 95.1 percent at the Cedar Drive (with predictors) crossing. For train wait times of 10-20 seconds, the percentage of motorists who stopped and waited dropped sharply to 62.5, 51.1, and 64.1 percent, respectively. After 30 seconds the percentages dropped to below 30 percent in every case. These data again suggest that maximum warning times at crossings with flashing light signals should be as short as long vehicle clearance requirements will allow in order to minimize unwanted vehicles crossing during the warning period.

Dwell Time. Another important issue related to crossing behavior and warning time is dwell time, i.e., the time that drivers spend

deciding to cross. Going into the study, two possible dwell time responses were theorized. One possibility was that drivers would cross after having to wait a long time without the train arriving. The second possible dwell time behavior was that arriving drivers would look for a train, and if no train was near, they would cross quickly. Obviously, there could be a mixture of these two response groups in the traffic stream.

Figure 15 summarizes the dwell time characteristics observed at the three study crossings. Dwell times at the crossings with flashing light signals ranged from around one second to over 30 seconds; however, the large majority of dwell times at these crossings were relatively short. Around 90 percent were less than five seconds and 70 percent were less than four seconds. Thus, the majority of the drivers who crossed at the crossings with flashing light signals did so after taking a "quick" look for the train.

At the Cherry Street crossing, dwell times tended to be longer, but were still relatively short. As shown in Figure 15, dwell times ranged from around one second to over 30 seconds. However, approximately 50 percent of the times were less than 5 seconds, and 80 percent were less than 10 seconds. From these results, it is concluded that drivers at gated crossings take more time evaluating the risks, assessing the path they must take, and checking the actions of other drivers. Still, the dwell times do not suggest that drivers are crossing after they get frustrated and tired of waiting, rather they are crossing just as soon as they feel comfortable doing so.



¹ Includes only those vehicles which stopped, then crossed during the warning period.

Figure 15. Dwell time characteristics.

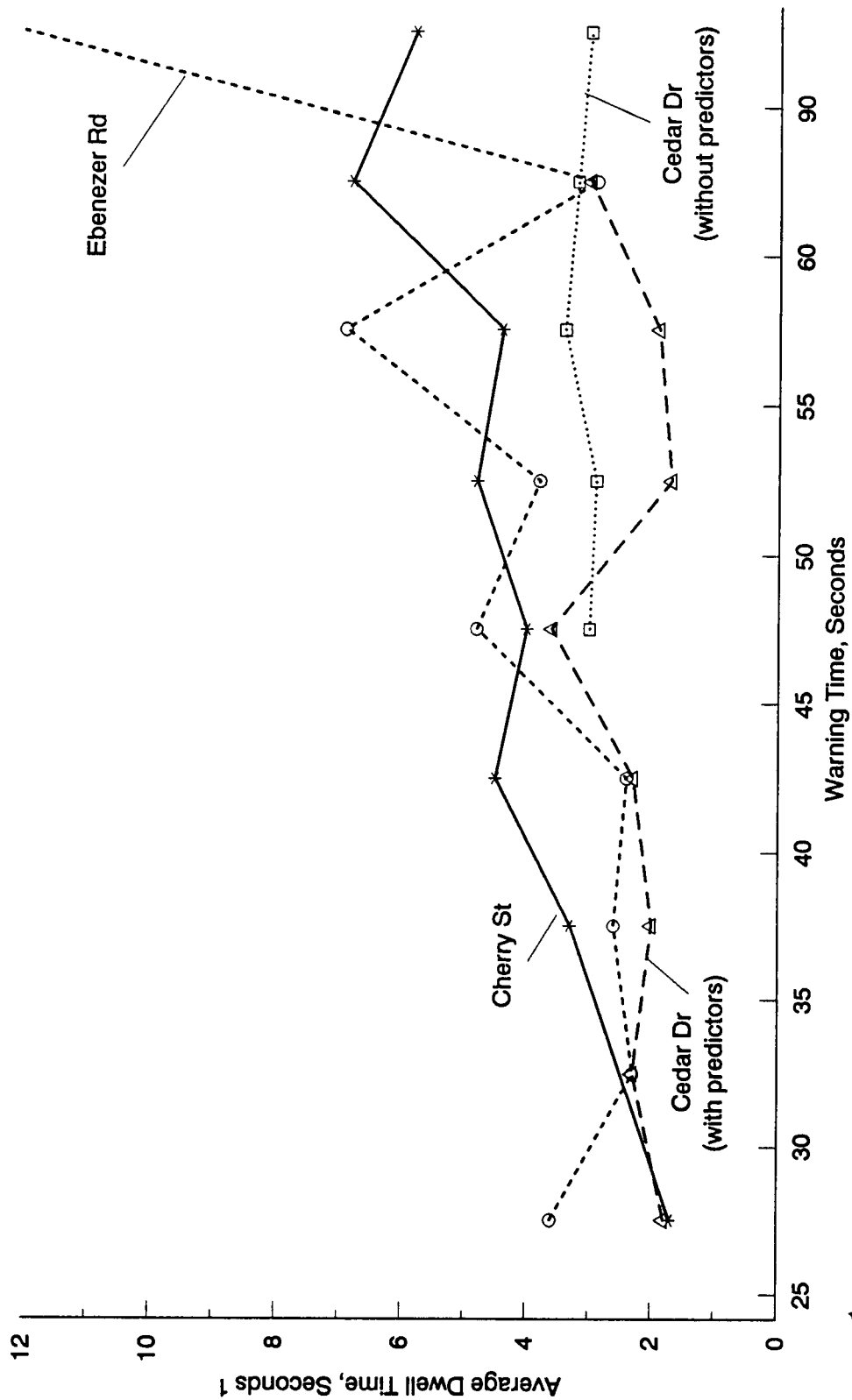
Figure 16 shows the relationship between mean dwell time and length of the warning time period for the three study crossings. As indicated in Figure 16, there was no apparent relationship between warning time and dwell time at the study crossings. This in fact was confirmed by Kruskal-Wallis tests at the .01 confidence level.

Warning Time Effects on Clearance Times

In the interest of crossing safety, an active traffic control system should provide adequate time separation between vehicular traffic and train traffic. If this "clearance time" becomes too short, the slightest misjudgment on the driver's part can result in disastrous consequences. As part of the research, the effects of warning times on clearance times were evaluated at the three study crossings.

Table 12 and Figure 17 show the mean clearance times observed at each of the crossings by warning time. Clearance time is simply the difference in train arrival time and vehicle crossing time for those vehicles which crossed. As seen in Table 12 and Figure 17, the mean clearance time tended to increase with increasing warning times at each of the crossings. This result is expected given that drivers who cross do so fairly quickly (if they are going to cross).

However, it is interesting to note in Figure 17 that, taking warning time into account, the clearance times were very similar at all three study crossings, including the Cherry Street crossing. This result is somewhat surprising since the crossings had different geometrics, sight distances, and traffic control conditions. It is also significant to note that, at the shorter warning times observed (25-35 seconds), the



¹ Dwell time refers to the amount of time that a driver waits before crossing. It only applies to those drivers who stop first and then cross during the warning period.

Figure 16. Relationship between mean dwell time and warning time.

Table 12. The effects of warning time on mean clearance times.

Warning Time (seconds)	Mean Clearance Time (seconds) ¹			
	Cherry Street	Ebenezer Road	Cedar Drive No Predictors	Cedar Drive Predictors
25-30	22.7	16.3	--	17.5
30-35	--	18.1	--	19.7
35-40	21.7	21.2	--	24.3
40-45	26.0	23.4	--	23.6
45-50	28.1	28.2	23.7	32.2
50-55	28.5	36.0	26.9	27.7
55-60	33.1	33.9	32.3	37.1
60-90	37.7	57.8	39.0	41.4
>90	51.7	67.3	61.7	--

¹Clearance time = train arrival time - vehicle crossing time.

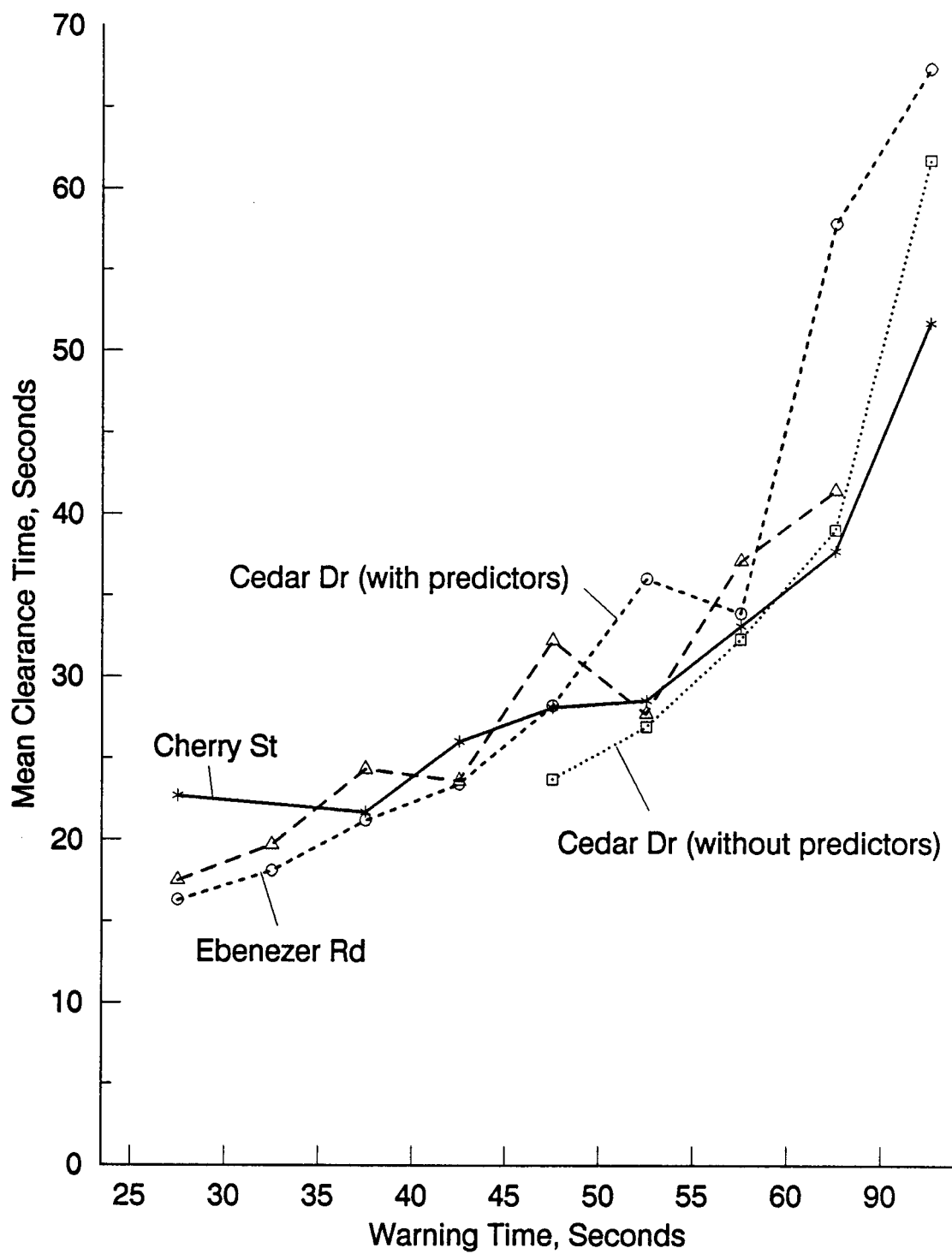


Figure 17. Relationship between mean clearance time and warning time.

mean clearance times were sufficiently large and near 20 seconds. This finding supports the current 20-second minimum warning time as an appropriate minimum level. Even when the warning time was relatively short, clearance times tended to remain near 20 seconds, suggesting that the majority of drivers would not regularly accept clearance times much less than 20 seconds.

Clearance Times Less Than 20 Seconds. CL20s, i.e., the number of clearance times less than 20 seconds, were defined in the previous research by Heathington et al.⁽⁴⁾ as an indication of aggressive driver behavior. It would be desirable to minimize CL20s at any crossing in the interest of safety. Table 13 and Figure 18 show the effects of warning time on CL20 rates, or the number of CL20s per 100 train events. CL20s were lowest for warning times of 20-30 seconds, and they increased significantly for longer warning times.

At the Cherry Street crossing, no CL20s were observed for warning times of 20-30 seconds. It should be noted that the sample size was very small, i.e., only two trains. For warning times of 30-40 seconds, the average CL20 rate increased to 78.8 per 100 trains. Most of these vehicles actually crossed during the gate delay/descent period and not while the gates were down. This fact emphasizes the earlier finding that drivers are not responding as intended to the advance warning provided by the flashing light signals but are attempting to "beat the gates" whenever possible. For warning times greater than 40 seconds, the CL20 rate remained high, and was highest for warning times of 50-60 seconds.

In Table 13 and Figure 18, the data for the crossings with flashing light signals are combined. This is appropriate since driver behavior

Table 13. Effects of warning time on CL20s.

Warning Time (seconds)	Gates with Flashing Light Signals		Flashing Light Signals ¹	
	CL20s per 100 Train Events	# of Train Events Observed	CL20s per 100 Train Events	# of Train Events Observed
20-30	0	2	52.6	19
30-40	78.8	9	113.0	131
40-50	53.3	30	122.5	71
50-60	69.2	39	142.1	19
60-90	52.3	44	103.3	60
>90	20.0	5	93.8	16
All times	57.4	129	110.4	316

¹Composite data from Ebenezer Road crossing and Cedar Drive crossing (with and without predictors).

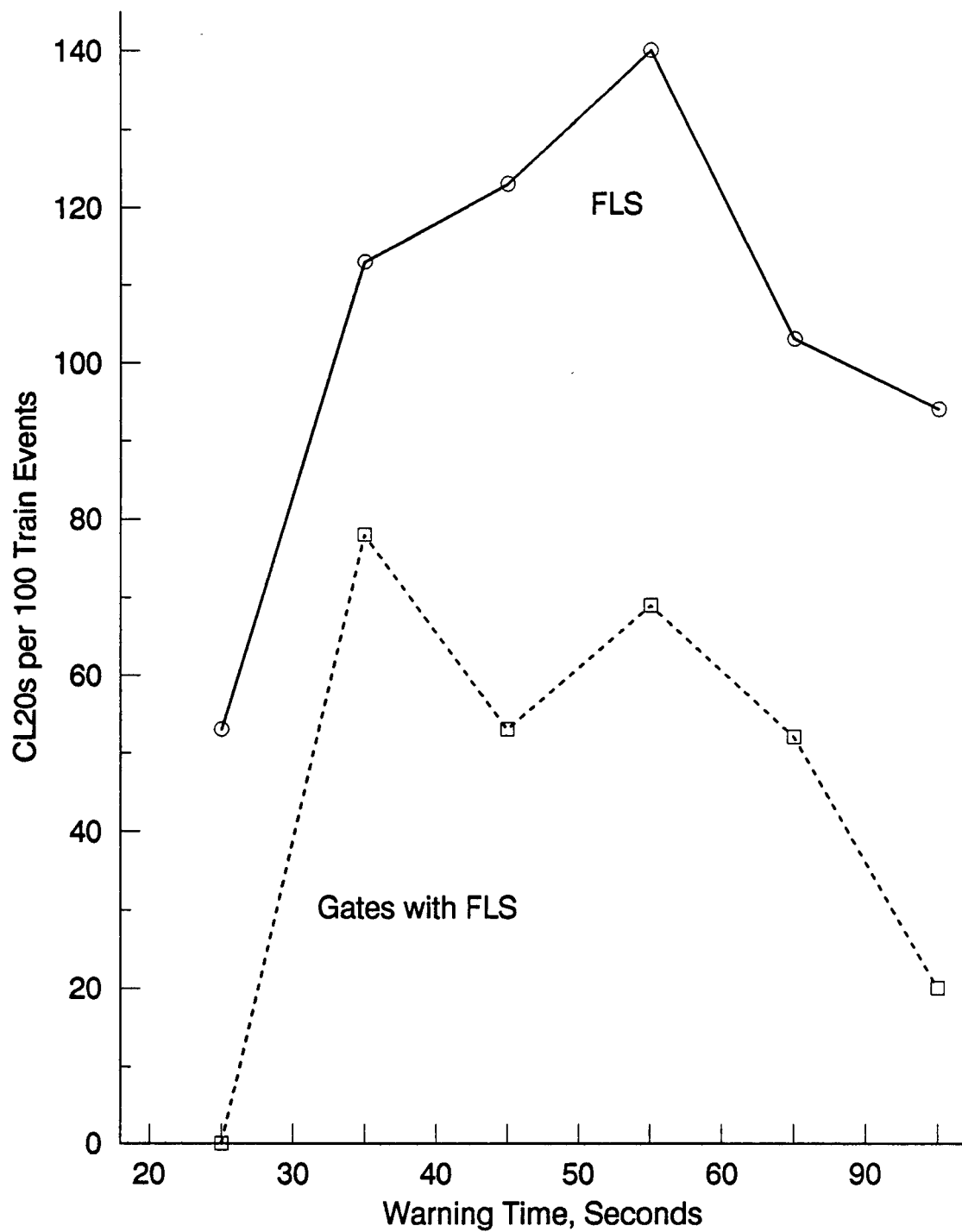


Figure 18. Relationship between CL20s and warning time.

during the last 20 seconds before train arrival was very similar at both crossings. Based on the combined data there was an average of 52.6 CL20s per 100 trains for warning times of 20-30 seconds. At higher warning times, the CL20 rate rose significantly. The highest rate (142.1 CL20s per 100 trains) was observed for warning times of 50-60 seconds.

Clearance Times Less Than 10 Seconds. The research by Heathington et al.⁽⁴⁾ also defined CL10s, i.e., the number of clearance times less than 10 seconds, as a measure of risky driver behavior. Certainly, it would be desirable to minimize (or better yet, totally eliminate) CL10s at all crossings.

Table 14 and Figure 19 show the effects of warning times on CL10 rates per 100 train events. At the Cherry Street crossing, there were no CL10s for warning times of 20-30 seconds. The sample size was very small, i.e., two trains. For warning times of 30-40 seconds, there was an average of 11.1 CL10s per 100 train events at the Cherry Street crossing. This rate was based on only one CL10 observed in 9 train events and thus may be somewhat misleading. The next highest CL10 rate (10.3 CL10s per 100 train events) was observed for warning times of 50-60 seconds.

At the crossings with flashing light signals, there were no CL10s for warning times of 20-30 seconds. This rate of zero is based on a sample of 19 train events. For warning times of 30-40 seconds, there were an average of 6.9 CL10s per 100 trains, and this rate increased to 16.9 CL10s per 100 trains for warning times of 40-50 seconds. Clearly

Table 14. Effects of warning time on CL10s.

Warning Time (seconds)	Gates with Flashing Light Signals		Flashing Light Signals ¹	
	CL10s per 100 Train Events	# of Train Events Observed	CL10s per 100 Train Events	# of Train Events Observed
20-30	0	2	0	19
30-40	11.1	9	6.9	131
40-50	3.3	30	16.9	71
50-60	10.3	39	15.8	19
60-90	0	44	10.0	60
>90	0	5	12.5	16
All times	4.7	129	11.5	316

¹Composite data from Ebenezer Road crossing and Cedar Drive crossing (with and without predictors).

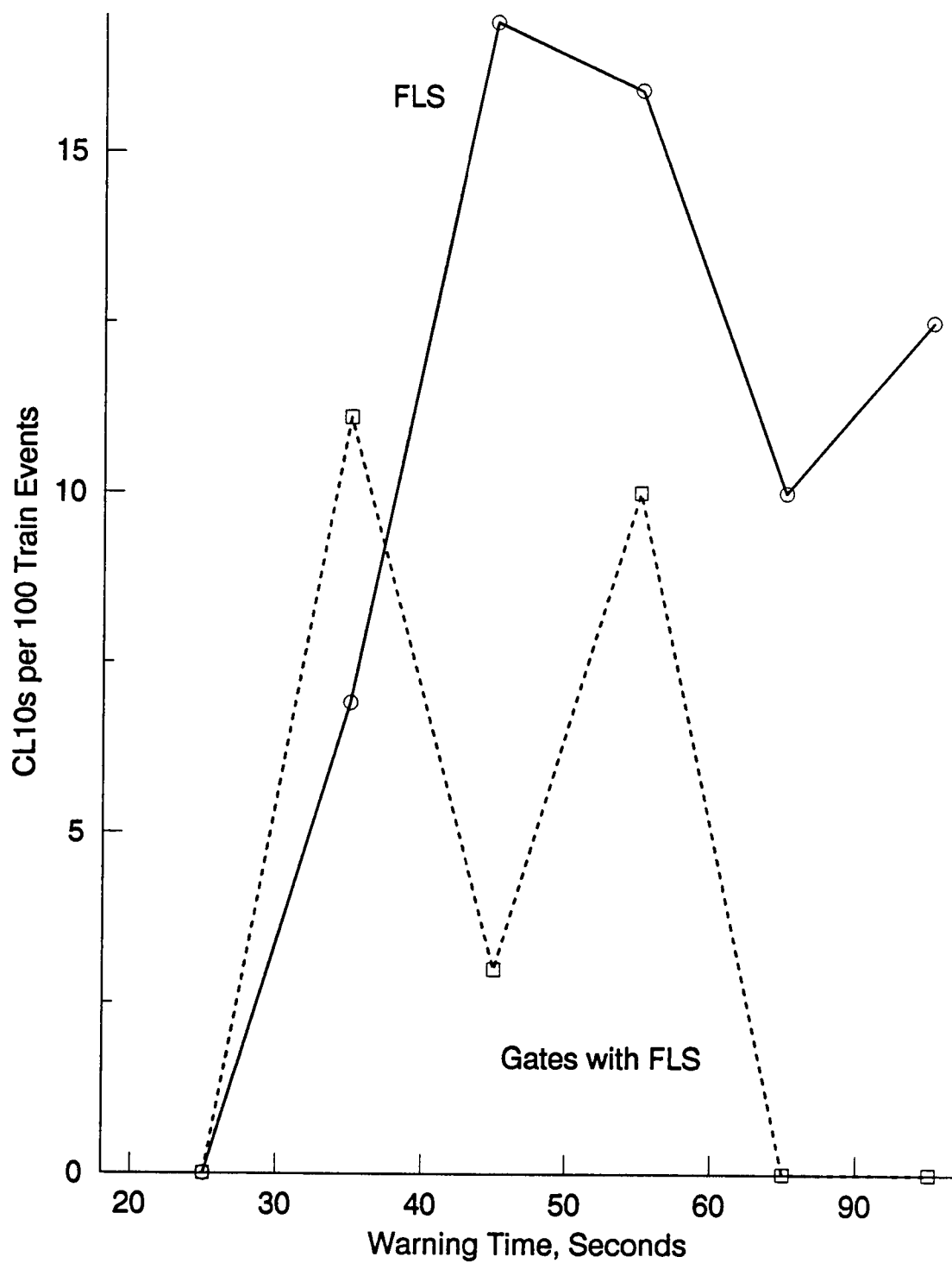


Figure 19. Relationship between CL10s and warning time.

from these data, shorter warning times discouraged CL10s at the two crossings with flashing light signals.

Warning Time Effects on Exposure Times

Exposure time is the time that a crossing vehicle is on the tracks and directly exposed to a potential car-train accident. Exposure time is important at crossings with flashing light signals since it is logical that minimum warning times at these crossings should be greater than the exposure times of crossing vehicles. Exposure times are also an issue with mandatory stop vehicles.

Figure 20 summarizes the exposure times observed at the study crossings. For the purpose of this study, exposure time was defined as the time it took a crossing vehicle to travel from the stop line to completely clear of the tracks. The data in Figure 20 are for all vehicle types, including large trucks and buses. However, the sample included very few trucks and a single bus, thus the results predominantly represent passenger car characteristics.

At the Cherry Street crossing, exposure times ranged from under two seconds to just over 13 seconds. This crossing has two closely spaced tracks and is essentially level. From Figure 20, approximately 50 percent of the exposure times at Cherry Street were less than four seconds, and about 90 percent were less than nine seconds. A few large trucks drove around the lowered gate arms at the Cherry Street crossing, and these trucks had the longer exposure times. The longest exposure time of 13 seconds was experienced by a semi-trailer unit which stopped and then drove around the lowered gate arms.

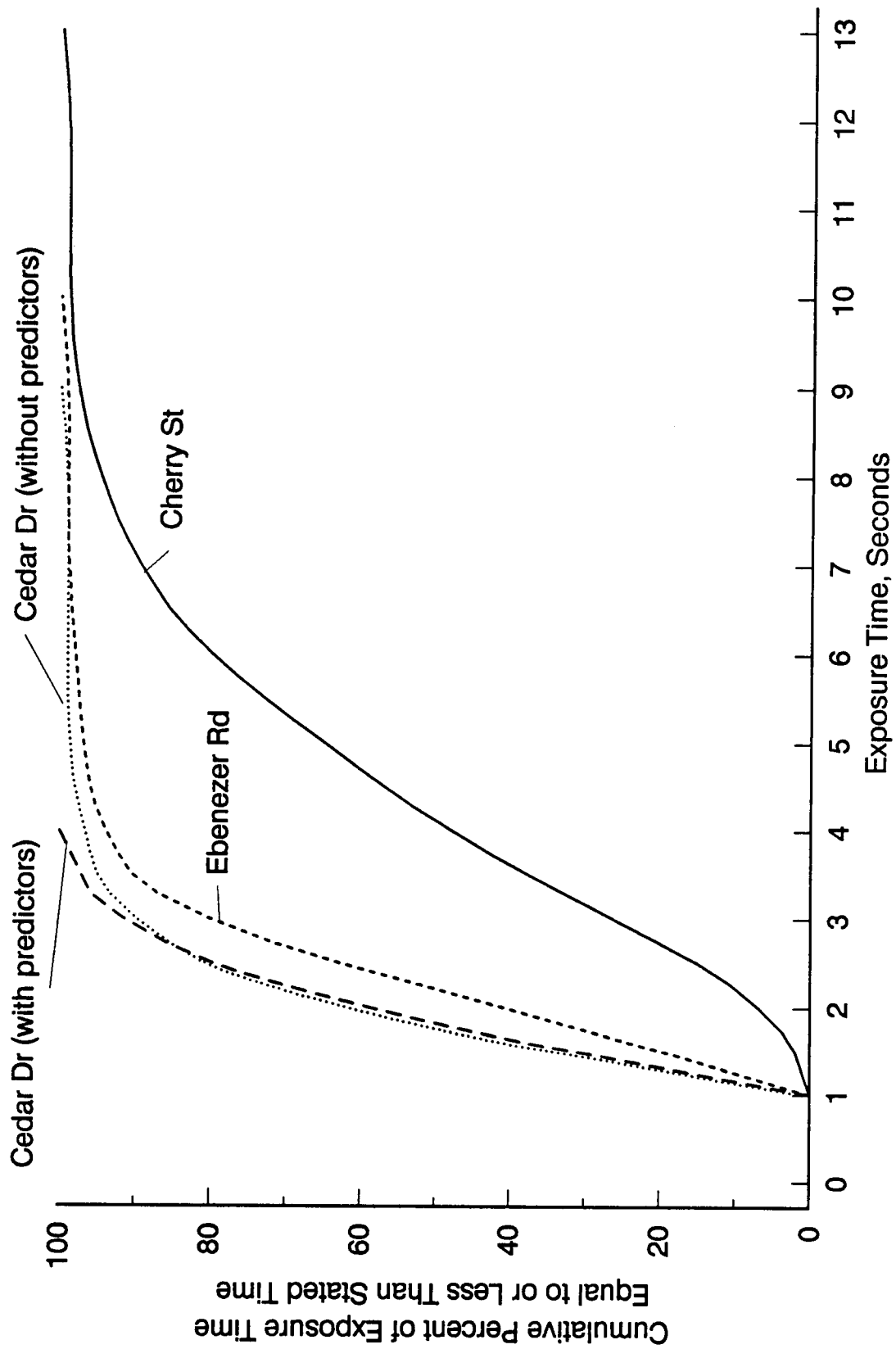


Figure 20. Exposure time characteristics.

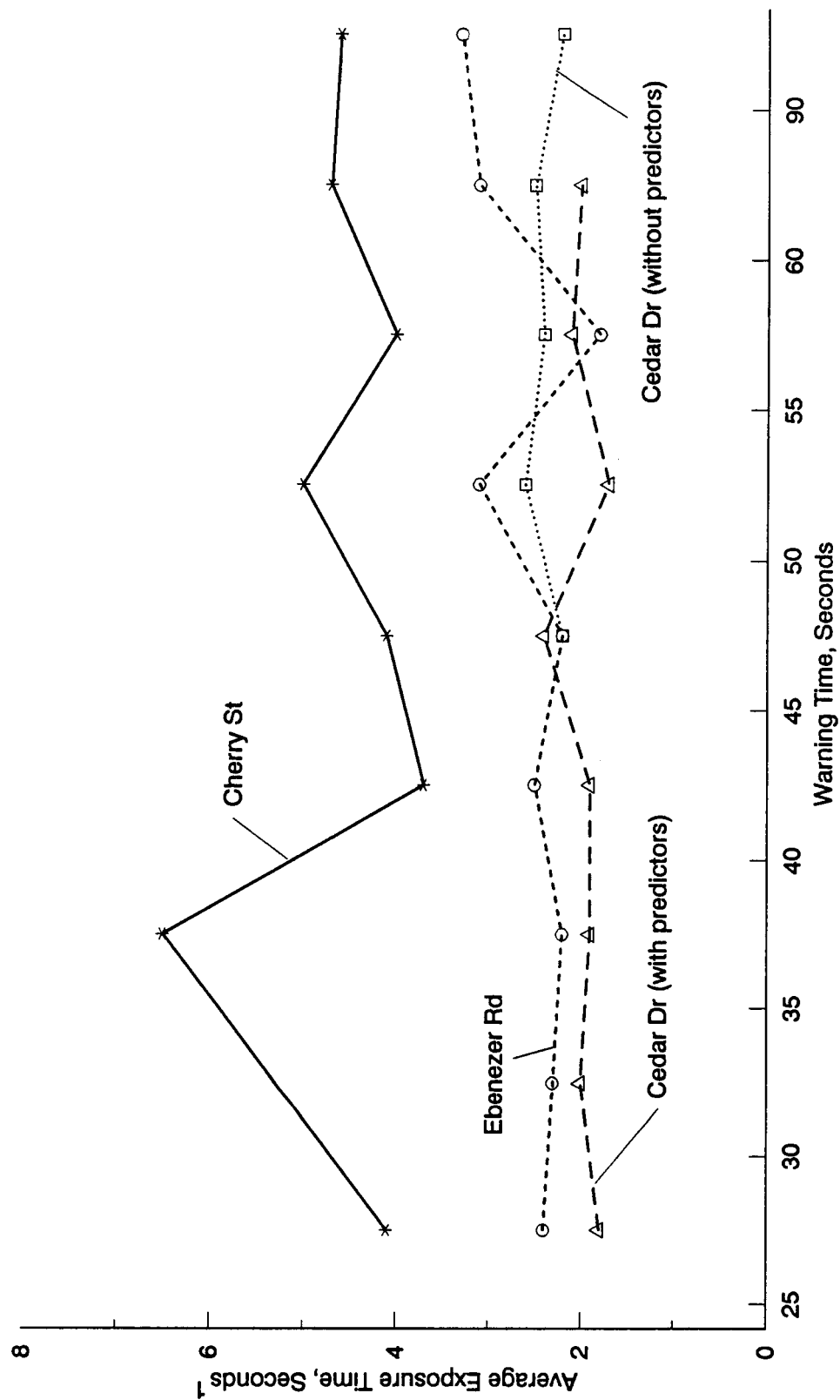
At the crossings with flashing light signals, exposure times were much shorter and more consistent than at the Cherry Street crossing. From Figure 20, exposure times at the Ebenezer Road and Cedar Drive crossings ranged from between one and 11 seconds; however, approximately 80 percent of the times were less than three seconds. As was the case at the Cherry Street crossing, there were very few trucks or buses in the sample; however, a few of these large vehicles did cross and they tended to have the longer exposure times. Both the Ebenezer Road and Cedar Drive crossings are level single-track crossings.

Figure 21 shows the effects of warning times on vehicle exposure times. As illustrated in Figure 21, warning time had no apparent effects on exposure time at any of the crossings.

Other Results

The effects of total vehicle arrivals during the warning period and vehicle position in the queue on driver crossing behavior were also evaluated. These variables were found to be directly related to the length of the warning period, thus it is appropriate to discuss their effects here, following the discussion of warning time effects.

Total Arrivals. Figure 22 shows the relationship between total vehicle arrivals during the warning period and driver stopping/waiting behavior. Data are presented for gates with flashing light signals, i.e., data from the Cherry Street crossing, as well as composite data for flashing light signals from the Cedar Drive and Ebenezer Road crossings. In Figure 22, "total vehicle arrivals" include all traffic arriving at the crossing from both directions, excluding those vehicles which were



¹ Exposure time refers to the amount of time that a crossing vehicle occupies the crossing area, generally measured from the near side stop bar to the far side stop bar.

Figure 21. Relationship between mean exposure time and warning time.

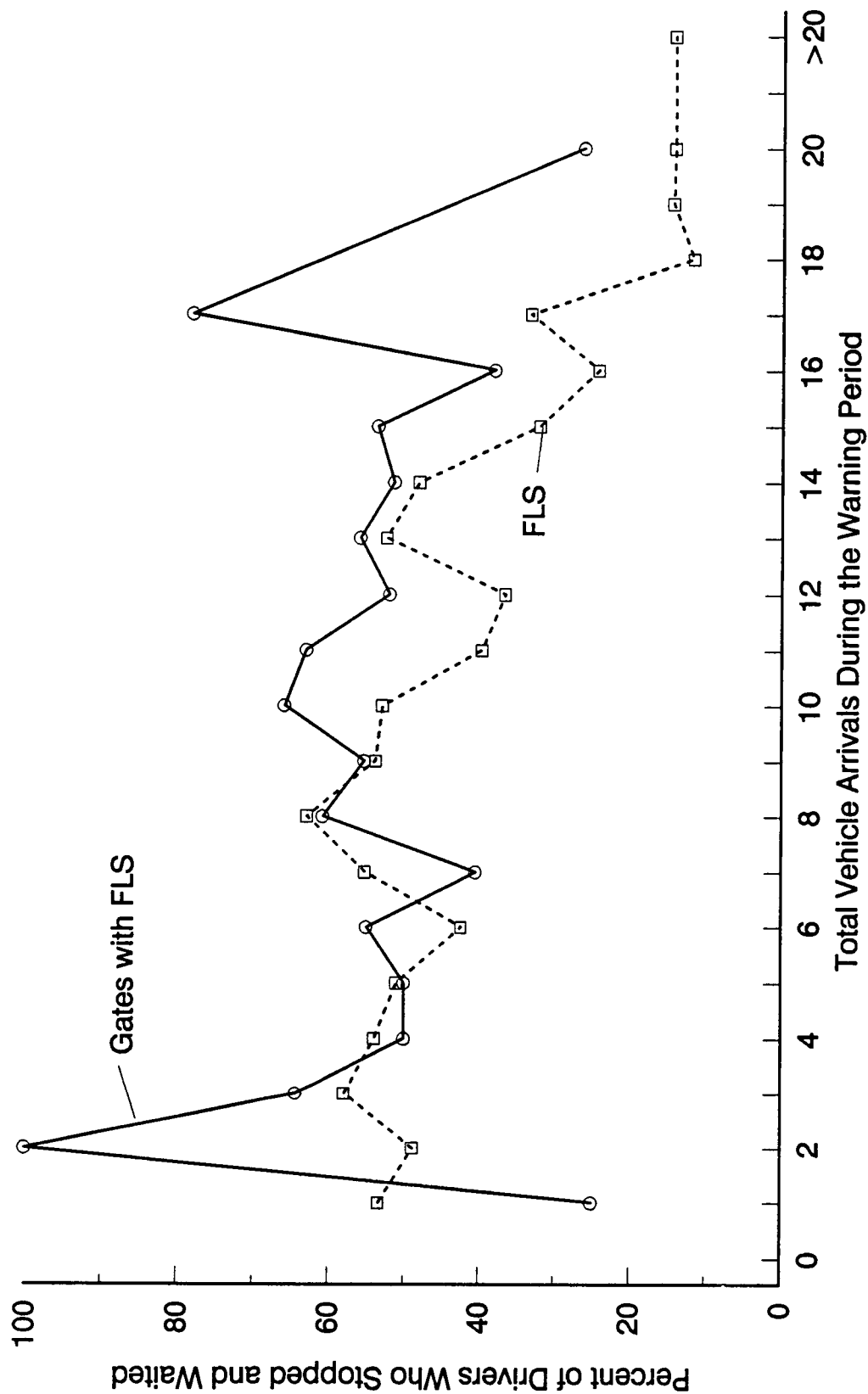


Figure 22. Relationship between total vehicle arrivals and driver behavior.

within four seconds of the crossing when the traffic control device activated.

From Figure 22, the percentage of drivers who stopped and waited for the flashing light signals remained fairly constant, about 55 percent, for queue sizes from one vehicle to 10 vehicles. For larger queue sizes, the percentage of drivers who stopped and waited decreased. In fact, for queue sizes larger than 18 vehicles, only about 20 percent of drivers stopped and waited. For these larger queues to occur, the warning times generally had to be long; thus, the trend observed for flashing light signals relative to queue size is actually directly associated with warning time. When the warning time was long, more vehicles arrived at the crossing. Since the warning time was very long, fewer drivers, percentage-wise, elected to wait.

For gates with flashing light signals, no obvious trends were observed associated with queue size. As seen in Figure 22, the percentage of drivers who stopped and waited varied between 40 and 70 percent, with significant "spikes" in the data curve at queue sizes of two vehicles and 17 vehicles. The spike at 17 vehicles is due to a very small sample of only two trains, and thus it is considered a normal fluctuation of the data. The high percentage (100 percent) of drivers who stopped and waited for the queue size of two vehicles is believed to be related to warning time. All of the train events which produced a queue size (during the warning period) of only two vehicles had short warning times in the range of 20-40 seconds. It has already been established that drivers tend to stop and wait if the warning time is reasonably short.

Order of Arrival. Figure 23 illustrates the relationship between vehicle order of arrival (i.e., first, second, third, etc., vehicle to arrive during the warning period) and driver behavior. Data for the three study crossings are presented, and the data include all traffic in both directions of travel which arrived during the warning period. However, those vehicles which were less than four seconds from the crossing when the traffic control device activated are not included.

As seen in Figure 23, the Cherry Street, Ebenezer Road, and Cedar Drive (with predictors) crossings all showed a similar trend. Only about 20-30 percent of the first drivers to arrive at the crossing stopped and waited. For each successive arrival, the percentage rose steadily. By the tenth vehicle to arrive, the percentage of drivers who stopped and waited ranged from 60 percent to over 80 percent. The data for Cherry Street include those vehicles arriving during the gate delay/descent period. Thus, the first several drivers to arrive would not have to drive around lowered gates to cross.

The trend observed for the three crossings in Figure 23 is not unexpected. Drivers arriving well into the warning period would not have as much time to cross the tracks before the train arrival, thus they would be more hesitant to cross. Also, there would be the increased likelihood of impedance by earlier arriving vehicles. What is surprising in Figure 23 is the very low percentage of drivers arriving in the first and second positions who stopped and waited.

Figure 23 also shows the percentage of drivers who stopped and waited by order of arrival for the Cedar Drive (without predictors) crossings. As seen in Figure 23, the percentages were much lower at this

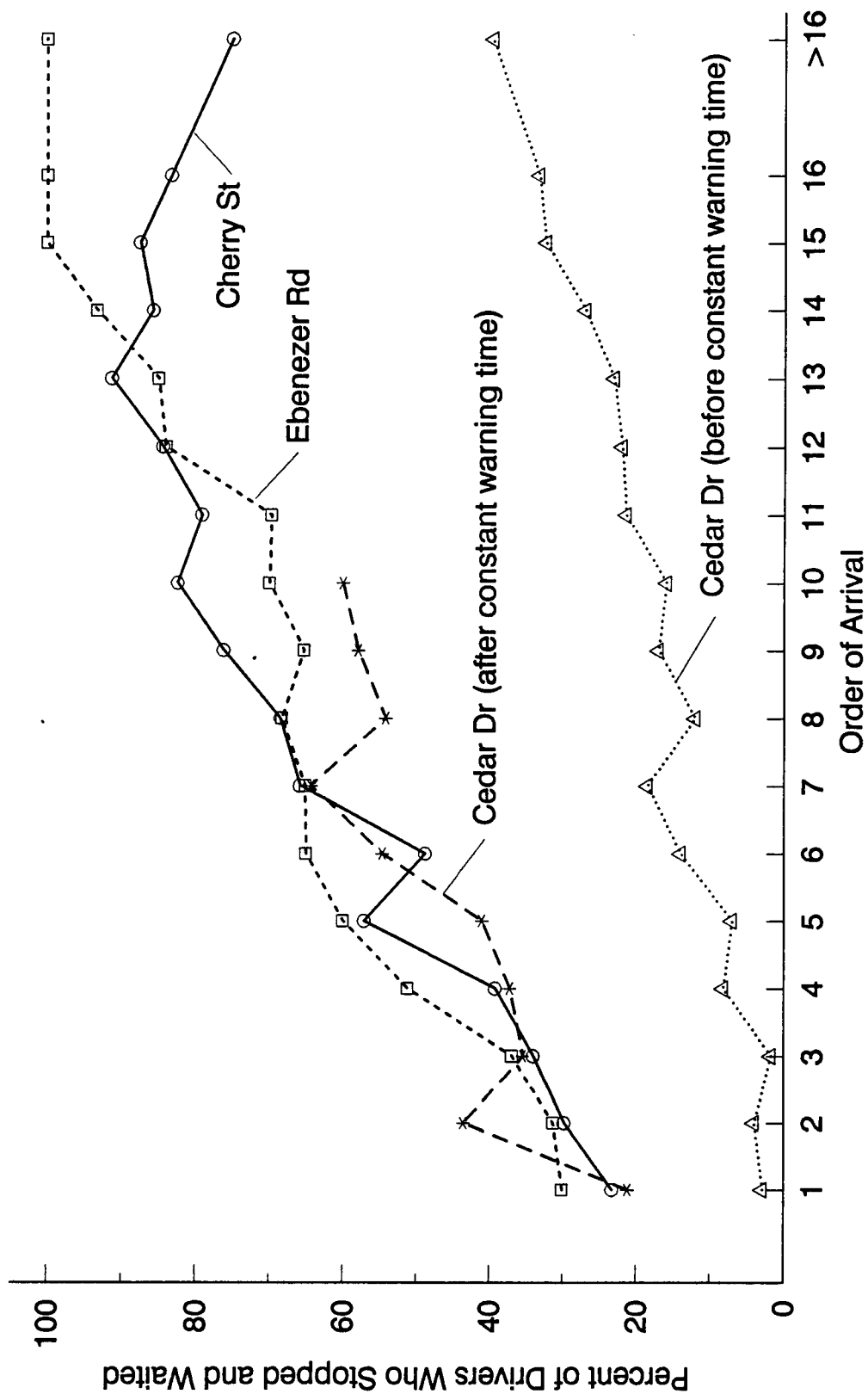


Figure 23. Relationship between vehicle order of arrival at the crossing and driver behavior.

crossing compared to the others, but the same increasing trend was observed. The low percentages of drivers who stopped and waited at the Cedar Drive (without predictors) crossing is explained by the excessively long warning times at the crossing. Although most of the drivers crossed the tracks long before the train arrived, these undesirable driver actions would have a negative impact on general crossing safety because they tend to erode driver credibility in the traffic control.

Summary of Field Study Results

The results of the field studies confirm that undesirable driver actions at active crossings are a significant and recurring problem. Some of these actions are unlawful and/or inherently unsafe. The others are undesirable since they represent a general lack of trust and respect in active traffic control on the part of motorists. At the crossings with flashing light signals, between 10 and 19 percent of the motorists arriving during the warning period crossed without stopping, and another 20-54 percent crossed after stopping. At the gated study crossing, about 12 percent of the motorists arriving during the warning period crossed without stopping, even after the gates were fully lowered, and another 28 percent crossed after stopping.

Based on the results of the field studies, the length of the warning period was found to have a major influence on crossing behavior. Generally, when the warning period was between 20 and 35 seconds, the number of vehicles crossing (or violations in the case of gated crossings) was minimized, and particularly if the warning time was near the 20-second minimum. As the warning time increased above 35 seconds,

undesirable driver behavior increased significantly, both in response to flashing light signals and automatic gates.

More important is the fact that CL20s and CL10s increased significantly when the warning time was greater than 30 seconds, while there were no CL10s observed at any of the active crossings studied when the warning time was less than 30 seconds, and there were no CL20s at the gated crossing when the warning time was less than 30 seconds. CL10s and CL20s refer to the number of vehicles crossing within 10 and 20 seconds of train arrival, respectively. They are measures of risky and aggressive behavior, respectively.

Undesirable crossing behavior was directly related to train wait time, or the time that a motorist arrives at a crossing relative to the train's arrival. When the train wait time was less than 10 seconds, virtually 100 percent of drivers stopped and waited. However, for greater wait times the percentage of motorists who stopped and waited declined steadily for both flashing light signals and gates.

The field studies also indicated that the majority of motorists who elect to drive through or around a functioning active warning device, both at crossings with flashing light signals and at gated crossings, will not cross with a clearance time of less than 20 seconds. Furthermore, drivers make the decision to cross in a very short time period, i.e., generally less than five seconds for flashing light signals and less than 10 seconds for gates. When they do elect to cross, their exposure times tended to be less than five seconds. However, a limited number of long exposure times were observed, even though all three study crossings were relatively narrow. Exposure times up to 11 seconds were

observed at the single-track crossings with flashing light signals, and exposure times up to 13 seconds were observed at the double track gated crossing. In both cases, these times were experienced by large trucks.

CHAPTER 5

CROSSING VIOLATION AND DELAY MODEL

Introduction

The field study results support the premise that unnecessarily long warning times can adversely affect driver behavior at active crossings. Most notably, as warning times increase beyond 30 seconds, the number and rate of vehicle crossings (at crossings with flashing light signals) and violations (at crossings with gates) rise sharply. These increased vehicle crossings (or violations) are indicative that driver trust in and respect for the traffic control system has declined, and thus drivers are choosing to rely on their own judgment. It follows that the potential for certain types of crossing accidents is increased.

The field studies produced driver response data for only a limited number of train events at the test crossings. To assess more generally the effects of warning times on crossing safety and operations, it would be desirable to quantify the impacts over a long time period for all train events. Ideally, it would be most advantageous to quantify the long-term effects of warning times on total accident experience. However, this evaluation approach would be cost-prohibitive because of the rarity of crossing accidents and the difficulty associated with continuously monitoring warning times at a crossing or group of crossings.

Therefore, an alternative approach to assessing the general effects of warning times on crossing safety and operations was developed as part of the research. This alternative approach involved the use of a

computer simulation model to estimate vehicle crossings (or violations) and vehicle delay as functions of warning time. It is rationalized that vehicle crossings (or violations) are both a surrogate safety measure and a measure of driver respect for and trust in the traffic control system. Vehicle delay is a measure of the operational efficiency and "quality of service" provided by the traffic control system.

This chapter describes the computer simulation model, including the model inputs, outputs, assumptions, and principle logic. The verification of the model's ability to replicate observed conditions is presented. Also presented are the results of applying the model to assess the general safety and operational impacts of warning times at a crossing with flashing light signals and a crossing with gates and flashing light signals.

Model Description

The simulation model was adapted from a model which had been developed by this researcher for a previous FHWA study.⁽⁴⁾ The disaggregate model incorporates basic traffic flow theory and characteristics, along with performance data from the field studies. The computer program for the model is written in IBM BASICA and was compiled using BASCOM. The program is presented in Appendix B.

The model generates train and vehicular traffic at a crossing, based on input traffic characteristics. Each train arrival at the crossing is handled as a separate event, and the results of each event are "cumulated" as additional train events are generated. As a new train arrives (is generated), it is first assigned a warning time, thus

defining the warning period for that train event. Then, vehicular traffic is generated as this warning period progresses. As each new vehicle appears (is generated) at the crossing, its type is designated, and the model "predicts" whether the driver will cross (violate) during the warning period or wait for the train. Lastly, the delay experienced by each vehicle which does not cross is calculated. Delay is defined as the wait time during the warning period plus the time which the train occupies the crossing.

Model Inputs. The variable inputs to the model are average daily vehicular traffic (ADT), distribution of ADT by vehicle type, total trains (during the period under investigation), mean warning time, type of traffic control (flashing light signals with or without gates), and assumed crossing (or violation) rates.

With respect to vehicle types, the model is designed to accommodate four general classes of vehicles: (1) passenger cars, pickups, and vans; (2) light trucks; (3) heavy trucks; and (4) buses. These four classifications are typically used in summary traffic data published by FHWA and state departments of transportation.

The model also allows the input of up to five different vehicle crossing (or violation) rates for each vehicle type. The five rates correspond to the time of arrival of a vehicle relative to a train's arrival, recognizing that drivers who arrive early in the warning period are more likely to cross (violate) compared to drivers who arrive just before the train reaches the crossing. Accordingly, separate crossing (violation) rates may be input to handle the following five situations:

1. Vehicle arrives less than 10 seconds before train arrival;

2. Vehicle arrives 10-20 seconds before train arrival;
3. Vehicle arrives 20-40 seconds before train arrival;
4. Vehicle arrives 40-60 seconds before train arrival; and
5. Vehicle arrives more than 60 seconds before train arrival.

Model Outputs. The model predicts the cumulative number of crossings (or violations) at a crossing by type of vehicle and for all vehicles combined. It also predicts the cumulative number of vehicle arrivals during the combined warning periods, again by type of vehicle and for all vehicles combined. The average number of vehicle crossings (or violations) per train event and the average number of total arrivals per train event are calculated.

With respect to vehicle delay, the model estimates the cumulative delay experienced by motorists who do not cross and the average delay per train event for these motorists. The delay times include the time spent waiting during the warning period plus the time that the train occupies the crossing. Train occupancy time is assumed to be 120 seconds, although this value can be adjusted readily if desired. Vehicles which cross (or violate) during the warning period are assumed to experience no appreciable delay, and in fact the field studies support this assumption.

Assumptions. The model incorporates several basic assumptions and limiting factors. These are enumerated below:

1. Warning times are assumed to be distributed normally, with a standard deviation equal to one-third the input mean warning time. These assumptions about normality and spread are based on the results of the field studies. The model

could be adapted easily to handle other warning time distributions if desired.

2. Trains are assumed to arrive randomly throughout the day and night, and throughout the week. This assumption was made given the lack of precise information on train operations. The model could be adopted to accommodate a different train traffic distribution if desired.
3. Vehicular traffic is assumed to fluctuate throughout the day and night on an hourly basis. Within a given hour, the flow per unit time, e.g., vehicles per second, is constant. A typical hourly flow distribution for an urban arterial/major collector is incorporated into the program as a subroutine. Obviously, any appropriate flow distribution could be used.
4. During a specific train event, vehicle arrivals at the crossing are assumed to have a Poisson distribution.
5. A Bernoulli process is incorporated into the model to predict which arriving drivers will elect to cross during the warning period. The Bernoulli process utilizes empirical crossing (violation) rates from the field studies which are variable inputs to the program.
6. The model establishes limits on crossing capacity. For crossings with gates, it is assumed that crossing headways cannot be less than four seconds. At crossings with flashing light signals, the crossing headways cannot be less than two seconds.

7. Restrictions on maximum and minimum warning times are incorporated in the model in recognition of practical limits. Maximum warning times cannot exceed 300 seconds, and minimum warning times must be greater than 15 seconds. Warning times less than 20 seconds have been reported, thus an absolute minimum of 15 seconds was defined as a reasonable, practical minimum.
8. Limitations on driver behavior at the start and end of the warning period are accommodated in the model. It is recognized that drivers within four seconds of the crossing when the traffic control device activates generally cannot stop. Thus, these vehicles are not counted. Also, it is reasonable to assume that a driver would never cross less than 1 second before a train reaches the crossing, except in those very rare instances when a train/car accident actually occurs. Therefore, for the purpose of the simulation, no vehicles were allowed to cross in less than 1 second before train arrival.

Model Application

In order to assess the general impacts of warning times on grade crossing safety and operations, the simulation model was applied to the two basic crossing situations which were observed in the field studies, i.e., a crossing with flashing light signals and a crossing with gates and flashing light signals. In both cases, it was assumed that there was an average of 10 trains per day and 15,000 vehicles per day at the

crossing. (These traffic characteristics are similar with those observed at the field study crossings.) In addition, a vehicular distribution typical of an urban arterial/major collector was assumed for both situations. It was assumed that 85 percent of the traffic stream was cars, pickups, or vans; seven percent was light trucks; six percent was heavy trucks; and two percent was buses.

The other major inputs to the model were the crossing (violation) rates shown in Table 15. These rates were assumed based on the results of the field studies, primarily those presented in Figure 14 in Chapter 4 (page 93). For the gates with flashing light signals, the passenger car rates reflect those violation rates observed at the Cherry Street crossing, with appropriate rounding off and interpolation. For flashing light signals, the rates observed at the Ebenezer Road and Cedar Drive crossings were combined into the passenger car rates shown in Table 15. The rates in Table 15 for other types of vehicles are based some on the limited field study observations, but mostly on intuition. The accuracy of these values should be confirmed when the overall accuracy of the model is verified. Also, due to the fact that 85 percent of the traffic was assumed to be passenger cars, the model is not particularly sensitive to the violation rates of other vehicle types.

With the above inputs, the simulation program was run with mean warning times of 20, 30, 40, 60, and 90 seconds. The results of these multiple runs provided insight into the overall safety and operational effects of warning times for the two crossing situations.

Model Verification. Before discussing the results of the simulation application, it is appropriate to verify the model's ability to

Table 15. Assumed crossing and violation rates.

Traffic Control	Vehicle Type	Percentage Crossing (or Violating)				
		Arrival Time Prior to Train (seconds)				
		<10	10-20	20-40	40-60	>60
Gates with Flashing Light Signals	Cars, Pickups, Vans	2	10	40	60	85
	Light Trucks	2	10	40	60	85
	Heavy Trucks	0	5	20	40	85
	Buses	0	5	20	40	85
Flashing Light Signals	Cars, Pickups, Vans	2	40	80	95	98
	Light Trucks	2	40	80	95	98
	Heavy Trucks	0	20	40	80	95
	Buses	0	20	40	80	95

replicate conditions observed at the study crossings. To do this, the average number of vehicles crossing (or violations) per train event were "estimated" using the model output for both crossing situations for a range of warning times. Then these "model" estimates were compared to the actual values observed at the test crossings. Since the assumed conditions in the simulation model were purposely selected to match those at the test crossings, it follows that the model results should be consistent with the field study results, that is, if the model is accurate.

Figure 24 shows the results of the model verification. As illustrated in Figure 24, the model results match the field study results closely. It is concluded that the model can replicate observed conditions with reasonable accuracy, and thus it is appropriate to use the model to assess the general effects of warning times under the assumed crossing conditions. The model results for the flashing light signal in fact match the field study results very closely, i.e., the two curves essentially overlap. For the case of gates with flashing light signals, the model results match the field study results fairly closely for warning times ranging from about 20 seconds to 50 seconds and for times greater than or equal to 90 seconds. However, there is modest divergence of the two curves in the 60-90 second range. Actually, the divergence is caused by a single data point from the field studies, thus the divergence does not appear to be significant.

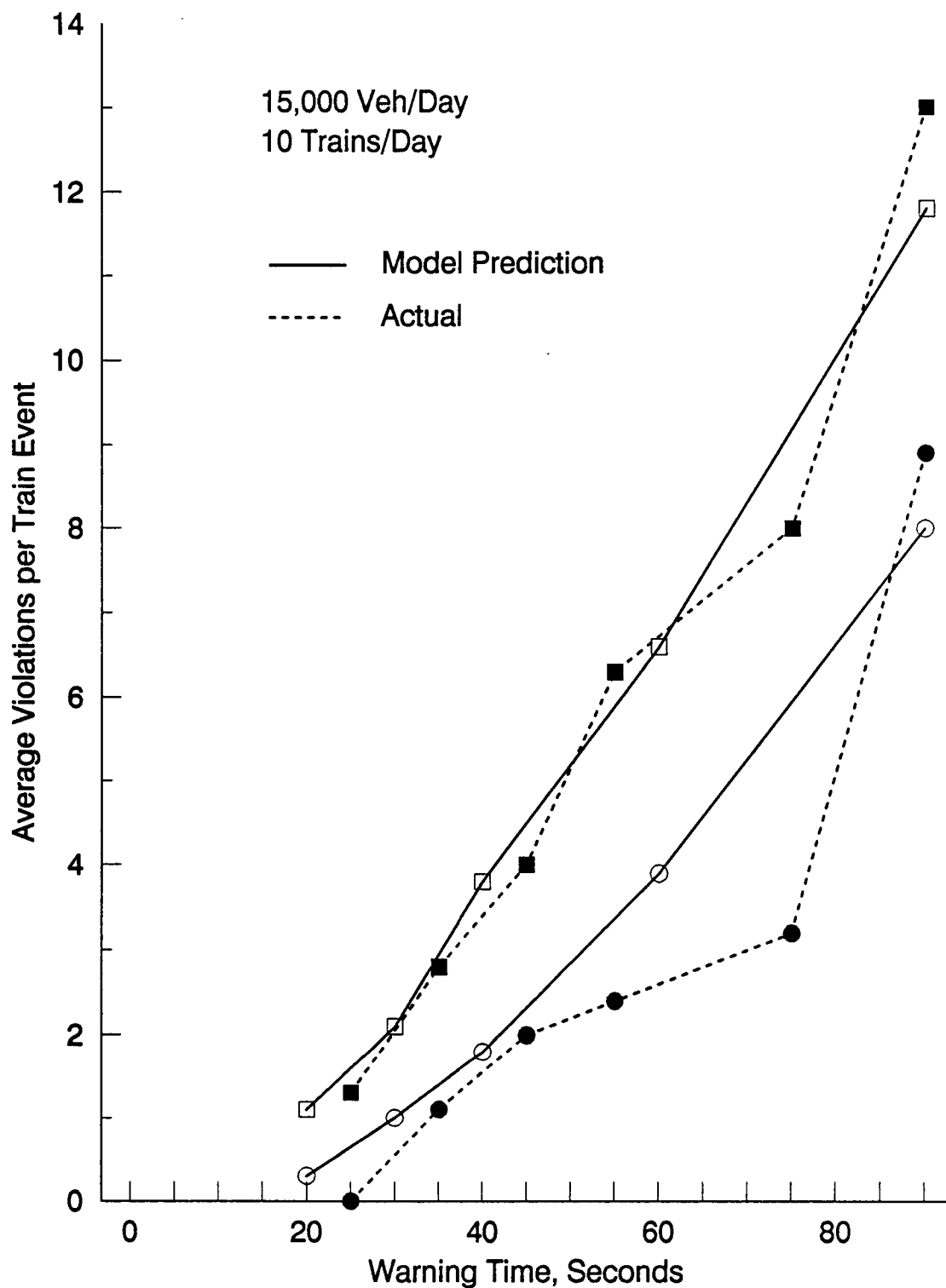


Figure 24. Warning time effects on average violations per train (model verification).

Results and Conclusions

The model application yielded estimates of annual vehicles crossing/violations and annual motorist delay for each crossing type. These estimates are illustrated and discussed in the following subsections.

Vehicles Crossing (Violations). Figure 25 illustrates the relationship between annual vehicles crossing (or violations) and warning times for both flashing light signals and gates with flashing light signals. Annual vehicles crossing (violations) increase very rapidly with increasing mean warning times, and the absolute numbers of vehicles crossing (or violations) become extremely large at the higher warning times. For example, for the flashing light signals, a 20-second warning time would result in approximately 4,800 annual vehicles crossing during the warning period, while a 90-second warning time would increase this number to approximately 43,000 annual vehicles crossing during the warning period. Thus, a 70-second increase in the mean warning time results in an 800 percent increase in vehicles crossing (violations). In the case of the gates with flashing light signals, a 20-second warning time would result in about 1,200 annual gate violations, whereas a 90-second warning time would result in almost 30,000 annual gate violations. From these data, potential for the loss of driver trust and respect is very obvious as the warning time increases beyond 20-40 seconds. The increase in accident potential should also be obvious.

Also from Figure 25, the number of annual vehicles crossing/violations during device activation is considerably higher for flashing light signals than for gates with flashing light signals, given the same traffic, train, and warning time characteristics. This trend

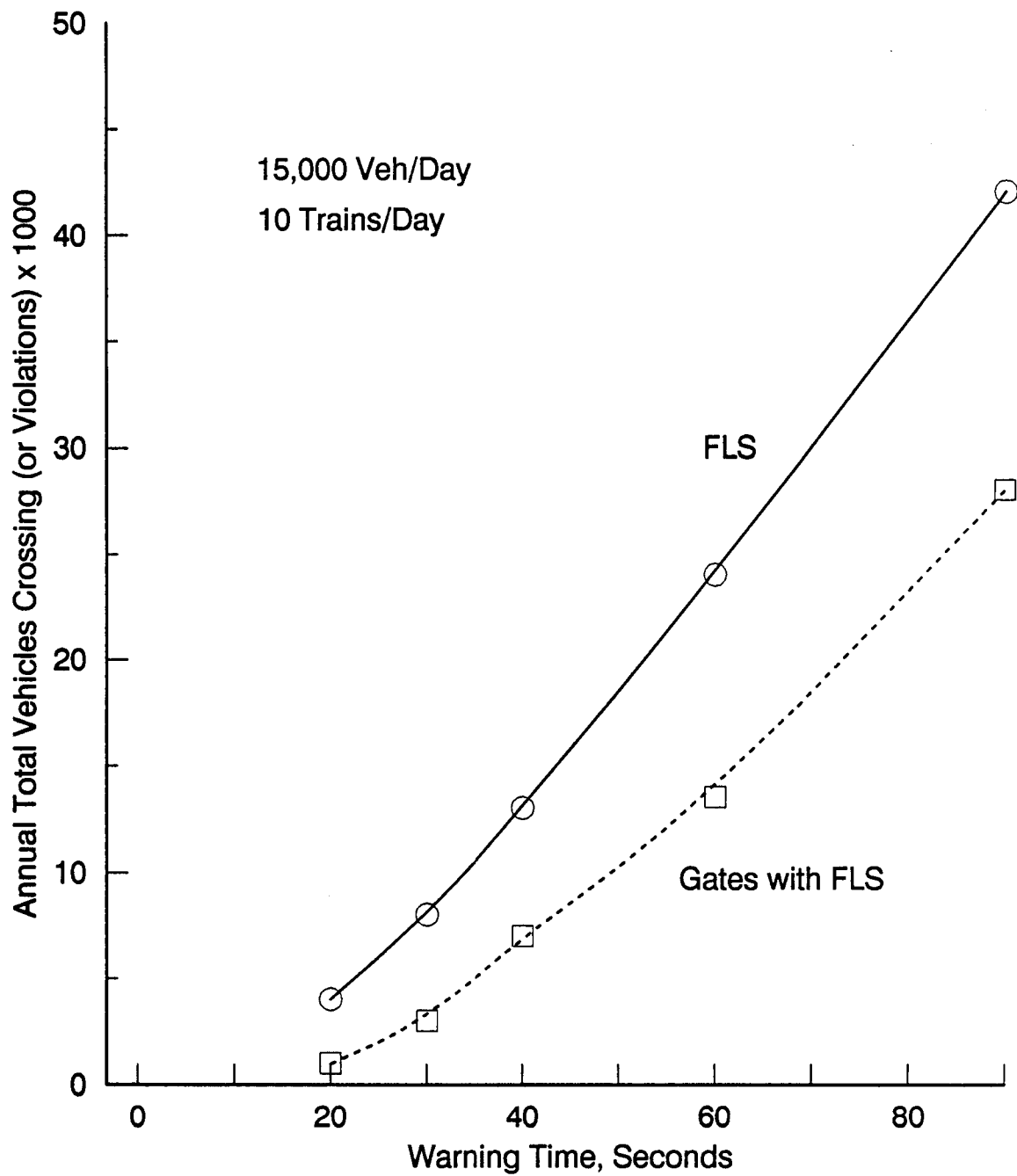


Figure 25. Warning time effects on annual total vehicles crossing or violations.

is consistent with the field study results and the less restrictive physical appearance and legal status of flashing light signals. Also from Figure 25, warning time appears to have a greater effect on vehicles crossing (violations) for flashing light signals compared to gates with flashing light signals. This trend is seen in the greater slope of the flashing light signal curve, and it is due to the fact that drivers do not have as much tolerance for excessive warning times at crossings with flashing light signals versus crossings with gates. Again, this finding is consistent with the field data.

Figure 26 shows the "additional" annual vehicles crossing (violations) which would be expected as the mean warning time is increased above the current 20-second minimum warning time recommended in the MUTCD.⁽¹²⁾ As seen in Figure 26, thousands of vehicles crossing (while the flashing light signals are activated) and violations (at crossings with gates) could be eliminated each year at crossings with excessive warning times by keeping warning times near or at the 20-second minimum warning time. This would increase overall driver respect for active traffic control devices and thereby enhance overall grade crossing safety. For example, if the warning time at a crossing with flashing light signals was reduced from 60 seconds to 20 seconds, approximately 20,000 vehicles crossing (while the signals are activated) would be eliminated. That is, 20,000 drivers would cross safely before the lights activated, and their respect for the traffic control system would be reinforced rather than lessened.

Delay. Figure 27 summarizes the effects of warning time on annual vehicle delay for flashing light signals and gates with flashing light

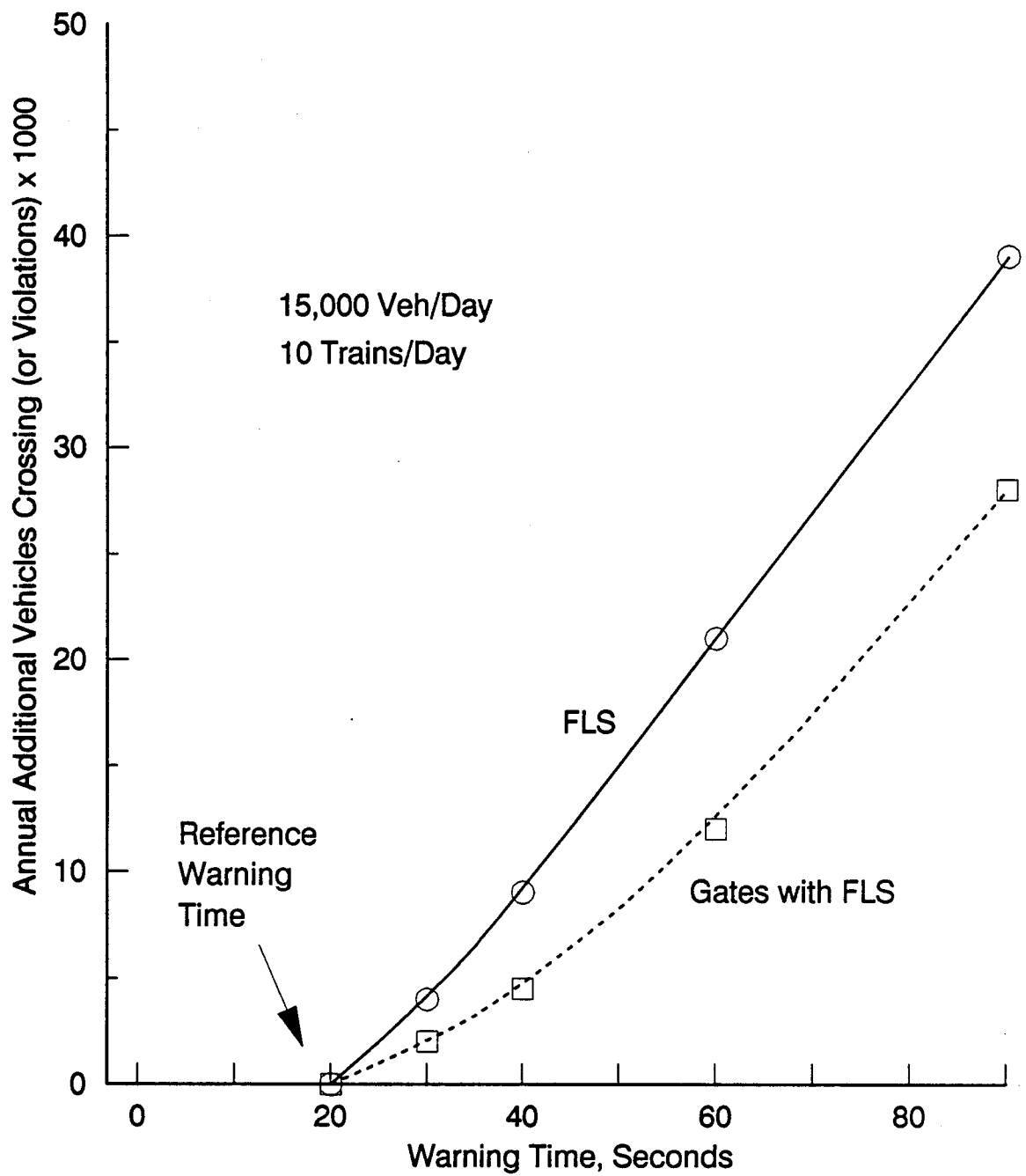
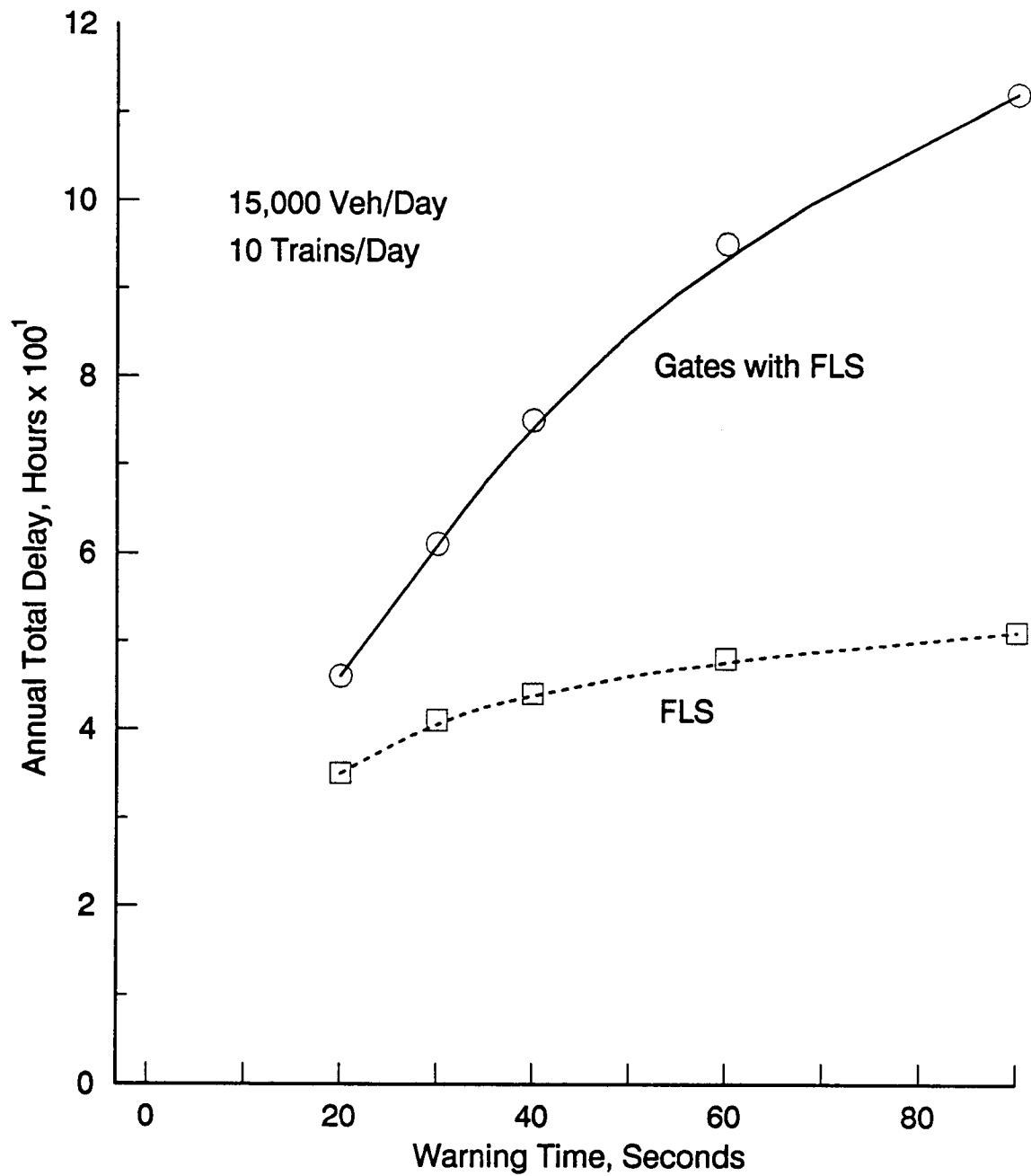


Figure 26. Warning time effects on annual additional vehicles crossing or violations.



¹ Delay = Warning period wait time + 120-second train occupancy time.

Figure 27. Warning time effects on annual total delay.

signals. Delay is defined as a driver's wait time during the warning time period plus the time that the train occupies the crossing. It was assumed that only those drivers which waited for the train experienced delay, i.e., drivers who crossed during the warning period were not delayed. Also, the annual delays shown in Figure 27 do not include delay incurred by those drivers who arrived while the train already occupied the crossing. These drivers, in fact, would be unaffected by the length of the warning time. Lastly, a uniform train occupancy time of 120 seconds was assumed.

From Figure 27, warning time has a very pronounced effect on motorist delay for gates with flashing light signals, i.e., as the warning time increases beyond the 20-second minimum, total annual delay rises sharply. For example, with a 20-second mean warning time there are approximately 420 hours of delay. With a 90-second mean warning time, the annual delay rises to almost 1,200 hours. It is interesting to note that the delay curve for gates with flashing light signals starts to flatten at higher warning times. This is not a positive sign since it indicates that many drivers are simply unwilling to wait through the long warning period, so they drive around the lowered gates.

The delay curve for flashing light signals in Figure 27 is relatively flat, indicating that warning time does not have a great effect on motorist delay at crossings with flashing light signals. Again, this is not a positive trend, but a very negative one. As the warning time increases above the 20-second minimum, drivers simply cross while the signals are activated. This undesirable behavior is neither illegal nor blatantly unsafe. However, this behavior may be "subtly"

unsafe in that it is indicative of the drivers' lack of trust and respect for the traffic control system.

Figure 28 shows the "additional" annual delay which would be expected as the mean warning time is increased above the current 20-second minimum warning time recommended in the MUTCD.⁽¹²⁾ At a typical gated crossing experiencing excessive warning times, hundreds of hours of motorist delay could be eliminated each year by controlling warning times near or at the minimum. This would save vehicle operating costs, pollution costs, lost-time costs, etc. It would also increase overall driver respect for active traffic control devices and thereby enhance overall grade crossing safety. For example, if the average warning time at a crossing with gates was reduced from 60 seconds to 20 seconds, approximately 500 hours of delay would be avoided each year.

Summary

A computer simulation model was developed and applied in order to assess the general impacts of warning time on grade crossing safety and operations. The model incorporated basic traffic flow theory and characteristics as well as empirical data from the field studies. The model was found to be relatively accurate for assessing crossing situations similar to those evaluated in the field studies. As a side note, the model should have broad application to active crossings, provided appropriate input data are available. Most notably, reasonably accurate violation rates by vehicle type would be needed for the crossings being evaluated.

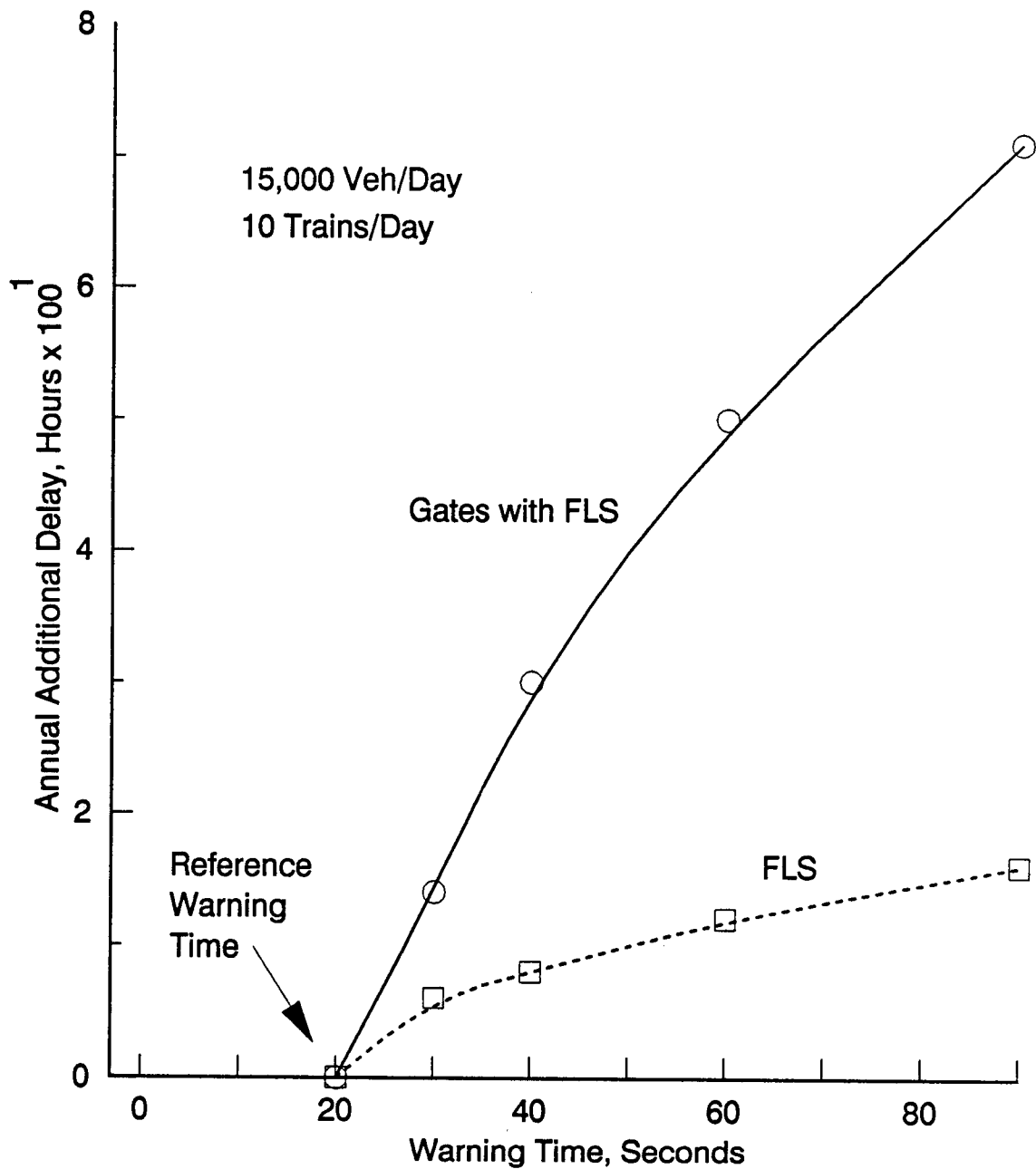


Figure 28. Warning time effects on annual additional delay.

The model was applied to two grade crossing situations--a crossing with gates and flashing light signals and one with only flashing light signals. The effects of various warning times (20, 30, 40, 60, and 90 seconds) on the number of vehicles crossing during the warning period (violations) and on delay were evaluated for each of these situations. The general findings of the evaluation are enumerated as follows:

1. Annual vehicle crossings (violations) would increase rapidly as the average warning time increases beyond the 20-second minimum warning time recommended in the MUTCD.⁽¹²⁾ This is true both for flashing light signals and gates with flashing light signals.
2. For a given mean warning time, annual vehicles crossing (violations) would be significantly higher (approximately 50 percent higher) for flashing light signals compared to gates with flashing light signals. This is consistent with the field study findings and the restrictive physical appearance and legal status of gates.
3. Long warning times have a greater effect on vehicle crossing (violation) rates at crossings with flashing light signals versus crossings with gates and flashing light signals.
4. Motorist delay would increase significantly at grade crossings with gates and flashing light signals as the warning time increases. However, as the mean warning time increases above 60 seconds, the increase slows because more drivers violate the gates.

5. Motorist delay at crossings with flashing light signals is not greatly affected by increases in warning time. This is because most drivers cross the tracks to avoid the longer wait time.

CHAPTER 6

LABORATORY STUDY

The field study results suggest that drivers have certain expectancies and tolerance levels associated with warning times at active grade crossings. These expectancies and tolerance levels undoubtedly influence drivers' behavior at active crossings and, thus, overall grade crossing safety. It follows that any guidelines for minimum and maximum warning times, to be effective, must be consistent with the warning time expectancies and tolerances of drivers. It is reasonable to assume that warning time expectancies and tolerance levels vary among drivers since driver behavior varies, and since drivers' experiences and personality characteristics vary. However, the extent of this variation among drivers has not been studied. Also, drivers' warning time perceptions may be different at crossings with flashing light signals versus crossings with gates and flashing light signals.

In order to explore warning time expectancies and tolerance levels more fully, a laboratory study was developed and conducted as part of the overall research effort. This chapter describes the objectives and methodology of this laboratory study and presents the study results.

Study Objectives

The purpose of the laboratory study was to gain insight into motorists' expectancies and tolerances with respect to warning times at grade crossings with active traffic control. This input, together with the findings of the field studies and the simulation exercise, were used

to develop the suggested guidelines for minimum and maximum warning times which are presented in Chapter 7.

The specific objectives of the laboratory study were to:

1. Determine the extent of variation among drivers with respect to their warning time expectancies and tolerances;
2. Compare warning time expectancies and tolerances at crossings with flashing light signals versus crossings with gates and flashing light signals; and
3. Identify general trends in warning time expectancies and tolerance levels, and to associate these trends to the driver behavior observed in the field studies.

Study Description

Subjects, on an individual basis, were shown a videotape of a "staged" traffic control device activation event at an active grade crossing. While viewing the activation event, subjects were asked to indicate: (1) when they would expect a train to arrive at the crossing; and (2) when the elapsed time without a train arriving had become too long. The activation event was "staged" in that no train actually was approaching; however, the subjects were unaware of this fact and the field of coverage of the video camera did not provide sight distance down the tracks. In addition, during the activation sequence, no vehicular traffic was allowed to enter the field of view of the camera, since the presence of other traffic might influence subjects' responses.

One-half of the subjects viewed a videotape which showed the activation sequence at a crossing with flashing light signals (Tape 1).

The other half viewed a videotape showing the activation sequence at a crossing with gates and flashing light signals (Tape 2). Both videotapes were filmed from the perspective of a driver approaching and stopping at the crossing as the traffic control device activation sequence began.

The videotapes were filmed at two different Norfolk-Southern crossings in the Knoxville, Tennessee, area. Tape 1 was recorded at the Ebenezer Road crossing shown in Figure 29; this crossing had flashing light signals. Tape 2 was recorded at the Prosser Road crossing shown in Figure 30; the Prosser Road crossing had automatic gates with flashing light signals. Both crossings were on two-lane suburban roads and were selected because of their similar appearance and because vehicular traffic could be restricted easily during the recording sessions.

Subjects. Sixty volunteer subjects participated in the study. All of the participants lived in the East Tennessee area, and each had a valid Tennessee driver's license. Table 16 shows the distribution of subjects who viewed Tape 1 (flashing light signals) and Tape 2 (gates with flashing light signals) by age and gender. Table 16 also gives the subject distribution for the combined subject pool. Forty five (45) percent of the subjects were male, and the average age was 33 years. There were no significant differences in subject demographics between the two groups, i.e., those who viewed the crossing with flashing light signals (Tape 1) versus those who viewed the crossing with gates and flashing light signals (Tape 2). Also, the subjects had a variety of socioeconomic backgrounds.

Study Administration. The study was administered in an office setting. After completing a brief bio-data survey, each subject was



Figure 29. Ebenezer Road crossing--flashing light signals.



Figure 30. Prosser Road crossing--gates with flashing light signals.

Table 16. Summary of laboratory study subject demographics.

	Flashing Light Signals (Tape 1)	Flashing Light Signals (Tape 2)	Combined Studies (Tapes 1 & 2)
Total Subjects	30	30	60
% Male	46.7	43.3	45.0
Age Range	18-62	19-71	18-71
Average Age	32	35	33

seated at a chair in front of a video monitor. Before the videotape was started, the subject was told to "imagine that he/she had come upon a railroad crossing while driving, and as he/she approached the crossing, the lights and/or gates activated." The subjects then witnessed the activation of the devices on the tape.

Subjects were instructed to indicate verbally when they would expect a train to arrive at the crossing and when they thought the elapsed time without a train arriving was too long or excessive. Following these instructions and a confirmation of understanding by the subject, the videotape was started. While the tape was running, no other commands or instructions were given. After the subject had responded appropriately, the tape was stopped, ending the study session. Each subject viewed only one tape only once.

The verbal announcements by the subject for expected train arrival time and excessive elapsed time were timed inconspicuously by the study administrator using a digital stopwatch. Some judgment had to be used by the study administrator in timing the subjects' verbal responses. Every effort was made to record the time when the subject first began to give a response. Also, the same administrator timed all of the responses.

Data Reduction and Analysis. Standard statistics (means, standard deviations, and ranges) were calculated for the subjects' two responses, i.e., expected train arrival time and excessive elapsed time. The mean times for these responses by device type and gender were then compared. Chi-square tests and F-tests indicated that the various data sets had approximate normal distributions and equal variance, respectively. Thus,

pooled-variance t-tests were used to compare the group means.⁽⁵⁶⁾ The results of the laboratory studies are presented in the next section. Gender effects were not significant in any of the analyses and therefore gender is not discussed further.

Study Results

Table 17 presents a summary of the results of the laboratory studies. Included in Table 17 are the mean times, standard deviations, and ranges of subjects' responses to the two questions--when would they expect a train to arrive and when would the elapsed time without a train arriving be too long. The data are broken down by device type, i.e., flashing light signals versus gates with flashing light signals.

There are two distinct phases of the warning period at a gated crossing, that is, the gate delay/descent phase and the phase when the gates are fully lowered. Since many drivers continue to cross the tracks while the gates are descending, it was hypothesized that drivers may "anchor" their expectancies and tolerance levels to the end of the gate delay/descent phase rather than the beginning of the warning period. Thus, Table 17 presents summary data for the gates with flashing light signals both including and excluding the gate delay/descent time. The gate descent time (time between activation of the flashing light signals and full lowering of the gates) was 17.4 seconds at the Prosser Road crossing.

Flashing Light Signals. As shown in Table 17, the mean expected time to train arrival for the flashing light signals was 14.5 seconds. This mean time is 5.5 seconds less than the 20-second minimum warning

Table 17. Summary of laboratory study results.

	Time to Train Arrival (seconds)			Excessive Elapsed Time (seconds)		
	Mean	S.D. ¹	Range	Mean	S.D. ¹	Range
Flashing Light Signals	14.5	7.7	6.9-32.2	39.7	10.6	26.0-57.8
Gates with Flashing Light Signals (including gate descent time)	30.6	7.1	20.9-47.4	66.2	14.1	33.6-86.7
Gates with Flashing Light Signals (excluding gate delay/descent time) ²	13.2	7.1	3.5-30.0	48.8	14.1	16.2-69.3

¹Standard deviation.

²Gate descent time = 17.4 seconds.

time currently required at crossings with flashing light signals. The fact that drivers, on the average, expect warning times to be less than the minimum time supports the need to keep warning times as short as possible. It is also interesting to note that no drivers, out of the 30 tested, expected a warning time greater than 35 seconds. (The highest time was 32.2 seconds.) This result is very consistent with the field studies which found that vehicles crossing greatly increased at crossings with flashing light signals when the warning time increased above 35 seconds.

The range of expected times to train arrival was 6.9 to 32.2 seconds, a spread of 25.3 seconds. This relatively large spread is consistent with the variations observed in actual driver behavior, i.e., the fact that some drivers cross very quickly while others are willing to wait 20 seconds or more.

The mean excessive elapsed time was 39.7 seconds for the flashing light signals. Again, this time is consistent with driver behavior observed in the field studies. In the field studies, crossing violations were very frequent when the warning time exceeded 35 seconds, while violations decreased as the warning time dropped below 35 seconds. It is also significant to note that the mean excessive time was approximately 25 seconds (39.7 seconds vs. 14.5 seconds) greater than the mean expected train arrival time. This fact supports the premise that there is a range of warning times which minimize gate violations and reinforce the credibility of the warning system.

The range of excessive elapsed times was 26.0-57.8 seconds, a spread of 31.8 seconds. It is particularly significant to note that the

low end of this range, i.e., 26.0 seconds, is only 6 seconds higher than the 20-second minimum warning time currently required. This supports the contention that the majority of drivers would not lose respect in flashing light signals if warning times were kept at or slightly higher than the current minimum value of 20 seconds.

Gates with Flashing Light Signals. As shown in Table 17, the mean expected time to train arrival at the crossing with gates with flashing light signals was 30.6 seconds, including the gate delay/descent time. This mean time is approximately 10 seconds higher than the 20-second minimum warning time required at crossings with active traffic control. Thus, at crossings with gates and flashing light signals, warning times which are only slightly higher than the current minimum allowable warning time of 20 seconds should promote driver trust in and respect for the active warning. Many grade crossings with gates have warning times greatly exceeding 30 seconds. In fact, the average warning time at the Cherry Street crossing observed in the field studies was approximately 60 seconds. The relatively long warning times at Cherry Street apparently violated drivers' expectancies. This may explain why approximately 40 percent of the drivers drove around the gates.

The mean expected train arrival time, including the gate delay/descent time, was significantly longer than the mean time for flashing light signals (30.6 seconds for gates vs. 14.5 seconds for flashing light signals). However, after the gate delay/descent time is subtracted, the mean expected train arrival time for a crossing with gates and flashing light signals is approximately the same as for a crossing with flashing only light signals. The mean expected train arrival time

for the crossing with gates and flashing light signals, excluding gate delay/descent time, was 13.2 seconds, compared to 14.5 seconds for the crossing with only flashing light signals. Thus, it is concluded that drivers tend to "anchor" their warning time expectancies and tolerances at gated crossings to the end of the gate delay/descent period, rather than the beginning of the initial warning. This conclusion is consistent with observed driver behavior in the field studies.

The range in expected times to train arrival for the crossing with gates and flashing light signals was 20.9-47.4 seconds including the gate delay/descent time and 3.5-30.0 seconds excluding the gate delay/descent time. This spread of 26.5 seconds is not significantly different than the spread of 26.3 seconds for gates with only flashing light signals. However, it is important to note the lower limit (i.e., 3.5 seconds) of the range after subtracting out the gate delay/descent time. Apparently, some drivers may grow impatient if the train does not arrive almost immediately after the gates are fully lowered. This is consistent with the field studies which found that some drivers drove around the gates almost immediately upon arriving at the crossing if a train was not imminently close.

Table 17 also shows the means and ranges for excessive elapsed times at the crossing with gates and flashing light signals. The mean excessive elapsed time was 66.2 seconds including the gate delay/descent time and 48.8 seconds excluding the gate delay/descent time. These mean times combined with the expected train arrival times support the premise that there is an "optimal" range of warning times for crossings with gates which minimize gate violations and maximize driver trust in and

respect for the traffic control system. Based on laboratory study results, this range would be approximately 20-60 seconds including the gate delay/descent time.

Even subtracting the gate delay/descent phase, the mean excessive elapsed time for the crossing with gates and flashing light signals was significantly higher (based on a t-test .01 confidence level) than the mean time for the crossing with only flashing light signals (i.e., 48.8 seconds for gates versus 39.7 seconds for flashing light signals). The difference of about 10 seconds is consistent both with driver behavior observed in the field studies and with the generally more restrictive appearance and legal status of gates. Drivers apparently tolerate longer total warning times at crossings with gates before losing respect for the traffic control.

The ranges of excessive elapsed times for the crossing with gates and flashing light signals were 33.6-86.7 seconds including the gate delay/descent time and 16.2-69.3 seconds excluding the gate delay/descent time. This spread of 53.1 seconds is significantly longer than the corresponding spread in excessive elapsed times of 31.8 seconds reported for flashing light signals. This difference again indicates that many drivers apparently will tolerate longer warning times at crossings with gates before losing respect for the traffic control system.

Discussion

The laboratory study was conducted in a nondriving setting, and this could certainly affect drivers' "absolute" time expectancies and tolerances. However, it is reasonable to assume that "relative" time

expectancies and tolerances would be valid. In particular, the relative differences measured between flashing light signals and gates should carry over to the field; so should the finding that drivers "anchor" their warning time expectancies and tolerances to the end of the gate delay/descent period at gated crossings. (In fact, both of these findings were consistent with the field study results.)

With regard to the accuracy and validity of the "absolute" times observed in the laboratory study, it is significant that the times were reasonable and consistent with actual driver behavior observed in the field studies. This fact lends credibility to the laboratory study results as being representative of drivers' actual expectancies and tolerance levels at grade crossings with active traffic control.

Summary of Laboratory Study

The results of the laboratory study further confirm and expand upon a major finding of the field studies. That is, drivers have certain warning time expectancies and tolerance levels at active crossings, and when these are violated, driver respect for the active traffic control systems will suffer and undesirable behavior will occur. In particular, the laboratory studies indicated that warning times at active crossings should fall into a fairly narrow range to maintain driver trust and respect. For crossings with flashing light signals, the results support a range from 20 seconds to approximately 35 seconds. For crossings with automatic gates and flashing light signals, the data support a slightly broader range, i.e., from around 20 seconds up to 60 seconds; however, shorter times of 20-30 seconds would be most desirable. It is

significant to note that these same ranges were supported by the field study results. The laboratory study also confirmed the field study observation that most drivers "anchor" their warning time expectancies and tolerances to the end of the gate delay/descent phase at gated crossings, and they will drive to beat the gates.

Based upon the field and laboratory study results, warning time appears to have a very significant influence on driver behavior, safety, and motorist delay at active crossings. Given this importance, warning time guidelines which establish maximum values and desirable ranges are presented in the following chapter, Chapter 7. These guidelines incorporate the findings of the field and laboratory studies, and address the issue of mandatory stop vehicles identified in the literature review.

CHAPTER 7

WARNING TIME GUIDELINES

This chapter summarizes the overall research results relative to warning times, and presents suggested guidelines for minimum, maximum, and desirable warning times at grade crossings with active traffic control. Guidelines for gate delay/descent times at gated crossings are also presented.

Warning Time Research Results

The results of the field studies confirm that undesirable driver behavior at active crossings is a significant and recurring problem. This is true at grade crossings with flashing light signals and crossings with automatic gates and flashing light signals. Furthermore, the length of the warning period is a major factor contributing to the undesirable behavior. The results of both the field and laboratory studies indicate that the optimal range of warning times is 20 to 35 seconds at crossings with flashing light signals and at gated crossings. Warning times near or at the current 20-second minimum are most desirable to minimize undesirable driver actions and motorist delay. Warning times lower than 20 seconds do not appear to be justified since most drivers do expect and will tolerate warning times near 20 seconds. The data do not indicate that overall driver behavior would be improved if warning times were less than 20 seconds. Furthermore, it is recognized that warning times in excess of the 20 second minimum may be needed to accommodate mandatory

stop vehicles, if such vehicles are present and if the crossing width and grade dictate.

With regard to specific safety measures, the field study results indicate that warning times between 20 and 35 seconds minimize the number of vehicles crossing during the warning period at active crossings, as well as the number of vehicles crossing with clearance times less than 10 seconds (CL10s) and less than 20 seconds (CL20s). In addition, warning times in this range of 20 to 35 seconds will not adversely affect the mean clearance times of those drivers who do cross.

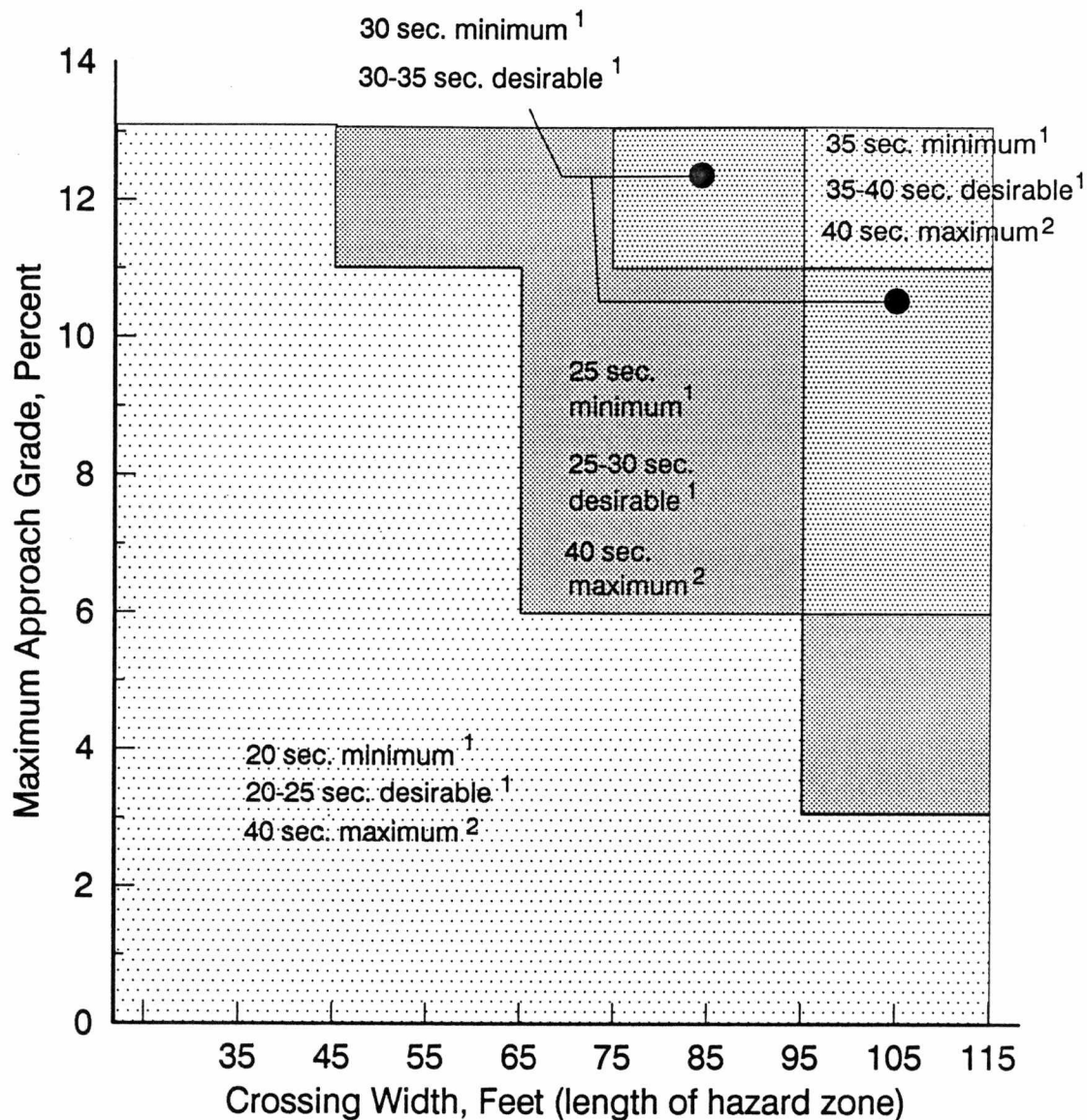
Potential violators (or crossing drivers) make their decision to cross very soon after arriving at an active crossing. If a train is not imminently close, these drivers will generally cross within a few seconds. The studies suggest that "imminently close" to most drivers is generally around 20 seconds, but may be as low as 10 seconds for a relatively few drivers. The exposure times of crossing vehicles is typically only a few seconds; however, exposure times in excess of 10 seconds were observed at the study crossings. These longer exposure times further support that the current 20-second minimum time should not be decreased in the interest of safety.

With specific regard to gated crossings, the research indicates that drivers will generally tolerate (and expect) a longer warning time than at crossings with only flashing light signals; nevertheless, warning times in the 20-35 second range are still highly desirable. In addition, there is considerable evidence that drivers "anchor" their warning time expectancies and tolerances to the end of the gate delay/descent period at gated crossings, and drive to beat the gates. This undesirable

behavior can be minimized by providing an "optimal" gate delay/descent time duration.

Warning Time Guidelines. Based on the findings of research, warning time guidelines were developed to supplement the very general "standards" in the MUTCD.⁽¹²⁾ The guidelines are supported by current warning time practices in this country and abroad, and they recognize train detection and traffic control hardware capabilities and limitations. The recommended warning times and gate delay/descent times are intended to minimize accidents and motorist inconvenience at crossings with active traffic control. Specifically, they are designed to: (1) provide sufficient time for stopping; (2) minimize vehicles crossing during the warning period; (3) minimize CL10s and maintain adequate clearance times; (4) minimize unnecessary driver delay; and (5) promote driver trust in active traffic control systems at grade crossings. The recommended minimum warning times also are designed to provide safe clearance time for those vehicles which by law must stop at all crossings. These safe clearance times, as reported by Bowman and McCarthy,⁽¹⁸⁾ are presented in Table 2 (page 47).

Flashing Light Signals. Figure 31 presents the suggested guidelines for warning times at crossings with flashing light signals. Figure 31 shows both the recommended minimum warning times and desirable ranges of warning times for various crossing conditions. The suggested minimum warning times range from 20 seconds to 35 seconds based on the width and grade of the crossing. These minimum times are necessary to allow large, mandatory stop vehicles to safely clear. They should be increased by 10 percent if twin or triple tractor-trailer combinations



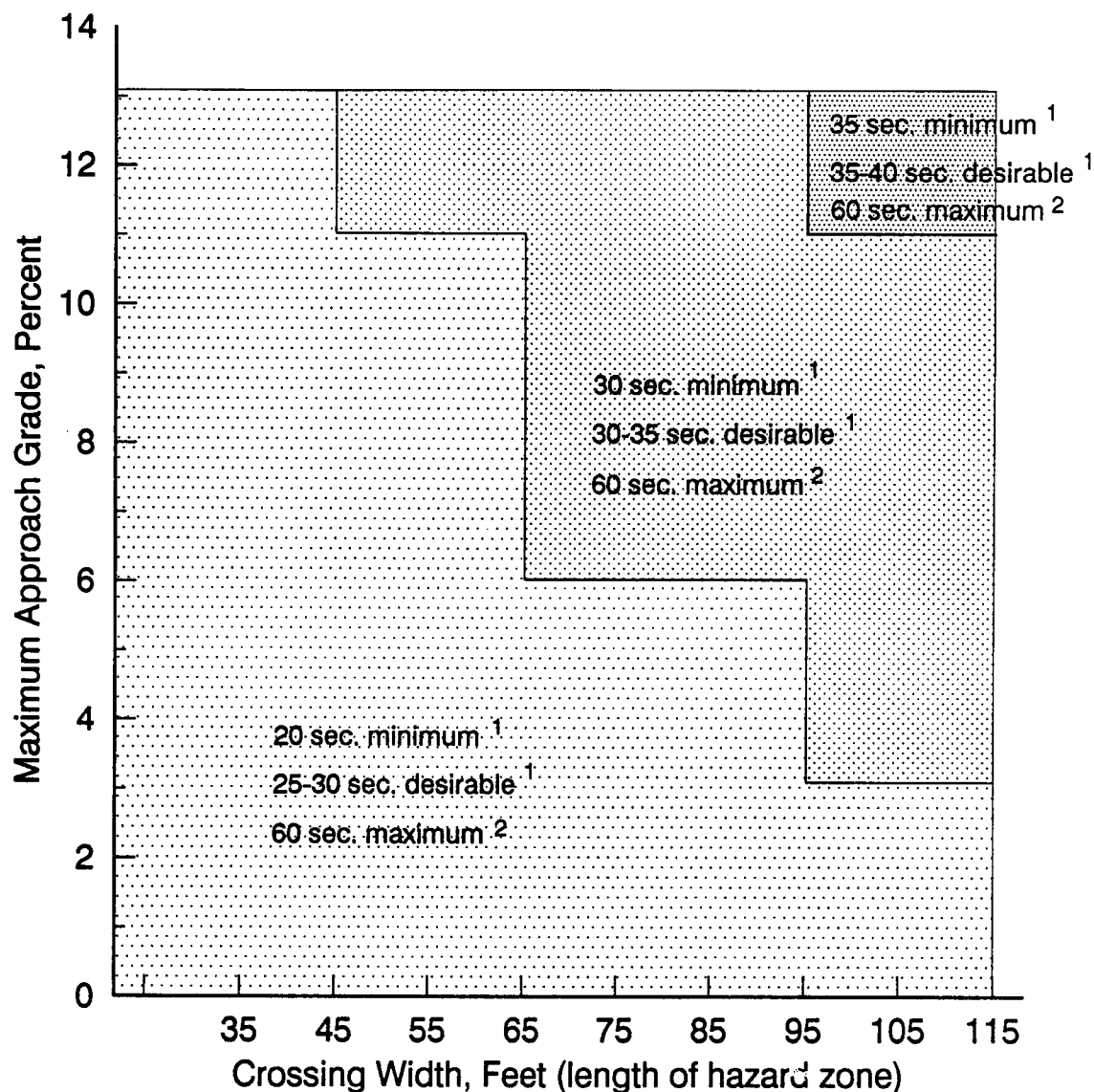
¹ Times shown apply to crossings with no twin or triple tractor-trailer combinations. If twins or triples are expected, times should be increased by 10 percent.

² If more than 10 percent of the warning times exceed 40 seconds, installation of motion sensors or train predictors is recommended. If motion sensors or predictors cannot reduce warning times to the desired level, installation of gates should be considered.

Figure 31. Suggested warning time guidelines for crossings with flashing light signals.

are present. The suggested ranges of warning times are relatively narrow, i.e., five seconds desirable range. These narrow ranges are strongly supported by the field and laboratory study results. Some longer warning times would be allowed, recognizing practical limitations of train operations and train detection hardware. However, if more than 10 percent of the warning times exceed 40 seconds, then the installation of motion sensors or train predictors is strongly urged. The 10 percent value is somewhat arbitrary; however, it is intended to define the upper limit of "occasional" excessive warning times. If motion sensors or predictors were not effective in limiting the warning times to the desired range, then the installation of gates should be considered.

Gates with Flashing Light Signals. Figure 32 presents the suggested guidelines for warning times at crossings with standard gates and flashing light signals. The suggested minimum warning times range from 20 seconds to 35 seconds based on the width and grade of the crossing. These minimum times are needed to allow large mandatory stop vehicles to safely cross. These minimum values should also be increased by 10 percent if twin or triple tractor-trailer combinations are present. As was the case for flashing light signals, the suggested ranges of warning times for crossings with gates and flashing light signals are relatively narrow, i.e., five seconds desirable. These narrow ranges are strongly supported by the field and laboratory study results. Some longer warning times, of course, would be allowed recognizing practical limitations of train operations and train detection hardware. However, if more than 10 percent of the warning times exceed 60 seconds, then the installation of motion sensors or train predictors is strongly urged.



¹ Times shown apply to crossings with no twin or triple tractor-trailer combinations. If twins or triples are expected, times should be increased by 10 percent.

² If more than 10 percent of the warning times exceed 60 seconds, installation of motion sensors or train predictors is recommended. If motion sensors or predictors cannot reduce warning times to the desired level, installation of four-quadrant gates should be considered.

Note: All warning times include gate delay/descent time.

Figure 32. Suggested warning time guidelines for crossings with gates and flashing light signals.

The 10 percent value is the assumed upper limit of "occasional" excessive warning times. If motion sensors or predictors were not effective in limiting the warning times to the desired range, then the installation of four-quadrant gates would seem appropriate;⁽⁴⁾ however, at this time⁽¹²⁾ four-quadrant gates are not adopted in the MUTCD.

The gate delay/descent time must be sufficiently long to allow large, slow-moving vehicles to clear; however, it should not be too long, or else drivers will try to "beat the gates." Based on the research results, the following guidelines for gate delay/descent times are suggested:

1. The total gate delay/descent period ideally should be 10-12 seconds, and should not exceed 15 seconds. These times are supported by the data in Figure 12.
2. The gate delay time (i.e., the time that the flashing light signals are activated before the gates are activated) should be approximately 3 to 4 seconds. Slightly longer times may be justified if vehicle approach speeds are above 60 mph. This is consistent with accepted traffic engineering principles for the warning phase at signalized intersections, and would be appropriate at crossings with gates and flashing light signals.

The above guidelines for gate delay/descent time should minimize the number of drivers who try to "beat the gates." The recommended times are also adequate to avoid excessive gate rub incidents.

Applicability of Results. In addition to providing practical goals for the operation of existing grade crossing traffic control systems, the

warning time guidelines presented in this chapter afford an objective means to determine if a warning system upgrade is needed. For example, the guidelines could be used to establish eligibility for Federal funding of train detection upgrades to include constant warning time components or to upgrade to a higher level of traffic control.

It is recognized that the field and laboratory results reported in Chapters 3-6, upon which the suggested guidelines are primarily based, represent a limited number of crossing conditions in one area of the country. However, the fact that current warning time standards abroad and in this country are so consistent with the research results lends considerable support to the recommended guidelines.

CHAPTER 8

DESCRIPTION OF DRIVER SURVEY

The results of the field studies, together with past research results, reveal that many drivers intentionally drive through or around functioning active traffic control systems at railroad-highway grade crossings. The research results also support the contention that this undesirable driver behavior accounts for a significant portion of the overall grade crossing safety problem.

Based on the evaluation of warning time effects presented in Chapters 3 through 7, it is concluded that some of the observed undesirable behavior is a direct result of excessive warning times. However, it is apparent that certain other factors also contribute to drivers' undesirable actions at active crossings. The literature supports this contention, as do the results of the field studies which showed that many drivers will drive around lowered gate arms or through flashing signals after waiting only a few seconds, and with a train visibly approaching. In these cases, warning time is not the only influencing factor.

In order to investigate those factors which, in addition to excessive warning times, encourage undesirable driver actions at active grade crossings, a further analysis of drivers' crossing behavior was conducted. A driver survey approach was deemed appropriate for this analysis, since driver surveys have been effectively utilized to investigate factors which influence unwanted driver actions.^(37,53,54) This chapter summarizes the objectives and scope of the driver survey, and

describes the survey development and administration. Chapters 9 and 10 present the results of the survey.

Driver Survey Objectives and Scope

The overall purpose of the driver survey was to identify and evaluate those factors which, in combination with warning time, influence drivers to intentionally drive around or through functioning active warning devices at grade crossings. The specific objectives of the driver survey were to:

1. Identify which of the following factors, if any, influence a driver's behavior in response to active grade crossing devices: the driver's demographic characteristics; the driver's exposure to active crossings and previous experiences at these crossings; the driver's knowledge and comprehension of active devices and associated laws; the driver's risk-taking tendencies; the driver's perceptions of hazard and enforcement; and the driver's general trust in and respect for active devices.
2. Determine which of the above mentioned factors collectively have the most bearing on crossing behavior.
3. Develop a "discriminating function" which combines the most influential factors to identify drivers who are most likely to engage in undesirable crossing behavior in response to functioning active devices.

As will be discussed, the survey focused on the particular issue of drivers' intentional violation of automatic gates. However, the

results apply indirectly to undesirable driver behavior at all active crossings. In addition, an effort was made to gather a heterogenous sample of drivers from all regions of the country in order to assess any regional differences which may exist.

Survey Development

The literature review identified several factors which may influence driver actions at active crossings. These include the driver's demographic characteristics; exposure and previous experience at active crossings; knowledge and comprehension of active devices and associated laws; risk-taking tendencies; perceptions of hazard and enforcement; and trust in and respect for active warning devices. In developing a survey procedure and instrument to evaluate these factors, it was necessary to obtain additional driver input on these factors, and to assess how drivers would respond to various forms of questioning and terminology. Both of these needs were accomplished through a series of group discussion sessions.

Small Group Discussions. In the small group discussion sessions "typical" drivers were queried about their knowledge and response to active grade crossing traffic control systems. Each discussion group consisted of six or seven volunteer participants, both male and female, of various ages, socioeconomic backgrounds, and education levels. All the participants were licensed drivers with varying levels of driving experience and exposure.

A total of three group sessions were conducted, one in each of the following locales: Knoxville, Tennessee; Lexington, Kentucky; and Bryan,

Texas. The sessions were approximately two hours in duration. They were held in a casual meeting room environment with open discussion at a round table. These discussions were lead by a session leader (this researcher) who followed the same basic format with each group. This format which incorporated accepted focus group procedures,^(60,61) consisted of a brief introductory presentation followed by a "loosely structured" combination of probe questions, follow-up questions, and periods of open discussions. Appendix C contains the probe questions used in group sessions, and other relevant information on the sessions.

All of the sessions were held in April and May of 1989. The Knoxville session was conducted first. It intentionally included a homogeneous group of drivers from Tennessee, and this session provided a base of driver input to expand in the other sessions. Since this first session was in Tennessee, it is significant to note that Tennessee's traffic laws relative to active crossings are consistent with the UVC. The Lexington session was conducted next. This session included four local drivers, one of whom was an older driver (79 years old); a New York driver; and a driver who had lived primarily in two midwestern states. Kentucky was selected as a group session site since it is one of the states whose traffic code does not explicitly prohibit motorists from driving around a lowered gate arm. The final session in Bryan, Texas, had six local drivers, two of whom were young drivers (16 and 17 years of age), and one driver who spent most of her life on the West coast. Texas' traffic laws relative to active crossings are consistent with the UVC.

Each group discussion session was recorded, and all dialogue was later transcribed. The transcribed dialogue was reduced and analyzed to provide input for survey development.

Results of Group Sessions. The group sessions defined the issues to be addressed in the driver survey, and they provided insight for selecting an appropriate survey approach. The most significant results which aided in developing the survey are enumerated and discussed below:

1. The drivers were not reluctant to reveal and openly discuss their crossing behavior, even when they recognized this behavior to be illegal or risky. There did not appear to be a strong social stigma attached to driving around or through functioning active devices at grade crossings, and as a result, it was concluded that most drivers would accept and attempt to accurately respond to a survey involving self-reported driver behavior at active crossings.
2. As a result of the group discussions (and based on the results of the literature review, field studies, and laboratory studies), ten major areas of interest were identified for inclusion in the driver survey. These were:
 - General driving experience
 - Exposure to active systems
 - Perception of system reliability
 - Warning time credibility
 - Perception of hazard
 - Perception of enforcement threat
 - Tolerance for delay

- Comprehension and knowledge
- Risk-taking tendency
- Demographic characteristics

To illustrate the nature of driver responses in these areas, a sampling of participants comments' is presented in Appendix C.

3. There were many consistencies in driver attitudes and comprehension with respect to both types of active traffic control devices, i.e., flashing light signals with and without automatic gates. Most of the drivers did not recognize them as two separate devices, but rather considered gates an "extension" of the warning provided by flashing light signals. Consistent with this finding and in recognition of the available resources, a decision was made to focus the survey on the issue of undesirable driver behavior at gated crossings, and then expand the results where appropriate to crossings with flashing light signals.
4. Drivers generally understood the grade crossing terminology used by the traffic and railroad engineering professions. Based on the participants' input (see Appendix C), the following terms were selected for use in the survey as appropriate: "railroad crossing," "gate arms (striped bars)", "railroad crossing warning lights."
5. The drivers generally understood the overall intent of active devices and associated laws, but they did not understand their duties in certain situations, namely when a train is

not visible and when a train is present, but appears to be stopped or very far away. These situations appear to account for much of the undesirable driver behavior observed at active crossings. Thus, it was decided that the survey should distinguish between and evaluate driver behavior under these two circumstances.

6. There were no detectable differences in how drivers from Kentucky viewed their duties at active crossings compared to drivers from Tennessee and Texas, even though Kentucky has different traffic laws. The Kentucky drivers were not aware that their laws were different, nor were they any more or less informed on the specific meaning of their state's laws. Based on this observation, it was decided to include "generic" questions about driver duties at active crossings which could be interpreted without specific reference to the laws in the home state of the survey participant.

The preceding six major issues influenced the overall approach which was used in the survey. The group discussion sessions also provided input for developing and wording individual questions. In particular, the group discussions were helpful in developing questions to address the more abstract issues such as risk-taking and hazard perception. In these cases, it was necessary to develop questions with manifest and latent content as recommended in the literature.⁽³⁷⁾

Survey Instrument

The questionnaire developed for the driver survey is shown in Figure 33. This survey instrument was printed for distribution on one page, front and back. It included an introductory statement which assured anonymity and encouraged subjects to be truthful and accurate in their responses. A simple sketch of a grade crossing with automatic gates in the "down" position was shown, and subjects were instructed to complete the questionnaire referring to this type of crossing.

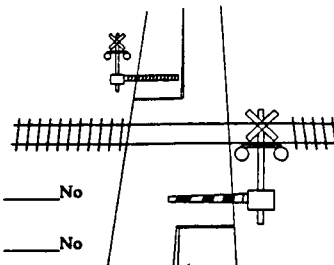
As seen in Figure 33, the questionnaire consisted of 32 closed-ended questions. Some of these questions were forced-choice questions (most notably the questions dealing with self-reported behavior), while others allowed the participant to indicate uncertainty. The questions solicited driver input in the following areas:

1. Self-reported crossing behavior at gated crossings when: no train is visible (Question 1); the train appears stopped (Question 2); and the train is approaching but there appears to be time to cross (Question 3).
2. General driver experience in terms of annual mileage (Question 6) and years of driving (Question 7), and driver exposure to gated crossings in particular (Questions 4 and 5).
3. Driver attitudes with regard to gate reliability (Questions 8, 9, and 13), and excessive warning times (Questions 10-12).

DRIVER SURVEY

Please complete this survey based upon your own driving patterns and experiences. It is important that you answer every question, and that you report your true actions and opinions. Your responses will be confidential and you do not need to give your name.

Some railroad crossings have gate arms (or striped bars) which lower across the road when a train is near or at the crossing. The questions on this survey refer to this type of railroad crossing.



1. Would you normally drive around a lowered gate arm if no train was in sight? ____ Yes ____ No
2. Would you normally drive around a lowered gate arm if you could see that the train had stopped before it reached the crossing? ____ Yes ____ No
3. Would you normally drive around a lowered gate arm if a train was coming, but you had enough time to get across the tracks before the train arrived? ____ Yes ____ No
4. In your daily driving, how often do you see a railroad crossing that has gate arms (whether the arms are lowered or not)?
____ Never
____ Less than once a month
____ At least once a month but not every day
____ Every day or almost every day
5. When was the last time you were at one of these crossings when the gate arms were lowered across the road?
____ Never
____ More than 6 months ago
____ Within the last 6 months but not in the last month
____ Within the last month
6. Approximately how many miles did you drive last year? 7. How many years have you been driving? _____
____ 0-5,000 miles
____ 5,000-10,000 miles
____ 10,000-15,000 miles
____ Over 15,000 miles
8. Do you agree that the gate arms used at railroad crossings come down only when a train is coming? (circle one.)

1
Strongly
Disagree

2
Disagree

3
No
Opinion

4
Agree

5
Strongly
Agree
9. Have you ever been at a crossing where the gate arms were lowered across the road, but no train was coming?
____ More than 5 times
____ 2-5 times
____ 1 time
____ Never
10. Do you agree that the gate arms usually are lowered too early before the train gets to the crossing? (circle one.)

1
Strongly
Disagree

2
Disagree

3
No
Opinion

4
Agree

5
Strongly
Agree
11. Have you ever been at a railroad crossing where the gate arms came down too early before the train got to the crossing?
____ More than 5 times
____ 2-5 times
____ 1 time
____ Never
12. Do you agree that the amount of time from when the gate arms go down until the train arrives is about the same for each train? (circle one)

1
Strongly
Disagree

2
Disagree

3
No
Opinion

4
Agree

5
Strongly
Agree
13. Do you agree that the gate arms used at railroad crossings are adequately serviced and repaired? (circle one.)

1
Strongly
Disagree

2
Disagree

3
No
Opinion

4
Agree

5
Strongly
Agree

(MORE ON THE BACK)

Figure 33. Survey instrument.

14. Do you agree that if you drive around lowered gate arms, you are likely to get caught by the police and given a ticket? (circle one.)

1 Strongly Disagree 2 Disagree 3 No Opinion 4 Agree 5 Strongly Agree

15. Do you agree that if you drive around lowered gate arms, you are likely to get hit by a train? (circle one.)

1 Strongly Disagree 2 Disagree 3 No Opinion 4 Agree 5 Strongly Agree

16. How much time after the gate arms are lowered should there be before the train gets to the crossing?

_____ 0-5 seconds _____ 20-25 seconds
 _____ 5-10 seconds _____ 25-30 seconds
 _____ 10-15 seconds _____ over 30 seconds
 _____ 15-20 seconds

17. Is it against the law to drive around lowered gate arms if no train is in sight?

_____ Yes _____ No _____ Don't Know

18. Is it against the law to drive around lowered gate arms if the train stops before it reaches the crossing?

_____ Yes _____ No _____ Don't Know

19. Is it against the law to drive around lowered gate arms if a train is coming, but you have time to get across the tracks before the train arrives?

_____ Yes _____ No _____ Don't Know

20. What type(s) of formal driver training have you had? (check all that apply.)

_____ None
 _____ High school driver's ed course
 _____ Defensive driving course
 _____ Other (specify: _____)

21. If you could see that no cars were coming and that no police were around, would you normally run a stop sign at an intersection? _____ Yes _____ No

22. If you were stopped at a red light at an intersection and no other cars were coming and no police were around, would you normally run the red light? _____ Yes _____ No

23. If there were no police in the area, would you normally drive more than 10 MPH over the posted speed limit on an Interstate Highway? _____ Yes _____ No

24. Do you ever drive after having more than two drinks? _____ Yes _____ No

25. Do you almost always wear your seat belt while you are driving? _____ Yes _____ No

26. Your age? _____ 27. Sex: _____ Male _____ Female

28. Circle the highest education level completed.

Grade school College
 1 2 3 4 5 6 7 8 9 10 11 12 (GED) 1 2 3 4 4+

29. What is your approximate family income?

_____ 0 - \$15,000
 _____ \$15,000 - \$25,000
 _____ \$25,000 - \$50,000
 _____ \$50,000 - \$100,000
 _____ over \$100,000

30. What type of driver's license do you currently have? (check all that apply.)

_____ Operator's license
 _____ Chauffeur's license (or Commercial license)
 _____ Learner's permit
 _____ Other (specify: _____)

31. Which state issued your license?

32. What type of vehicle do you regularly drive? (check all that apply.)

_____ Car
 _____ Pick-up or van
 _____ Motorcycle
 _____ Truck
 _____ Bus

Figure 33 (continued)

4. Driver perceptions concerning the threat of enforcement at gated crossings (Question 14), and the level of hazard (Question 15).
5. The importance to the driver of time relative to safety (Question 16), or in other words, the driver's tolerance for delay.
6. Driver knowledge of their duties at gated crossings when: no train is visible (Question 17); the train appears stopped (Question 18); the train is approaching but there is time to cross (Question 19); and level of overall driver training (Question 20).
7. Driver risk-taking tendencies as indicated by their willingness to take various driving risks (Questions 21-25).
8. Driver demographic characteristics including: age (Question 26); gender (Question 27); education (Question 28); family income (Question 29); license type (Question 30); home state (Question 31); and vehicle type (Question 32).

Survey Design Issues. Several points concerning the wording and organization of the survey instrument deserve mention. First of all, the questions soliciting self-reported driver behavior were worded so as not to invoke unnecessary social stigmas. The questions concerning the legal status and relative risk of undesirable driver behavior were also purposely placed on the back side of the form, well removed from the self-reported driver behavior questions.

Several questions in the survey employed a five-interval rating scale with the categories: strongly agree, agree, no opinion, disagree,

and strongly disagree. A similar five-interval scale was successfully used by Marks et al. in a study⁽³⁷⁾ of unwanted driver actions; however, the middle interval in the previous research was called "Neither." This word choice resulted in some confusion and thus was dropped in favor of "No Opinion."

The questions dealing with exposure generally have four categories ranging from "Never" to some very frequent interval, and specific values are given to define the categories. It was recognized in the group sessions that drivers are not able to precisely state exposure levels, but rather they are able to estimate "rough" levels of exposure. The exposure categories used in the survey were intended only to establish a general interval scale of increasing exposure, e.g., 1-4.

The questions relating to a driver's demographic characteristics were purposely placed at the end of the questionnaire, since some respondents might be sensitive to providing this information. By placing these questions at the end, it was hoped that drivers would be encouraged to complete the remainder of the questionnaire, and even if they elected not to continue, they would have already provided most of the needed information.

Pilot Testing. The survey instrument was first pilot tested in Knoxville, Tennessee, with 10 drivers. After personal interviews with these drivers, minor wording changes were made for the sake of clarity and consistent interpretation. For example, the word "normally" was added to Questions 1-3. In addition, the original single question concerning the legal status of lowered gates was split into the three separate questions corresponding to the three categories of driver

response. With these changes, the survey was administered to 15 additional drivers. Follow-up interviews with these drivers were favorable, and no further changes to the questionnaire were made.

Survey Administration

Approximately 3,000 questionnaires were distributed in all regions of the country during a two month period in the spring of 1989. Two distribution methods were utilized as described below:

1. In Tennessee, Texas, and Kentucky, questionnaires were distributed by hand to volunteer participants at selected businesses, schools, and shopping centers. Completed questionnaires were collected a few hours or days later.
2. Questionnaires were mailed to contacts in 30 states who in turn followed the procedure in #1 above. The contacts were given appropriate instructions on the sampling procedure by telephone and in writing.

For the survey to be valid across the range of drivers, it was desirable to sample a heterogeneous group of driver types; however, it was not essential to generate a proportionally representative sample. Thus, every effort was made to gather a sample of drivers representing the range of demographic characteristics. To accomplish this objective, both white and blue collar businesses were targeted, along with high schools, college campuses, and shopping centers in neighborhoods representing diverse socioeconomic characteristics.

Survey Sample Description

A total sample size of 662 drivers was obtained for the survey. This number is sufficient to accomplish the objectives of the driver survey, and to satisfy the assumption of "large sample sizes" required of the statistical procedures used.

Table 18 summarizes the demographic characteristics of the survey participants. As seen in the table, the sample included a very heterogeneous mix of drivers, and there were no apparent sample anomalies with respect to gender, age, or family income.

With regard to education, however, drivers with a college education are overrepresented in the survey sample. This sample bias is not believed to represent a significant problem for two reasons. First of all, most previous research has concluded that education level does not significantly affect unwanted driver actions.⁽³⁷⁾ Secondly, the sample does include some drivers from each educational level. The level with the lowest number of respondents was "less than a high school education," with a sample size of 17.

Also from Table 18, the majority of participants in the survey (66.2 percent) were from the South region. As shown in Table 18, 17.8, 11.5, and 4.5 percent of the survey participants were from the Northeast, North Central, and West regions, respectively. These percentages represent 118, 76, and 30 drivers, respectively. These numbers, particularly those for the Northeast and North Central regions, were sufficient to assess regional differences.

For the purpose of this survey, the regional classifications adopted by the United States Census Bureau were used. The Census Bureau

Table 18. Summary of the driver survey participants.

Demographic Characteristic	Number	Percent
<u>Gender</u>		
No response	1	0.1
Male	307	46.4
Female	<u>354</u>	<u>53.5</u>
	662	100.0
<u>Age</u>		
No response	5	0.8
18 and under	14	2.1
19-24	133	20.1
25-34	196	29.6
35-44	153	23.1
45-54	83	12.5
55-64	54	8.2
65 and older	<u>24</u>	<u>3.6</u>
	662	100.0
<u>Education</u>		
No response	4	0.6
Less than high school	17	2.6
High school, no college	145 ¹	21.9
Some college	210	31.7
College degree	<u>286</u>	<u>43.2</u>
	662	100.0
<u>Family Income</u>		
No response	37	5.6
\$0-\$15,000	79	11.9
\$15,000-\$25,000	110	16.6
\$25,000-\$50,000	252	38.1
\$50,000-\$100,000	156	23.6
Over \$100,000	<u>28</u>	<u>4.2</u>
	662	100.0
<u>Region</u> ²		
Northeast	118	17.8
North central	76	11.5
South	438	66.2
West	<u>30</u>	<u>4.5</u>
	662	100.0

¹Includes non-high school graduates with G.E.D.

²Official United States Census Regions as defined in Reference 61.

has defined four major regions of the country: Northeast, North Central, South, and West. These regions, or state groupings, indicate commonalities in natural environments, population statistics, economies, subcultures, and political characteristics.⁽⁶²⁾

Data Reduction

Since the survey responses were closed-ended, multiple choice responses, the data reduction process was straightforward. All of the forms were scanned as they were returned, and forms with non-usable data were discarded. An example of an unusable survey was one with the self-reported behavior questions left blank. Fortunately, there were less than 5 of these out of over 660. After the initial scanning, the survey data were encoded into a SAS data file.⁽⁵⁸⁾ A summary of the data elements (i.e., study variables) is presented in the following section.

Data Analysis

Several types of analyses were performed on the survey data using the SAS battery of statistical programs. The principle evaluation procedures employed were: Multivariate Analysis of Variance (MANOVA) and Discriminate Analysis. These procedures are described in detail in Chapters 9 and 10, respectively. In addition to these procedures, cross-tabulation tables were generated for the study variables. A multiple regression procedure was also utilized at the beginning of the data analysis to assess gender or regional effects.

Study Variables

The 32 questions on the survey generated data corresponding to 26 study variables. Two of these variables were categorical variables of self-reported driver behavior, and the remaining 24 variables were related to the factors of interest, i.e., factors that may influence driver behavior. All the variables are summarized in Figure 34. They are grouped according to the major areas previously identified; the type and range of each variable is shown.

Some of the variables correspond to a single question on the survey, while others represent composite data from two or more questions. A few of the study variables, as will be noted, were found to be insignificant or unreliable at the outset; these variables were appropriately omitted from subsequent analyses or dropped altogether.

Self-Reported Driver Behavior. Two different variables (or groupings) of driver behavior were identified and analyzed separately. They were: "driver behavior--no train"; and "driver behavior--train." Both groupings represent categorical variables with two levels each, that is, violator and non-violator.

The first of these variables corresponds directly to Question 1 on the survey. The second represents a composite of responses to Questions 2 and 3. If a driver answered "yes" to either of these questions, he/she was defined as a potential violator relative to the variable "driver behavior--train." If he/she answered "no" to both questions, the driver was a non-violator.

General Driver Experience. There were two variables related to general driving experience: annual mileage (Question 6) and years of

Self-Reported Driver Behavior

1. Driver Behavior - No Train (Categorical, 2 levels)
2. Driver Behavior - Train (Categorical, 2 levels)

General Driving Experience

3. Annual Mileage (metric, 4 intervals)
4. Years of Driving (metric, continuous)¹

Exposure to Gated Crossings

5. Frequency of Exposure (metric, 4 intervals)
6. Recency of Exposure while Activated (metric, 4 intervals)

System Reliability

7. Likelihood of False Activations (metric, 5 intervals)
8. Exposure to False Activations (metric, 4 intervals)
9. Perceived Level of Maintenance (metric, 5 intervals)

Warning Time Credibility

10. Likelihood of Excessive WTs (metric, 5 intervals)
11. Exposure to Excessive WTs (metric, 4 intervals)
12. Recognition of Variable WTs (metric, 5 intervals)

Hazard Perception

13. Perceived Hazard (metric, 5 intervals: 1-5)

Enforcement Threat

14. Perceived Enforcement (metric, 5 intervals: 1-5)

Tolerance for Delay

15. Delay Tolerance (metric, 7 intervals: 1-7)

Comprehension and Knowledge

16. Perceived Duties - No Train (metric, 5 intervals: 0-4)
17. Perceived Duties - Train (metric, 5 intervals: 0-4)
18. Driver Training (metric, 3 intervals: 1-3)

Risk-Taking

19. Risk-Taking Propensity (metric, 6 intervals: 0-5)

Demographic Characteristics

20. Age (metric, continuous)
21. Gender (categorical, 2 levels)¹
22. Education (metric, interval: 1-7)
23. Region of Country (categorical, 2 or 4 levels)^{1,2}
24. Family Income (metric, 5 intervals: 1-5)¹
25. License Type³
26. Vehicle Type³

¹Omitted from certain analyses.

²In certain analyses, these four census regions were combined to form 2 regions: south and non-south.

³Not used.

Figure 34. Summary of 26 driver survey variables.

driving (Question 7). However, "years of driving" was found to be highly correlated to driver age, one of the demographic variables; thus, it was omitted from several of the analyses.

Exposure to Gated Crossings. There were two variables associated with a driver's exposure to gated crossings: frequency of exposure and recency of exposure. These correspond directly to Questions 4 and 5 on the survey, respectively.

System Reliability. Three study variables associated with a driver's perception of system reliability were defined. They were: likelihood of false activations, exposure to false activations, and perceived level of maintenance. These variables correspond to Questions 9, 10, and 13, respectively.

Warning Time Credibility. There were also three study variables associated with a driver's perceptions about warning time (WT) credibility at gated crossings. They were: likelihood of excessive WTs, exposure to excessive WTs, and recognition of variable WT. These variables correspond directly to Questions 10, 11, and 12, respectively.

Hazard Perception. There was one study variable used to assess drivers' perceptions about the hazard associated with violating gates. This variable, perceived hazard, used the latent content approach to assess a driver's fear of having an accident when violating a gate. This variable corresponds to Question 15.

Enforcement Threat. The variable, perceived enforcement, was used to assess the influence of the threat of enforcement. This variable corresponds to Question 14.

Tolerance for Delay. The variable termed "delay tolerance" corresponds to Question 16, and it is based on the latent content and meaning of question. It was theorized that drivers would tend to report shorter times if they had less tolerance for delay or were impatient at active crossings. The variable had an interval scale of 1 to 7, indicating an increasing tolerance for delay.

Comprehension and Knowledge. Two study variables were used to assess driver comprehension of their duties under the situations studied. These variables were termed: "perceived duties--no train" and "perceived duties--train". The first of these corresponds to Question 17; the second represents a composite of Question 18 and 19 responses. With regard to this second variable, if a driver believed it was alright to cross in both Questions 18 and 19, his/her duty comprehension would be "0." If the driver indicated that it was illegal to cross in both cases, his/her comprehension level would be "4"; intermediate levels were also possible.

The first variable, perceived duties--no train, was considered when evaluating driver behavior when no train was visible. The second variable, perceived duties--train, was used when evaluating driver behavior for the case when a train was present.

An additional study variable, driver training, was defined based on responses to Question 20. The variable had three increasing interval levels of training: (1) no training; (2) some training, but no high school drivers' education course; and (3) training, including high school drivers' education course. This variable was retained, but was evaluated with caution because of the artificial interval scale employed.

Risk-Taking. A driver's propensity for risk-taking was evaluated using a composite variable. This variable was a composite of Questions 21-25 on the survey, and it had an increasing interval scale of 0-5. A driver who did not take any of the risks referred to in these questions would have a "0" propensity, while a driver who took all the risks would have a risk-taking propensity of "5."

Demographic Characteristics. Seven variables relating to the driver's demographic characteristics were evaluated: age (Question 26); gender (Question 27); education (Question 28); region of country (from Question 31); family income (Question 29); license type (Question 30); and vehicle type (Question 32). However, the last three of these variables (income, license, and vehicle) were omitted from most of the analyses since they apparently did not have any measurable effects on behavior, and/or since many subjects did not provide the information.

Summary

A driver survey was developed to evaluate driver-related factors which, in combination with warning time, influence drivers to intentionally go around or through functioning active traffic control devices at grade crossings. The content and format of the survey instrument was based on input from a series of small group discussion sessions in Tennessee, Texas, and Kentucky, as well as insight gained through the literature review and field and laboratory studies.

The survey included 32 closed-ended questions which queried drivers on their behavior at gated crossings, and on their comprehension,

attitudes, perceptions, and exposure relative to gated crossings. Driver demographic information was also solicited in the survey.

Following successful pilot tests, the survey was administered to 662 volunteer drivers from all regions of the country. The participating drivers represented a heterogeneous sampling of the total driver population.

The survey data were reduced and encoded into a SAS data file. The 32 questions on the survey generated data corresponding to 26 study variables. These variables, representing driver-related factors which possibly influence undesirable driver behavior, were analyzed using MANOVA and discriminant analysis procedures. The results of the survey analyses are presented in the following two chapters, Chapters 9 and 10.

CHAPTER 9

RESULTS OF DRIVER SURVEY: MANOVA

This chapter presents the results of the driver survey, based on a Multivariate Analysis of Variance (MANOVA) evaluation of the study variables previously identified as possibly influencing undesirable driver behavior at gated crossings. First, an overview of the general evaluation approach is presented, including a detailed discussion of the theory, assumptions, and procedures of MANOVA. Then, the self-reported behavior of the survey respondents is summarized. Lastly, the MANOVA results are summarized for the two crossing situations, i.e., when no train is present and when a train is present at the crossing.

General Approach

A MANOVA approach was employed to determine if there are significant overall differences in the characteristics (e.g., knowledge, attitudes, exposures, demographics, etc.) of drivers who are likely to engage in undesirable driver actions versus those who are not. The MANOVA evaluation also provided some indication of which factors in particular appear to influence undesirable driver behavior, and the magnitude of influence of these factors.

In more specific terms, MANOVA was used to compare the populations of drivers which normally drive around automatic gates to the population which do not. The comparisons were made on the basis of those driver attributes identified and discussed in Chapter 8. Using the MANOVA approach, these characteristics collectively formed a "vector" response

variable, and the effects of the treatments (i.e., whether a driver was a gate violator or not) on this vector response variable were determined. A detailed description of the MANOVA model formulation and application is presented in the next section. It should be noted that MANOVA is a multivariate extension of the more common ANOVA concept; the theory, assumptions, and procedures of MANOVA closely parallel those of ANOVA. For this reason and because the MANOVA procedure also generated useful univariate ANOVA tables corresponding to each response variable, a detailed summary of univariate ANOVA is presented in Appendix D.

MANOVA Model Discussion. MANOVA models are statistical tools for studying the relationship between two or more dependent variables, and one or more independent variables. They do not require making assumptions about the nature of the statistical relationship between the dependent and independent variables, nor do they require that the independent variables be qualitative or categorized; however, the dependent variables should be quantitative.⁽⁶³⁾ MANOVA techniques are appropriate for both observational data and data gathered on formal experiments.

In describing the general MANOVA model, it is assumed that there are several populations to be compared, and that random samples of response variables are collected from each population as follows:

Population 1: $x_{11}, x_{12}, \dots, x_{1n_1}$

Population 2: $x_{21}, x_{22}, \dots, x_{2n_2}$

Population g: $x_{g1}, x_{g2}, \dots, x_{gn_g}$

Each of the x_{ej} corresponds to a vector of responses related to one observational unit. For this study, a population would correspond to the

group of drivers reporting a certain driver action, and the observational unit would be one of the drivers in that group. An individual x_{ej} would be the vector of "characteristics" of that driver, and there would be a mean vector of characteristics (or components) for each population. MANOVA is used to assess if the population mean vectors are the same and, if not, which of the mean components differ significantly.

There are certain assumptions concerning the structure of the data which must be met to use MANOVA. First, the samples from different populations must be random and independent. Secondly, the populations should have a common covariance matrix. Lastly, each population should have a multivariate normal distribution; however, this last requirement can be relaxed based on the central limit theorem when the sample size is large.⁽⁶⁴⁾ The first assumption is met by the design and nature of the survey. The second condition is assumed for the MANOVA evaluation, and appropriate homogeneity tests of the covariance matrices were performed as part of the discriminant analysis to follow in Chapter 10. The assumption of multivariate normalcy was precluded by collection of a large sample.

To continue with the MANOVA model description, the model for comparing population means can be expressed as follows:

$$x_{ej} = \mu + \tau_e + \epsilon_{ej}$$

where: x_{ej} is the value of the j th observation vector for the i th factor level or treatment
 μ is the overall mean level
 τ_e is the e th treatment effect

e_j is the residual

The treatment effects on the response variable (in this case a vector of response variables) can be evaluated by partitioning the variation in the data into two components: variation due to the treatment and variation due to residual error. Then, a ratio of these two sources of variation is analyzed to determine the significance of treatment effects, if any. In the case of MANOVA, variation is expressed in terms of sums of squares of the deviations and cross-products. This parallels ANOVA in which variation is expressed simply in terms of sums of squares of the deviations (see Appendix D).

Corresponding to an ANOVA table, a MANOVA table for comparing the population mean vectors is generated as shown in Table 19. Note in Table 19 that the total variation is the sum of treatment variation (B) and residual variation (W), where:

$$B = \sum_{g=1}^g n_g (\bar{x}_g - \bar{x}) (\bar{x}_g - \bar{x})'$$

$$W = \sum_{g=1}^g \sum_{j=1}^{n_g} (x_{gj} - \bar{x}_g) (x_{gj} - \bar{x}_g)'$$

Also equivalent to the univariate ANOVA procedure, the null hypothesis to be tested is that there are no treatment effects, that is, $H_0: \tau_1 = \tau_2 = \dots = 0$. For the purpose of this study, the null hypothesis is that there are no differences in the characteristics of violating versus non-violating drivers. The alternative hypothesis is that there are differences in the characteristics of the two groups of drivers.

Table 19. MANOVA table for comparing population mean vectors.

Source of variation	Matrix of sum of squares and cross-products (SSP)	Degrees of freedom (d.f.)
Treatment	$B = \sum_{\ell=1}^g n_{\ell} (\bar{x}_{\ell} - \bar{x}) (\bar{x}_{\ell} - \bar{x})'$	$g - 1$
Residual (Error)	$W = \sum_{\ell=1}^g \sum_{j=1}^{n_{\ell}} (x_{\ell j} - \bar{x}_{\ell}) (x_{\ell j} - \bar{x}_{\ell})'$	$\sum_{\ell=1}^g n_{\ell} - g$
Total (corrected for the mean)	$B + W = \sum_{\ell=1}^g \sum_{j=1}^{n_{\ell}} (x_{\ell j} - \bar{x}) (x_{\ell j} - \bar{x})'$	$\sum_{\ell=1}^g n_{\ell} - 1$

To test the hypothesis, the Wilks' Lambda test statistic is used, where Wilks' Lambda = $\frac{|W|}{|B + W|}$. Wilks' Lambda is related to the likelihood ratio criterion, and its distribution depends on the numbers of variables and groups.⁽⁶⁴⁾ The use of Wilks' Lambda for hypothesis testing with MANOVA is equivalent to using the F-statistic for hypothesis testing with ANOVA (see Appendix D). In fact, Wilks' Lambda is often converted to an F-statistic. If there are treatment effects, then the treatment sum of squares and cross-products will be relatively large compared to the total sum of squares and cross-products, and Wilks' Lambda will approach 1.

Univariate Tests. The MANOVA evaluation was performed using the General Linear Models (GLM) procedure of SAS.⁽⁵⁸⁾ The usual outputs of a SAS MANOVA run include univariate ANOVA tables corresponding to each response variable. These ANOVA tables are useful for further assessing the effects of individual variables. Specifically, individual F-tests were performed to determine if there were treatment effects on the various individual factors under study. The two treatments or factor levels were: violating versus non-violating crossing behavior. Appendix D discusses the ANOVA and F-test procedures in detail.

Also as part of the MANOVA procedure, Bonferroni tests were performed to test the significance of differences, if any, between the main-effect univariate means. The Bonferroni test is appropriate for evaluating a "family" of pairwise comparisons, regardless of whether the treatment sample sizes are equal.⁽⁶³⁾ An alpha level of .05 was used in the Bonferroni tests.

Results: Self-Reported Driver Behavior

Before presenting the results of the MANOVA evaluation, it is appropriate to summarize the survey respondents' self-reported driver behavior. This summary is presented in Table 20 which shows the percentage and number of drivers who reported they would normally drive around lowered gate arms when: (1) no train was present (i.e., visible) and (2) when a train was present but appeared to be stopped or sufficiently far away to permit safe crossing. From Table 20, 38.4 percent of the survey respondents indicated they would normally drive around lowered gate arms if no train was present. A smaller percentage, 32.5 percent of the respondents, said they would normally drive around the gates when a train was present if the train appeared stopped or far away. These data further illustrate the widespread problem of motorists engaging in undesirable driver actions at grade crossings with active traffic control.

In Table 20, the data for the second crossing situation is separated into two subcategories, i.e., when the train appears stopped versus when it appears sufficiently far away ("not close"). The categories are not additive since some drivers indicated that they would cross under both conditions. From Table 20, 32.5 percent of the 662 survey respondents (215 drivers) said would cross if the train appeared stopped; 4.5 percent (30 drivers) said they would cross even when a train was visibly approaching the crossing, provided it was not too close.

The latter subcategory of drivers represents a group of drivers at particular risk; however, a meaningful analysis of this group alone was

Table 20. Summary of self-reported driver behavior.

Crossing Situation	Percent (Number) of Respondents		
	Would Cross	Would <u>Not</u> Cross	Totals
No Train Present	38.4(254)	61.3(408)	100.0(662)
Train Present	32.8(217)	67.2(445)	100.0(662)
Train Stopped	32.5(215)	67.5(447)	100.0(662)
Train Not Close	4.5(30)	95.5(632)	100.0(662)

not possible due to the small sample size of only 30 drivers. Nevertheless, there is rationale for combining this subcategory "train not close" with the subcategory "train stopped," since in both cases the hazard (or train) is present, the driver can cross and yet avoid the hazard, and the intent of the warning system is confounded by the apparent lack of relationship between the warning and the hazard.

It is also significant to note that the self-reported driver behavior in the survey is consistent with actual observed behavior. The field studies (see Chapter 4) revealed that 39.7 percent of drivers arriving during the warning period at the Cherry Street crossing drove around the lowered gate arms. This percentage compares favorably to the survey respondents' self-reported behavior (38.4 and 32.8 percent violation rates), thus lending credibility to the survey results.

Results: Gender and Region Effects

Before presenting the MANOVA results it is also appropriate to discuss the special handling of two of the study variables: gender and region. These variables are both qualitative and categorical variables. As such, they could not effectively be handled as response (dependent) variables in the MANOVA evaluation. They could, however, be handled as additional "factors," possibly interacting with the main factor, "crossing behavior."

In order to assess whether gender and/or region should be included as factors in the MANOVA evaluation, a preliminary regression analysis of the data were performed with "crossing behavior" as the dependent variable and all the driver attribute variables, including gender and

region, as the independent variables. In building the regression models, both gender and region were accommodated as "dummy" independent variables. In the case of gender, there was one dummy variable. In the case of region, there were three dummy variables to handle the four regions. Two separate regression models were necessary, one for each crossing situation, i.e., no train is present versus train present.

When regression is used in the manner described herein, major assumptions are violated, e.g., the dependent variable (crossing behavior) is not truly quantitative in nature and is not normally distributed. Nevertheless, this approach can be effectively utilized to determine whether an independent variable in the model contributes significantly to explaining the variability of the dependent variable, given all the other variables in the model. This is accomplished by analyzing the resulting TYPE III sum of squares and associated F-statistic for the variable(s) of interest.

The results of the preliminary regression analysis with respect to gender and region are summarized in Table 21. This table shows the resulting F-values and associated confidence levels for the TYPE III sums of squares corresponding to the gender and region dummy variables. With one exception, neither gender nor region effects are significant at the .05 level. (The .05 level is considered a very liberal confidence level given the number of variables in the model.) In other words, in the presence of the other independent variables in the regression model, gender and region do not account for significant variability in driver behavior. The one notable exception is the significance of gender relative to driver behavior when a train is present. Upon further

Table 21. Preliminary assessment of the effects of gender and region on driver behavior.

Dummy Variable	Driver Behavior- No Train		Driver Behavior- Train	
	F-statistic	PR>F ¹	F-statistic	PR>F ¹
Gender	0.63	0.4269	6.81	0.0092
Region1	0.14	0.7070	0.14	0.7061
Region2	1.14	0.2850	3.64	0.0569
Region3	1.31	0.2520	3.72	0.0541

¹Probability of a larger F, or in other words, probability that the variable is not significant.

investigation, it was revealed that gender is related to driver behavior when a train is present, but there are no significant interactions between behavior and gender relative to the other response variables.

Thus, as a result of the regression analysis and to simplify interpretation of the subsequent evaluation results, region was not added to the MANOVA models. Gender, with no interactions, was included as a main effect in the MANOVA model for driver behavior when a train is present, but not in the MANOVA model for the case when no train is present.

MANOVA Results: No Train

Using the GLM procedure of SAS, a MANOVA evaluation of driver behavior when no train is present was performed. The MANOVA model in this case had a single factor, driver behavior, with two levels: violators and non-violators. There were multiple response variables corresponding to the various driver attributes under study. Based on the preliminary regression analysis discussed previously, gender and region were omitted from the model.

The resulting model had a Wilks' Lambda value of 0.756 with a corresponding F-value of 11.74 (df. 17,620). This F-value is sufficiently large to reject the null hypothesis of no overall effects at the 0.0001 confidence level. In other words, it is concluded that there are significant differences in the attributes of violators versus non-violators.

As part of the MANOVA evaluation, univariate ANOVA tables were generated for each of the response variables under study. These tables

provide insight into which specific driver attributes influence crossing behavior, and also indicate the relative magnitude of influence. The ANOVA results are summarized in Table 22. Included in Table 22 for each response variable is the resulting F-value and its associated confidence level, as well as the mean responses of the two groups: violators and non-violators. The results of Bonferroni tests performed on the family of means are also presented to show which means are significantly different at the 0.05 "family" confidence level.

The means shown in Table 22 represent the means of the "interval values" of the particular variables. As such, the nature and extent of differences between the responses of violators and non-violators may not be obvious. To aid in evaluating the mean responses, frequency distributions for all the variable responses, by violator versus non-violator, are presented in Appendix E.

In the following sections, the results of the ANOVA evaluations and Bonferroni tests relative to each of the study variables are discussed in detail. Those factors which appear to influence crossing behavior when no train is present are identified.

General Driving Experience. Annual driving mileage, as reported by the survey respondents, had a significant influence on their behavior when no train was present (.0002 confidence level). The mean overall driving mileage of violators was significantly different than the mean for non-violators. Survey respondents who drove more miles were more likely to be violators compared to less frequent drivers.

Exposure to Gated Crossing. Both frequency of exposure to gated crossings and recency of exposure to activated gates were found to have

Table 22. MANOVA results: driver behavior--no train.

Major Area/Variable	F-Value	PR>F	Mean Response Violator	Mean Response Non-Violator	BON Test Significance ¹
<u>General Driving Experience</u>					
Annual Mileage	14.39	.0002	2.98	2.67	Yes
<u>Exposure to Gated Crossings</u>					
Frequency of Exposure	9.13	.0026	2.98	2.74	Yes
Recency of Exposure	6.85	.0091	3.20	3.01	Yes
<u>System Reliability</u>					
Likelihood of False Activations	27.05	.0001	3.11	3.57	Yes
Exposure to False Activations	77.18	.0001	2.93	2.15	Yes
Perceived Level of Maintenance	2.96	.0858	3.15	3.26	No
<u>Warning Time (WT) Credibility</u>					
Likelihood of Excessive WTs	4.60	.0324	2.66	2.48	Yes
Exposure to Excessive WTs	25.52	.0001	2.37	1.91	Yes
Recognition of Variable WTs	2.41	.1214	2.95	3.06	No
<u>Hazard Perception</u>					
Perceived Hazard	94.92	.0001	2.73	3.53	Yes
<u>Enforcement Threat</u>					
Perceived Enforcement	14.23	.0002	2.74	3.07	Yes
<u>Tolerance for Delay</u>					
Delay Tolerance	0.54	.4625	5.59	5.69	No

Table 22 (continued)

<u>Comprehension and Knowledge</u>				
Perceived Duties - No Train	29.67	.0001	1.34	1.59
Driver Training	5.97	.0148	1.40	1.23
<u>Risk Taking</u>				
Risk-Taking Propensity	5.96	.0149	1.67	1.53
<u>Demographic Characteristics</u>				
Age	12.11	.0005	33.86	37.70
Education	0.83	.3639	14.79	14.59

¹Bonferroni test results; "Yes" indicates that means are significantly different.

significant influence on self-reported driver behavior when no train is present (.0026 and .0091 confidence intervals, respectively). Drivers who often encountered gated crossings were more likely to be violators, and drivers who had recently been at a gated crossing while the gates were activated were also more likely to be violators.

System Reliability. The drivers' perceptions regarding the likelihood of false activations had a significant influence of their self-reported behavior, as did their frequency of exposure to false gate activations. Both of these factors were significant at the .0001 confidence level. In fact, exposure to false activations had the second largest F-value of all variables, second only to "Hazard Perception." As expected, drivers who indicated that false activations occurred often tended to be violators, as did drivers who had more often been exposed to false activations.

The drivers' perception regarding level of maintenance did not have a significant effect on their behavior with no train present as indicated by a relatively low F-value of 2.96 with a confidence level of .0858. Also, there was no significant difference between violators versus non-violators in their mean responses to the question on maintenance.

Warning Time Credibility. The drivers' perceptions about the likelihood of excessive warning times had a marginally significant effect on their self-reported behavior in the case when no train is present. This is indicated by an F-statistic of 4.60 with a confidence level of .0324. (The influence is said to be "marginally significant" at the 0.0324 level because the relatively large number of variables being considered simultaneously increases the probability of a hypothesis

testing error.) The mean responses to the question dealing with the likelihood of excessive warning times indicate that violators are more likely to anticipate warning times that are excessive.

Drivers' exposure to excessive warning times at gated crossings was found to have a very significant effect on their behavior (.0001 confidence level). Drivers who reported encountering frequent excessive warning times tended to be violators.

Drivers' recognition of variable warning times had no apparent effects on their self-reported behavior in the absence of a train as indicated by a relatively low F-value of 2.41 with a confidence level of .1214. Even though the difference was not statistically significant, non-violators tended to agree, more frequently than violators, that warning times were consistent.

Hazard Perception. The most significant factor influencing driver behavior, based on its F-value of 94.92, was drivers' perception of the grade crossing hazard (.0001 confidence level). Drivers who shunned the idea that they might have an accident if they drove around lowered gates tended to be violators. Drivers who recognized the hazard and feared an accident more often were non-violators.

Enforcement Threat. Perceived enforcement also was found to be significantly influential in determining driver behavior when no train is present (.0002 confidence level). Drivers who feared getting a ticket if they violated gates tended to be non-violators, while drivers who believed enforcement unlikely were typically violators.

Tolerance for Delay. The study variable used to assess drivers' tolerance for delay was not significant with an F-value of only 0.54.

It is acknowledged that this abstract topic (tolerance for delay) is difficult to evaluate in a driver survey of this type. The fact that the variable was not found to be significant may be due to the failure of question and survey process with respect to this area. Nevertheless, it is interesting to note that the mean delay tolerance for non-violators was slightly higher than the mean for violators. The difference is not statistically significant, but it is in the logical direction.

Comprehension and Knowledge. Drivers' comprehension of their duties at gated crossings when no train is present had a significant influence on their reported behavior (.0001 confidence level). Violators more often believed that it was legal to drive around gates when no train was present. It should be noted here that in a few of the survey states it is not explicitly illegal to drive around the gates in this situation, and in these cases the use of the term "violation" is not meant to be misleading.

Driver training as defined by the 3-level interval scale was found to be marginally significant at the .0148 level. However, a review of the means indicates that drivers with more training tended to be violators. Due to the "weakness" of the scaling of this variable and since its effects are contrary to logic, caution should be used in interpreting these results.

Risk-Taking. The composite variable used as a measure of risk-taking was marginally significant in influencing driver behavior when no train is present (.0149 confidence level). As expected, violators tended to engage in other risky driving actions more often than non-

violators; the means for the two groups were significantly different based on the Bonferroni test results.

Demographic Characteristics. As noted previously, some of the demographic variables were omitted from the MANOVA model for various reasons. Family income was not considered because many drivers did not give this information and MANOVA cannot handle missing values. Also, income did not appear to be even remotely significant in the preliminary regression analysis. Gender and region were omitted for the reasons discussed previously. Type of license and vehicle were omitted, even before the preliminary regression analysis, after a review indicated that these data had little variation within the survey sample and therefore would not be useful to the analysis.

A demographic characteristic that was significant was "age," as indicated by an F-value of 12.11 with a .0005 confidence level. As seen in Table 22, violators tended to be younger than non-violators, by an average of almost 4 years. The average age of violators was 33+ years, while the average age of non-violators was 37+ years.

As expected from the literature review, education level had no apparent influence on self-reported driver behavior as indicated by the low F-value of 0.83 with a confidence level of .3639.

MANOVA Results: Train

A MANOVA evaluation of driver behavior with a train present was also performed. The MANOVA model in this case had two factors, crossing behavior and gender, with no interactions. Each factor had two levels. There were multiple response variables corresponding to the various

driver attributes under study. In addition, based on the preliminary regression analysis discussed previously, region was omitted from the model.

With respect to the main effect, driver behavior, the resulting model had a Wilks' Lambda value of 0.854 with a corresponding F-value of 6.20 (df. 17,618). This F-value is sufficiently large to reject the null hypothesis of no overall effects at the 0.0001 confidence level. In other words, it is concluded that there are significant differences in the attributes of violators versus non-violators when a train is present.

For the second main effect, gender, the model yielded a Wilks' Lambda of 0.858 with a corresponding F-value of 6.52 (df. 17,618). This F-value is sufficiently large to reject the null hypothesis of no gender effects at the 0.0001 level. However, this result may be misleading since much of overall gender difference detected is probably due to differences unrelated to driver behavior such as annual mileage, education, and exposure. For this reason, it is acknowledged here that there are gender effects, but the MANOVA procedure does not permit a convenient means to assess these effects. The discriminant analysis in Chapter 9 will address the influence of gender.

Two-factor (driver behavior and gender) ANOVA tables were generated for each of the response variables under study. These tables provided insight into the specific driver attributes influencing driver behavior, and also indicated the relative magnitude of influence. The ANOVA results are summarized in Table 23. Included in the table for each response variable is the resulting Type III sum of squares F-value and its associated confidence level, as well as the mean responses of the two

Table 23. MANOVA results: driver behavior--train.

Major Area/Variable	F-Value	PR>F	Mean Response Violator	Mean Response Non-Violator	BON Test Significance ¹
<u>General Driving Experience</u>					
Annual Mileage	12.03	.0006	3.04	2.67	Yes
<u>Exposure to Gated Crossings</u>					
Frequency of Exposure	11.12	.0009	3.03	2.74	Yes
Recency of Exposure	5.15	.0236	3.19	3.03	Yes
<u>System Reliability</u>					
Likelihood of False Activations	27.01	.0001	3.06	3.55	Yes
Exposure to False Activations	27.21	.0001	2.81	2.27	Yes
Perceived Level of Maintenance	4.03	.0452	3.14	3.26	No
<u>Warning Time Credibility</u>					
Likelihood of Excessive WTs	2.03	.1550	2.63	2.51	No
Exposure to Excessive WTs	7.92	.0050	2.28	1.99	Yes
Recognition of Variable WTs	7.82	.0053	2.87	3.09	Yes
<u>Hazard Perception</u>					
Perceived Hazard	36.12	.0001	2.82	3.41	Yes
<u>Enforcement Threat</u>					
Perceived Enforcement	5.08	.0245	2.77	3.02	Yes
<u>Tolerance for Delay</u>					
Delay Tolerance	0.15	.6984	5.55	5.70	No

Table 23 (continued)

<u>Comprehension and Knowledge</u>					
Perceived Duties - Train	15.48	.0001	2.96	3.26	Yes
Driver Training	4.39	.0366	1.39	1.24	No
<u>Risk Taking</u>					
Risk-Taking Propensity	3.77	.0525	1.66	1.55	Yes
<u>Demographic Characteristics</u>					
Age	11.01	.0010	33.98	37.23	Yes
Education	1.33	.2488	14.60	14.70	No

¹Bonferroni test results; "Yes" indicates that means are significantly different.

driver behavior groups: violators and non-violators. The results of Bonferroni tests performed on the family of means are also presented to show which means are significantly different. Appendix F presents frequency tables of the responses for each of the study variables, for violators and non-violators.

The following sections discuss in detail the results presented in Table 23 relative to the individual study variables. In particular, those variables which appear to influence crossing behavior when a train is present are identified.

General Driving Experience. As was the case when no train is present, annual driving mileage significantly influenced the drivers' self-reported behavior when a train is present (.0006 confidence level). The mean responses indicate that motorists who drive more often are more likely to be violators compared to less frequent drivers.

Exposure to Gated Crossing. Frequency of exposure to gated crossings had a significant influence on self-reported behavior when a train is present (.0009 confidence level). Recency of exposure to activated gates was found to have a marginally significant influence on driver behavior when a train is present (.0236 confidence level). The means reveal that drivers who encountered gated crossings more frequently were more likely to be violators; also, drivers who had recently been at a gated crossing while the gates were activated were more likely to be violators.

System Reliability. Drivers' perceptions regarding the likelihood of false activations had a significant influence on their self-reported behavior when a train was present, as did their frequency of exposure to

false gate activations. Both of these factors were significant at the .0001 confidence level. Exposure to false activations had the second largest F-value of all variables, second only to "Hazard Perception." As expected, drivers who indicated that false activations occurred frequently tended to be violators, as did drivers who had more frequently been exposed to false activations.

The drivers' perceptions regarding the level of maintenance had a marginal influence at best on their behavior when a train is present based on the F-value of 4.03 with a confidence level of .0452. There was no significant difference in mean responses to the question on maintenance between violators versus non-violators.

Warning Time Credibility. Drivers' perceptions about the likelihood of excessive warning times had no apparent effect on their self-reported behavior when a train is present. This is indicated by an F-statistic of only 2.03 with a confidence level of .1550. This result is consistent with the field study observation that the majority of drivers who violate gates do so within seven or eight seconds after arrival at the crossing, unless the train is very near. Excessive warning time does not appear to be the motivating factor in these cases. However, excessive warning times create the opportunity for more drivers to violate, and thus these long times "reinforce and encourage" what many drivers want to do anyway.

Drivers' exposure to excessive warning times at gated crossings was found to have a significant effect on their self-reported driver behavior (.0050 confidence level). Drivers who more frequently encountered excessive warning times tended to be violators.

Drivers' recognition of variable warning times also had a significant effect on their self-reported behavior with a train present at the crossing as indicated by a F-value of 7.82 with a confidence level of .0053. Non-violators tended to agree, more frequently than violators, that warning times were consistent. In other words, violators expected there to be greater variability in the warning period from one situation to the next.

Hazard Perception. The most significant factor influencing behavior when a train was present, based on its F-value of 36.12, was perception of the grade crossing hazard (.0001 confidence level). Drivers who shunned the idea that they might have an accident if they drove around lowered gates tended to be violators. Drivers who perceived a high degree of hazard and feared an accident more often were non-violators.

Enforcement Threat. Perceived enforcement had a marginally significant influence on drivers' self-reported behavior with a train present (.0245 confidence level). There was a significant difference in mean responses of violators verses non-violators on the enforcement question. Drivers who feared getting a ticket if they violated gates tended to be non-violators, while drivers who believed enforcement unlikely were typically violators.

Tolerance for Delay. As was the case with no train, this variable had no significant effect on driver behavior when a train is present.

Comprehension and Knowledge. Drivers' comprehension of their duties at gated crossings when a train is present had a very significant influence on their reported behavior (.0001 confidence level). Violators

tended to believe that it was legal to drive around gates when the train was stopped or far away compared to non-violators.

Driver training was found to be marginally influential at the .0366 level. However, the mean responses indicate that drivers with more training tended to be violators. Since this relationship is contrary to logic, the apparent effects of this variable are questionable.

Risk-Taking. Based on the ANOVA results propensity for risk-taking was not significant in influencing undesirable behavior with a train present, assuming an alpha level of .05. (The confident level was .0525 in this case.) However, violators tended to engage in other risky driving actions more often than non-violators; the means for the two groups, in fact, were significantly different based on the Bonferroni test results.

Demographic Characteristics. As indicated by an F-value of 12.11 with a .0005 confidence level, age had a significant influence on driver behavior with a train present. As seen in Table 22 (page 196), violators tended to be younger than non-violators, by an average of almost 4 years. The average age of violators was approximately 34 years, while the average age of non-violators was 37+ years.

Education level had no apparent influence on driver behavior with a train present as indicated by the low F-value of 1.33 with a confidence level of .2488.

Violator Profile

The MANOVA results identify driver attributes which influence undesirable driver actions at crossings with automatic gates. It is

reasonable to assume that these same factors would significantly influence driver behavior at all active crossings. Combining these factors, Figure 35 presents a profile of the typical driver who engages in undesirable behavior at grade crossings with active traffic control. Because of the similarities in results for the two situations studied, i.e., with and without a train present, a single profile is deemed appropriate. The value of this profile is to aid in identifying "target" groups for various countermeasures.

Results: MANOVA Summary

The results of the MANOVA evaluation indicate that drivers who normally violate automatic gates have overall different characteristics and attitudes than non-violators. This is true whether a train is present or not. Furthermore, the MANOVA evaluation identified a number of major areas and individual variables within these areas which significantly influence driver behavior.

When no train is present, the major influential "areas" are: (1) hazard perception; (2) system reliability; (3) comprehension and knowledge; (4) warning time credibility; (5) general driving experience; (6) enforcement threat; (7) exposure to gated crossings; and (8) demographic characteristic (age). These are arranged in descending order based on the ANOVA F-values of the most significant study variable in each of the major areas.

When a train is present, the major areas in order of significance are: (1) hazard perception; (2) system reliability; (3) comprehension and knowledge; (4) general driving experience; (5) exposure to gated

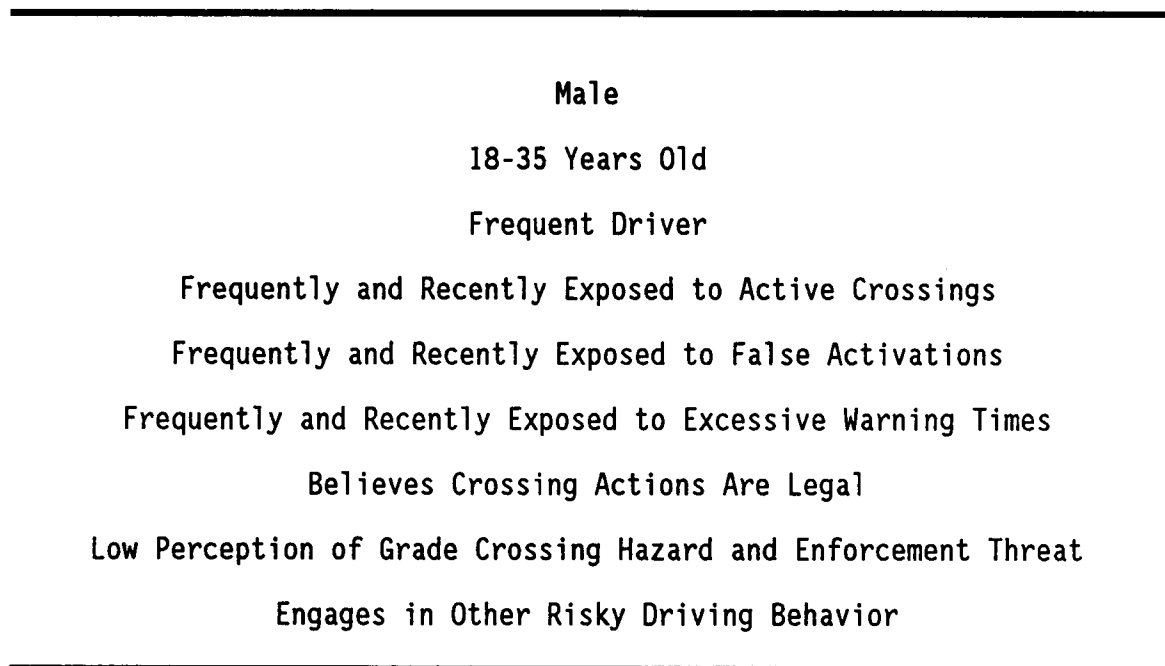


Figure 35. Profile of typical violator at active grade crossings.

crossings; and (6) demographic characteristic (age); and (7) warning time credibility.

The MANOVA results confirm that there are significant differences in the attributes of violators versus non-violators, and they define a typical profile of the driver who engages in undesirable behavior at active crossings. The results do not reveal which factors, in combination, most influence undesirable driver behavior. This combination is identified in Chapter 10, which presents the results of a discriminant analysis of the survey data.

CHAPTER 10

RESULTS OF DRIVER SURVEY: DISCRIMINANT ANALYSIS

The previous chapter revealed that there are significant differences in the overall characteristics, attitudes, and perceptions of drivers who intentionally drive around automatic gates compared to those who do not. Chapter 9 also gave some indication of the influence of the various driver-related factors on driver behavior. Following up on these findings, this chapter will more fully evaluate the significance of the individual factors based on the results of a "discriminant analysis" performed on the survey data.

Presented first is a detailed discussion of the theory, assumptions, and procedures of the discriminant analysis approach. This discussion is followed by the results of the discriminant analysis. The most influential or "discriminating" factors are identified, and linear functions are developed for identifying drivers who are likely to engage in undesirable driver actions at gated crossings.

General Approach

A discriminant analysis approach was used to identify those driver factors which collectively have the greatest influence, of those factors studied, on undesirable driver actions at crossings with automatic gates. The discriminant analysis generated linear functions for "classifying" drivers as potential violators based on those driver attributes found to be most important. Separate analyses were performed to evaluate self-

reported driver behavior when no train is present versus when a train is present.

Discriminant analysis is comparable to MANOVA in the underlying theory and assumptions, yet opposite in one respect. In discriminant analysis, the dependent variable is categorical and the independent variables are quantitative (except in the case of dummy variables). On the other hand, MANOVA involves quantitative dependent variables and categorical independent variables (called factors).

The discriminant analysis was performed in two stages using SAS.⁽⁵⁸⁾ First, the STEPDISC procedure of SAS was employed to identify the subset of factors which collectively have the greatest influence on driver behavior. This was done separately for the two crossing situations, i.e., no train present and train present. Next, the DISCRIM procedure of SAS was used to develop an appropriate "linear combination" of these factors for classifying drivers as potential violators or non-violators of automatic gates. This procedure was repeated for both crossing situations. The discriminant models were developed using a portion of the total sample, and the models were validated by applying them to the remainder of the sample.

Discriminant Analysis Discussion. Discriminant analysis is a multivariate technique for separating or classifying observations into two or more distinct groups. It also can be an exploratory tool, used on a one-time basis to investigate observed differences when causal relationships are not well understood.⁽⁶⁴⁾ In the case of this research, discriminant analysis was used to accomplish both of these goals.

Discriminant analysis attempts to derive an optimal linear combination of two or more independent variables that will best discriminate or classify the observational units between "a priori" defined groups. For this research, the independent variables were those factors which influence driver behavior, and the pre-defined groups were potential violators versus non-violators.

It is desirable that certain conditions be met for proper application of discriminant analysis. These conditions or assumptions include the following:

1. The distributions must be multivariate normal distributions.
2. The dispersion and covariance structures for the groups do not have to be known but must be equal.

However, the procedure is not very sensitive to violations of these assumptions unless the violations are extreme, particularly with large sample sizes.⁽⁶⁵⁾

In deriving the "optimal" discriminating function, SAS uses a measure of generalized squared distance; that is, the function is derived such that the squared distances from the observations to their group centroid are minimized. Likewise, when classifying a new observation, the procedure will place the observation in the group which minimizes this generalized squared distance. The classification criterion is different depending on whether or not the groups' covariance matrices are homogeneous and thus can be pooled, and on whether the prior probabilities are equal. Prior probability refers to the probability that an observation will be assigned to a group. For a study of this nature, it is simply the percentage distribution of responses for the classification variable.

In developing the "generalized squared distance" used in discriminate analysis, the following notation is used:

- t a subscript to distinguish the groups
- S_t the covariance matrix within group t
- $|S_t|$ the determinant of S_t
- S the pooled covariance matrix
- x a vector containing the variables of an observation
- m_t the vector containing means of the variables in the group t
- q_t the prior probability for group t.

Given this notation, the generalized squared distance from x to group t is:

$$D_t^2(x) = g_1(x, t) + g_2(t)$$

In this equation, if the within-group covariance matrices are used, the first term, $g_1(x, t)$, is computed as follows:

$$g_1(x, t) = (x - m_t)' \bar{S}_t^{-1} (x - m_t) + \text{Log}_e |S_t|$$

If the pooled covariance matrix is used, the first term is:

$$g_1(x, t) = (x - m_t)' \bar{S}^{-1} (x - m_t)$$

If the prior probabilities are not all equal, the second term, $g_2(t) = -2\text{Log}_e(q_t)$. If the prior probabilities are all equal, then $q_2(t)=0$.

As noted previously, the first stage of the discriminant analysis was performed in a stepwise manner, using the STEPDISC procedure of SAS. This procedure enters (or deletes) a variable into the model based on its partial F-statistic. The F-statistic is an indicator of the importance of the variable after the effects of previously entered variables have been controlled. Using the stepwise procedure, the importance of

individual variables can be determined and/or the overall importance of a group of variables can be evaluated.

Model Performance. The effectiveness of the discriminant model in classifying observations can be evaluated based on statistical criteria, and based on the model's success in classifying a test group of observations. The appropriate statistical indice is Wilks' Lambda, which was also used for the MANOVA evaluation. The Wilks' Lambda statistic is typically converted into an approximate F-statistic, as is the case in the SAS output.

Another important measure of a discriminant model's performance is the percentage of observations which it can correctly classify when applied to a test group. In order to avoid an upward bias using this measure, the test group should be different from the group of observations used to formulate the model. SAS in fact has the capability to split a total sample into two groups; the first group is used to formulate the discriminant model, and the second is used as a test sample to validate the resulting model. Using this procedure, SAS directly outputs the percentages of correct and incorrect classifications based on application of the model to the designated test group.

Discriminant Analysis Results--No Train

For the "no train" situation, all of the driver attribute variables, except gender and region, were entered as independent variables in the STEPDISC procedure. It has been established previously that gender and region do not significantly influence driver behavior when no train is present, and since these variables are purely categorical, it is

desirable to omit them. The STEPDISC procedure identified a group of five variables which most influence undesirable driver behavior when no train is visible. A liberal default alpha value of 0.15 was used for the partial F-statistic cut-off point, and still only five variables were able to enter the model under this criterion

The second step involved developing a discriminant model (or linear function) containing these five most influential variables using the DISCRIM procedure of SAS. The DISCRIM procedure divided the data set into an "original" group from which the model was developed and a "test" group which was used to validate the model. The "original" group contained two-thirds of the total sample and the "test" group contained the remaining one-third. The procedure automatically performed the validation step and output the results.

Discriminant Variables and Function. Table 24 shows the five most influential variables selected into the model, their partial F-values, and the order in which the variables entered the model. Also presented are the variable coefficients and a constant for both driver behavior groups: violators and non-violators. The function defined by these coefficients and constants represent the "optimal" linear combination for discriminating violators versus non-violators when no train is present. If an individual's responses to the five variables were entered into both resulting equations, the equation resulting in largest value would classify that individual.

As seen in Table 24, the five most influential variables in the order which they entered the model were: (1) perceived hazard; (2) exposure to false activations; (3) age; (4) perceived duties-no train; and

Table 24. Results of discriminant analysis--no train.

Step Entered	Variable	Coefficients		Partial F ¹
		Violator	Non-Violator	
1	Perceived hazard	3.23081	3.85387	94.9
2	Exposure to false activation	2.63060	2.10152	50.0
3	Age	0.16550	0.18382	16.3
4	Perceived duties- no train	3.72132	4.15779	12.9
5	Annual mileage	2.69645	6.38138	5.4
	Constant	-18.80150	-19.36399	

¹The probability of larger partial F must be less than 0.15 to be included in the model.

(5) annual mileage. These variables correspond to the major areas: (1) hazard perception; (2) system reliability; (3) driver demographics (age); (4) comprehension and knowledge; and (5) general driving experience. In this case, the partial-F values are the best indicators of the importance of the variables in the model. The magnitude of the linear function coefficients are misleading because the variables have different scales.

Model Validation. Table 25 presents the validation results of the discriminant model. The numbers in parentheses represent the percentage of correct classifications or "hits." As seen in Table 25, the model performs very well. Relative to the "original" group which was used to develop the model, the model correctly classified 82.5 percent of the non-violators and 59.7 percent of the violators. The overall hit rate for the original group was 73 percent, or 328 of 445 survey respondents.

The critical test of the model, however, is its capability to correctly classify a new group, or in this case the "test" group. As seen in Table 25, the model correctly classified 83.7 percent of the non-violators in the "test" group and 62.6 percent of the violators. Overall, 74 percent of the "test" group drivers were correctly classified. It is unusual for a model to perform better on the "test" group, and it is acknowledged that such excellent results could not be achieved consistently; however, the model does appear to be very effective.

The effectiveness of the model is further indicated when "a priori" probabilities are considered. That is, if a group of respondents was classified randomly based on prior odds, one would expect to correctly classify 38.0 percent of the non-violators and only 14.8 percent of the violators. In contrast, the model correctly classified more than 80

Table 25. Validation of discriminant model--no train.

	Predicted Violators	Predicted Non-Violators	Totals
<u>Original Group</u>			
Actual Violators	102(59.7) ¹	69	171
Actual Non-Violators	48	226(82.5) ¹	274
Totals	150	295	445
<u>Test Group</u>			
Actual Violators	52(62.6) ¹	31	83
Actual Non-Violators	21	108(83.7) ¹	129
Totals	73	139	212

¹Numbers in parentheses represent percent correct classifications or "hits."

percent of the non-violators and approximately 60 percent of the violators.

Discriminant Analysis Results--Train is Present

For the "train is present" situation, all of the quantitative driver attribute variables were entered as independent variables in the STEPDISC procedure. The categorical variable "region" was omitted, and the categorical variable "gender" was entered as a dummy independent variable. The gender dummy variable had the value of "1" for male drivers and "0" for female drivers. The introduction of this categorical dummy variable violates the assumption of multivariate normalcy (even more so than the artificial interval variables such as level of training); thus, the statistical test results could be questioned. For this reason, emphasis is placed on the resulting model's ability to correctly classify the "test" group.

Based on a default F confidence level of .15, the STEPDISC procedure identified a group of eight variables which most influence undesirable driver behavior when a train is present; however, only the first six of these variables were used to develop the final discriminant model. Two of eight variables were dropped from the model because they had "marginally" significant partial-F values, and the inclusion of these two variables did not result in a better predictive model. In addition, inclusion of these variables resulted in non-homogeneous within-covariance matrices. SAS can handle this situation, but does not output a linear discriminant function.

The final discriminant model was developed with the top six variables using the DISCRIM procedure of SAS. As for the previous "no-train" analysis, the DISCRIM procedure divided the total data set into an "original" group from which the model was developed, and a "test" group which was used to validate the resulting model. The "original" group contained two-thirds of the total sample; the "test" group contained the remaining one-third.

Discriminant Variables and Function. Table 26 shows the eight most influential variables, their partial F-values, and the order in which the variables were selected. It also shows the resulting coefficients and associated constants for the six variables used in the final model.

As seen in Table 26, the eight most influential variables in the order which they were selected were: (1) perceived hazard; (2) likelihood of false activations; (3) annual mileage; (4) age; (5) perceived duties-train; (6) gender; (7) frequency of exposure; and (8) recognition of variable warning times. Only 1-6 were used in the final model. These six most significant variables correspond to the major areas: (1) hazard perception; (2) system reliability; (3) general driving experience; (4) driver demographics (age and gender); and (5) comprehension and knowledge. The partial-F values are the best indicators of the importance of the variables in the model.

Model Validation. Table 27 presents the validation results of the discriminant model. The numbers in parentheses represent the percentage of correct classifications or "hits." As seen in Table 27, the resulting model performed reasonably well. Relative to the original group which was used to develop the model, the model correctly classified 86.2 percent of

Table 26. Results of discriminant analysis--train present.

Step Entered	Variable	Coefficients		Partial F ¹
		Violators	Non-Violators	
1	Perceived hazard	2.47011	2.96008	42.3
2	Likelihood of false activation	2.40868	2.77080	18.6
3	Annual mileage	3.34908	3.01861	13.6
4	Age	0.16838	0.19304	10.5
5	Perceived duties - train	3.01098	3.21332	9.6
6	Gender	1.08115	0.47058	9.3
7	Frequency of exposure	(not used in final model)		5.3
8	Recognition of variable WT	(not used in final model)		3.9
	Constant	-21.10007	-23.47717	

¹The probability of larger partial F must be less than 0.15 to be included in the model.

Table 27. Validation of discriminant model--train present.

	Predicted Violators	Predicted Non-Violators	Total
<u>Original Group</u>			
Actual Violators	72(47.1) ¹	81	153
Actual Non-Violators	40	249(86.2) ¹	289
Totals	112	330	
<u>Test Group</u>			
Actual Violators	30(46.9) ¹	34	64
Actual Non-Violators	23	127(84.7) ¹	150
Totals	53	161	214

¹Numbers in parentheses indicate percent correct classifications or "hits."

the non-violators and 47.1 percent of the violators. The overall hit rate for the original group was 72.6 percent, or 321 of 442 survey respondents.

With regard to the model's capability to correctly classify the "test" group, the model correctly classified 84.7 percent of the non-violators in the "test" group and 46.9 percent of the non-violators. Note that the model performed very well in classifying non-violators, but was not as successful in classifying violators. Still, 73.4 percent of the "test" group drivers overall were correctly classified.

The effectiveness of the model is further indicated when "a priori" probabilities are considered. Using random selection, 42.3 percent of the non-violators would be classified correctly on the average, and only 12.0 percent of the violators would be classified correctly. In contrast, the model correctly classified more than 80 percent of the non-violators and approximately 47 percent of the violators. In the case of violators, the model performs approximately four times better than random selection based on the known percentage of violators.

Discriminant Analysis Summary

For both crossing situations (i.e., no train and train present), the discriminant analyses were successful in identifying a relatively small group of variables which explain most of the variance in drivers' self-reported behavior at gated crossings. In the case when no train is present, the five most influential factors or variables were: (1) perceived hazard; (2) exposure to false activations; (3) age; (4) perceived duties-no train; and (5) annual mileage. These variables correspond to the major areas: (1) hazard perception; (2) system

reliability; (3) driver demographics (age); (4) comprehension and knowledge; and (5) general driving experience.

In the case of when a train is present, the discriminant analysis identified a combination of eight most influential variables: (1) perceived hazard; (2) likelihood of false activations; (3) annual mileage; (4) age; (5) perceived duties-train; (6) gender; (7) frequency of exposure; and (8) recognition of variable warning times. Only the first six of these variables were used in the final model. These six most significant variables correspond to the major areas: (1) hazard perception; (2) system reliability; (3) general driving experience; (4) driver demographics (age and gender); and (5) comprehension and knowledge.

Based on the results of the discriminant analysis, it is apparent that undesirable driver actions at gated crossings (and active crossings in general) are largely influenced by a limited number of driver-related variables. Several of these variables are the type which can be impacted through appropriate countermeasures. In other cases, it may not be possible to alter the driver factor (e.g., in the case of gender and age), but identifying these factors will help to appropriately "target" related countermeasures.

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the major conclusions and recommendations of the research. These conclusions and recommendations relate to the problem of drivers intentionally driving around or through functioning active traffic control devices (i.e., flashing light signals with and without automatic gates) at railroad-highway grade crossings. They are based on the results of the field and laboratory studies and the national driver survey.

Conclusions

The major conclusions of the research are enumerated below. They are grouped into three areas: (1) extent of undesirable driver behavior at grade crossings with active traffic control; (2) warning time issues; and (3) driver-related factors.

Extent of Undesirable Behavior

1. The number of undesirable driver actions, i.e., drivers intentionally going around or through functioning active traffic control devices, can be high at individual crossings. At the three study crossings, 10 to 20 percent of drivers arriving while the traffic control devices were activated crossed without stopping. At the gated study crossing, an additional 28 percent of arriving motorists stopped but then drove around the lowered gates. At the two study crossings with flashing light signals, 30 to 60 percent

of arriving motorists stopped and then crossed while the signals were flashing.

2. Undesirable driver behavior at grade crossings with active traffic control is a widespread problem, affecting crossings and many drivers. In the national driver survey, over 35 percent of the respondents said they "normally" engage in undesirable behavior under certain crossing circumstances. Such behavior has a very negative impact on overall crossing safety, and accounts for over one-half of all grade crossing accident fatalities.
3. Countermeasures are needed to reduce the extent of undesirable driver behavior at grade crossings with active traffic control.

Warning Time Issues

1. The length of the warning period has a significant influence on drivers' behavior at grade crossings with active traffic control. Warning times between 20 and 35 seconds generally minimize the number of undesirable driver actions, both at crossings with flashing light signals and crossings with gates and flashing light signals.
2. The approach grade and width of a crossing should be considered in establishing the minimum warning time.
3. Warning times in excess of 40 seconds at crossings with flashing light signals, and in excess of 60 seconds at gated crossings, erode drivers' trust in and respect for the active warning, thereby increasing the number of undesirable driver actions.

4. Excessive warning times result in a higher incidence of aggressive driver behavior (CL20s) and very risky behavior (CL10s). (CL20s and CL10s refer to the numbers of drivers crossing within 20 and 10 seconds of train arrival, respectively.)
5. The research results suggest that warning times below 20 seconds will not result in further reductions in undesirable driver actions, nor will they enhance driver trust in or respect for the active warning. Warning times less than 20 seconds may increase the hazard for mandatory stop vehicles and large, slow-moving vehicles in general.
6. Drivers generally will tolerate slightly longer warning times at gated crossings compared to crossings with only flashing light signals.
7. At crossings with automatic gates, the majority of drivers who drive during the gate delay/descent period do not respond by attempting to stop, but rather these drivers attempt to "beat the gates."
8. The length of the gate delay/descent period has a significant influence on driver behavior during the onset of the warning period at gated crossings. The gate delay should be a minimum of three or four seconds to allow time for initial driver perception and reaction. The gate descent time should be adequate to allow vehicles already on or very the tracks to clear, but not so great as to encourage drivers to attempt to "beat the gates." Gate descent times between 8 and 10 seconds appear to be most desirable.

Driver-Related Factors

1. The driver-related factors identified in the survey as influencing behavior at gated crossings would also logically influence driver behavior at crossings with flashing light signals.
2. There are significant driver-related factors which, together with the warning time, influence driver behavior at grade crossings with active traffic control. The most significant of these factors are: (1) the driver's perception of the grade crossing hazard; (2) the driver's comprehension of his/her duties at active crossings; (3) the driver's perceptions regarding system reliability; and (4) the drivers' age, gender, and driving experience.
3. Drivers who intentionally engage in undesirable behavior generally do not perceive that their actions are hazardous. This failure to perceive the grade crossing hazard is the most influential factor discriminating drivers who engage in undesirable behavior from those who do not.
4. Drivers who intentionally engage in undesirable actions at active crossings tend to believe it is legal to go around or through a functioning active device, or they are uncertain as to the legal status of their actions. It follows that educating these drivers as to their specific duties may reduce undesirable driver behavior.
5. Level of education, nor the fact that a driver has completed a standard high school driver's education or defensive driving course, influence the driver's behavior in response to active grade crossing devices.

6. Drivers who intentionally engage in undesirable behavior generally have been exposed more often to false activations and/or they believe that false activations occur frequently. Through negative exposure, these drivers have lost trust and respect for the active warning. It follows that if the number and duration of false activations can be reduced, then driver trust in and respect for the active warning will be enhanced and undesirable driver behavior will be minimized.
7. Drivers who engage in intentional undesirable actions at grade crossings with active traffic control tend to be males between the ages of 18 and 35, and frequent drivers in terms of annual driving mileage. By targeting countermeasures at this group of drivers, the measures should have a greater impact on crossing safety.
8. Perceived level of enforcement of grade crossing laws does influence driver behavior, however, this influence is relatively small compared to other factors. It appears that enforcement countermeasures would have limited success, particularly if implemented on a minor scale. The enforcement resources required to significantly deter undesirable driver actions at the 54,000 active crossings would probably not be cost effective.

Recommendations

Based on the preceding conclusions, several recommendations are offered. These recommendations, enumerated below, are intended to mitigate undesirable behavior at grade crossings with active traffic control and increase overall grade crossing safety.

1. The current 20-second minimum warning time established in the MUTCD should not be changed.
2. Standards for maximum warning times should be adopted into the MUTCD. A maximum warning time of 40 seconds is recommended for crossings with flashing light signals, and a 60-second maximum warning time is recommended for gated crossings.
3. Guidelines for desirable warning times should be implemented. Depending on the crossing approach grade and width, desirable warning times should be in the range of 20 to 40 seconds; warning times should be as close to 20 seconds as possible, while providing adequate clearance time for mandatory stop vehicles if they are present.
4. If train operations and fixed-distance train detection equipment at a crossing result in warning times in excess of the maximum values, constant warning time train detection equipment should be installed. If such equipment is infeasible or ineffective due to hardware limitation or cost considerations, then a more restrictive type of traffic control should be installed, (i.e., upgrade from flashing light signals to gates with flashing light signals or upgrade from standard gates to four-quadrant gates).
5. Minimum and maximum gate descent times should be adopted into the MUTCD.
6. Efforts should be maximized to reduce the number and duration of false activations at crossings with active traffic control. Steps should be taken to: (1) improve the overall reliability of train detection and traffic control hardware; (2) identify and remedy

crossings with a history of false activations; (3) enhance procedures for identifying and reporting false activations; and (4) minimize false activation response and repair times. (Malfunction rates and repair response times similar to those for highway traffic signals should be achieved.)

7. Educational and media promotional efforts intended to improve crossing safety should focus attention in two principal areas: (1) increasing drivers' specific knowledge of their duties at active crossings and (2) increasing the level of perceived hazard at active crossings.
8. Innovative strategies are needed to increase driver comprehension of their specific duties at active crossings, and to increase their awareness of the grade crossing hazard. Given the nature and extent of the problems, innovative regulatory and/or warning signing should be considered to complement standard active devices and signing.
9. Countermeasures for reducing undesirable driver behavior at grade crossings with active traffic control should be targeted at male drivers, between the ages of 18 and 35, who drive over 15,000 miles annually.

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APPENDICES

APPENDIX A

WARNING TIME PRACTICES IN FOREIGN COUNTRIES

Introduction

As part of the research conducted for this study, a survey of warning time practices in selected foreign countries was conducted. Letters were sent to the official Transportation Research Board Liaisons of eight countries requesting information on warning time standards for active grade crossings as well as information on research on warning times. The eight countries were Australia, Canada, France, United Kingdom, West Germany, Japan, South Africa, and Sweden. These countries were selected based on the availability of a suitable local contact individual and, in some cases a foreign language translator. The countries also represent a broad range of train/highway travel characteristics and cultures. A response form was included with each inquiry, and a follow-up letter was sent approximately one month after the initial information request.

Survey Results

Six of the eight countries--Australia, United Kingdom, Sweden, West Germany, Canada, and Japan--responded to the request for warning time information. Each of these countries provided specific information concerning their guidelines and/or regulations governing warning time length at active grade crossings. The findings of the foreign survey, as well as warning time-related research in some of the countries, are discussed herein.

United Kingdom. The United Kingdom Department of Transport has established minimum and maximum warning time requirements for crossings

with active traffic control.⁽¹⁾ It should be noted that British grade crossings are designed somewhat differently from those in the United States. The signals include a steady amber light which provides a brief initial warning period. An "illuminated" sign displaying the message "ANOTHER TRAIN COMING" is also installed at multi-track crossings with active traffic control. This sign is interconnected with the track circuitry and is illuminated after one train passes in the event of a trailing second train. Finally, the British standards do not allow automatic, unmanned signals or gates to be used at grade crossings where train speeds exceed 100 mph.

In the United Kingdom, the minimum warning time for crossings with active traffic control which are less than 15 meters (49.2 feet) wide is 27 seconds. For the first 3 seconds of the warning period, a steady amber light is displayed, followed by a flashing red light for the remainder of the warning period and while the train occupies the crossing. If the crossing is greater than 15 meters wide (from stop bar to point of safe clearance), the minimum warning time is increased by 1 second for each additional 3 meters (9.8 feet) of width. This minimum warning time requirement is used for crossings with flashing light signals and crossings with gates and signals. An additional stipulation applying to crossings with gates is that the gate arms should start down at the end of the amber phase, and must be fully lowered in 6 to 8 seconds.

With respect to maximum warning times, the British standards state that the train should arrive "as soon thereafter" the minimum warning time of 27 seconds. Furthermore, no more than 5 percent of the trains at a crossing can have warning times greater than 75 seconds, and no more than 50 percent can have warning times greater than 50 seconds.

In addition to providing details of British warning time standards, the respondent reported the results of warning time studies at two crossings with flashing light signals.⁽²⁾ Both crossings are on the Tyne-Wear Metro system. The study results indicate that, as in the United States, British warning times vary both from crossing to crossing and at individual crossings. More importantly, they reveal that relatively short warning times (even shorter than prescribed in British standards) are sometimes observed without adverse effects. (It is not known if the United Kingdom imposes penalties on railroads for noncompliance with warning time standards.)

At the first crossing in the British study, the average duration of the warning period was only 15.1 seconds. This includes a 3-second steady amber phase plus the flashing red phase. The shortest warning time at the crossing was only 10 seconds, and only 10 percent of the trains observed had a warning time greater than 18 seconds. Despite these relatively short warning times, the British researchers concluded that the crossing operated at "a very high standard." There was no evidence of any widespread nonobservance of the signals by drivers, and pedestrian behavior was satisfactory.

The second crossing in the British study had an average warning time of 38.4 seconds. Again this included a 3-second steady amber phase. The shortest warning time at this crossing was 31 seconds, and the longest was 58 seconds. Compared to many active crossings in the United States, this range (31-58 seconds) is relatively small. The average time of 38.4 seconds would be comparable to many crossings in this country. However, it is significant to note that the British researchers found that there were

problems with pedestrian violations at this crossing and attributed these problems in part to the "long and variable warning times."

Sweden. Swedish standards recommend both minimum and maximum warning times for crossings with active traffic control, and the recommended times differ by type of traffic control.⁽³⁾ At crossings with flashing light signals, the minimum warning time is 20 seconds and the maximum warning time is 40 seconds.

At crossings with gates (referred to as "half gates" in Sweden), the maximum warning time is 60 seconds. The minimum warning time is dictated by the required location of the "signal activation point" relative to the crossing. This point is a function of train speed in accordance with the formula: Activation Distance (in meters) = $600 + (10 \times S)$, where S is maximum train speed in meters per seconds. Thus, if the maximum train speed is 60 mph (26.8 m/s), the activation distance would be 868 meters or 2,847 feet. The minimum warning time for this crossing would be approximately 32 seconds, that is, 2,847 feet divided by 88 feet per second (60 mph). The maximum allowable warning time would be 60 seconds as dictated by the maximum limit.

Japan. The Japanese Ministry of Transport has adopted formal standards for warning times at active grade crossings.⁽⁴⁾ With respect to flashing light signals, the Japanese standards require a minimum warning time of 20 seconds; a "standard" time of 30 seconds is generally used. The Japanese regulations do not specify a maximum warning time for flashing light signals. However, the Japanese guidelines state that "the time period between the beginning of warning and the train's arrival should not be affected by train and/or vehicle speed." This provision implies that

the Japanese do not permit highly variable (or excessively long) warning times due to the presence of variable speed trains. It should also be noted that in Japan flashing light signals are only allowed at low-volume crossings.

With respect to gated crossings, the Japanese standards do not specify a minimum or maximum warning time; however, a minimum warning time is implied through the summation of other controlled times. Japanese regulations require a minimum of 10 seconds from the beginning of the warning to the completion of the gate lowering; a standard time of 15 seconds generally is provided. The Japanese standards also require a minimum 15-second wait period after the gates are fully lowered until a train arrives at the crossing; a 20-second wait period is standard. Combining the minimum gate descent time and minimum wait time results in a minimum total warning time of 25 seconds (i.e., 10-second gate descent time plus 15-second wait time). Combining the desirable gate descent time and desirable wait time results in a desirable total warning time of 35 seconds (i.e., 15-second gate descent time plus 20-second wait time).

As with flashing light signals, the Japanese standards state that the warning time at a gated crossing should not be affected by train and/or vehicle speeds. It should also be noted that the Japanese standards do not specify a minimum gate delay time, where gate delay time is the length of time from the beginning of the warning to the start of the gate descent. However, the Japanese standards do state that this time must be sufficient so as "not to affect crossing traffic."

Australia. The Australian State Transport Authority has adopted minimum warning time standards for grade crossings with active traffic

control.⁽⁵⁾ The minimum warning time at crossings with flashing light signals is 20 seconds, and at crossings with gates the minimum warning time is 25 seconds. At crossings with multiple tracks, these minimum times are generally increased. Australia does not have guidelines for maximum warning times; however, the Australian State Transport Authority reports that "discriminating" detectors are often used at crossings with mixed speed train traffic in order to avoid long and variable warning times.

The respondent from Australia reported on the results of several case studies conducted at active crossings in Australia which suggest that warning times can be highly variable. At a group of eight crossings with flashing signals, typical warning times ranged from 18 to 89 seconds, with a mean time of 40 seconds. However, at two of these crossings some very atypical times were observed due to switching and/or multiple train situations. At one crossing, a 3-second warning time was reported, as well as two times in excess of 150 seconds. At a second crossing, a warning time in excess of 5 minutes was observed. The research documented severe safety and driver behavior problems resulting from these very short and long times.

The Australian research evaluated one crossing with gates. At this crossing, observed warning times ranged from 31 to 73 seconds, with a mean time of 49.2 seconds. The average time for the gate to fully descend was 15.5 seconds, with descent times ranging from 11 to 19 seconds. No data or opinion on the adequacy of these warning times were offered by the researchers.

One of the recommendations of the Australian research deserves special mention. The researchers concluded that an advance warning phase

for flashing light signals was desirable. It was suggested that this second signal be an audible bell commencing approximately 8 seconds before the flashing light signal and standard bell. Although not clearly stated, it is thought that this warning would primarily aid pedestrians.

Canada. Canada has adopted national regulations governing warning times at grade crossings with active traffic control. These regulations are presented in Chapter 1183 of the Canadian National Transportation Act and are referred to as "General Order No. E-6." This order establishes specific requirements for minimum warning times at crossings with active traffic control. The minimum warning time for crossings with flashing light signals with or without gates is 20 seconds. This minimum time applies to crossings up to 35 feet wide, with train speeds greater than 10 mph. At crossings wider than 35 feet and with train speeds in excess of 10 mph, the minimum warning time "shall be increased 1 second for each additional 10 feet (of width) or fraction thereof." At crossings with train speeds of 10 mi/h or less, a minimum warning time of only 7 seconds is allowed, regardless of the crossing width.

With regard to crossings with gates, the Canadian regulations state that gates "shall be installed as adjuncts to signals of the flashing light type," and that "the gate mechanism shall preferably be mounted on the same mast as the flashing light signal." The gates cannot start their downward motion less than 3 seconds after the signal lights start to operate, and they must reach a "full horizontal position before any train on a main track reaches the crossing."

The Canadian regulations do not present specific requirements for maximum warning times at active crossings. However, the regulations do

state that "where train speeds on a main track vary considerably, additional control circuits may be required with timing devices so arranged that a warning time, adequate for the slower trains, will be automatically adjusted."

Canadian officials are considering revising the above warning time regulations. Under the proposed new standards, the minimum advance warning time at active crossings would be calculated using the following formula:

$$\text{MAWT (in seconds)} = \text{BOT} + \text{CT} + \text{AT}.$$

where:

MAWT is minimum advance warning time

BOT is basic operating time

CT is clearance time

AT is adjustment time

BOT, or basic operating time, is 20 seconds for crossings with train speeds in excess of 10 mph, and 15 seconds for crossings of secondary tracks with train speeds of 10 mph or less. If the crossing is wider than 35 feet, the BOT must be increased by one second for each 10 feet, or portion thereof, of the clearance distance over 35 feet. This additional time is referred to as the CT, or clearance time. Finally, when train detection systems other than motion sensitive systems are used, a 2 second AT, or adjustment time, must be added to the minimum warning time. When motion sensitive systems are used, the AT shall be based on the equipment manufacturer's recommendation.

The proposed new regulations also address the maximum warning time issue. The proposed standards state that "when a warning system operates more than 13 seconds over the calculated MAWT, its warning time is considered

to be excessive." Furthermore, the proposed regulations require the use of constant warning time control equipment for new warning systems at crossings with variable speed trains. For existing warning systems at crossings with variable speed trains, the regulations state that "consideration should be given to retro-fitting with constant warning time control equipment."

West Germany. West Germany distinguishes between the two basic types of active traffic control (flashing light signals with and without gates) in their warning time standards. For crossings with active traffic control but without gates, the minimum warning time is 20 seconds. Maximum warning time is dealt with in a unique way. Instead of specifying a single number, the regulations provide two formulas for calculating maximum warning time at individual crossings. For crossings where the slowest traffic is expected to travel at 10 km/h, the time is 13 seconds plus 36 percent of the distance between the two lines where vehicles must stop on either side of the tracks or the distance between the two railroad crossing signs. For crossings where the slowest traffic is expected to travel at 5 km/h, the maximum warning time is 19 seconds plus 72 percent of either distance discussed above. In all cases the distance is measured in meters but is converted in the formula to seconds.

For crossings with gates and flashing light signals, the minimum warning time is 22 seconds for one-track crossings under ideal conditions. The regulations decompose these times as follows:

- 8 seconds interval between beginning of lights flashing and beginning of gates closing;

- 6-10 seconds 10 seconds for gates over 6 meters long, otherwise 6 seconds (thus, the minimum time for crossings with long gates is 26 seconds); and
- 8 seconds interval between closing of gates and arrival of train.

The maximum warning time is 30 seconds and is broken out as:

- 12 seconds interval between beginning of lights flashing and beginning of gates closing;
- 6-10 seconds 10 seconds for gates over 6 meters long, otherwise 6 seconds (thus the maximum time for crossings with short gates is 26 seconds); and
- 8 seconds interval between closing of gates and arrival of train.

References

1. Department of Transport, Railway Construction and Operation Requirements: Level Crossings. Her Majesty's Stationery Office, 1981.
2. Grayson, G.B., "Road User Behaviour at Two Metro Level Crossings," Working Paper WP(HSF)42, Transport and Road Research Laboratory, 1986.
3. Sandstrom, J., "Vagskyddanslaggningar, Signalering mot bannan, Anvisningar for projektering" (Road-Rail Protection: Railway Signal Design Guidelines), 1987, (Sweden)
4. Article 44 of Ordinance No. 14 and Articles 21 and 22 of Notice No. 177, Ministry of Transport, Japan.
5. Minute No. 224/81--Standardisation of Level Crossing Protection, Railways of Australia Committee, 1982.

APPENDIX B

CROSSING SIMULATION PROGRAM

```
10 RANDOMIZE
11 READ PERPC, PERLT, PERHT, PERBUS
12 READ PCVR10, PCVR20, PCVR40, PCVR60, PCVRMAX
13 READ LTVR10, LTVR20, LTVR40, LTVR60, LTVRMAX
14 READ HTVR10, HTVR20, HTVR40, HTVR60, HTVRMAX
15 READ BVR10, BVR20, BVR40, BVR60, BVRMAX
20 CUMVEH=0
30 TOTVEH=0
40 TOTPC=0
50 TOTLT=0
60 TOTHT=0
70 TOTBUS=0
80 CUMVT10=0
90 SUMV10=0
100 SUMPCV=0
110 SUMLTV=0
120 SUMHTV=0
130 SUMBV=0
140 CUMWT=0
150 CUMVPH=0
160 CUMDEL=0
220 READ T, ADT, MEANWT, CAP
221 SDWT=.3333*MEANWT
230 FOR N=1 TO T
240 TIME=INT (RND*24)
250 GOSUB 1340
260 VPH=CINT (PDV*ADT)
270 VPS=VPH/3600
280 CRAN=0
290 FOR J=1 TO 12
300 RAN=RND
310 CRAN=CRAN+RAN
320 NEXT J
330 WT=(SDWT*CRAN) + (MEANWT-(6*SDWT))
340 IF WT<15 THEN 280
350 IF WT>300 THEN 280
360 TOTTIME=0
370 MAXVIO=(WT-4)/CAP
380 QUEUE=0
390 VTIME=(-1*LOG(RND))/VPS
400 IF VTIME>WT THEN 1020
410 TOTTIME=TOTTIME+VTIME
420 IF TOTTIME>WT THEN 1020
430 TOTVEH=TOTVEH+1
440 WAITTM=WT-TOTTIME
450 QUEUE=QUEUE+1
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460 VTYPE=RND
470 IF VTYPE<PERPC GOTO 510
480 IF VTYPE<PERLT GOTO 630
490 IF VTYPE<PERHT GOTO 750
500 IF VTYPE<=PERBUS GOTO 870
510 TOTPC=TOTPC+1
520 IF QUEUE>=MAXVIO THEN PCVIO=0: GOTO 590
525 IF WAITTM<10 THEN VRATE=PCVR10: GOTO 570
530 IF WAITTM<20 THEN VRATE=PCVR20: GOTO 570
540 IF WAITTM<40 THEN VRATE=PCVR40: GOTO 570
550 IF WAITTM<60 THEN VRATE=PCVR60: GOTO 570
560 IF WAITTM>=60 THEN VRATE=PCVRMAX: GOTO 570
570 PROBPIO=RND
580 IF PROBPIO<VRATE THEN PCVIO=1 ELSE PCVIO=0
590 SUMPCV=SUMPCV+PCVIO
600 IF PCVIO=1 THEN DELAY=0
610 IF PCVIO=0 THEN DELAY=WAITTM+120
620 GOTO 990
630 TOTLT=TOTLT+1
640 IF QUEUE>=MAXVIO THEN LTVIO=0: GOTO 710
645 IF WAITTM<10 THEN VRATE=LTVR10: GOTO 690
650 IF WAITTM<20 THEN VRATE=LTVR20: GOTO 690
660 IF WAITTM<40 THEN VRATE=LTVR40: GOTO 690
670 IF WAITTM<60 THEN VRATE=LTVR60: GOTO 690
680 IF WAITTM>=60 THEN VRATE=LTVRMAX: GOTO 690
690 PROBPIO=RND
700 IF PROBPIO<VRATE THEN LTVIO=1 ELSE LTVIO=0
710 SUMLTV=SUMLTV+LTVIO
720 IF LTVIO=1 THEN DELAY=0
730 IF LTVIO=0 THEN DELAY=WAITTM+120
740 GOTO 990
750 TOTHT=TOTHT+1
760 IF QUEUE>=MAXVIO THEN HTVIO=0: GOTO 830
765 IF WAITTM<10 THEN VRATE=HTVR10: GOTO 810
770 IF WAITTM<20 THEN VRATE=HTVR20: GOTO 810
780 IF WAITTM<40 THEN VRATE=HTVR40: GOTO 810
790 IF WAITTM<60 THEN VRATE=HTVR60: GOTO 810
800 IF WAITTM>=60 THEN VRATE=HTVRMAX: GOTO 810
810 PROBPIO=RND
820 IF PROBPIO<VRATE THEN HTVIO=1 ELSE HTVIO=0
830 SUMHTV=SUMHTV+HTVIO
840 IF HTVIO=1 THEN DELAY=0
850 IF HTVIO=0 THEN DELAY=WAITTM+120
860 GOTO 990
870 TOTBUS=TOTBUS+1
880 IF QUEUE>=MAXVIO THEN BUSVIO=0: GOTO 950
885 IF WAITTM<10 THEN VRATE=BVR10: GOTO 930
890 IF WAITTM<20 THEN VRATE=BVR20: GOTO 930
900 IF WAITTM<40 THEN VRATE=BVR40: GOTO 930
910 IF WAITTM<60 THEN VRATE=BVR60: GOTO 930
920 IF WAITTM>=60 THEN VRATE=BVRMAX: GOTO 930
930 PROBPIO=RND

```

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940 IF PROBPIO<VRATE THEN BUSVIO=1 ELSE BUSVIO=0
950 SUMBV=SUMBV+BUSVIO
960 IF BUSVIO=1 THEN DELAY=0
970 IF BUSVIO=0 THEN DELAY=WAITTM+120
980 GOTO 990
990 SUMVIO=SUMPCV+SUMLTV+SUMHTV+SUMBV
1000 CUMDEL=DELAY+CUMDEL
1010 IF TOTTIME<WT THEN 390
1020 CUMWT=WT+CUMWT
1030 AVEWT=CUMWT/T
1040 AVEARR=TOTVEH/T
1050 CUMVPH=CUMVPH+VPH
1060 AADT=24*CUMVPH/T
1070 AVEVIO=SUMVIO/T
1080 DELRATE=CUMDEL/T
1090 DELHRS=CUMDEL/3600
1100 NEXT N
1110 LPRINT
1120 IF CAP=4 THEN 1150
1130 LPRINT "TRAFFIC CONTROL:                FLASHING LIGHT SIGNALS"
1140 GOTO 1160
1150 LPRINT "TRAFFIC CONTROL:                GATES WITH FLASHING LIGHT SIGNALS"
1160 LPRINT "AVE TRAFFIC EXPOSURE (VPD):      ";AADT
1170 LPRINT "TOTAL TRAINS:                      ";T
1180 LPRINT "AVE WARNING TIME (SEC):              ";AVEWT
1190 LPRINT "AVE ARRIVALS PER TRAIN:                ";AVEARR
1200 LPRINT "TOTAL VEHICLE ARRIVALS:                ";TOTVEH
1210 LPRINT "VEH. DELAY PER TRAIN (SEC):            ";DELRATE
1220 LPRINT "AVE VIOLATIONS PER TRAIN:              ";AVEVIO
1230 LPRINT "CUMULATIVE VEH. DELAY (HRS):          ";DELHRS
1240 LPRINT
1250 LPRINT "PASSENGER CAR VIOLATIONS (TOTAL CARS):      ";SUMPCV;"
      (";TOTPC;")
1260 LPRINT "LIGHT TRUCK VIOLATIONS (TOTAL LIGHT TRUCKS):";SUMLTV;"
      (";TOTLT;")
1270 LPRINT "HEAVY TRUCK VIOLATIONS (TOTAL HEAVY TRUCKS):";SUMHTV;"
      (";TOTHT;")
1280 LPRINT "BUS VIOLATIONS (TOTAL BUSES):              ";SUMBV;"
      (";TOTBUS;")
1290 LPRINT
1300 LPRINT "TOTAL VIOLATIONS (TOTAL VEHICLES):          ";SUMVIO;"
      (";TOTVEH;")
1310 LPRINT
1320 GOTO 20
1330 END
1340 IF TIME=0 THEN PDV=.0189: GOTO 1580
1350 IF TIME=1 THEN PDV=.0132: GOTO 1580
1360 IF TIME=2 THEN PDV=.009001: GOTO 1580
1370 IF TIME=3 THEN PDV=.0076: GOTO 1580
1380 IF TIME=4 THEN PDV=.0076: GOTO 1580
1390 IF TIME=5 THEN PDV=.0105: GOTO 1580
1400 IF TIME=6 THEN PDV=.0253: GOTO 1580

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1410 IF TIME=7 THEN PDV=.0369: GOTO 1580
1420 IF TIME=8 THEN PDV=.0442: GOTO 1580
1430 IF TIME=9 THEN PDV=.0534: GOTO 1580
1440 IF TIME=10 THEN PDV=.0573: GOTO 1580
1450 IF TIME=11 THEN PDV=.0542: GOTO 1580
1460 IF TIME=12 THEN PDV=.0534: GOTO 1580
1470 IF TIME=13 THEN PDV=.0618: GOTO 1580
1480 IF TIME=14 THEN PDV=.0656: GOTO 1580
1490 IF TIME=15 THEN PDV=.0688: GOTO 1580
1500 IF TIME=16 THEN PDV=.0771: GOTO 1580
1510 IF TIME=17 THEN PDV=.073: GOTO 1580
1520 IF TIME=18 THEN PDV=.0612: GOTO 1580
1530 IF TIME=19 THEN PDV=.0572: GOTO 1580
1540 IF TIME=20 THEN PDV=.0474: GOTO 1580
1550 IF TIME=21 THEN PDV=.0385: GOTO 1580
1560 IF TIME=22 THEN PDV=.0318: GOTO 1580
1570 IF TIME=23 THEN PDV=.0261: GOTO 1580
1580 RETURN

APPENDIX C

DISCUSSION GROUP PROBE QUESTIONS

1. I am going to show you slides of some things that you have undoubtedly seen in your daily driving. I want you simply to tell me what you call these things. However, before you say anything out loud, write down your answer or answers. We will discuss our ideas together.

(Do this exercise for railroad crossings, flashing light signals, gates, and passive crossings.)
2. (Referring to an appropriate slide) Tell me what you think the law says you are supposed to do at this crossing when the warning lights are flashing (when the gate arm is lowered)?

(Do this exercise for crossings with FLS and gates with FLS. As a follow-up, find out what drivers think the law says to do when the lights/gates are off, for trucks/buses, and at passive crossings.)
3. (Referring to an appropriate slide) Now let's look at some of the signs and markings used at railroad crossings. What do you call this sign? Where and how is it used? Is this sign at all crossings? What is the sign trying to tell drivers?
4. (Referring to an appropriate slide) What do these markings on the pavement mean? Where are they used? What is their purpose?
5. Now let's look at a video tape of a crossing situation. What is going through your mind? What are you looking for? How do you feel?
6. Name 3 complaints that you have about grade crossings. Write down your responses and then we will go around the table and discuss them. What are your 3 biggest complaints at gated crossings (crossings with FLS)?
7. Why do you think accidents occur at crossings with gates (at crossings with flashing light signals)? Have any of you had a "close call" or "near miss" at a crossing? If so, what happened?
8. Why do people drive around lowered gates? Why do people cross in front of an approaching train when the lights are flashing?
9. What types of crossings need gates? What types need flashing light signals?
10. Can you recall any certain crossings which you believe are particularly dangerous? Why do you think they are hazardous.

SAMPLE COMMENTS OF GROUP SESSION PARTICIPANTS

Terminology

Participants were shown slides of a railroad-highway grade crossing, a flashing light signal installation, and an automatic gate installation, and asked the common names for them. Below is a summary of their responses.

<u>Official Name</u>	<u>Common Name</u>
Railroad-highway grade crossing	Railroad crossing; railroad track; railroad intersection
Flashing light signals	Railroad crossing warning lights; train signals; railroad signals; train warning light; railroad caution lights
Automatic gates with flashing light signals	Crossing gate; cross bars; arms; gates; railroad warning gate; railroad guard rail; railroad guard; traffic stopping arm

Knowledge and Comprehension

The group session participants made a number of comments which demonstrated their lack of comprehension of the meaning and specific intent of active traffic control at grade crossings. Some of the pertinent statements related to driver understanding and knowledge are presented below.

I don't know about that one (the law concerning gates). It might be okay if there's nothing coming.

If there's no train coming you should pull up, look, and if it's clear go on across.

I'd say they treat that as a stop light or stop sign. If you go through it, it is illegal.

I'm not real sure.

I wouldn't think it was against the law if there's enough distance.

I don't know if this has any connection, but there are times in which red means stop, but if you come to an intersection that has a red flashing light it means to stop and then proceed after you make sure it's clear. So I'm wondering if maybe the flashing red lights on that track with bars would mean that you should stop and proceed with caution.

Law Enforcement

A few subjects made specific reference to their perceptions of law enforcement and/or the influence of this perceived enforcement on their behavior.

Cops are looking for more speeders than you hear about catching people for train crossing.

I imagine I did feel like I was breaking the law, but I didn't see any cops around so that's probably the reason I did it. If there was a cop right behind me, I would have stayed still.

I don't know if you could really be given a ticket. I think it's (the gates are) there for your advantage

I think speeding could be more dangerous (than a gate violation). If you're speeding, you could hurt someone else.

Importance of Time

Many drivers associated their crossing behavior with being in a hurry and/or the length of the waiting period. Some of the drivers' most pertinent statements related to the importance of time and the length of the warning period are cited below:

We live by the clock. We are so rushed and so pushed.

When your in a hurry, 10 seconds seems like minutes.

The minute the lights come on and the bars come down, I'm immediately agitated, because of having to wait for the train to go by.

I was impatient I guess. In a hurry or something.

I didn't want to sit there. I might be late for work.

It's a function of time. I even turn the motor off now when I come up to the one on Walnut Avenue. Isn't there a limit of what -- five minutes crossing? It seems more like five hours!

. . . sometimes I think there are too many damn cars. I've counted over a hundred.

If I see one (a train) coming, I'll wait for it to come by. I don't really care how long it is.

Perception of Hazard and Risk-Taking

The group session participants made comments that indicated their different perceptions of the grade crossing hazard and their different levels of risk-taking. Some of these comments are cited below.

I've always had this terror connected with railroad tracks.

We live by our own rules, not by the one's that are set up for us.

If there's a warning, I'd say that it would have to be a person's own responsibility to use their own judgment, risk their own lives.

If I were in a car by myself and I was responsible only for my own life then I feel like I would surely do something like that. But if I was responsible for someone else, I don't think I would.

Credibility of the Devices

Drivers' trust and credibility in active grade crossing devices appear to have a major influence over crossing behavior. The participants gave several responses showing their lack of confidence and mistrust in active devices. Examples of these comments follow.

. . . it's just that sometimes the gates come down and you look both ways and you don't see a train.

I wonder how many times they're actually checked. . . . It seems like it would be hard to keep them all up.

I think it bothers me that they won't come on when they're supposed to and it's just kind of my life I don't want thrown away on bad lights.

I think that I did remember doing that (gate violation) once and it was a place where gate the kept going up and down. We stopped for a while and no train came and we eventually decided it was broken and drove around it.

I'm sure there's a certain time period that the lights have to run, but I've seen it before where I've gone over railroad tracks one time and come back ten minutes later and the lights are still flashing and you look and can't see a train down the tracks.

The fact that trains stall, they change rails, and that takes time, and you don't know whether to go, or if they're coming forward, or they take some of the cars off. You're just sitting there wondering what to do.

Summary

The above sampling of participants' comments demonstrates that there are several factors which influence drivers' perceptions and attitudes regarding active traffic control systems at grade crossings. It follows that some of these factors influence undesirable driver behavior in response to the active devices.

APPENDIX D

DESCRIPTION OF UNIVARIATE ANOVA

Univariate ANOVA models are used when there is only one quantitative response variable, and one or more factors (independent variables). Considering a single-factor ANOVA study, the purpose is generally to determine if the mean responses at the different factor levels (called treatments) are significantly different from one another. There is a probability distribution of responses corresponding to each factor level. The ANOVA model assumes that:

1. The probability distributions for each factor level are normal and have the same variance.
2. The observations for each factor level are random and independent observations.

With these basic assumptions, the single factor ANOVA model is stated as follows:

$$x_{ij} = \mu_i + \epsilon_{ij}$$

where: x_{ij} is the value of the response (dependent) variable in the j th trial for the i th factor level
 μ_i is the mean response of the i th factor level
 ϵ_{ij} is the random sampling error of the j th observation of the i th factor level

The parameters of the ANOVA model are unknown and must be estimated from the sample data. The method of least squares is used to provide

estimators of the model parameters and "fit" the ANOVA model to the data. According to the least squares criterion, the sum of the squared deviations of the observations around their expected values must be minimized with respect to the parameters. The parameter which must be estimated in this fashion is μ_i , and it can be shown that the least square estimator of this parameter for a total sample size of n is:

$$\bar{x}_{i.}, \text{ where } \bar{x}_{i.} = \frac{\sum_{j=1}^{n_i} x_{ij}}{n_i} = \frac{x_{i.}}{n_i}$$

Residuals are used to examine the aptness of the ANOVA model in a given application. The residual ϵ_{ij} is defined as the difference between the observed value and the treatment mean, that is:

$$\epsilon_{ij} = x_{ij} - \bar{x}_{i.}$$

The ANOVA approach to assessing factor level differences is based on the partitioning of sums of squares and degrees of freedom associated with the response variable. In developing the approach to partitioning, the deviation $x_{ij} - \bar{x}_{..}$ is recognized to be the basic quantity measuring the variation of the observations x_{ij} ($\bar{x}_{..}$ is the grand or overall mean of all observations.) Furthermore, this quantity can be decomposed as follows:

$$\underbrace{x_{ij} - \bar{x}_{..}}_{\text{Total deviation}} = \underbrace{\bar{x}_{i.} - \bar{x}_{..}}_{\text{Deviation of factor level mean around overall mean}} + \underbrace{x_{ij} - \bar{x}_{i.}}_{\text{Deviation around factor level mean}}$$

Thus, the total deviation $x_{ij} - \bar{x}_{..}$ can be viewed as the sum of two components:

1. The deviation of the factor level mean around the overall mean.
2. The deviation of the observation value around its factor level mean. This deviation is the residual.

It is also a remarkable property that if the deviations are squared, the same relationship (additive property) holds. That is, the sum of the squares of the total deviations equals the sum of the squares of the deviations of the factor level means around the overall mean plus the sum of the squares of the deviations of the observation values around their factor level mean. This relationship is written as:

$$\sum_i \sum_j (x_{ij} - \bar{x}_{..})^2 = \sum_i n_i (\bar{x}_{i.} - \bar{x}_{..})^2 + \sum_i \sum_j (x_{ij} - \bar{x}_{i.})^2$$

The first term, $\sum_i \sum_j (x_{ij} - \bar{x}_{..})^2$, is the sum of the squares of the total deviations (SSTO). The second term, $\sum_i n_i (\bar{x}_{i.} - \bar{x}_{..})^2$, is the sum of the squares of the deviations of the treatment means from the overall mean (SSTR), and the final term, $\sum_i \sum_j (x_{ij} - \bar{x}_{i.})^2$, is the sum of the squares of the deviations of the individual observations around the appropriate treatment mean (SSE).

Corresponding to the decomposition of the total sum of squares, the degrees of freedom associated with the various sums of squares are partitioned as follows:

SSTO has $n-1$ degrees of freedom

SSTR has $r-1$ degrees of freedom, where r is number of factor levels

SSE has $r-1$ degrees of freedom

Also, mean square values are obtained by dividing each of the three partitioned sum of squares by its associated degrees of freedom. Once this is done, then the basic ANOVA table can be constructed as shown in Table 1.

In order to test whether there are significant differences in the factor level means, an F-test is used to test the null hypothesis, $H_0: \mu_1 = \mu = \dots \mu_r$, that is, all treatment means are equal. The alternative hypothesis is that not all μ_i are equal. The F-statistic is calculated by dividing the mean treatment sum of squares by the mean error sum of squares as follows:

$$F^* = \frac{MSTR}{MSE}$$

Large values of F^* support the alternative hypothesis, since MSTR will tend to exceed MSE if there is much difference in the treatment means and/or the variation among the observations about their factor level mean is relatively small. Values of F^* near one support the null hypothesis since both MSTR and MSE have the same expected value when H_0 holds. F^* is distributed as F with $r-1, n-1$ degrees of freedom, where r is the number of factor levels or treatments and n is the total number of observations sampled.

An alternative form of the single factor ANOVA model is often presented which splits up the factor level means, μ_i , into two components:

an overall constant $\mu_{.}$ and a specific factor level effect, τ_i . The resulting model is stated as follows:

$$X_{ij} = \mu_{.} + \tau_i + \epsilon_{ij}$$

where:

$\mu_{.}$ is a constant component common to all observations

τ_i is the effect of the i th factor level

ϵ_{ij} is the random error of the j th observation in i th treatment

In the alternate form of the ANOVA model, $\mu_{.}$ can be defined in different ways and the definition of $\mu_{.}$ will subsequently define τ_i . Most often, $\mu_{.}$ is defined as the unweighted average of all factor level means as follows:

$$\mu_{.} = \frac{\sum_{i=1}^r \mu_i}{r}$$

where r is the number of factor levels and μ_i are the mean responses of the factor levels or treatments.

In the alternative form of the ANOVA model, the null hypothesis becomes: $H_0: \tau_1 = \tau_2 = \dots \tau_i = 0$. The alternative hypothesis is that not all factor level effects are equal. An F^* statistic is constructed in the same manner for testing this hypothesis.

REFERENCES

1. Neter, John, William Wasserman, and Michael H. Kutner. Applied Linear Statistical Models: Second Edition. Richard D. Irwin, Inc., Homewood, Illinois, 1985.
2. Steel, Robert G.D. and James H. Torrie. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc., New York, New York, 1960.

Table 1. ANOVA table for single-factor study.

Source of Variation	SS	df	MS
Between treatments	$SSTR = \sum n_i (\bar{x}_{i.} - \bar{x}_{..})^2$	$r - 1$	$MSTR = \frac{SSTR}{r - 1}$
Error (within treatments)	$SSE = \sum \sum (x_{ij} - \bar{x}_{i.})^2$	$n_r - r$	$MSE = \frac{SSE}{n_r - r}$
Total	$SSTO = \sum \sum (x_{ij} - \bar{x}_{..})^2$	$n_r - 1$	

APPENDIX E

FREQUENCY DISTRIBUTION TABLES: NO TRAIN

CROSSING BEHAVIOR - NO TRAIN

BY ANNUAL MILEAGE

FREQUENCY PERCENT ROW PCT COL PCT	ANNUAL MILEAGE				TOTAL
	1	2	3	4	
NON-VIOLATORS	69	114	121	104	408
	10.42	17.22	18.28	15.71	61.63
	16.91	27.94	29.66	25.49	
	74.19	68.26	60.50	51.49	
VIOLATORS	24	53	79	98	254
	3.63	8.01	11.93	14.80	38.37
	9.45	20.87	31.10	38.58	
	25.81	31.74	39.50	48.51	
TOTAL	93	167	200	202	662
	14.05	25.23	30.21	30.51	100.00

CROSSING BEHAVIOR - NO TRAIN

BY FREQUENCY OF EXPOSURE

FREQUENCY PERCENT ROW PCT COL PCT	FREQUENCY OF EXPOSURE				TOTAL
	1	2	3	4	
NON-VIOLATORS	52	115	134	107	408
	7.85	17.37	20.24	16.16	61.63
	12.75	28.19	32.84	26.23	
	75.36	64.61	62.62	53.23	
VIOLATORS	17	63	80	94	254
	2.57	9.52	12.08	14.20	38.37
	6.69	24.80	31.50	37.01	
	24.64	35.39	37.38	46.77	
TOTAL	69	178	214	201	662
	10.42	26.89	32.33	30.36	100.00

BY RECENCY OF EXPOSURE

FREQUENCY PERCENT ROW PCT COL PCT	RECENCY OF EXPOSURE				TOTAL
	1	2	3	4	
NON-VIOLATORS	19	115	121	153	408
	2.87	17.37	18.28	23.11	61.63
	4.66	28.19	29.66	37.50	
	82.61	67.65	60.20	57.09	
VIOLATORS	4	55	80	115	254
	0.60	8.31	12.08	17.37	38.37
	1.57	21.65	31.50	45.28	
	17.39	32.35	39.80	42.91	
TOTAL	23	170	201	268	662
	3.47	25.68	30.36	40.48	100.00

BY LIKELIHOOD OF FALSE ACTIVATIONS

FREQUENCY PERCENT ROW PCT COL PCT	LIKELIHOOD OF FALSE ACTIVATIONS					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	12	77	49	214	56	408
	1.81	11.63	7.40	32.33	8.46	61.63
	2.94	18.87	12.01	52.45	13.73	
	46.15	44.51	68.06	69.71	66.67	
VIOLATORS	14	96	23	93	28	254
	2.11	14.50	3.47	14.05	4.23	38.37
	5.51	37.80	9.06	36.61	11.02	
	53.85	55.49	31.94	30.29	33.33	
TOTAL	26	173	72	307	84	662
	3.93	26.13	10.88	46.37	12.69	100.00

BY EXPOSURE TO FALSE ACTIVATIONS

FREQUENCY PERCENT ROW PCT COL PCT	EXPOSURE TO FALSE ACTIVATIONS				TOTAL
	1	2	3	4	
NON-VIOLATORS	170	63	119	56	408
	25.68	9.52	17.98	8.46	61.63
	41.67	15.44	29.17	13.73	
	80.57	67.02	57.77	37.09	
VIOLATORS	41	31	87	95	254
	6.19	4.68	13.14	14.35	38.37
	16.14	12.20	34.25	37.40	
	19.43	32.98	42.23	62.91	
TOTAL	211	94	206	151	662
	31.87	14.20	31.12	22.81	100.00

BY PERCEIVED LEVEL OF MAINTENANCE

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED LEVEL OF MAINTENANCE					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	6	50	193	151	8	408
	0.91	7.55	29.15	22.81	1.21	61.63
	1.47	12.25	47.30	37.01	1.96	
	40.00	58.14	61.27	65.09	57.14	
VIOLATORS	9	36	122	81	6	254
	1.36	5.44	18.43	12.24	0.91	38.37
	3.54	14.17	48.03	31.89	2.36	
	60.00	41.86	38.73	34.91	42.86	
TOTAL	15	86	315	232	14	662
	2.27	12.99	47.58	35.05	2.11	100.00

BY LIKELIHOOD OF EXCESSIVE WARNING TIMES

FREQUENCY PERCENT ROW PCT COL PCT	LIKELIHOOD OF EXCESSIVE WARNING TIMES					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	48 7.25 11.76 66.67	200 30.21 49.02 63.69	81 12.24 19.85 60.90	74 11.18 18.14 58.27	5 0.76 1.23 31.25	408 61.63
VIOLATORS	24 3.63 9.45 33.33	114 17.22 44.88 36.31	52 7.85 20.47 39.10	53 8.01 20.87 41.73	11 1.66 4.33 68.75	254 38.37
TOTAL	72 10.88	314 47.43	133 20.09	127 19.18	16 2.42	662 100.00

BY EXPOSURE TO EXCESSIVE WARNING TIMES

FREQUENCY PERCENT ROW PCT COL PCT	EXPOSURE TO EXCESSIVE WARNING TIMES				TOTAL
	1	2	3	4	
NON-VIOLATORS	212	61	96	39	408
	32.02	9.21	14.50	5.89	61.63
	51.96	14.95	23.53	9.56	
	69.74	69.32	53.04	43.82	
VIOLATORS	92	27	85	50	254
	13.90	4.08	12.84	7.55	38.37
	36.22	10.63	33.46	19.69	
	30.26	30.68	46.96	56.18	
TOTAL	304	88	181	89	662
	45.92	13.29	27.34	13.44	100.00

BY RECOGNITION OF VARIABLE WARNING TIMES

FREQUENCY PERCENT ROW PCT COL PCT	RECOGNITION OF VARIABLE WARNING TIMES					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	9	104	150	141	4	408
	1.36	15.73	22.69	21.33	0.61	61.72
	2.21	25.49	36.76	34.56	0.98	
	45.00	57.78	63.56	65.58	40.00	
VIOLATORS	11	76	86	74	6	253
	1.66	11.50	13.01	11.20	0.91	38.28
	4.35	30.04	33.99	29.25	2.37	
	55.00	42.22	36.44	34.42	60.00	
TOTAL	20	180	236	215	10	661
	3.03	27.23	35.70	32.53	1.51	100.00

BY PERCEIVED HAZARD

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED HAZARD					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	9 1.36 2.02 34.62	107 16.16 24.04 53.50	60 9.06 13.48 67.42	221 33.38 49.66 76.47	48 7.25 10.79 82.76	445 67.22
VIOLATORS	17 2.57 7.83 65.38	93 14.05 42.86 46.50	29 4.38 13.36 32.58	68 10.27 31.34 23.53	10 1.51 4.61 17.24	217 32.78
TOTAL	26 3.93	200 30.21	89 13.44	289 43.66	58 8.76	662 100.00

BY PERCEIVED ENFORCEMENT

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED ENFORCEMENT					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	15	148	62	152	30	407
	2.27	22.39	9.38	23.00	4.54	61.57
	3.69	36.36	15.23	37.35	7.37	
	41.67	56.92	62.00	66.09	85.71	
VIOLATORS	21	112	38	78	5	254
	3.18	16.94	5.75	11.80	0.76	38.43
	8.27	44.09	14.96	30.71	1.97	
	58.33	43.08	38.00	33.91	14.29	
TOTAL	36	260	100	230	35	661
	5.45	39.33	15.13	34.80	5.30	100.00

BY DELAY TOLERANCE

FREQUENCY PERCENT ROW PCT COL PCT	DELAY TOLERANCE				TOTAL
	1	2	3	4	
NON-VIOLATORS	6 0.93 1.52 75.00	8 1.23 2.02 53.33	35 5.40 8.84 64.81	51 7.87 12.88 53.68	396 61.11
VIOLATORS	2 0.31 0.79 25.00	7 1.08 2.78 46.67	19 2.93 7.54 35.19	44 6.79 17.46 46.32	252 38.89
TOTAL	8 1.23	15 2.31	54 8.33	95 14.66	648 100.00

FREQUENCY PERCENT ROW PCT COL PCT				TOTAL
	5	6	7	
NON-VIOLATORS	35 5.40 8.84 59.32	71 10.96 17.93 58.20	190 29.32 47.98 64.41	396 61.11
VIOLATORS	24 3.70 9.52 40.68	51 7.87 20.24 41.80	105 16.20 41.67 35.59	252 38.89
TOTAL	59 9.10	122 18.83	295 45.52	648 100.00

BY PERCEIVED DUTIES - NO TRAIN

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED DUTIES - NO TRAIN			TOTAL
	0	1	2	
NON-VIOLATORS	8	152	248	408
	1.21	22.96	37.46	61.63
	1.96	37.25	60.78	
	32.00	53.15	70.66	
VIOLATORS	17	134	103	254
	2.57	20.24	15.56	38.37
	6.69	52.76	40.55	
	68.00	46.85	29.34	
TOTAL	25	286	351	662
	3.78	43.20	53.02	100.00

BY DRIVER TRAINING

FREQUENCY PERCENT ROW PCT COL PCT	DRIVER TRAINING			TOTAL
	0	1	2	
NON-VIOLATORS	127	64	217	408
	19.18	9.67	32.78	61.63
	31.13	15.69	53.19	
	66.49	74.42	56.36	
VIOLATORS	64	22	168	254
	9.67	3.32	25.38	38.37
	25.20	8.66	66.14	
	33.51	25.58	43.64	
TOTAL	191	86	385	662
	28.85	12.99	58.16	100.00

BY RISK-TAKING PROPENSITY

FREQUENCY PERCENT ROW PCT COL PCT	RISK-TAKING PROPENSITY				TOTAL
	0	1	2	3	
NON-VIOLATORS	224	155	26	3	408
	33.84	23.41	3.93	0.45	61.63
	54.90	37.99	6.37	0.74	
	65.50	58.49	56.52	33.33	
VIOLATORS	118	110	20	6	254
	17.82	16.62	3.02	0.91	38.37
	46.46	43.31	7.87	2.36	
	34.50	41.51	43.48	66.67	
TOTAL	342	265	46	9	662
	51.66	40.03	6.95	1.36	100.00

BY AGE

FREQUENCY PERCENT ROW PCT COL PCT	AGE				TOTAL
	16-18	19-24	25-34	35-44	
NON-VIOLATORS	7 1.07 1.74 50.00	72 10.96 17.87 54.14	105 15.98 26.05 53.57	108 16.44 26.80 70.59	403 61.34
VIOLATORS	7 1.07 2.76 50.00	61 9.28 24.02 45.86	91 13.85 35.83 46.43	45 6.85 17.72 29.41	254 38.66
TOTAL	14 2.13	133 20.24	196 29.83	153 23.29	657 100.00

FREQUENCY PERCENT ROW PCT COL PCT	45-54	55-64	65 AND OLDER	TOTAL
NON-VIOLATORS	54 8.22 13.40 65.06	37 5.63 9.18 68.52	20 3.04 4.96 83.33	403 61.34
VIOLATORS	29 4.41 11.42 34.94	17 2.59 6.69 31.48	4 0.61 1.57 16.67	254 38.66
TOTAL	83 12.63	54 8.22	24 3.65	657 100.00

BY EDUCATION

FREQUENCY PERCENT ROW PCT COL PCT	EDUCATION				TOTAL
	LESS THAN HI SCHOOL	HI SCHOOL GRAD	SOME COLLEGE	COLLEGE GRAD	
NON-VIOLATORS	14 2.13 3.47 82.35	95 14.44 23.51 65.52	129 19.60 31.93 61.43	166 25.23 41.09 58.04	404 61.40
VIOLATORS	3 0.46 1.18 17.65	50 7.60 19.69 34.48	81 12.31 31.89 38.57	120 18.24 47.24 41.96	254 38.60
TOTAL	17 2.58	145 22.04	210 31.91	286 43.47	658 100.00

APPENDIX F

FREQUENCY DISTRIBUTION TABLES: TRAIN PRESENT

CROSSING BEHAVIOR - TRAIN

BY ANNUAL MILEAGE

FREQUENCY PERCENT ROW PCT COL PCT	ANNUAL MILEAGE				TOTAL
	1	2	3	4	
NON-VIOLATORS	78	126	123	118	445
	11.78	19.03	18.58	17.82	67.22
	17.53	28.31	27.64	26.52	
	83.87	75.45	61.50	58.42	
VIOLATORS	15	41	77	84	217
	2.27	6.19	11.63	12.69	32.78
	6.91	18.89	35.48	38.71	
	16.13	24.55	38.50	41.58	
TOTAL	93	167	200	202	662
	14.05	25.23	30.21	30.51	100.00

CROSSING BEHAVIOR - TRAIN

BY FREQUENCY OF EXPOSURE

FREQUENCY PERCENT ROW PCT COL PCT	FREQUENCY OF EXPOSURE				TOTAL
	1	2	3	4	
NON-VIOLATORS	57	125	145	118	445
	8.61	18.88	21.90	17.82	67.22
	12.81	28.09	32.58	26.52	
	82.61	70.22	67.76	58.71	
VIOLATORS	12	53	69	83	217
	1.81	8.01	10.42	12.54	32.78
	5.53	24.42	31.80	38.25	
	17.39	29.78	32.24	41.29	
TOTAL	69	178	214	201	662
	10.42	26.89	32.33	30.36	100.00

CROSSING BEHAVIOR - TRAIN

BY REGENCY OF EXPOSURE

FREQUENCY PERCENT ROW PCT COL PCT	REGENCY OF EXPOSURE				TOTAL
	1	2	3	4	
NON-VIOLATORS	18	123	134	170	445
	2.72	18.58	20.24	25.68	67.22
	4.04	27.64	30.11	38.20	
	78.26	72.35	66.67	63.43	
VIOLATORS	5	47	67	98	217
	0.76	7.10	10.12	14.80	32.78
	2.30	21.66	30.88	45.16	
	21.74	27.65	33.33	36.57	
TOTAL	23	170	201	268	662
	3.47	25.68	30.36	40.48	100.00

CROSSING BEHAVIOR - TRAIN
BY LIKELIHOOD OF FALSE ACTIVATIONS

FREQUENCY PERCENT ROW PCT COL PCT	LIKELIHOOD OF FALSE ACTIVATIONS					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	9	94	51	228	63	445
	1.36	14.20	7.70	34.44	9.52	67.22
	2.02	21.12	11.46	51.24	14.16	
	34.62	54.34	70.83	74.27	75.00	
VIOLATORS	17	79	21	79	21	217
	2.57	11.93	3.17	11.93	3.17	32.78
	7.83	36.41	9.68	36.41	9.68	
	65.38	45.66	29.17	25.73	25.00	
TOTAL	26	173	72	307	84	662
	3.93	26.13	10.88	46.37	12.69	100.00

CROSSING BEHAVIOR - TRAIN
BY EXPOSURE TO FALSE ACTIVATIONS

FREQUENCY PERCENT ROW PCT COL PCT	EXPOSURE TO FALSE ACTIVATIONS				TOTAL
	1	2	3	4	
NON-VIOLATORS	163 24.62 36.63 77.25	70 10.57 15.73 74.47	140 21.15 31.46 67.96	72 10.88 16.18 47.68	445 67.22
VIOLATORS	48 7.25 22.12 22.75	24 3.63 11.06 25.53	66 9.97 30.41 32.04	79 11.93 36.41 52.32	217 32.78
TOTAL	211 31.87	94 14.20	206 31.12	151 22.81	662 100.00

CROSSING BEHAVIOR - TRAIN
BY PERCEIVED LEVEL OF MAINTENANCE

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED LEVEL OF MAINTENANCE					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	9 1.36 2.02 60.00	54 8.16 12.13 62.79	204 30.82 45.84 64.76	171 25.83 38.43 73.71	7 1.06 1.57 50.00	445 67.22
VIOLATORS	6 0.91 2.76 40.00	32 4.83 14.75 37.21	111 16.77 51.15 35.24	61 9.21 28.11 26.29	7 1.06 3.23 50.00	217 32.78
TOTAL	15 2.27	86 12.99	315 47.58	232 35.05	14 2.11	662 100.00

CROSSING BEHAVIOR - TRAIN
BY LIKELIHOOD OF EXCESSIVE WARNING TIMES

FREQUENCY PERCENT ROW PCT COL PCT	LIKELIHOOD OF EXCESSIVE WARNING TIMES					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	47 7.10 10.56 65.28	221 33.38 49.66 70.38	87 13.14 19.55 65.41	83 12.54 18.65 65.35	7 1.06 1.57 43.75	445 67.22
VIOLATORS	25 3.78 11.52 34.72	93 14.05 42.86 29.62	46 6.95 21.20 34.59	44 6.65 20.28 34.65	9 1.36 4.15 56.25	217 32.78
TOTAL	72 10.88	314 47.43	133 20.09	127 19.18	16 2.42	662 100.00

CROSSING BEHAVIOR - TRAIN
BY EXPOSURE TO EXCESSIVE WARNING TIMES

FREQUENCY PERCENT ROW PCT COL PCT	EXPOSURE TO EXCESSIVE WARNING TIMES				TOTAL
	1	2	3	4	
NON-VIOLATORS	216	67	109	53	445
	32.63	10.12	16.47	8.01	67.22
	48.54	15.06	24.49	11.91	
	71.05	76.14	60.22	59.55	
VIOLATORS	88	21	72	36	217
	13.29	3.17	10.88	5.44	32.78
	40.55	9.68	33.18	16.59	
	28.95	23.86	39.78	40.45	
TOTAL	304	88	181	89	662
	45.92	13.29	27.34	13.44	100.00

CROSSING BEHAVIOR - TRAIN
BY RECOGNITION OF VARIABLE WARNING TIMES

FREQUENCY PERCENT ROW PCT COL PCT	RECOGNITION OF VARIABLE WARNING TIMES					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	8	112	161	158	6	445
	1.21	16.94	24.36	23.90	0.91	67.32
	1.80	25.17	36.18	35.51	1.35	
	40.00	62.22	68.22	73.49	60.00	
VIOLATORS	12	68	75	57	4	216
	1.82	10.29	11.35	8.62	0.61	32.68
	5.56	31.48	34.72	26.39	1.85	
	60.00	37.78	31.78	26.51	40.00	
TOTAL	20	180	236	215	10	661
	3.03	27.23	35.70	32.53	1.51	100.00

CROSSING BEHAVIOR - TRAIN

BY PERCEIVED HAZARD

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED HAZARD					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	9	107	60	221	48	445
	1.36	16.16	9.06	33.38	7.25	67.22
	2.02	24.04	13.48	49.66	10.79	
	34.62	53.50	67.42	76.47	82.76	
VIOLATORS	17	93	29	68	10	217
	2.57	14.05	4.38	10.27	1.51	32.78
	7.83	42.86	13.36	31.34	4.61	
	65.38	46.50	32.58	23.53	17.24	
TOTAL	26	200	89	289	58	662
	3.93	30.21	13.44	43.66	8.76	100.00

CROSSING BEHAVIOR - TRAIN

BY PERCEIVED ENFORCEMENT

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED ENFORCEMENT					TOTAL
	1	2	3	4	5	
NON-VIOLATORS	17	169	65	165	28	444
	2.57	25.57	9.83	24.96	4.24	67.17
	3.83	38.06	14.64	37.16	6.31	
	47.22	65.00	65.00	71.74	80.00	
VIOLATORS	19	91	35	65	7	217
	2.87	13.77	5.30	9.83	1.06	32.83
	8.76	41.94	16.13	29.95	3.23	
	52.78	35.00	35.00	28.26	20.00	
TOTAL	36	260	100	230	35	661
	5.45	39.33	15.13	34.80	5.30	100.00

CROSSING BEHAVIOR - TRAIN

BY DELAY TOLERANCE

FREQUENCY PERCENT ROW PCT COL PCT	DELAY TOLERANCE				TOTAL
	1	2	3	4	
	+	+	+	+	
	+	+	+	+	
NON-VIOLATORS	6	10	35	56	436
	0.93	1.54	5.40	8.64	67.28
	1.38	2.29	8.03	12.84	
	75.00	66.67	64.81	58.95	
VIOLATORS	2	5	19	39	212
	0.31	0.77	2.93	6.02	32.72
	0.94	2.36	8.96	18.40	
	25.00	33.33	35.19	41.05	
TOTAL	8	15	54	95	648
	1.23	2.31	8.33	14.66	100.00

FREQUENCY PERCENT ROW PCT COL PCT				TOTAL
	5	6	7	
	+	+	+	
	+	+	+	
NON-VIOLATORS	39	86	204	436
	6.02	13.27	31.48	67.28
	8.94	19.72	46.79	
	66.10	70.49	69.15	
VIOLATORS	20	36	91	212
	3.09	5.56	14.04	32.72
	9.43	16.98	42.92	
	33.90	29.51	30.85	
TOTAL	59	122	295	648
	9.10	18.83	45.52	100.00

CROSSING BEHAVIOR - TRAIN

PERCEIVED DUTIES - TRAIN

FREQUENCY PERCENT ROW PCT COL PCT	PERCEIVED DUTIES - TRAIN					TOTAL
	0	1	2	3	4	
NON-VIOLATORS	3	3	126	63	250	445
	0.45	0.45	19.03	9.52	37.76	67.22
	0.67	0.67	28.31	14.16	56.18	
	42.86	75.00	62.07	54.31	75.30	
VIOLATORS	4	1	77	53	82	217
	0.60	0.15	11.63	8.01	12.39	32.78
	1.84	0.46	35.48	24.42	37.79	
	57.14	25.00	37.93	45.69	24.70	
TOTAL	7	4	203	116	332	662
	1.06	0.60	30.66	17.52	50.15	100.00

CROSSING BEHAVIOR - TRAIN

BY DRIVER TRAINING

FREQUENCY PERCENT ROW PCT COL PCT	DRIVER TRAINING			TOTAL
	0	1	2	
NON-VIOLATORS	139	61	245	445
	21.00	9.21	37.01	67.22
	31.24	13.71	55.06	
	72.77	70.93	63.64	
VIOLATORS	52	25	140	217
	7.85	3.78	21.15	32.78
	23.96	11.52	64.52	
	27.23	29.07	36.36	
TOTAL	191	86	385	662
	28.85	12.99	58.16	100.00

CROSSING BEHAVIOR - TRAIN
BY RISK-TAKING PROPENSITY

FREQUENCY PERCENT ROW PCT COL PCT	RISK-TAKING PROPENSITY				TOTAL
	0	1	2	3	
NON-VIOLATORS	237 35.80 53.26 69.30	179 27.04 40.22 67.55	23 3.47 5.17 50.00	6 0.91 1.35 66.67	445 67.22
VIOLATORS	105 15.86 48.39 30.70	86 12.99 39.63 32.45	23 3.47 10.60 50.00	3 0.45 1.38 33.33	217 32.78
TOTAL	342 51.66	265 40.03	46 6.95	9 1.36	662 100.00

CROSSING BEHAVIOR - TRAIN

BY AGE

FREQUENCY PERCENT ROW PCT COL PCT	AGE				TOTAL
	16-18	19-24	25-34	35-44	
NON-VIOLATORS	12	77	129	103	440
	1.83	11.72	19.63	15.68	66.97
	2.73	17.50	29.32	23.41	
	85.71	57.89	65.82	67.32	
VIOLATORS	2	56	67	50	217
	0.30	8.52	10.20	7.61	33.03
	0.92	25.81	30.88	23.04	
	14.29	42.11	34.18	32.68	
TOTAL	14	133	196	153	657
	2.13	20.24	29.83	23.29	100.00

FREQUENCY PERCENT ROW PCT COL PCT	AGE			TOTAL
	45-54	55-64	65 AND OLDER	
NON-VIOLATORS	51	48	20	440
	7.76	7.31	3.04	66.97
	11.59	10.91	4.55	
	61.45	88.89	83.33	
VIOLATORS	32	6	4	217
	4.87	0.91	0.61	33.03
	14.75	2.76	1.84	
	38.55	11.11	16.67	
TOTAL	83	54	24	657
	12.63	8.22	3.65	100.00

CROSSING BEHAVIOR - TRAIN

BY EDUCATION

FREQUENCY PERCENT ROW PCT COL PCT	EDUCATION				TOTAL
	LESS THAN HI SCHOOL	HI SCHOOL GRAD	SOME COLLEGE	COLLEGE GRAD	
NON-VIOLATORS	13 1.98 2.95 76.47	95 14.44 21.54 65.52	148 22.49 33.56 70.48	185 28.12 41.95 64.69	441 67.02
VIOLATORS	4 0.61 1.84 23.53	50 7.60 23.04 34.48	62 9.42 28.57 29.52	101 15.35 46.54 35.51	217 32.98
TOTAL	17 2.58	145 22.04	210 31.91	286 43.47	658 100.00

VITA

Stephen H. Richards was born in Austin, Texas, on July 19, 1952, the son of Harold and Janice Richards. He graduated from Austin's McCallum High School in 1970, and he received a Bachelor of Science Degree in Civil Engineering from the University of Texas at Austin in 1976.

While working on his bachelor's degree, the author worked for five years as an Engineer Aide for the Texas State Department of Highways and Public Transportation. Upon receiving his bachelor's degree, he attended Texas A&M on a FHWA Highway Safety fellowship, and was awarded a Master of Engineering Degree in Civil Engineering in 1977. He began working at the Texas Transportation Institute at Texas A&M as a graduate student and remained on the TTI staff after graduation as an Engineering Research Associate and later as Associate Research Engineer.

In 1984, the author accepted a position as Assistant Director of the Transportation Center at the University of Tennessee. He is still on the Center staff, currently serving as Acting Director. In 1989, the author received a Doctor of Philosophy Degree in Civil Engineering from the University of Tennessee. The author is a Registered Professional Engineer in Tennessee and Texas, and he is active in numerous professional organizations. Presently, he is serving a four-year term as a Commissioner on the Knoxville Transportation Authority.

The author is married to the former Pamela Hobbs, and they reside in Knoxville, Tennessee, with their three children, Adam, Nicole, and Holly.