To the Graduate Council:

I am submitting herewith a dissertation written by John Edward Tidwell, Jr. entitled "Highway-Railway Grade Crossing Safety: Driver Perception of Hazard and Risk." I recommend that it be accepted in partial fullfillment of the requirements for the degree of Doctor of Philosophy, with a major in Civil Engineering.

Jack B. Humphreys, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

HIGHWAY-RAILWAY GRADE CROSSING SAFETY: DRIVER PERCEPTION OF HAZARD AND RISK

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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ABSTRACT

Research was conducted in the area of driver knowledge and perception of hazard and risk relative to highway-railway grade crossing safety. The literature was reviewed for prior work in this area. A questionnaire was developed to determine driver knowledge regarding grade crossing safety. The questionnaire was administered to 829 subjects at a drivers' license examining station. The results of this effort indicated several areas of deficient driver knowledge concerning grade crossings.

Field studies were then conducted to relate safe driving behavior on approaches to grade crossings to the knowledge level of the drivers approaching the crossing. A criteria for classifying a driver as performing safely was developed. Various indices of driver behavior were related to the knowledge groups. No relationship was found between good knowledge and good driving performance. Driver behavior at the crossings indicated that many drivers manifested a desire to perform safely, by making head movement, at restricted sight distance crossings. However, the drivers were making head movement at inappropriate locations. Thus, they could not be classified as safe performers.

The findings from the field observations led to the development of a procedure for establishing advisory speeds for passive grade crossings. These would ensure an accident free crossing for motorists desiring to perform safely.

A new priority procedure was also developed for upgrading passive crossings. This procedure uses the concept of safe-unsafe performing drivers at the crossings under consideration. The procedure gives a direct evaluation of the drivers perception of the geometrics and sight distance at the crossing.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	Problem Description	1
	Review of the Literature	5
	Objectives	13
	Research Procedure	13
II.	DRIVER KNOWLEDGE INVESTIGATION	16
	Data Collection Procedures Available	16
	Legal requirements	18
	Traffic control devices	20
	Driver acquisition of knowledge	22
	Prior Research Concerning Driver Knowledge	25
III.	METHODOLOGY FOR DRIVER KNOWLEDGE INVESTIGATION	29
	Study Design	29
	Description of Data Collection Procedure	31
IV.	RESULTS AND CONCLUSIONS FROM DRIVER KNOWLEDGE INVESTIGATION	38
	Results	38
	Findings and Recommendations	50
V.	LITERATURE REVIEW FOR INVESTIGATION OF RELATIONSHIP OF DRIVER PERFORMANCE TO DRIVER KNOWLEDGE	57
VI.	METHODOLOGY FOR INVESTIGATION OF RELATIONSHIP OF DRIVER PERFORMANCE TO DRIVER KNOWLEDGE	59
	Study Design	59
	Procedure for Collecting Driver Performance Data	60
	Procedure for Collecting Data on Driver Knowledge	64
	Conduct of Study	66
VII.	RESULTS AND CONCLUSIONS FROM INVESTIGATION OF RELATIONSHIP OF DRIVER PERFORMANCE TO DRIVER KNOWLEDGE	70
	Results	70
	Analysis of Data	70
	Findings and Recommendations	88

CHAPTER		PAGE
VIII.	LITERATURE REVIEW FOR INVESTIGATION OF ADVISORY SPEEDS FOR GRADE CROSSINGS	92
	The Need for Advisory Speed Signing at Grade Crossings	92
	Current Practice for Advisory Speed Signing	92
IX.	METHODOLOGY FOR INVESTIGATION OF ADVISORY SPEEDS FOR GRADE CROSSINGS	95
	Establishing an Advisory Speed for Grade Crossings	95
	Illustration of Procedure for Establishing Advisory Speeds	96
	Location of Advisory Speed Signs for Grade Crossings	103
X.	RESULTS AND CONCLUSIONS FROM INVESTIGATION OF ADVISORY SPEEDS FOR GRADE CROSSINGS	106
	Results	106
	Findings and Recommendations	106
XI.	LITERATURE REVIEW FOR INVESTIGATION OF PRIORITY PROCEDURES FOR GRADE CROSSING IMPROVEMENTS	108
	Evaluation of Driver Performance at Passive Crossings	108
	Importance of Sight Distance	109
	Current Measures of Effectiveness for Evaluating Driver Performance	110
	Procedures Currently Used to Develop Priorities	115
	Priority Procedures Used by the States	117
XII.	METHODOLOGY FOR INVESTIGATION OF PRIORITY PROCEDURES FOR GRADE CROSSING IMPROVEMENTS	123
	Incorporation of Driver Performance into Priority Procedures	123
	New Method for Developing Priorities	124
	Illustration of New Priority Procedure	133
XIII.	RESULTS AND CONCLUSIONS FROM INVESTIGATION OF PRIORITY PROCEDURES FOR GRADE CROSSING IMPROVEMENTS	142
	Results	142
	Findings and Recommendations	142
XIV.	CONCLUSIONS	144

CHAPTER PAGE

Summary 144
Overall Findings and Recommendations 144

BIBLIOGRAPHY 148

APPENDICES 153

A. DEFICIENCIES IN STATE LAWS REGARDING GRADE CROSSINGS 154

B. DRIVERS' TRAINING MATERIAL RELATIVE TO RAILROAD CROSSINGS 160

C. DERIVATION OF EQUATION USED TO DETERMINE DISTANCE AND SPEED AT THE TIME OF HEAD MOVEMENT 165

D. RESPONSES TO QUESTIONNAIRE ADMINISTERED AT SITE ONE 169

E. RESPONSES TO QUESTIONNAIRE ADMINISTERED AT SITE TWO 171

F. OBSERVED DRIVER BEHAVIOR AT SITE ONE 174

G. OBSERVED DRIVER BEHAVIOR AT SITE TWO 177

H. FORMULAE AND WARRANTS USED BY STATES WHICH CONSIDER SIGHT DISTANCE (1977) 180

VITA 213

LIST OF TABLES

TABLE		PAGE
1.	Federal-Aid Highway Funds Authorized for Projects to Reduce the Hazards at Grade Crossings (2)	3
2.	Response to Questions from Dommasch (12) and Sanders (9) Study	27
3.	List of Suggestions Made by Questionnaire Respondents-Regarding other Traffic Related Measures to Improve Safety at Grade Crossings	40
4.	Frequency Distribution of Correct Answers for Respondents	41
5.	Comparison of Age Distribution of Sample with that of Population of Licensed Tennessee Drivers	43
6.	Comparison of Sex Ratio of Sample with that of Population of Licensed Tennessee Drivers	44
7.	Sight Distances at Sites One and Two	68
8.	Aggregated Responses to Questionnaire Administered at Sites One and Two and Pooled Data	71
9.	Perception-Reaction Times and Braking Distances for Various Speeds (Dry Pavement)	78
10.	Driver Behavior at Sites One and Two and Pooled Data Related to Responses to Questions Grouped According to Correct and Incorrect Answers	81
11.	Results of Statistical Tests for Significant Differences between Groups-Site One	83
12.	Results of Statistical Tests for Significant Differences between Groups-Site Two	84
13.	Comparison of Responses to Four Questions Asked at Two Field Sites to Those Received at the Drivers' License Examining Station	85
14.	Results of Statistical Tests for Significant Differences between Groups-Pooled Data	87

TABLE		PAGE
15.	Candidate Advisory Speeds-Crossing Number One	97
16.	Candidate Advisory Speeds-Crossing Number Two	100
17.	Stopping Sight Distance Requirements Assuming Wet Pavement Conditions	101
18.	Illustrative Data for Use in Priority Procedures	134
19.	Results of Illustrative Ranking Using New Hampshire Formula	136
20.	Results of Illustrative Ranking Using NCHRP 50 Formula	138
21.	Results of Illustrative Ranking Using New Procedure	139
22.	Comparison of Illustrative Ranking of Ten Grade Crossings by Three Methods	140
23.	Responses to Questionnaire Administered at Site One	170
24.	Responses to Questionnaire Administered at Site Two	172
25.	Observed Driver Behavior at Site One	175
26.	Observed Driver Behavior at Site Two	178

LIST OF FIGURES

FIGURE		PAGE
1.	Questionnaire Used at Drivers' License Examining Station . .	32
2.	Questionnaire Used in Field Study	65
3.	Plot of Time Space Diagram for Train Arrival at Site One	72
4.	Plot of Time Space Diagram for Train Arrival at Site Two	73
5.	Two Conditions of Train and Highway Vehicle Interaction Necessary for Safe Performance	76
6.	Flow Chart for Data Collection to Determine Number of Unsafe Drivers Using a Grade Crossing	126
7.	Approach Speed Profile Used to Determine Distance and Speed at Time of Head Movement	166

CHAPTER I

INTRODUCTION

This dissertation contains a description of research into methods of developing and selecting countermeasures to improve safety at railroad highway grade crossings, hereafter referred to as grade crossings. Driver knowledge, attitudes, and behavior associated with grade crossings were investigated. Methods for evaluating driver performance at passive grade crossings were also examined and an improved technique was developed for use in evaluating driver performance at grade crossings and establishing priorities for grade crossing improvements.

I. PROBLEM DESCRIPTION

The intersection of highways and railways has been a safety problem since the beginning of the American Railroad Industry in 1830. In 1976, there were 12,114 accidents, 4,886 injuries, and 1,168 fatalities at grade crossings. (1) During the period from 1920 to 1974, 79,157 persons lost their lives at the intersection of highways with railroads. (2) Beginning with the Federal-Aid Road Act of 1916, the United States Congress acknowledged the national interest in this problem by making Federal funds available for reducing the hazards of grade crossings. These efforts have been directed at "construction" oriented solutions to the problem. Federal-Aid funds have been used to construct highway-railway grade separation structures and to install warning devices. In some instances railroads were required to contribute to the cost of the projects.

However, prior to 1973 there was no special class of funds set aside to be used only for grade crossing improvement. Any funds used for this purpose had to come from a state's total apportionment of Federal-Aid funds. In other words, grade crossing projects had to compete with other types of highway projects.

When Congress enacted the Federal Highway Safety Act of 1973, Section 203 of this act provided separate funding for grade crossing projects. The funding was substantial and has been continued through the 1978 Federal Aid Highway Act. Federal funds which have been authorized for reducing the hazards of highway railway grade crossings are shown in Table 1.

These funds are available at a 90% Federal matching ratio. The remaining 10% is to come from state and/or local governments. The projects are to be administered by the state with appropriate agreements with the railroads and local governments. These funds total $1.35 billion and will generate $1.5 billion in construction project funding when the required 10% matching funds are included.

The bulk of the expenditure of these funds has been to convert passive crossings to active crossings. (3) The standard traffic control devices at a passive railroad grade crossing consist of signs and pavement markings to warn a driver that a grade crossing is being approached. There is no warning provided when a train is approaching the crossing. A passive crossing requires that the driver adjust the vehicle's approach speed properly and look for a train to avoid a collision. On the other hand, an active crossing does have a warning device (flashing lights, with or without gates) to warn of an approaching train.

TABLE 1

FEDERAL-AID HIGHWAY FUNDS AUTHORIZED FOR PROJECTS
TO REDUCE THE HAZARDS AT GRADE CROSSINGS (2)

FEDERAL AID HIGHWAY ACT	FISCAL YEAR FUNDS	ON FEDERAL SYSTEM	OFF FEDERAL SYSTEM	ALL PUBLIC ROADS
1973	74	$ 25M		
	75	75		
1976	76	75	$18.75M	
	77	125	75	
1978	78	125	75	
	79			$190M
	80			190
	81			190
	82			190

The United States General Accounting Office (GAO) investigated the Federal-Aid Grade Crossing Program in 1978 (4) and made the following recommendations:

> The Secretary of Transportation should require the Federal Highway Administration, Federal Railroad Administration, and the National Highway Traffic Safety Administration to cooperate with the states and railroads in establishing a nationwide level of safety acceptable for rail-highway crossings and determining the best mixture of methods, including education and enforcement, to achieve that level.

The GAO recommendations were based on the fact that there are no nationally recognized warrants for providing separation structures or active warning signals at grade crossings. At present, the states are developing priority lists based on various hazard ranking formulas and procedures. The states then apply their share of the $1.5 billion to their lists and improve the most hazardous crossings. However, an acceptable level of risk has not been established in order to determine how far down the lists projects should be funded. The GAO also pointed out that the program is completely construction oriented with no attention being directed at education or enforcement.

According to the 1976 National Railroad-Highway Grade Crossing Inventory, the following facts are applicable to low volume crossings (Crossings with less than five train movements per day). (2)

Trains Per Day	Urban Crossings No.	Urban Crossings Percent	Rural Crossings No.	Rural Crossings Percent	Total Crossings No.	Total Crossings Total
0-2	51,490	47	53,508	49	104,998	48
3-5	17,088	16	17,483	16	34,571	16
Grand Total	109,587		109,714		219,301	

Therefore, there are a substantial number of low train volume crossings. Due to the limited availability of funds for improving grade crossings, it is anticipated that most of these low train volume crossings will remain passive crossings.

II. REVIEW OF THE LITERATURE

The problem of accidents at grade crossings is critical, particularly when severity ratio is considered. When transportation related accidents are considered, the accident severity for grade crossing accidents is exceeded only by aviation accidents. (2) As stated in the previous section, almost all the Federal funding effort has been directed at construction oriented solutions. However, the grade crossing system is composed of the highway vehicle, highway driver, train, locomotive engineer, environment (physical crossing, signs, etc.) and legal requirements concerning grade crossings. A failure in any part of the system increases the probability of an accident. For instance, a car that stalls on the crossing or an active warning device that fails to operate are contributory factors to accident potential. Many parts of the system such as highway vehicle condition, highway driver sobriety, distractions to the driver which occur inside of the highway vehicle, etc. are related to highway safety in general. Failure of these types of system components would affect highway safety at all points along the highway. However, there are parts of the system which directly relate to safety at the crossing. Throughout the past 60 years, research has

been conducted on various components of the system specifically related to crossing safety.

The following documents summarize the published grade crossing research:

1. Railroad-Highway Grade Crossing Bibliography, 1976, Transportation Research Board. (5)

2. Summary of Railroad-Highway Grade Crossing Research Activity, Transportation Research Board, Circular 190. (6)

3. Federal Coordinated Research Program--Task 1-0-1, Railroad Grade Crossings. (7)

4. Highway Research Information Service (HRIS) Selections Pertaining to Rail-Highway Grade Crossing Safety. (8)

A brief discussion concerning some of the more significant research findings and work presently in progress follows.

Extensive research has taken place in an effort to improve signing at passive crossings. (9, 10, 11, and 12) In 1973, Sanders (9) investigated techniques for evaluating countermeasures for improving safety at passive grade crossings. Procedures were developed using driver looking behavior, crossing speed, and speed decrease as response measures in experimental designs for evaluating new countermeasures. The techniques were demonstrated on a system of advance warning signals using continuous flashing lights attached to the standard advance warning sign.

In 1977, Dommasch, et al. (12) experimented with two combinations of experimental advance warning and crossing signs. "Before" and "after" studies measured the effectiveness of the treatments. The effectiveness was measured using motorist interviews, observed brake light applications, and spot-speed studies. The study concluded that

all of the control changes increased awareness of the crossing as measured by the selected response measures.

During the period from 1975 to 1978, a comprehensive study was undertaken to investigate improved signing for passive crossings. (10) This research was a joint effort between the Federal Highway Administration and some 25 states which participated in the pooled-fund effort. Candidate signing systems were proposed by an advisory committee composed of representatives of each of the sponsoring states, the Federal Railroad Administration, the Association of American Railroads, and the Federal Highway Administration.

Seven treatments were selected for evaluation and comparison with the standard signing for passive crossings. The signs were evaluated at five test sites in Ohio and one site in Maine. The treatments were evaluated by the use of driver head movements and speed profiles. The most effective signs from the initial experiment were then tested at a national level (18 sites in 14 states). These tests showed that drivers demonstrated more awareness of the crossing, as evidenced by head movements, with the new signs. As a result of the research findings, the State Advisory Committee concluded that one of the revised signs could be translated into 2-3% reduction in average accident rate.

The group subsequently recommended to the National Advisory Committee (NAC) on Uniform Traffic Control Devices that a new red and yellow advance warning sign be adopted as a national standard. However, the NAC denied the request for the following reasons:

1. The new sign did not reduce the speed of vehicles.

2. The significance of a 5% increase in head movements was not sufficient justification upon which to base a change in the national standards.
3. There were no indications of the potential safety benefits of the proposed new sign.
4. The economic impact of replacing the existing standard signs had not been determined. (13)

However, the NAC did recommend that additional experimentation with the proposed advance warning sign be permitted to determine its safety potential.

As a follow-up to the NAC's recommendation for further experimentation, Berg (14) investigated the development of an experimental design and analysis plan for field testing and evaluating the accident reduction potential of the new sign. The results of this investigation indicated that due to the need for a large sample size, the proposed accident study would be both experimentally and economically impractical. At present, the probability of adopting the new sign is extremely low.

The joint State-FHWA pooled fund investigation (10) was comprehensive and required considerable funding. However, it did not result in a change from the standard signing. Therefore, it is reasonable to assume that, at least for the next several years, passive grade crossings will continue to be signed in accordance with the present signing system.

One signing countermeasure available to public officials is the STOP sign. Section 2B-2 of the Manual of Uniform Traffic Control Devices (15) permits the use of STOP signs at grade crossings after their need has been determined by a detailed traffic engineering study. Approach speeds, sight distance restrictions, volumes, accident records, etc. are to be considered. STOP signs are to be used only as an interim measure until active devices can be installed or other actions taken. The traffic engineering profession has been reluctant to go to extensive use of STOP signs at grade crossings because of the potential of the driver ignoring the signs at grade crossings and, thereby, breeding contempt for the standard STOP sign which could carry over to highway intersection applications. Sanders et al. (16) investigated the use of STOP signs at grade crossings. This study examined grade crossings which were signed with STOP signs. Field studies were conducted to compare driver behaviors for crossbuck-only crossings to driver behavior for similar crossings having a standard STOP sign in addition to the crossbuck. The measures of driver behavior were speed profiles, looking behavior, and observance of STOP signs. The study found that there was no transfer of adverse stopping behavior between the grade crossing STOP sign and a nearby intersection STOP sign. The acceptable stopping rate at an adjacent intersection was similar to that reported by other researchers on driver obedience to intersection STOP signs. When compared with crossings without STOP signs, accident rates were lower for the similar high vehicle-train volume exposure crossings with STOP signs.

The study concluded that STOP signs should be applied selectively only at hazardous passive grade crossings. The report gives criteria for the effective use of STOP signs at grade crossings.

The area of active warning devices has also been well investigated. A substantial problem exists with the standard railroad flasher due to the requirement for standby power in the event of a line power failure. The flashers are limited to a 25 watt bulb to reduce standby battery drain in the event of a power failure. Because of this wattage limitation, the flasher uses special reflectors and tightly focused lens to concentrate the light at the point where a driver must make a decision to stop in order to safely decelerate to the crossing. Investigations into the use of strobe bulbs have indicated a potential for better conspicuity without additional battery drain. (17, 18) A research project currently being considered by the Transportation Research Board may investigate the feasibility of using line current and high wattage bulbs. This study would use the existing grade crossing signal hardware as a base. A system would be developed which provides illumination at least equal to that of a standard 12 inch traffic signal by using 110 volt commercial power during the time the signals are not operating on standby power. The problem statement calls for the demonstration of the new warning system at a number of field locations. The effectiveness of the new system will be evaluated. As of this time, the study has not been funded.

Another project has recently been completed that demonstrated the feasibility of reducing the cost of active protection with gates. (19)

The Federal Highway Administration is currently sponsoring a project to investigate the feasibility of providing active advance warning signing. (20) This system would be activated shortly before the signal at the crossing is activated.

Methods of setting priorities for installing grade crossing safety devices have been well investigated. Perhaps the best known method is based on the use of the Peabody-Dimmick equation. (21) As a requirement for use of the Federal-Aid funds for improving grade crossings, each state has had to select some rational method for determining the relative hazard for grade crossings. There are, at present, several formulas available. (2, 22) The priority formalae used by several states are presented in Appendix A. The Federal Railroad Administration's (FRA) accident data and the U. S. Department of Transportation (DOT)-American Association of Railroads (AAR) grade crossing inventory data were used to develop regression equations for predicting accidents based on several variables. (23) To date, no satisfactory method has been developed to include all pertinent variables into a rational formula.

The evaluation of grade crossing improvements has been carried out in a limited number of studies. (24, 25) Statistical evaluation of grade crossing improvements is difficult due to the relatively low number of accidents which are spread over a great number of crossings. Perhaps the best known evaluation study was that conducted by the California Public Utilities Commission which investigated the scope of the vehicle-train accident problem in California. (25) The effectiveness of various types of protection devices was investigated and accident

records were examined. Questionnaires were also sent to all cities and counties in California to determine the warrants and decision making processes used by the units of local governments in selecting crossings for improvement. The research did not yield a satisfactory regression equation to predict future accident rates. However, a schedule was developed for use as an estimate of the relative value of protective devices in California. Using crossbucks as a base, the ratios of estimated reductions in vehicle-train accident rate for wig-wag, flashing lights, and automatic gates were 0.63, 0.33, and 0.13, respectively. In other words, gates were almost three times as effective as signals alone.

One conclusion from this review indicates that the bulk of the current grade crossing research funding has been directed at grade crossing traffic control devices. However, more and better traffic control devices may not be the optimum management solution to the problem. The 1976 National FRA accident statistics indicated that 454 persons (44% of total fatalities) were killed at crossings with active protection. Of these, 61 fatalities occurred when a driver drove around a lowered gate. Recent studies have indicated that up to 35% of the drivers surveyed believed that all grade crossings had active protection. (9, 12) It may well be that a contributing factor to the grade crossing accident problem is the lack of knowledge on the part of a significant portion of drivers concerning traffic control devices and driver responsibility at the crossing. Whether or not a driver performs

safely at a grade crossing may be influenced by the driver's perception of the true hazard and risk associated with grade crossings.

Based on the potential for adding to the level of knowledge concerning crossing safety, research in the area of driver perception of risk and hazard associated with grade crossings was conducted by the author and is reported herein.

III. OBJECTIVES

The objective of this research was to investigate driver knowledge and behavior relative to grade crossings. Using the results of these investigations, recommendations were to be made regarding improved countermeasures for grade crossings and an improved grade crossing program management process. As a major part of this management process, a rational method for establishing priorities for upgrading passive grade crossings were to be developed.

Current methods of establishing priorities do not utilize driver behavior at the crossings under consideration, thereby omitting one of the most important considerations in determining the relative probability of train-vehicle collisions at grade crossings. The method to be developed was to include driver behavior at the grade crossings under consideration as an independent variable in the evaluation process.

IV. RESEARCH PROCEDURE

The problem to be investigated was composed of four parts. The first part was a determination of the proportion of drivers who have

knowledge deficiencies in the following areas:

1. The standard traffic control devices used at grade crossings.
2. Actions which should be taken upon seeing the traffic control devices used at grade crossings.
3. The true hazard of grade crossings.

The second part of the problem was to determine which, if any, of the above knowledge deficiencies contribute to unsafe behavior at grade crossing.

Based on observation of driver performance at passive crossings, advisory speed signing procedures were then developed.

The last part of this effort was to make a detailed investigation of driver behavior at passive crossings and develop techniques for evaluating driver behavior on approaches to grade crossings. These techniques were utilized to modify existing procedures for establishing priorities for improving grade crossings.

The present research effort is documented in four modules:

1. Investigation of Driver Knowledge (Chapters II-IV).
2. Investigation of Relationship of Driver Performance to Driver Knowledge (Chapters V-VII).
3. Investigation of Advisory Speeds for Grade Crossings (Chapters VIII-X).
4. Investigation of Priority Procedures for Grade Crossing Improvements (Chapters XI-XIII).

Each of the four modules contains a chapter on the literature review, the methodology, and the results and conclusions from the particular investigation. Chapter XIV summarizes the conclusions from the entire present research effort.

CHAPTER II

DRIVER KNOWLEDGE INVESTIGATION

I. DATA COLLECTION PROCEDURES AVAILABLE

The passive grade crossing system requires that a driver select a safe approach speed and look and listen for a train. Public authorities and the railroads use standard traffic control devices to warn a driver of the presence of a crossing. The states also have legal requirements for driving behavior on approaches to grade crossings.

Therefore, the operation of a safe passive grade crossing system requires that drivers have adequate knowledge of the traffic control devices and laws associated with grade crossings. Also, drivers need to know the true hazard at a grade crossing if they are to have the volition to perform safely.

The problem may be compared to a marketing problem. Public authorities are striving to sell a product (safe behavior) each time a driver approaches a grade crossing. The product is safe driving behavior at the crossing. It is apparent from the accident statistics that the product is not being "purchased" by a portion of the driving public (the customers). A businessman trying to sell a product is concerned with a marketing mix. (26) The marketing mix is made up of product, place, price, and promotion. In this case, the product (safe behavior) is fixed. The place is, of course, every grade crossing location. The price the customer (driver) is asked to pay is time and

attention. The promotion might be compared to the traffic control devices, driver education, safety campaigns, and enforcement actions which strive to persuade the driver to operate the vehicle safely at grade crossings.

In order to find out why the customer is not buying the product, public authorities need to know if the customer recognizes the product. Then, the customer's desire to buy the product needs to be known. The pertinent questions are; "Do drivers recognize grade crossing traffic control devices and is their knowledge of the true hazard of grade crossings sufficient to motivate them to perform safely?" There are two basic means of gathering data for marketing research purposes--communication and observation. (27) The communication technique is based upon questionnaires. These may be administered verbally or in writing, with written or verbal responses. The observation technique includes laboratory or natural settings.

The present research effort utilized questionnaires and field observation studies to determine the scope and types of driver knowledge deficiencies that may significantly contribute to the grade crossing accident problem. A carefully designed questionnaire was used. Information was gathered from a sample of licensed Tennessee drivers. The information gathered included:

1. Recognition of standard traffic control devices (both active and passive).

2. Knowledge concerning action which should be taken when encountering these devices.
3. Knowledge concerning facts which may affect a driver's perception of the hazard of grade crossings.

However, prior to presenting the present research methodology and findings, a review of the pertinent literature relative to this subject is presented. Also, a general discussion concerning driver knowledge acquisition of grade crossing information follows.

Legal Requirements

Each state has laws concerning driver responsibilities at railroad grade crossings. For example, Section 59-845 of the Tennessee Motor Vehicle Laws (28) states:

> Obedience to signal indicating approach of train (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 fifty (50) feet but not less than fifteen (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 electrical 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 one thousand five hundred (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.

Other grade crossing related sections of the Tennessee Motor Vehicle Laws concern stop signs at crossings, vehicle types which must stop at all crossings, heavy equipment movement at crossings, parking near crossings, and driving to the left of the centerline when approaching a crossing. (28) It should be noted that Tennessee's laws do not state how a driver should approach a crossing when none of the four conditions listed above are present. In other words, "How should drivers approach a crossing, with limited sight distance, where they may not see or hear a train, if they are driving at the speed limit for the highway?"

Section 11 of the Uniform Vehicle Code (UVC) (29) covers drivers' duties at railroad grade crossings. Many states have revised their laws to closely conform with the Uniform Vehicle Code. However, in 1979, the National Highway Traffic Safety Administration (NHTSA) conducted a comparative study of the railroad grade crossing laws of the various states. This study (30) pointed out 18 areas where a substantial number of states have serious deviations from the Uniform Vehicle Code. (See Appendix A) Concerning the Tennessee deficiency noted earlier, the UVC states:

> No person shall drive a vehicle at a speed greater than is reasonable and prudent under the conditions and having regard to the actual and potential hazards then existing. Consistent with the foregoing, every person shall drive at a safe and appropriate speed when approaching and crossing an intersection or railroad crossing, when approaching and going around a curve, when approaching a hill crest, when traveling upon any narrow or winding roadway, and when special hazards exist with respect to pedestrians or other traffic or by reason of weather or highway conditions.

Tennessee is cited as not having this basic speed rule. Other states are also cited as deviating from the UVC. However, the nonuniformity of motor vehicle laws will probably continue to be a fact of life unless Federal rules of the road are instituted, which seems relatively unlikely. The NHTSA, no doubt, will continue to encourage the states to voluntarily adopt the UVC. The goal of Uniform Traffic Laws is clearly set forth in National Highway Safety Standard No. 2 (31) as authorized under the 1966 Highway Safety Act.

In summary, even though there is nonuniformity and degrees of deficiencies all states have laws regarding grade crossings.

Traffic Control Devices

In order for drivers to obey the legal requirements concerning grade crossings they must be aware that they are approaching a grade crossing. This awareness is typically obtained through signs or other traffic control devices. The Manual on Uniform Traffic Control Devices (MUTCD) (15) sets forth the traffic control devices for use in various circumstances, including grade crossings.

The MUTCD calls for the following devices at passive crossings:

1. Advance Railroad Warning Sign at essentially all crossings, with a few exceptions, which are stated in Section 8B-3 of the MUTCD. This sign is to be located 750 feet in advance of a rural crossing and 250 feet in advance of an urban crossing. (Section 8B-3 MUTCD) (15)

2. Railroad Crossing (Crossbuck) Sign at all crossings. At least one sign shall be errected at each crossing approach. There is provision for a back-to-back installation in Section 8B-3 of the MUTCD.

3. Pavement Markings are required at all approaches to all active grade crossings and all passive crossings where the prevailing speed of highway traffic is 40 mph or greater. (Section 8B-3, MUTCD)

Various other signing as described in the MUTCD is also available to public authorities, such as signs to specify multiple tracks, crossing exempt from mandatory stops, turn restrictions, no stopping on tracks, and advisory speed plates. The traffic control devices described as relating to passive crossings serve the purpose of warning drivers in a standard manner that they are approaching a crossing. It is anticipated that the driver will take note that a crossing is being approached and give a standard safe response in accordance with legal requirements.

Traffic control devices at active crossings (signalized) are basically the same. However, along with the crossbuck sign, a flashing light signal with or without a gate, is provided. Those signals may be post mounted or cantilevered. The criteria for using cantilevered signals or gates instead of post mounted signals is contained in Section 8C-3 of the MUTCD. (15) These signals are activated upon the approach of a train to the crossing. The drivers are expected to note the activated signals and perform in a safe and lawful manner, since they have been warned of the presence of a train.

The various states use a multitude of formulae and procedures in selecting passive crossings for upgrading to active protection. These various formulae have been documented by Sandford. (32) The basic procedure is for a state to use a hazard ranking formula process to rank its railroad crossings. The high priority crossings are considered to be those which the formula process identifies as being the more hazardous.

Driver Acquisition of Knowledge

A basic question to be considered is, "How do drivers learn about traffic control devices and driver responsibility associated with grade crossings?" Drivers generally acquire knowledge in these areas through:

1. Formal driver training programs conducted by public schools.
2. Commercial driver training organizations.
3. Public Safety campaigns.
4. Drivers' licensing and testing procedures (review of drivers' handbook).
5. Instruction from parents or friends.
6. Driving experience.

The driver licensing process is fairly standard among the states. The basic source of communication concerning all driving rules, including driving safety at railroad crossings, is a drivers' handbook published by each state. The handbooks are used in preparing a new applicant to take a driver's test and as supplemental texts in drivers' education courses. Given the heavy reliance on these manuals, any deficiencies in them are very important. In 1972 and 1974, the American Railway Engineering Association conducted a study of the drivers' handbooks of the 50 states to examine railroad crossing information being provided to drivers. (33)

Some of the deficiencies in the driver instruction manuals used by the 50 states which were pointed out in that study were:

1. Six of the 50 states do not display and define the railroad advance warning sign.

2. Only 25 manuals pictured the crossbuck sign.

3. Only 11 states displayed the standard railroad signal.

From the above deficiencies it can be concluded that the differences between active and passive crossings and driver responsibilities at each are not adequately covered in several states. The railroad signal was not displayed in 39 states and the crossbuck is not displayed in 25 states. Of course, the advance warning sign does not distinguish between active and passive crossings. These deficiences are of great interest, since the driver's manual is the prime means of communicating driving knowledge.

The present research reported herein was conducted in the State of Tennessee. The Tennessee Motor Vehicle Laws (28) describe actions that a driver should take when a train is close to a crossing. However, the action required when approaching a crossing where a driver is not certain whether or not a train is nearby is not detailed. The Tennessee Drivers' Handbook (34) describes the standard signing, but it does not discuss the pavement markings. The actions required at activated railroad crossing signals are described, but no information is given as to the probability of encountering passive crossings. If the driver was clearly told that the majority of the crossings which will be encountered are passive, then active protection should not be expected unless a standard signal is actually seen.

The most structured form of driver acquisition of knowledge is the formal driver training courses conducted in both the public and private sectors of society. Some states require that high school students take

driver training courses offered in the public schools. In other states, the course if offered as an option, or in some instances it may not be available in the public schools. Private driving schools are generally available throughout the country. Appendix B is taken from the State of Tennessee's Standard Curriculum for Driver Training Courses. The material in Appendix B covers the portion of the driver training curriculum dealing with railroad grade crossing safety. This is presented as an illustration of the public school material taught to new drivers. Curriculum for driver schools in the private sector are varied and depend on the interests and views of the officials of the private driving school.

In both the public and private domain, it is reasonable to assume that with the great quantity of material which must be covered with a new driver, the time and effort spent on grade crossings is probably a relatively small percentage of the instruction time. At present, there is no uniform national curriculum for the grade crossing portion of a driver training course.

Another medium through which the driver can acquire knowledge is the national and local highway safety campaigns emphasizing various aspects of the highway safety problem. Recently, the railroad industry has developed a concentrated public information program entitled "Operation Life Saver." (35) There are on-going programs in several states at this time. The program seeks to combine the 3-E's of Education, Enforcement, and Engineering into a coordinated effort to reduce accidents at railway-highway grade crossings. The program is heavily

oriented toward driver education through various public information campaigns, including program materials such as speeches, elementary school education materials, news media guides, etc.

In order to better carry out educational programs and other grade crossing public information campaigns, it would be helpful to public officials if some idea of the present level of driver knowledge regarding railroad grade crossing safety was available. The purpose of this phase of the research was to determine the grade crossing related knowledge level of a sample of drivers and draw inferences from the findings.

III. PRIOR RESEARCH CONCERNING DRIVER KNOWLEDGE

Past research efforts by others to obtain driver knowledge in the grade crossing area have used questionnaires to obtain information on driver knowledge. Questionnaires were administered to drivers in a New Jersey Study (12) and a Federal Railroad Administration Study. (9) Questionnaires were completed at grade crossing sites. The purpose of the questionnaire was to evaluate different signing techniques and the driver's awareness of the crossing. These investigations indicated that the experimental signs resulted in increased awareness of the crossing by drivers.

A question regarding the extent of active protection at grade crossings was included in a questionnaire utilized in both the Dommasch (12) and Sanders (9) studies. Those questionnaires were administered at grade crossings to drivers who had just passed across the tracks.

The question was asked, "Do you think that all railroad crossings have a signal bell or other warning device which tells you that a train is approaching?" Table 2 indicates the responses to this question. Approximately 21% to 25% of the drivers believed that all crossings have active protection.

A Purdue Study (36) used a laboratory observational approach with questionnaires to evaluate proposed sign messages. That study also used a panel of subjects to rank the hazard of grade crossings against other roadway hazards. The respondents considered grade crossings to be relatively more hazardous than other highway hazards, but none of the potential hazards were considered very serious. The New Jersey (12) and Federal Railroad Administration Studies (9), along with other studies, have also used the observation techniques to evaluate countermeasures. Those studies used approach speed, speed change, crossing speed, driver looking behavior, and other measures as indices of "safe" driving behavior.

In connection with driver knowledge, Stoke (37) investigated the benefits from a mandatory driver knowledge testing program for all license renewals. Driver knowledge testing is required for license renewals under USDOT Highway Safety Program Standard Number 5, Driver Licensing. The Commonwealth of Virginia obtained a waiver from the knowledge testing requirement while an experiment was conducted to evaluate the testing requirement for license renewals.

Four groups of renewal applicants (14,588 assigned to each group) were established as follows:

TABLE 2

RESPONSE TO QUESTIONS FROM DOMMASCH (12) AND SANDERS (9) STUDY

STUDY	NUMBER OF SITES	NUMBER OF INTERVIEWS	INDICATED ALL CROSSINGS HAVE ACTIVE PROTECTION	PERCENT
Dommasch	10	227	57	25
Sanders	9	1267	266	21

1. Control--no testing required.
2. Driver's manual mailed with renewal form--no test.
3. Driver's manual mailed with renewal form--with an in-home test.
4. Drivers manual mailed with renewal form--an in-station test was given.

The accident experience, convictions of driving offenses, and administrative actions were recorded for each group, as well as subgroups (passed test, failed test, and refused to take test) for two years. The findings showed there was no statistical evidence to support requiring reexamination of the general renewal population on knowledge items. The finding most pertinent to the Stokes (37) effort was that subsequent driving records could not be distinguished on the basis of whether the applicants had passed, failed, or refused to take a knowledge test at the examining station.

CHAPTER III

METHODOLOGY FOR DRIVER KNOWLEDGE INVESTIGATION

I. STUDY DESIGN

In order to further investigate driver knowledge concerning grade crossing matters, it was necessary to develop a method of obtaining feedback from drivers. Consideration was given to several alternative methods of obtaining feedback from drivers including mail-out questionnaires, oral interviews, and questionnaires to members of various organizations. After considering the advantages and disadvantages of the various methods, it was decided to use a Tennessee Highway Patrol Drivers' Licensing Station as a sampling point. Drivers who arrive at an examining station include drivers who have recently studied the Tennessee Drivers' Handbook, those recently completing drivers' education courses, both new drivers and experienced out-of-state drivers applying for licensing, and drivers who are merely accompanying those who are to be tested, such as parents or friends of those undergoing the testing. The latter category would not be expected to have reviewed the driving rules recently. This allowed data to be obtained from drivers who were both prepared and unprepared to be tested.

The Tennessee Highway Patrol has eight district drivers' license examining stations and three substations throughout the State. The station at Knoxville was chosen as reasonably representative of all

stations throughout the State. All drivers in the Knoxville area, including rural and urban residents desiring a license, must come to the Knoxville station.

The Tennessee Department of Public Safety granted permission to use the Knoxville site. It should be noted that this is apparently the first time that driver questionnaires have been used in Tennessee for evaluating the effectiveness of the efforts of public authorities in communicating specific highway safety information to drivers.

The sampling plan required that at least 400 drivers be contacted. This would allow 95% confidence that the proportion of correct answers from the sample would be within 5% of the proportion of the entire population of drivers arriving at the Knoxville Station. To achieve this, two members of the research staff spent an entire week at the driver license station. An attempt was made to intercept all drivers arriving at the station. The week of June 25-29, 1979 was selected for the interviews.

In order to obtain uniform data and to eliminate the possibility of bias resulting from staff member interaction with the subject, a written questionnaire was developed. The purpose was to obtain information relative to the knowledge of the drivers being questioned regarding:

1. Recognition of standard traffic control devices associated with railroad grade crossings.
2. Required actions at active and passive crossings.
3. Perception of the hazard at railroad crossings.
4. Perceived criteria for installing active devices.

Demographic information on the respondents was obtained. The drivers were also allowed to give their views regarding the effectiveness of the present traffic control devices at railroad crossings.

Several drafts of the questionnaire were developed. The later drafts were reviewed and critiqued by representatives of The University of Tennessee's Department of Civil Engineering and Department of Management. The questionnaire was also critiqued by representatives of the Office of Safety of the Southern Railway Company and the Office of Research, Federal Highway Administration. After these reviews were completed and the questionnaire modified to reflect the comments of the reviewers, it was then pretested.

In order to determine if the questionnaire communicated as desired to drivers, a pretest was conducted using staff and students in The University of Tennessee's Department of Civil Engineering. After discussions with the subjects and making minor changes, it was again pretested using drivers at the Kingston Pike Drivers' Examination Station. Following additional discussions and changes, the questionnaire shown in Figure 1 was used for data collection during this phase of the research.

II. DESCRIPTION OF DATA COLLECTION PROCEDURE

During the data collection phase, every driver who arrived at the Kingston Pike Examination Station was asked to cooperate in the project by a member of the research staff. This included drivers who were there to be tested and also escort drivers. A large sign stating:

Your answers to the following questions will be used in a research project which is attempting to find a way to improve highway safety. We need to have all questions answered, so please answer to the best of your present knowledge. Thank you for your assistance.

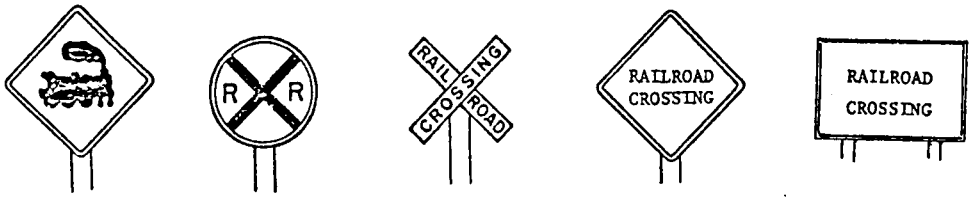
1. Do you recall specific instructions concerning driving safety at railroad crossings from any of the following sources? Check only those you remember something from.

   Safety Campaign (Radio, TV, etc.) (21) Tennessee Driver's Handbook (66)

   Driver's Education Course (35) Don't recall any instructions (12)

   Other (7) _____ Specify

2. Which of the following is usually placed just at the point where the railroad tracks cross the highway? Check only one.

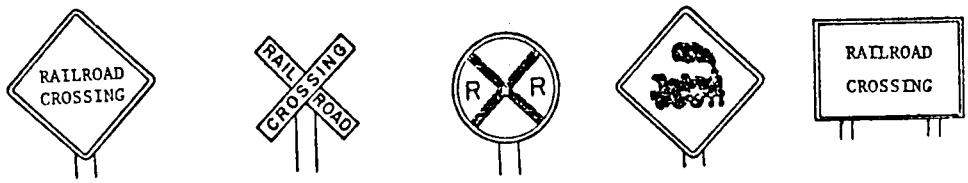


(3) (21) (71) * (2) (0.1)

3. Are you male or female?

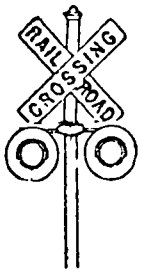
   Male (50) Female (50)

4. Which of the following is usually located several hundred feet in advance of a railroad crossing? Check only one.



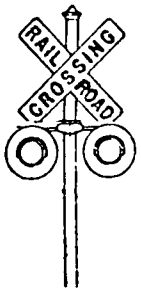
(19) (15) (62) * (1) (0.1)

Figure 1. Questionnaire used at drivers' license examining station. Results are shown as overall percentage response beside the circles. Correct answers are marked by asterisk.



5. What does it mean when this railroad signal is flashing? Check only one.

You are approaching a crossing	(2)	This is a warning to the train engineer	(0.2)
Slow down for rough crossing	(0.1)	Don't know	(0.2)
A train is coming	(97) *		



6. At which railroad crossings is this railroad signal usually placed? Check only one.

All railroad crossings	(35)	Only the most dangerous crossings	(27) *
All except the ones rarely used by trains	(19)	Crossings with more than one track	(13)
Crossings where there have been fatal accidents	(4)		

7. How long does it generally take for a train to reach the crossing after the railroad signal begins to flash? Check only one.

A flashing signal has nothing to do with a train coming	(4)	10 - 30 seconds	(22)
0 - 10 seconds	(7)	30 - 60 seconds	(36)
		Over 1 minute	(30)

8. In general, how does the distance needed to stop a train compare with that needed to stop a large truck traveling at the same speed? Check only one.

Same	(2)	Train needs more distance to stop	(93) *
Truck needs more distance to stop	(4)		

9. What does this sign mean? Check only one.

Slow down to 20 miles per hour (mph) due to rough crossing	(24)	Slow down to 20 mph and look for a train	(72) *
The trains that use this crossing travel at 20 mph	(3)	Drive faster than 20 mph to cross safely.	(0.6)

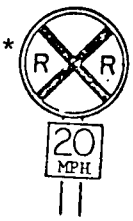
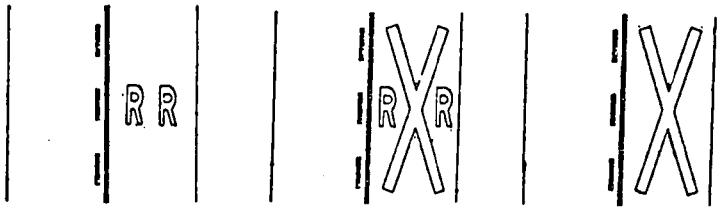


Figure 1. (Continued)

10. Which of the following are the standard markings painted on the pavement in advance of most railroad crossings? Check only one.



(7) (70) * (5) (18)

11. What should you do when approaching a crossing that does not have a railroad signal? Check only one.

Not applicable, since all crossing have railroad signals	(3)
Maintain speed, but be ready to stop if you see or hear a train	(2)
Slow down and be ready to stop if you hear or see a train	(38) *
Speed up and cross the tracks quickly to avoid an accident	(0) 7
Stop at the crossing and look for a train	(56)

12. What should you do when approaching a crossing that has a railroad signal? Check only one.

Slow down, look to see if the signal is flashing and look for a train	(43)
Slow down and be ready to stop if you hear or see a train	(16)
Slow down and look to see if the signal is flashing	(11) *
Maintain speed, but be ready to stop if you see of hear a train	(3)
Stop at the crossing and look for a train	(26)

13. Approximately how many motorists were killed in accidents at railroad crossings last year in the United States? Check only one.

10	(2)	10,000	(38)
100	(13)	100,000	(5)
1,000	(40) *		

Figure 1. (Continued)

14. What should you do when approaching a railroad signal that is flashing? Check only one.

Slow down and look for a train	(7)
Stop at the crossing and wait for the signal to quit flashing unless after stopping you are positive that no train is approaching	(81) *
Maintain speed and go through the crossing unless a train is already there	(1)
Stop at the crossing and wait for the train to cross unless it appears you can cross before the train arrives	(11)
No action required, since this signal just alerts you to the crossing	(0.3)

15. What is your age?

Under 25	25 - 34	35 - 44	45 - 59	Over 59
(41)	(26)	(20)	(10)	(3)

16. Are you satisfied with the current signs, signals, and pavement markings used at railroad crossings? If not what additional traffic related measures would you like to see taken to improve safety at railroad crossings?

Present system satisfactory (49)

Other measures needed (50)

29%

Specify _____

	YES	NO
17. Are you at the Driver Examining Station to take a test?	(31)	○
18. Have you reviewed the Tennessee Driver's Handbook in the last two weeks?	(23)	○
19. Have you or someone you know ever received a traffic citation (ticket) for improper driving at a railroad crossing?	(4)	○
20. Have you completed a Driver's Education course within the past year?	(9)	○
21. Are you licensed to drive (other than just a driver's permit) in Tennessee or some other state?	(84)	○

If you received this questionnaire at a Driver Examining Station, please wait to complete the last question until you have finished all tests. Thank you.

Figure 1. (Continued)

was placed on a stand in front of the entrance of the station to alert the drivers as to what was taking place. This gave the subjects advance warning and made the job of explaining the purpose of the questionnaire easier. The research staff would give a brief explanation of the study and request the cooperation of the subject.

The questionnaire was administered only to drivers who were presently licensed or to those anticipating that they would be licensed as a result of the testing they were to undergo. These subjects undergoing testing were asked to complete the questionnaire while waiting in line for the official drivers' licensing testing. In accordance with the agreement with the Department of Public Safety, those subjects were asked not to allow this questionnaire to interfere with the official drivers' licensing process. The subjects were also advised that this questionnaire had absolutely no bearing on the official drivers' licensing process. Escort drivers completed the questionnaire as they waited on the drivers being tested.

The questionnaire required approximately five minutes to complete. During the five day period, a total of 1,011 subjects were approached. This resulted in 829 responses. This is a response rate of 82%, which greatly exceeds the response that might have been expected from a mailout questionnaire. The high response rate is an indicator of the desirability of using candidates for drivers' licenses and their escorts

at examining stations as subjects for driver research in other areas. Perhaps drivers coming to an examining station are conditioned to a testing atmosphere and, therefore, they may be more cooperative than drivers in other settings, such as, shopping centers, club meetings, etc. The response rate was particularly encouraging when one considers the length of the questionnaire involved.

CHAPTER IV

RESULTS AND CONCLUSIONS FROM DRIVER KNOWLEDGE INVESTIGATION

I. RESULTS

Figure 1 also gives the aggregated responses to the questionnaire. The overall response percentages are noted in the circles adjacent to the answer. The correct answer, where one is appropriate, is indicated by an asterisk adjacent to the proper answer.

The first question was concerned with how drivers acquire knowledge relative to grade crossings. Of particular interest was determining which drivers remembered being exposed to some educational effort concerning grade crossing safety. The question was phrased to attempt to identify the drivers that were positive they had been exposed ("Do you recall specific instructions...") to an educational effort. The matter of interest was, "For each educational effort did the group which was exposed to the educational effort answer individual questions significantly better than the group which was not exposed to that effort?"

Of the 829 sampled drivers, the percentage recalling information concerning railroad grade crossings from various sources was as shown in Figure 1. Of the 7% who indicated that they recalled information from sources other than those shown on the questionnaire the sources were as follows:

Drivers' handbooks from other states and countries
Prior driving experience
Employee of the railroad
Word of mouth
Newspaper reports of grade crossing accidents
Parents
Employer safety meetings
Proximity of residence to a railroad
Signs on the back of mandatory stop vehicles
School teachers

The subjects were asked if they were satisfied with the current signs, signals, and pavement markings used at railroad crossings. Forty-nine percent indicated that they were satisfied with the present system. Those who were not satisfied were asked to suggest other measures. Twenty-nine percent of the respondents made suggestions which are shown in Table 3.

Perhaps as an indication of the knowledge level of a segment of the driving population, the answer to the request for suggestions made by respondent Number 285 is of interest. The respondent stated, "After completing this questionnaire, I really don't think I know much about the subject at all." A review of the aggregated responses to the questionnaire indicates that the level of knowledge was certainly less than would be desired by public officials. Table 4 indicates the frequency of correct responses for the participants in this study. It should be noted that 51% of the respondents missed four or more of the eleven gradeable knowledge questions (Questions 2, 4-6, 8-14). This seems to indicate a definite deficiency in knowledge of these grade crossing related questions.

TABLE 3

LIST OF SUGGESTIONS MADE BY QUESTIONNAIRE RESPONDENTS—REGARDING OTHER TRAFFIC RELATED MEASURES TO IMPROVE SAFETY AT GRADE CROSSINGS

SUGGESTIONS	NUMBER OF RESPONDENTS
Signs and Pavement Markings	
All crossings should have advance signs and pavement markings	30
Improve sign and pavement marking maintenance	6
Improve signing	
Use International System	1
Locate signs further ahead	6
Larger signs	2
Indicate the number of tracks	1
More stop signs at crossings	2
Active Signals and Gates	
More flashing lights needed	89
More gates needed	29
Improve signal maintenance to eliminate malfunctions	10
Improve signals	
Flashing signs	1
Bigger lights	2
Use blue lights	1
Louder signals	1
Improve Sight Distance at Crossings	9
Committee Investigations of Crossings	1
Slow Down the Speed of the Trains	1
Improve Driver Education Efforts	11
Build More Railroad Separations	2
Various Suggestions Regarding Specific Crossings	4

TABLE 4

FREQUENCY DISTRIBUTION OF CORRECT ANSWERS FOR RESPONDENTS

NUMBER OF CORRECT ANSWERS	RESPONDENTS	PERCENT	CUMMULATIVE PERCENTAGES OF RESPONDENTS ANSWERING CORRECTLY
0	3	0	100
1	15	2	99
2	10	1	97
3	35	4	96
4	77	9	92
5	108	13	83
6	172	21	70
7	181	22	49
8	139	17	27
9	69	8	10
10	20	2	2
11	0	0	0
	TOTAL 829		

All of the questionnaires were coded and key punched for analysis. The Statistical Analysis System (SAS) programs were used for cross tabulations.

Tables 5 and 6 show the comparison of the age and sex distrubtion for the sample against the total population of licensed drivers in Tennessee as provided by the Tennessee Department of Public Safety. The male-female distribution was not significantly different ($x^2 = 2.384$, $x^20.05 = 2.841$, d.f. = 1). However, the age distribution was significantly different ($x^2 = 9.488$, $x^20.05 = 3.841$, d.f. = 1). As might be expected, the population of the sample at the drivers' examining station was skewed toward the younger age groups. Perhaps this was due to inclusion of the high proportion of new drivers. This differential in age distribution should be considered when applying the results of this effort. On the one hand, the younger drivers could reasonably be expected to have had more recent exposure to driver information programs (driver's manual, driver's training, etc.) than the overall population of drivers. From this standpoint they might be expected to do better on a knowledge test than the overall population of drivers. The other side of the issue is that the population of licensed drivers is probably made up of more experienced drivers than the sample. This could assist them in a knowledge test. The latter possibility was not supported when a portion of the questionnaire was administered to drivers at a field interview site. This will be discussed in Chapter VII. A subjective conclusion regarding the effect of the distribution on the results is that the sample tested may have had knowledge levels at least as great as the overall population of drivers.

TABLE 5

COMPARISON OF AGE DISTRIBUTION OF SAMPLE WITH THAT OF POPULATION OF LICENSED TENNESSEE DRIVERS

	UNDER 25	25-34	35-44	45-59	OVER 59
TENNESSEE DRIVERS	576,029	629,179	445,216	565,465	381,136
PERCENT	22	24	17	22	15
SAMPLE	310	197	157	78	22
PERCENT	41	26	20	10	3

NOTE: Data furnished by the Tennessee Department of Public Safety.

TABLE 6

COMPARISON OF SEX RATIO OF SAMPLE WITH THAT OF POPULATION OF LICENSED TENNESSEE DRIVERS

	MALE	FEMALE
TENNESSEE DRIVERS	1,374,598	1,222,427
PERCENT	53	47
SAMPLE	409	406
PERCENT	50	50

NOTE: Data furnished by Tennessee Department of Public Safety.

The knowledge level of the sample could easily have been higher than the overall population due to the probable recent exposure of the younger drivers to educational efforts. However, it would not appear unreasonable to assume that the knowledge level of the sample was at least as high as the overall population. This would then lead to the conclusion that knowledge deficiencies in the population of licensed Tennessee drivers are as bad or even worse than those found in the sample. In any event, the effect of the age distribution of the sample should be considered when drawing conclusions from the data.

In order to determine whether the fact that a respondent recalled railroad safety instructions from a safety campaign was related to the correctness of his/her answers to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated into a 2 X 2 contingency table, recall or nonrecall of instructions from a safety campaign (independent variable) being a dichotomous variable as was the correctness of the answer (Pass or Fail; dependent variable). Of the Chi Square's calculated, only the correctness of the answers to questions 4, 10, and 14 were related to the recall of safety campaign instructions. Those who recalled the safety campaign instructions answered the three questions significantly better. The findings suggest that those recalling safety campaign instructions had more information about the advance railroad warning sign, standard pavement markings, and drivers duties upon approaching an activated railroad signal. This would seem to

indicate that these items were adequately emphasized in the safety campaign to which these drivers were exposed.

In order to determine whether the fact that a respondent recalled railroad safety instructions from a drivers' education course was related to the correctness of his/her answer to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated into a 2 X 2 contingency table, the recall of railroad safety instructions from a drivers' training course (independent variable) being a dichotomous variable as was the correctness of the answer (Pass or Fail; dependent variable). Of the Chi Squares calculated, there were none where the correctness of the answer was related to recall of grade crossing instructions from a drivers' training course.

In order to determine whether the recall of grade crossing instruction, from a driver's handbook, was related to the correctness of his/her answer to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated into a 2 X 2 contingency table, recall of grade crossing instructions from a driver's handbook (independent variable) being a dichotomous variable as was the correctness of the answer (Pass or Fail; dependent variable). Of the Chi Squares calculated, there were none where the correctness of the answer was related to the recall of grade crossing instructions from a driver's manual.

In order to determine whether the recall of grade crossing safety instructions from sources other than those listed on the questionnaire

was related to the correctness of his/her answer to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated into a 2 X 2 contingency table, the recall of instructions from other sources (independent variable) being a dichotomous variable, as was the correctness of the answer (Pass or Fail; dependent variable). Of the Chi Squares calculated, there were none where the correctness of the answer was related to the recall of grade crossing safety instructions from other sources.

In order to determine whether the sex of the respondent was related to the correctness of his/her answers to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated into a 2 X 2 contingency table, sex (independent variable) being a dichotomous variable as was the correctness of the answer (Pass or Fail; dependent variable). Of the Chi Squares calculated only the correctness of the answers to questions 6, 10, and 11 were related to sex. The findings suggest that males had more information about which crossings have active protections, standard pavement markings, and drivers' responsibilities on approaches to passive crossings. This could be interpreted as a result of the probability that male drivers drive more frequently in rural areas than females and may be exposed to more rural passive crossings.

In order to determine whether expecting to be tested was related to the correctness of his/her answers to each of the eleven gradeable

knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated in a 2 X 2 contingency table, the fact that the respondent either did or did not expect to be tested (independent variable) being a dichotomous variable as was the correctness of the answer (Pass or Fail; dependent variable). Of the Chi Squares calculated, only the correctness of the answers to questions 6, 9, and 11 were related to the readiness of the respondents to be tested. The findings suggest that those who were expecting to be tested had more information about advisory speed signing for railroad crossings and required driver response on approaches to passive crossings. Whereas those who were not prepared to be tested provided more accurate answers concerning criteria for providing active protection. This would indicate that in the preparation for testing the drivers sampled received adequate information on the advisory speed signing and the required response at passive crossings. However, their preparation was not of any significant help in learning the criteria for installation of active protection.

In order to determine whether the fact that a respondent had reviewed the Tennessee Drivers' Handbook in the last two weeks was related to the correctness of his/her answer to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated into a 2 X 2 contingency table, review of the drivers' manual (independent variable) being a dichotomous variable as was the correctness of the answer (Pass or Fail; independent variable). Of the Chi Squares

calculated, only the correctness of the answers to questions 6 and 13 were related to the review of the drivers' manual. The findings suggest that those who had not reviewed the drivers' manual in the last two weeks had more information concerning the criteria for the installation of active protection and the number of grade crossing fatalities. This would seem to indicate that the drivers' manual does not convey adequate information on the criteria for installation of active devices or the extent of grade crossing fatalities.

In order to determine whether the fact that a respondent had recently completed a drivers' education course was related to the correctness of his/her answers to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. The data were incorporated in a 2 X 2 contingency table, recent drivers' training experience (independent variable) being a dichotomous variable as was the correctness of the answer (Pass or Fail; dependent variable). Of the Chi Squares calculated, only the correctness of the answers to questions 6 and 14 were related to recent drivers' training experience. The findings suggest that those who have not taken a drivers' training course in the past year have more information concerning the criteria for installing active protection and the required driver response upon approaching an activated railraod flashing light. This result would indicate that the drivers' training courses experienced by the sampled drivers did not emphasize the criteria for installing active devices or the required response on the approach to passive crossings.

In order to determine whether the age group of the respondent was related to the correctness of his/her answers to each of the eleven gradeable knowledge questions, a series of Chi Square analyses ($x = 0.05$, d.f. = 4) were conducted. The data were incorporated into a 2 X 5 contingency table, the age group of the respondent being an independent variable and the dependent variable was the correctness of the answers (Pass or Fail). Of the Chi Squares calculated, only the correctness of the answers to questions 6, 11, and 14 were related to the age group of the respondents. The findings suggest that those in the under 25 age group have less information concerning the criteria for installing active protection and required driver response at a flashing railroad signal. Also, those in the 25 to 35 age group have more information concerning required driver response upon approaching passive crossings. This would indicate that young drivers need to be informed of the criteria for the installing of active protection and the required response at passive crossings. The older drivers learn these facts through driving experience as evidenced by the increased knowledge in the 25 to 35 age group concerning driver response at passive crossings.

II. FINDINGS AND RECOMMENDATIONS

1. Finding - The data collection technique used in this effort is workable and produces useful data. Future studies to determine driver knowledge of various subjects could make use of highway patrol drivers' licensing stations as data collection points. The public is receptive to testing at these locations.

This particular effort did not interfere with the highway patrol staff operations. Therefore, the highway patrol would probably be agreeable to similar efforts in the future. This would be particularly useful for evaluating driver training courses and public education campaigns. This would also allow feedback to the engineer and education components of the highway safety effort to evaluate education efforts.

Recommendation - Future studies requiring feedback from drivers should consider using drivers' license examining stations as sampling points.

2. Finding - The present research indicated that 35% of the sampled drivers believed that all railroad crossings have active protection. Also, 19% believed that all crossings, except those rarely used by trains, have active protection. This means that 54% believe that all crossings, or all except those rarely used by trains, have active protection. The logical deduction from this would be that if these drivers did not observe a signal, they would conclude that it is a crossing rarely used by trains. This could be a significant problem since these drivers may be relying completely on an activated signal at all crossings to warn them as to the approach of a train.

The driver's perception of the type of protection provided is difficult since a passive crossing has very similar approach appearance to an active crossing. Both have round advance warning signs, pavement markings (if the passive crossing has an approach speed over 40 mph), and both have crossbucks at the crossing. The only difference at the active crossing with post mounted signals is the addition of two flashers under the crossbuck. These are surrounded by backplates painted a flat black to accentuate the flashers when activated.

However, the flat black finish is not conducive to assisting a motorist in distinguishing between an active crossing and a passive crossing.

As indicated previously, those drivers who were prepared to take a test, or who had reviewed the drivers' handbook, or completed a drivers' education course recently, actually answered incorrectly more often on question 6 concerning which grade crossings have active protection. This is not surprising since this point is not covered in the Tennessee Drivers' Handbook or drivers' education course curriculum outlines.

Since 35% of the respondents believed that all railroad crossings have active protection, they might be expected to drive without paying any special heed to railroad crossings unless they saw red lights flashing. This would have the potential for great accident risk at unsignalized crossings which are regularly used by trains.

Recommendation - Public information campaigns, drivers' handbooks, driver education courses, and other sources of driver information should clearly state that all crossings do not have active protection. Drivers should be made aware that they may experience hazardous crossings which are not signalized.

Traffic control devices should be developed to indicate clearly to an approaching driver whether the crossing has active protection or not. A driver is expected to perform substantially differently at an unsignalized crossing as opposed to one that has active protection. As noted earlier, the approaches to the two types are identical. Different advance signing for active and passive grade crossings would benefit the

unfamiliar driver plus serve as reinforcement to the more familiar driver that the highway vehicle does not have the right-of-way.

Another recommendation for consideration is to utilize the three color standard intersection control traffic signal at grade crossings. If the light is green, drivers know to proceed safely. Standard signing would still need to be developed to warn drivers when there is no signal at the crossing they are approaching. Of course, there are considerable funds and training invested in the current railroad signal. Therefore, it would have to be demonstrated that the increment of benefit in going from the current railroad signal device to the traffic signal would justify the costs of conversion of the system.

3. Finding - A significantly high percentage of the drivers correctly recognize that a train takes longer to stop than a truck, and that there are over 1,000 fatalities a year at railroad crossings. This would suggest that drivers have adequate knowledge concerning these two pieces of information and promotion of these facts would really not be very useful in a public education effort. It was surprising to note that 43% of the respondents thought that 10,000 or more drivers were killed at grade crossings each year. This seems to indicate the futility of reporting national accident statistics with which drivers have a difficult time relating.

Recommendation - Commensurate with the degree of reliance one is willing to place on the sample used in the present research as "representative" of a given driving population, public education campaigns should consider concentrating on matters other than train stopping

distances and fatalities, since the present level of knowledge in this area was found to be high.

4. Finding - An unusually high proportion of drivers, 56%, believed that they should stop at unsignalized crossings. In fact, 26% stated that they should stop at signalized crossings. This indicates that drivers believe that more is expected of them than actually is required. From a marketing standpoint, the customer is perceiving that one is being asked to pay more for the product (safe behavior) than actually has to be paid. This may be perceived as an unrealistic price; thus, these drivers are not buying the product. In practice, it is observed that despite what drivers may say is their duty, very few drivers actually stop at crossings (5 at the 2 crossings observed). It may be that drivers who believed that the required response was to stop and have rejected this perceived requirement as unreasonable, may be inclined to take the lesser action if they are informed that slowing down and looking and listening is the actual required response. Of course, those drivers who actually stop at grade crossings are creating potential rear-end collission situations when placed in a traffic mix with drivers who do not plan to stop at grade crossings.

Recommendation - Educational efforts should clearly advise drivers that it is their responsibility to slow down and look and listen for trains at unsignalized crossings, and that a driver is not required to stop unless public authorities have errected the standard STOP sign.

5. Finding - Only 4% of those questioned had received or knew of anyone who had received a traffic citation for improper driving at

railroad crossings. This indicates that there may be potential for improving driver behavior if more drivers perceive that they are subject to enforcement action at railroad crossings. At the present time, it appears that this motivation is almost entirely missing.

Recommendation - Spot enforcement efforts should be conducted and evaluated. Tennessee's laws should be revised to conform to the UVC's basic speed law. This will provide a basis for enforcement which is now missing.

6. Finding - Approximately 30% of the drivers did not recognize the standard signs or markings associated with railroad crossings. A high percentage did recognize the round advance sign and crossbuck as being associated with crossings, but 15 to 21% were not aware of which one was the advance sign and which one was at the crossing. Twenty-four percent believed that an advisory speed plate under a round advance warning sign indicated that they should slow to the indicated speed due to a rough railroad crossing.

Recommendation - Commensurate with the degree of reliance one is willing to place in the sample used in the present research as "representative" of a given driving population, public information campaigns should consider including as a component of the effort, identification of the standard signing.

7. Finding - Forty-three percent believed that when approaching an active crossing they should look to see if the signal is flashing and they should also look for a train. It is reasonable to assume that these drivers have been informed about malfunctions at signals, and,

therefore, do not perceive them as completely trustworthy. In fact, this is the recommended driving procedure contained in the Tennessee Driver Training Curriculum Outline in Appendix B.

Recommendation - Further research should be conducted to determine if there is a credibility problem with railroad signals. The drivers should be advised to always carefully observe a signal as it is being approached to determine if it has been activated.

CHAPTER V

LITERATURE REVIEW FOR INVESTIGATION OF RELATIONSHIP OF DRIVER PERFORMANCE TO DRIVER KNOWLEDGE

The next phase of this research was to investigate whether good driver knowledge was correlated with safe driver performance at railroad crossings. Two sites were selected for observation and interviews were conducted to determine which drivers had correct knowledge concerning several significant questions. Two groups were established based on correct or incorrect knowledge of grade crossing facts. The two groups were also examined as to their driving behavior. An effort was then made to determine if correct knowledge correlates with safe driving at these two railroad crossings. The only known prior work in this area as listed in Chapter I. These were the Dommasch (12), Sanders (9), and Stoke (37) studies. These studies were described earlier and will not be repeated in this chapter.

In the present research, a determination of percentage-reaction time for use in data analysis of field observations of drivers was required.

Richards (38), Voorhees (39), and Schoppert et al. (22) have performed research in determining the adequacy of sight distance at grade crossings. In the case with the worst conditions, these researchers have assumed wet pavements and a perception-reaction time sufficiently large enough to inlcude 85% of the drivers. Richards (38)

uses 2.5 to 3.0 seconds for the latter variable. It is noted by Schoppert (22) that the use of these values will allow a factor of safety for conditions encountered under unusual driving conditions. However, Schoppert (22) presents tabulations based on one second perception-reaction time and dry pavement braking distances. These are noted as being more liberal in judging the adequacy of existing conditions, and also as being minimum values. It is recommended that they be used with care.

The American Association of State Highway and Transportation Officials recommendations (40) assume a brake reaction time of one second in computing stopping sight distances. A perception time of 1.5 seconds is also assumed, giving a total of 2.5 seconds for perception and brake reaction time.

CHAPTER VI

METHODOLOGY FOR INVESTIGATION OF RELATIONSHIP OF DRIVER PERFORMANCE TO DRIVER KNOWLEDGE

I. STUDY DESIGN

Driver performance was recorded on approaches to grade crossings. The information desired for each observation was:

1. Whether the driver approached the crossing in a safe manner.
2. Speed 15 feet from the crossing.
3. Slope of speed profile approaching the crossing.
4. Whether the driver looked for trains.
5. Where a look took place.
6. The vehicle's speed at the time of the look.
7. Whether the driver stopped at the crossing.

The drivers were then stopped downstream from the crossing and asked four questions relative to their knowledge of grade crossing matters. Drivers were grouped into correct and incorrect knowledge groups for each of the four questions and the aggregated driving behavior of the groups compared to see if knowledge on the four questions was significantly related to driving performance. The four questions asked were from the larger group of items composing the survey form administered at the drivers' license station. The four questions selected dealt with passive crossing facts. It was believed that knowledge of the subjects the four questions selected dealt with had the

best probability for influencing driver behavior at the passive sites studied.

II. PROCEDURE FOR COLLECTING DRIVER PERFORMANCE DATA

The study procedure developed required that railroad crossing sites be chosen with restricted sight distance, such that to perform safely drivers would have to make obvious head movements. The sites had to be conducive to the use of hidden observers to record speed and looking behavior. Further, the sites had to have safe interview sites downstream from the crossing approach being observed.

In order to obtain speed data, the study site was marked with 100 foot speed traps on the approach roadway. Stakes were placed adjacent to the roadway at the appropriate distances from the crossing. The midpoint of the first trap was located 15 feet from the crossing in order to correspond with Tennessee's minimum legal distance that a driver is to bring his vehicle to a stop in the event a train is approaching. This required that markers be located 35 feet beyond the near rail and at distances of 65, 165, 265, 365, and 465 feet on the approach roadway.

An Estertine Angus 20 channel event recorder, powered by a 12 volt automobile battery, was used to record speed and information as to whether a driver made a head movement and when the head movement took place.

As a vehicle passed the first trap, a pen on the event recorder was activated by a remote switch to make a mark perpenducular to the trace line on the moving paper. As the vehicle crossed the second trap mark

another mark was made. This procedure was used as the vehicle went through all of the traps. The paper moved through the event recorder at a constant speed. Therefore, the distance between two marks was measured to determine the elapsed time for the vehicle to travel between the two marks. Knowing the time and the distance for a vehicle in the speed trap, the vehicle's speed was then computed. This speed was assumed to be the speed at the midpoint of the trap.

A speed profile was developed and plotted for each vehicle. In order to identify vehicles for later correlation with the responses to the questionnaires, an observer noted on the paper tape the last three digits of the license tag for each vehicle. This was also recorded on each speed profile plot.

This observer also noted on the tape if a driver actually stopped at the crossing. Any other noteworthy items were also placed on the tape, such as if a vehicle was constrained by a vehicle in front of it (e.g., a turning vehicle).

The location where the driver looked and the speed at the time of the look were also desired for the looking drivers. A second observer utilized another remote button on the event recorder to make a mark on the moving trace at the instant the driver was seen making an obvious head movement. Using the speed profile, the distance and speed data for the vehicle could be computed for the instant a looking motion took place. The speed trap marks and the looking marks were placed on adjacent channels. The elapsed time between the time the driver looked and the arrival of the vehicle at the next speed trap mark was determined

by measuring off of the tape. Using the speed profile, the distance and speed from the curve could be determined, which would have caused the vehicle to have arrived at the next trap mark in the time measured. The derivation of the formula used to determine the distance from the crossing where a head movement was made and to obtain the speed of the vehicle when the driver made the head movement is shown in Appendix C.

Knowing the speed that the vehicle was travelling and the distance from the crossing where the driver looked, drivers were classified as "safe" and "unsafe." This was done by the examination of the point where the driver looked with consideration for speed and available sight distance. The "safe"-"unsafe" determination was based on whether or not the driver could have either stopped prior to the arrival of a train or could have safely crossed ahead of a train which might have appeared just after the driver looked and made a "go" decision. If the driver met both requirements, then the driver was classified as a "safe" driver.

Sight distance down the tracks was measured from various points along the roadway approach. One observer stood on the roadway while a second observer carried a 12 foot rod (approximate height of locomotive) with a white flag attached at the top. The second observer would walk along the tracks, away from the crossing, until the flag disappeared from the first observer's view. The first observer would tell the flag bearer the instant the flag went out of sight and a mark was made at that point on the tracks. This was done for various locations along the roadway from the tracks, both to the right and left sides.

Measurements along the tracks were then taken and correlated with the corresponding roadway approach distance where the track sight distance limit was noted. This resulted in a table showing the minimum track sight distance available from several points along the roadway.

Knowing the maximum train speed, this minimum sight distance data could then be used to compute the time for a train travelling at that speed to reach the crossing, if it was just at the limit of the available track sight distance from each point on the approach roadway where sight distance had been recorded. Therefore, knowing the distance from the crossing and the speed the vehicle was travelling when the driver looked, a determination was made as to whether or not the vehicle could have stopped if the driver had seen a train coming. This determination was based on assumptions regarding perception time and braking distance calculations.

The other item investigated was, assuming the driver looked and made a "go" decision, based on the absence of a train, and then a train immediately came into view, "Could the driver traverse the crossing safely before the train arrived?" This would be determined using train speed to compute the time for a train to reach the crossing from the outer limit of track sight distance. The time for the vehicle to travel from the point where the look was made would be computed using the speed the vehicle was travelling and the distance the driver was from the crossing when he looked. If it took less time to reach the crossing along the roadway than it would for the train to arrive, then this was

considered a safe movement, assuming the look had been made at a greater distance than the stopping distance for the speed.

In other words, the drivers are considered safe if they could see the crossing and they looked far enough ahead of the crossing to stop commensurate with their speed. Further, the driver must also be travelling fast enough to clear the crossing ahead of a train should one suddenly appear after the look was made.

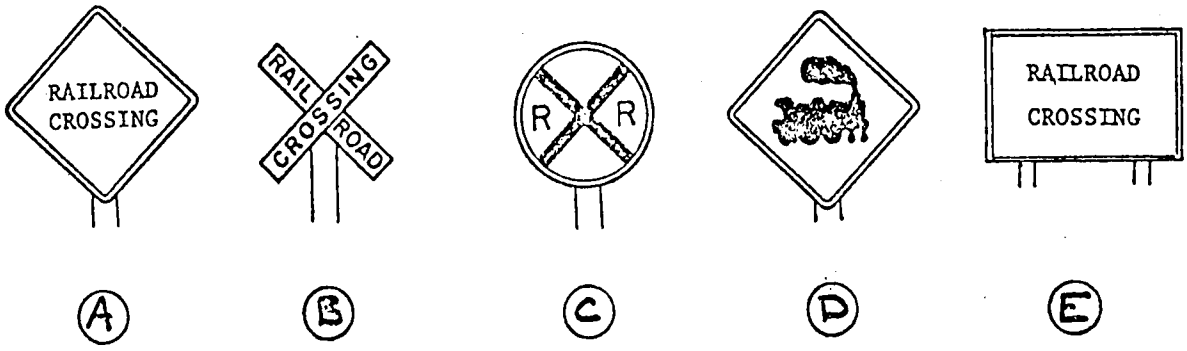
III. PROCEDURE FOR COLLECTING DATA ON DRIVER KNOWLEDGE

As discussed earlier, due to the limited time that a driver could be detained along the roadway to respond to a questionnaire, the field study used a reduced questionnaire. The four questions shown on Figure 2 were drawn from the longer questionnaire used at the drivers' license examining station. These four questions were considered to most likely involve driver knowledge which might affect driver performance at passive grade crossings.

The four questions were placed on a card and handed to drivers who had been stopped downstream from the crossing. Each driver was asked to respond to the questions by the alphabetical character matching the correct answer. The field personnel recorded the four responses and also noted the last three digits of the license tag as the vehicle pulled away.

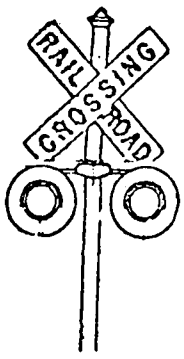
This methodology yielded speed and looking data on each vehicle such that the driver could be classified as "safe" or "unsafe." The responses to the questionnaire could then be correlated with driving behavior.

1. WHICH OF THE FOLLOWING IS USUALLY PLACED JUST AT THE POINT WHERE THE RAILROAD TRACKS CROSS THE HIGHWAY?



2. WHICH OF THE ABOVE IS USUALLY LOCATED SEVERAL HUNDRED FEET IN ADVANCE OF A RAILROAD CROSSING?

3. AT WHICH RAILROAD CROSSINGS IS THIS RAILROAD SIGNAL USUALLY PLACED?



   A. ALL RAILROAD CROSSINGS
   B. ALL EXCEPT THE ONES RARELY USED BY TRAINS
   C. CROSSINGS WHERE THERE HAVE BEEN FATAL ACCIDENTS
   D. ONLY THE MOST DANGEROUS CROSSINGS
   E. CROSSINGS WITH MORE THAN ONE TRACK

4. WHAT SHOULD YOU DO WHEN APPROACHING A CROSSING THAT DOES NOT HAVE A RAILROAD SIGNAL?

   A. NOT APPLICABLE, SINCE ALL CROSSINGS HAVE RAILROAD SIGNALS
   B. MAINTAIN SPEED, BUT BE READY TO STOP IF YOU SEE OR HEAR A TRAIN
   C. SLOW DOWN AND BE READY TO STOP IF YOU HEAR OR SEE A TRAIN
   D. SPEED UP AND CROSS THE TRACKS QUICKLY TO AVOID AN ACCIDENT
   E. STOP AT THE CROSSING AND LOOK FOR A TRAIN

Figure 2. Questionnaire Used in Field Study.

IV. CONDUCT OF STUDY

As stated earlier, the sites for this study were to be passive crossings with sight distance restrictions. Locations had to be available for observers to record data at the crossing without being noticed by the drivers. A safe location for the roadside interviews was needed. The interview site had to be close enough to the crossing so that most of those using the crossing would be intercepted.

Computer listings of grade crossings from the Tennessee Department of Transportation were examined for Knox County and the surrounding counties. The sites needed to have highway volumes that were high enough to obtain a good number of data points, but not so high that the roadside interviews would create a hazard. The train volumes and speeds were to be significant enough to class the crossing as relatively hazardous. After a review of the listing of grade crossings, two sites were selected as essentially meeting the requirements for study sites.

The first site selected was the Tipton Station Road-Southern Railroad crossing in Knox County. The ADT for the crossing is 1,000 vehicles per day. The train volume is four trains per day. The maximum train speed is 25 mph. This crossing has been included in the National Grade Crossing Inventory and is numbered 730 428Y.

The second site selected was in Loudon County. The site is located on Cossick Road (FAS 2588). It is also a Southern Railroad crossing. The ADT for this crossing is 1200 vehicles per day. The volume is two trains per day. The maximum train speed is 25 mph. The

National Grade Crossing Inventory number is 730 436R. The Tipton Station crossing is hereafter referred to as Site One and the Cossick Road crossing is referred to as Site Two.

Both of these sites have severe sight distance restrictions. Table 7 lists the right and left track sight distances from various points on the approach roadways for the two sites. Both of these sites had standard traffic control devices, considered necessary in order to correlate with the questions concerning signing.

On July 12, 1979, drivers approaching Site One were observed. The next week, on July 19, 1979, drivers approaching Site Two were observed. Five observers were used for data collection at each site. One observer operated the event recorder at the crossing and noted on the paper tape the last three digits of the vehicle's license tag. A second observer operated the remote button to mark the time when the vehicle passed the marks for the speed traps. A third recorded head movements with a remote switch. Two interviewers were used at the interview location downstream from the grade crossing.

An attempt was made to obtain a complete data set for as many of the vehicles using the grade crossing as possible. The interview sites were located near existing stop signs so the vehicles would already be preparing to stop when they approached the interview site. A 36 inch advance warning sign indicating

SURVEY AHEAD

was placed in advance of the interview sites. Traffic cones were placed in the center of the road for 200 feet in advance of and leading up to

TABLE 7

SIGHT DISTANCES AT SITES ONE AND TWO

ROADWAY DISTANCE FROM NEAR RAIL OF CROSSING (ft)	SITE ONE		SITE TWO	
	TRACK SIGHT DISTANCE LEFT (ft)	TRACK SIGHT DISTANCE RIGHT (ft)	TRACK SIGHT DISTANCE LEFT (ft)	TRACK SIGHT DISTANCE RIGHT (ft)
20	311	1464	2600	225
39	204	1045	1081	115
62	177	781	773	64
87	156	595	222	77
114	156	595	140	16
145	122	502	109	16
178	197	502	95	18
215	204	502	73	18
256	179	445	63	0
299	158	363	49	0
347	133	345	49	0
399	108	345	49	0
454	65	309	42	0

the actual interview site. The interviewers stood on the centerline of the roadway near the existing stop sign. A hand held STOP sign was used to indicate where the driver was to stop. Interviewers wore orange traffic vests.

The data collection at the crossing and the interviews went generally as envisioned. Some vehicles turned onto and on from side-roads downstream from the crossing, but prior to the interview station. Therefore, not all observations were matched by interviews and vice versa. The results of the data collection are discussed in the next chapter.

CHAPTER VII

RESULTS AND CONCLUSIONS FROM INVESTIGATION OF RELATIONSHIP OF DRIVER PERFORMANCE TO DRIVER KNOWLEDGE

I. RESULTS

At Site One, the speeds and looking behavior of 94 drivers were recorded. Responses from 84 drivers were obtained. Matches of interviews and observations were made for 42 drivers. Appendix D gives the results of the questionnaire phase at this site.

At Site Two, the speeds and looking behavior of 122 drivers were recorded. There were 137 drivers interviewed. Matches of interviews and observations were made for 47 drivers. Appendix E gives the results of the questionnaire phase at this site. Table 8 gives the aggregated responses for the two sites individually and pooled.

Appendices F and G include the driver behavior data for the matched drivers at Sites One and Two.

II. ANALYSIS OF DATA

Figures 3 and 4 are plots of the sight distance related time space diagram for train arrival at Sites One and Two respectively. These figures are based upon the track sight distance recorded in Table 7 For example, at Site One, if the driver is 145 feet from the crossing, a train can be seen to the left up to 122 feet from the

TABLE 8

AGGREGATED RESPONSES TO QUESTIONNAIRE ADMINISTERED AT SITES ONE AND TWO AND POOLED DATA

RESPONSES	SITE ONE QUESTIONS				SITE TWO QUESTIONS				POOLED QUESTIONS			
	1	2	3	4	1	2	3	4	1	2	3	4
A	0	13	4	0	0	21	4	0	0	34	8	0
B	28	4	5	1	38	3	2	1	66	7	7	2
C	14	22	1	15	9	19	0	14	23	41	1	29
D	0	1	15	2	0	0	19	0	0	1	34	2
E	0	0	17	24	0	1	18	32	0	1	35	56
Don't Know	0	2	0	0	0	3	4	0	0	5	4	0

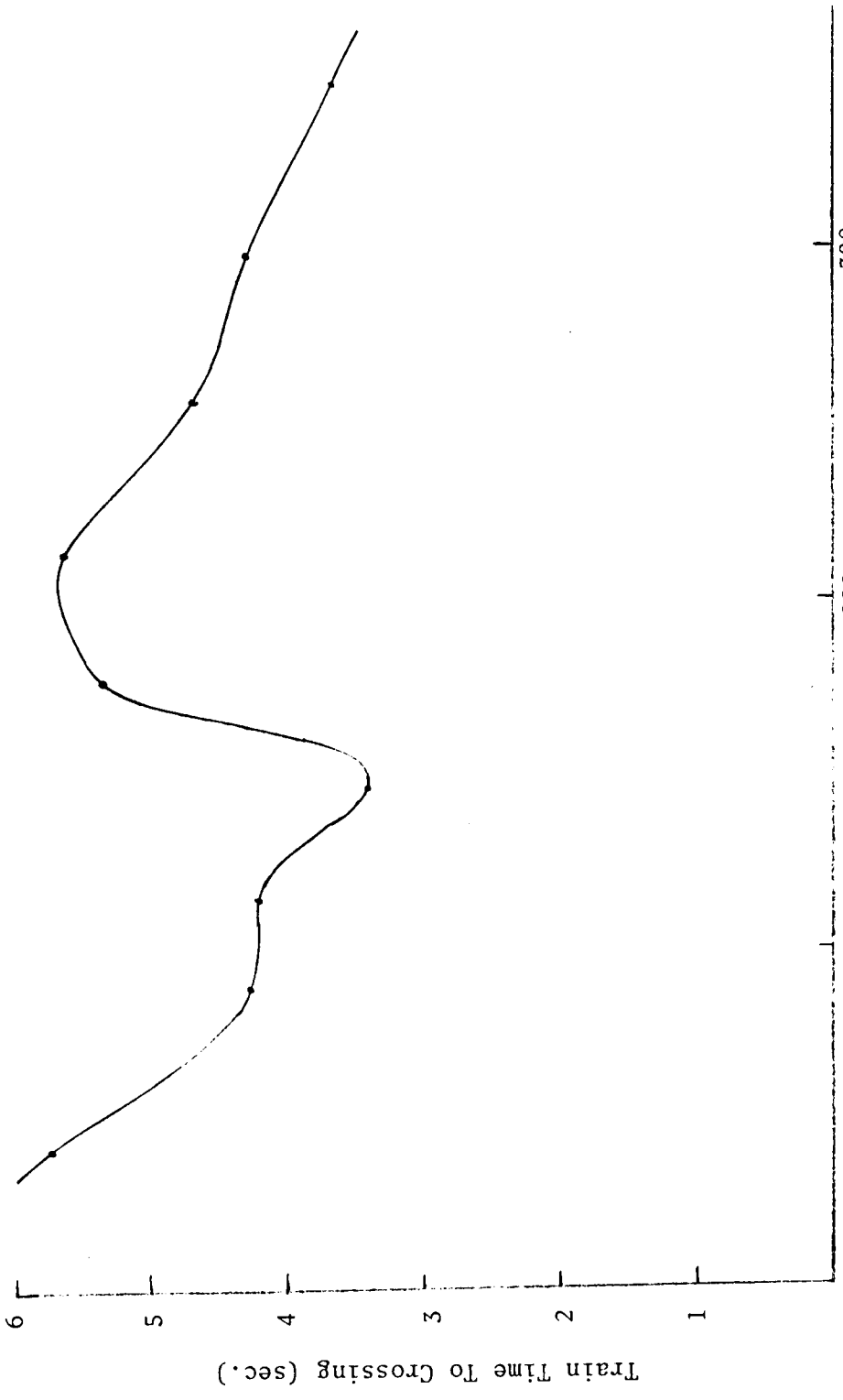


Figure 3. Plot of time space diagram for train arrival at Site One.

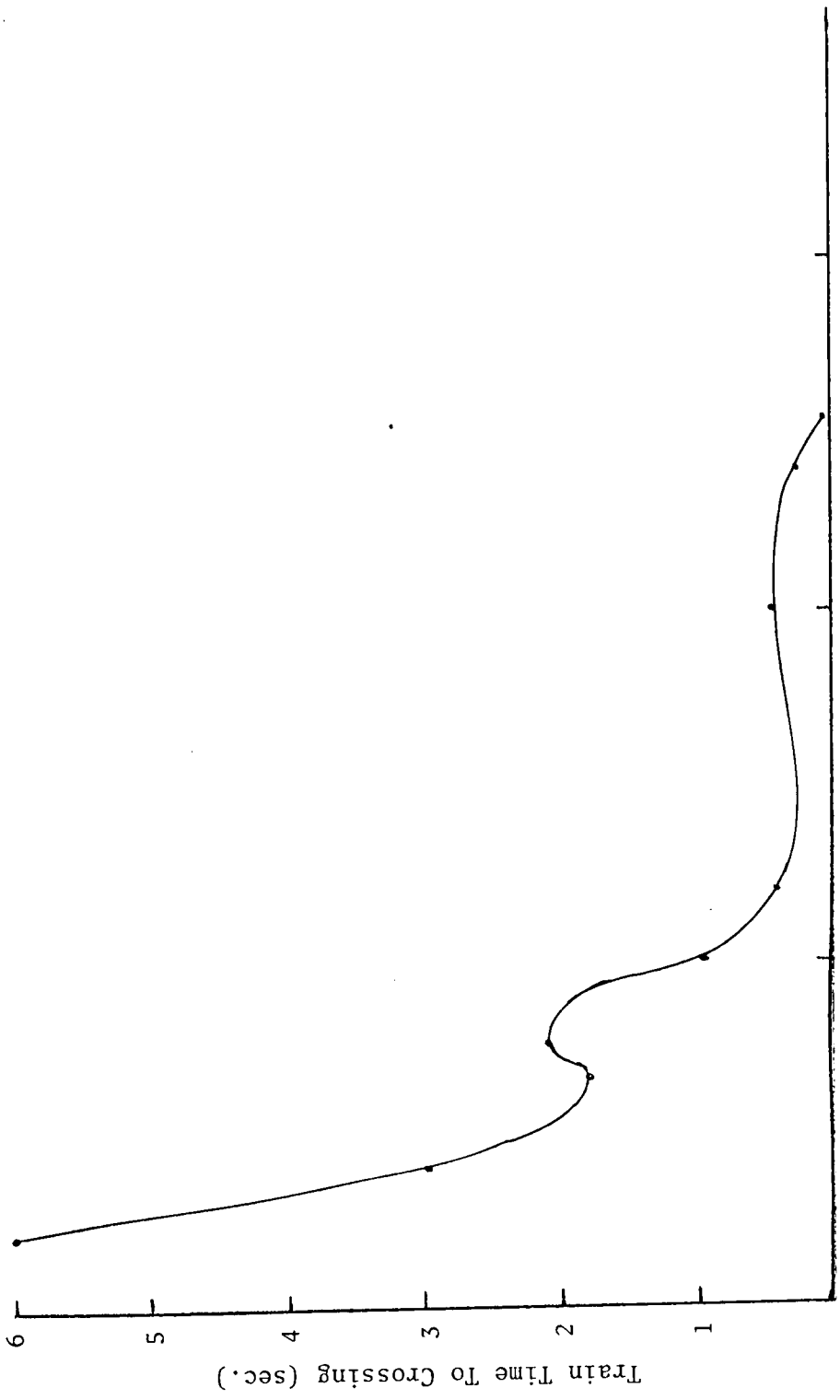


Figure 4. Plot of time space diagram for train arrival at Site Two.

crossing. A train could also be seen to the right of the crossing up to 502 feet away. Given that the maximum train speed is 25 mph, it will take 13.7 seconds for a train to travel 502 feet and 3.3 seconds to travel 122 feet. This means that if a driver looked to the left for a train and made a decision that no train was coming, to proceed safely, the vehicle would have to be traveling at a speed which would allow the driver to clear the crossing in 3.3 seconds. If the driver is traveling at a speed which will not allow the vehicle to clear the crossing in 3.3 seconds, there is a possibility that a train may have been just a little beyond the driver's sight limits when the "go" decision was made, and that train would arrive at the crossing before the driver arrives. Therefore, the "go" decision must be made far enough from the crossing to allow perception and safe stopping distance. Also, the speed at the time the decision is made must be adequate to allow the vehicle to clear the crossing.

If a driver looks and the speed and location of the look are proper, then the driver will safely clear the crossing if no train is detected, or the driver can safely stop if a train is detected. The driver may look many times but if at least one look meets the safe criteria, then a safe crossing should result.

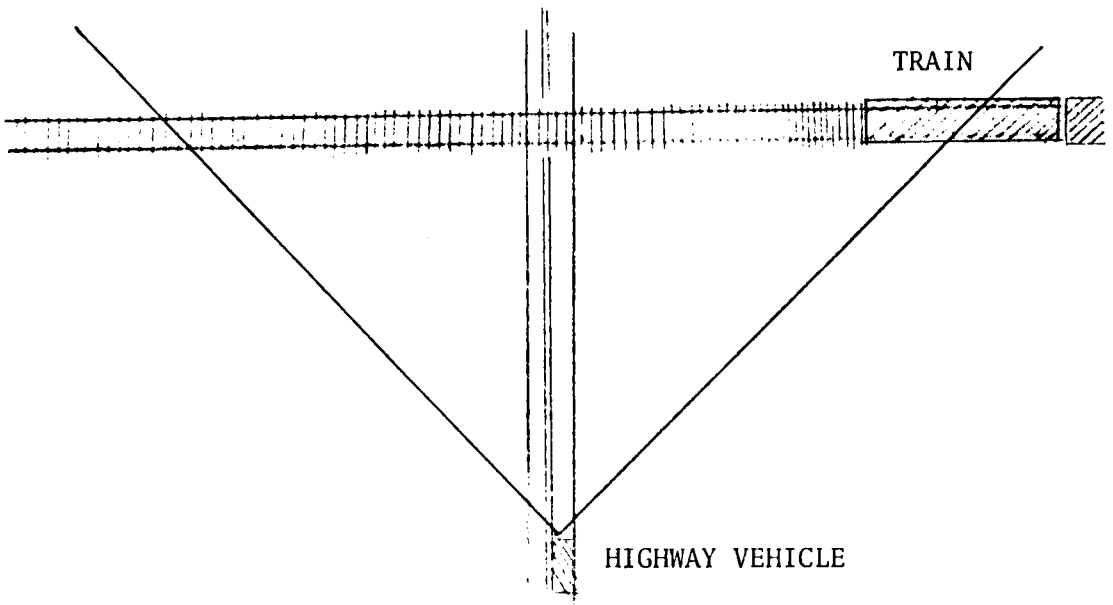
Figures 3 and 4 are plots of the minimum of the right and left train arrival times, since the worst case must be considered. It will be noted that the curves are not smooth and do not show a relatively uniform increase in train arrival times as an observer approaches the crossing. This is noted at many crossings, since sight distance may

actually decrease due to vegetation and topography. Figure 5 is a schematic drawing of the two possibilities of train arrival relative to a driver's looking behavior. Either of the two conditions may be encountered each time a driver makes a judgment at the crossing.

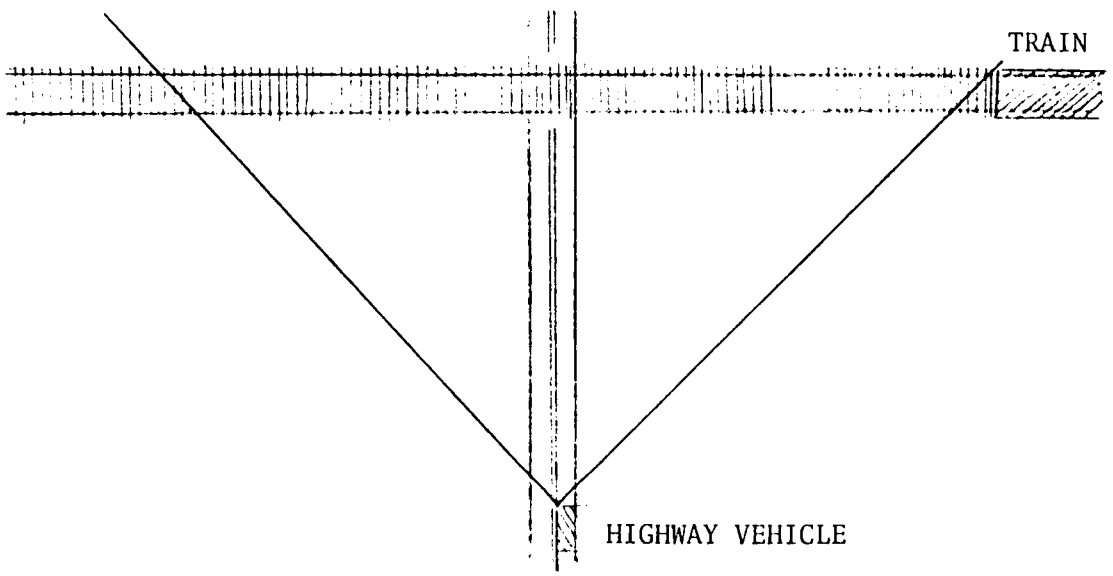
The driver is considered to have made a safe judgment if at the time a decision is made the vehicle is an adequate distance from the crossing to safely stop (reaction and braking), based on the vehicle speed when the judgment is made. Also, the vehicle speed must be such that it would allow the vehicle to clear the crossing before the arrival of a train which was barely beyond the sight distance limits. I would be expected that the perception of a train at night would be at least as good as that during daylight hours since the engine's searchlight would be more noticeable at night.

The next step was to compute the total stopping distances that would be required for drivers traveling at various speeds. The minimum distance from the crossing for a "go" decision to be made would have to be greater than the distance from which the driver could perceive that a train was present and then bring the vehicle to a safe stop short of the crossing.

In order to compute the total perception and stopping distances required for a safe stop at various speeds, an assumption was made concerning time for drivers to perceive a train at or near a crossing. Prior work in this area was consulted as described in Chapter V. The Richards (38), Voorhes (39), Schoppert (22) and American Association of



(a) Must be able to stop



(b) Must be able to clear crossing

Figure 5. Two conditions of train and highway vehicle interaction necessary for safe performance.

State Highway and Transportation Officials (40) references cited previously support the assumption of a 2.5 second perception time for drivers approaching passive grade crossings. Therefore, a 2.5 perception distance was assumed in the development of tabulations of perception plus braking distances for vehicles approaching a grade crossing at various speeds. Since the condition of the pavement was dry, it would appear that a reasonable set of assumptions would be dry pavement and a 2.5 second perception-brake reaction time. Table 9 is a tabulation of the perception and braking distances for various approach speeds. This table is based on dry pavement and a 2.5 second perception-brake reaction time. The pavement conditions at the time that observations are made should, of course, determine whether to use dry or wet pavements coefficients.

The point at which any vehicle makes a "go" or "no go" decision, as manifested by head movements, may be plotted on Figures 3 or 4, as appropriate. Knowing the distance from the crossing when the decision was made and the time it took to reach the crossing, a point is plotted. If the point falls below the plotted line, the vehicle will take less time to arrive at the crossing than the train. It will, therefore, clear the crossing. If the point falls above the plotted line, the vehicle will take longer to arrive at the crossing than the train. In that case, the vehicle would not clear the crossing prior to the arrival of the train.

Knowing the speed at the time of the head movement and the distance from the crossing, a judgment can be made as to whether or not the

TABLE 9

PERCEPTION–REACTION TIMES AND BRAKING DISTANCES FOR VARIOUS SPEEDS (DRY PAVEMENT)

SPEED MPH	V SPEED FPS	F DRY[1]	PERCEPTION DISTANCE @ 2.5 SEC.	S BRAKING DISTANCE[2]	REQUIRED PERCEPTION AND BRAKING DISTANCE + 20'[3]
5	7.33	.69	18	1	39
10	14.67	.68	37	5	62
15	21.99	.67	55	11	86
20	29.32	.65	73	21	114
25	36.65	.64	92	33	145
30	43.98	.62	110	48	178
35	51.31	.61	128	67	215
40	58.64	.60	147	89	256
45	65.97	.59	165	115	300
50	73.30	.58	183	144	347
55	80.63	.57	202	177	399
60	87.97	.56	220	215	455
65	95.29	.56	238	252	510
70	102.62	.55	257	297	574

[1]Coefficient of friction from 1964 AASHTO Policy on Geometric Design of Rural Highways. (40)

[2]Based on $S = \frac{V^2}{2(f)32.2}$

[3]Minimum legal clearance for stopped vehicle of 15 ft. plus 5 ft. from driver's head to front bumper.

driver could have stopped before reaching the crossing, by consulting Table 9.

It had been anticipated that there would be a reasonable proportion of the drivers at each site who exhibited safe behavior (those that looked at a distance where they could have stopped, while traveling at a speed which would have allowed them to clear the crossing before a train arrived). However, when one compares the total perception and braking distances, from Table 9, required for various approach speeds with the observed values in Appendices F and G, it is apparent that the majority of drivers were not performing safely. When their approach speed is considered, the drivers looked for trains much too close to the crossing to allow a safe stop short of the crossing. In fact, only the two drivers at Site One and the three at Site Two who actually stopped could be classified as safe. All of the other drivers were too close to the crossing when their looking movements took place to safely perceive a train and stop before the crossing. All of these drivers did meet the speed criteria for crossing clearance, but they were not classed as safe drivers due to their looking too close to the crossing to allow a safe stop.

To find the relation of knowledge to driver behavior, the 42 matched observations at Tipton Station Road and the 47 matched observations at Cossick Road were grouped by responses to the questionnaire. Those giving correct responses for each question were placed into one group and the remainder placed in the second group. The speed profile form for each vehicle was hand sorted each time the groups were formed. The number of drivers who stopped, number of lookers, mean speed at a

distance of 15 feet from the crossing, and the mean speed profile slope were computed for the two groups for each question at the Tipton Station Road and the Cossick Road sites. Table 10 tabulates three of the above measures for the correct and incorrect knowledge groups at Sites One and Two. N attempt was made to draw a statistical inference from the number of vehicles that stopped (Site One-2, Site Two-3) due to the low rates involved.

In order to determine whether the knowledge level of the respondents relative to each of the four questions was related to the dependent variable, looking behavior of the respondents, a series of Chi Square analyses ($x = 0.05$, d.f. = 1) were conducted. This was done for both sites. The data were incorporated into a 2 X 2 contingency table, the correct or incorrect knowledge being a dichotomous variable, as was the looking behavior (looked or did not look). Of the Chi Square calculated, only the looking behavior of those correctly answering question 2 at Site Two were related. The findings suggest that those who had more information regarding the advance warning sign exhibited less looking behavior. This finding was not replicated at Site One. When the data was pooled, this finding was replicated. In order to determine whether the knowledge level of the respondents relative to each of the four questions was related to the mean vehicle speed 15 feet from the crossing or the slope of the speed gradient for the vehicles approaching the crossing, a series of Student's "t" analyses were conducted. The hypothesis was tested ($x = 0.05$) as to whether the mean speed at 15 feet from the crossing or the mean speed gradient for the

TABLE 10

DRIVER BEHAVIOR AT SITES ONE AND TWO AND POOLED DATA RELATED TO RESPONSES TO QUESTIONS GROUPED ACCORDING TO CORRECT AND INCORRECT ANSWERS

QUESTION	SITE ONE		SITE TWO		POOLED DATA (BOTH SITES)	
	CORRECT	INCORRECT	CORRECT	INCORRECT	CORRECT	INCORRECT
1. Recognize Crossbuck						
Mean V at 15'	29.00	30.75	31.05	36.44	30.15	33.19
Slope	0.0695*	0.0446	0.0455	0.0411	0.0561	0.0431
Lookers	10	5	19	3	29	8
2. Recognize Advance Sign						
Mean V at 15'	29.92	29.00	33.52	31.11	31.51	30.28
Slope	0.0544	0.0614	0.0355	0.0527	0.0461	0.0561
Lookers	7	8	5	17	12*	25
3. Where Signals Placed						
Mean V at 15'	30.07	29.22	33.37	31.21	31.91	30.24
Slope	0.0524	0.0574	0.0437	0.0452	0.0475	0.0512
Lookers	5	10	9	13	14	23
4. Approach Passive Crossing						
Mean V at 15'	28.75	30.00	30.46	32.71	29.52	31.53
Slope	0.0669	0.0542	0.0385	0.0454	0.0541	0.0493
Lookers	5	10	6	16	11	26

*Significant (0.05) difference.

correct and incorrect knowledge groupings for each of the four questions at each site was significantly different. These analyses did not yield any significant differences between the two knowledge groups for each of the four questions using mean speed at 15 feet and mean speed gradient as the dependent variables. This was replicated for both sites and with the pooled data. The results of the statistical tests are shown in Tables 11 and 12.

The matched responses to the questionnaires given at the two field sites were compared with those obtained through the more detailed questionnaire. The short and long questionnaire had four common questions. Comaprison of these common questions is shown in Table 13. This comparison was made to see if the knowledge level at the field sites differed significantly from that at the drivers' examining station.

The responses to each question at the three sites were subjected to a Chi Square test to see if there was a significant ($x = 0.05$) difference among the responses (correct vs. incorrect) of the three groups for each of the four questions. There was no significant difference in the knowledge level for questions 1, 3, and 4, as administered in the field ($x^2 = 2.564$, 4.670, and 1.261, respectively; $x^2 0.05 = 5.991$, d.f. = 2). However, there was a significant difference in the response to question 2 (recognition of advance warning sign) with the field site respondents scoring significantly lower on this question ($x^2 = 10.131$, $x^2 0.05 = 5.991$, d.f. = 2). This indicates that the knowledge level of the field sample was lower than the drivers

TABLE 11

RESULTS OF STATISTICAL TESTS FOR SIGNIFICANT DIFFERENCES BETWEEN GROUPS—SITE ONE

VARIABLE	GROUP 1	GROUP 2	DEGREES OF FREEDOM	X^2	SIGNIFICANT[1]	t	SIGNIFICANT[2]
Mean V at 15'	Q-1 Correct	Incorrect	40			0.560	No
Speed Gradient	"	"	40			1.722	No
Lookers	"	"	1	0.249	No		
Mean V at 15'	Q-2 Correct	Incorrect	40			0.429	No
Speed Gradient	"	"	40			0.465	No
Lookers	"	"	1	1.085	No		
Mean V at 15'	Q-3 Correct	Incorrect	40			0.289	No
Speed Gradient	"	"	40			0.359	No
Lookers	"	"	1	0.072	No		
Mean V at 15'	Q-4 Correct	Incorrect	40			0.431	No
Speed Gradient	"	"	41			0.895	No
Lookers	"	"	1	0.212	No		

[1] $x^2 0.05 = 3.841$, d.f. = 1

[2] $t_{0.05} = 2.021$, d.f. = 40

TABLE 12

RESULTS OF STATISTICAL TESTS FOR SIGNIFICANT DIFFERENCES BETWEEN GROUPS—SITE TWO

VARIABLE	GROUP 1	GROUP 2	DEGREES OF FREEDOM	X^2	SIGNIFICANT[1]	t	SIGNIFICANT[2]
Mean V at 15'	Q-1 Correct	Incorrect	45			1.126	No
Speed Gradient	"	"	45			1.698	No
Lookers	"	"	1	0.795	No		
Mean V at 15'	Q-2 Correct	Incorrect	45			0.625	No
Speed Gradient	"	"	45			1.551	No
Lookers	"	"	1	5.397	Yes		
Mean V at 15'	Q-3 Correct	Incorrect	45			0.555	No
Speed Gradient	"	"	45			1.654	No
Lookers	"	"	1	0.042	No		
Mean V at 15'	Q-4 Correct	Incorrect	45			0.638	No
Speed Gradient	"	"	45			0.552	No
Lookers	"	"	1	0.003	No		

[1] $x^2 0.05 = 3.841$, d.f. = 1

[2] $t_{0.05} = 2.014$, d.f. = 45

TABLE 13

COMPARISON OF RESPONSES TO FOUR QUESTIONS ASKED AT TWO FIELD SITES TO THOSE RECEIVED AT THE DRIVERS' LICENSE EXAMINING STATION

QUESTION	SITE ONE		SITE TWO		DRIVERS' LICENSE STATION	
	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER	PERCENT
1. Correctly identify crossbuck.	28	67	38	81	580	71
Could not identify crossbuck.	14	33	9	19	238	29
2. Correctly identify advance sign.	22	52	19	40	510	62
Could not identify advance sign.	20	48	28	60	310	38
3. Knew conditions for active protection.	15	36	19	40	217	27
Did not know conditions for active protection.	27	64	28	60	579	73
4. Knew proper driving behavior for passive crossings.	15	36	14	30	296	38
Did not know proper driving behavior for passive crossings.	27	64	33	70	486	62

license sample, since the groups rated statistically the same for knowledge on three questions and the filed site fell statistically lower for one question.

The responses to the questionnaire obtained at the two sites were also compared statistically. There was no significant ($x = 0.05$) difference between the responses to each question at the two field sites ($x^2 = 4.042$, $x^20.05 = 14.067$, d.f. = 7).

The data from the two sites were also tested to see if it could be pooled. The mean speed at 15 feet from the crossing, slope of the speed profile, and number of drivers who looked for both sites were compared statistically using the Student's "t" test and the Chi Square test. The results of this analysis are presented in Table 14. The analysis indicated that at the 0.05 significance level, the hypothesis that the two groups were the same could not be rejected. Therefore, the data from the two sites were pooled and the driver performance and questionnaire response were analyzed. Statistical tests were made to determine if the knowledge groupings for the four questions resulted in significant differences in driving behavior. The results of pooling the field data are shown in Table 10, p. 81.

The pooled data did not support the hypothesis that good knowledge resulted in statistically better driving performance at grade crossings. The only significant difference between groups occurred with question 2. The group that answered question 2 incorrectly (advance warning sign) had a significantly greater number of drivers looking on the approach to the crossing, indicating a better awareness of the crossing.

TABLE 14

RESULTS OF STATISTICAL TESTS FOR SIGNIFICANT DIFFERENCES BETWEEN GROUPS—POOLED DATA

VARIABLE	GROUP 1	GROUP 2	DEGREES OF FREEDOM	X^2	SIGNIFICANT[1]	t	SIGNIFICANT[2]
Mean V at 15'	Site 1	Site 2	87			1.077	No
Speed Slope	"	"	87			1.095	No
Lookers	"	"		1.340	No		
Mean V at 15'	Correct Q-1	Incorrect	87			1.080	No
Speed Slope	"	"	87			1.009	No
Lookers	"	"	1	0.126	No		
Mean V at 15'	Correct Q-2	Incorrect	87			0.553	No
Speed Slope	"	"	87			0.849	No
Lookers	"	"	1	6.448	Yes		
Mean V at 15'	Correct Q-3	Incorrect	87			0.676	No
Speed Slope	"	"	87			0.406	No
Lookers	"	"	1	0.067	No		
Mean V at 15'	Correct Q-4	Incorrect	87			0.908	No
Speed Slope	"	"	87			0.499	No
Lookers	"	"	1	0.255	No		

[1] $x^2_{0.05} = 3.841$, d.f. = 1

[2] $t_{0.05} = 1.988$, d.f. = 87

In summary, the data did not indicate that the groups of drivers answering knowledge questions correctly performed significantly better at the sites studied.

III. FINDINGS AND RECOMMENDATIONS

1. Finding - Needless to say, it was surprising and somewhat disconcerting to learn that only five of the matched 89 drivers could be classified as safe drivers. Twenty-six drivers did make head movements, indicating that they were aware of the crossing, but they were not making their head movements when at a safe distance from the crossing or at a safe speed. Therefore, a significant number of drivers looked but still were unsafe due to their looking too close to the crossing.

Recommendation - To assist a looking driver to make a look at a proper location and speed, a signing system should be employed at crossings with restricted sight distance which will convey appropriate information to the driver. The advisory speed sign would be a candidate countermeasure since it can be used in conjunction with the advance railroad warning sign. A standard regulatory speed zone sign would also be a candidate countermeasure. A new sign may be appropriate since none of the traffic control devices clearly indicate to a driver the point where effective looking can take place and the appropriate speed relative to that point. In the event that no new sign is developed, consideration should be given to a revision in the MUTCD to specify that when the advisory speed plate is used the advance signing assembly should be erected at a location where effective looking can take place.

Locating an advisory speed plate 750 feet from the crossing may not be as effective as locating the warning at a distance from the crossing where effective looking can take place. If a driver is traveling at the recommended speed and looks for a train in the area of the sign, he/she should be able to traverse the crossing safely if a train is not detected or stop safely if one is detected.

This would have to be accompanied by an education effort to inform drivers as to the proper use of the information conveyed by the grade crossing advisory speed sign. As noted in Figure 1, p. 32, which shows the results of the questionnaire administered at the Tennessee Drivers' License Office, 72% of the drivers responded correctly to question 9. These drivers indicated that they should slow to the posted speed and look for trains. The educational effort should be directed at informing the driver that he or she should be traveling at the advisory speed upon arrival at the advance sign and at that point surveillance for a train should begin. This is a different program of desired actions from that used with advisory speeds for horizontal curves, where the sign is located in advance of the hazard for which a lower speed is required.

2. Finding - The noncorrelation of knowledge with indices of safe performance such as stopping, looking movements, mean speed profile slope, and mean speed 15 feet from the crossing seem to indicate that variables other than knowledge also have an effect on performance. Of course, a certain base level of knowledge is needed to perform safely. However, possessing that level of knowledge does not guarantee safe performance. The use of seat belts is a good example of this phenomenon.

This does not negate the need for public education recommended in connection with the advisory speed signing. If no drivers are informed of the desired behavior, then proper performance will be lower overall compared to that which would be expected if all drivers were properly informed. However, a segment of the knowledgeable drivers may still perform unsafely for other reasons.

Recommendation - Further research should be conducted at additional sites to confirm these results. Hopefully, sites might be found which yield more even proportions of safe and unsafe drivers as determined by observed speeds and head movements. If validated by a future study, the noncorrelation of performance with knowledge may have significant implication on public information campaigns such as Operation Life Saver.

3. Finding - Of the 89 matched questionnaires, 56 (63%) of the motorists interviewed believed that they were required to stop at all grade crossings.

Recommendation - Further research should be conducted in this area to determine the effect on driving behavior that the erroneous belief of a required stop has made. If the perceived requirement is considered too restrictive, then the driver may simply neglect to perform any special actions as he/she approaches a crossing. This was discussed in the findings from the questionnaire phase at the drivers' examination station.

4. Finding - The techniques used in this study are workable but they are limited to sites where observers will not be distracting, and where they will also have a view of the speed traps. This criteria severely limits the sites where this technique can be utilized.

Recommendation - The study technique would be greatly improved if a device such as the FHWA's Traffic Analyzer was utilized to develop the speed profile on vehicles approaching the crossing. Head movements also require hidden observers. If head movements were deleted from the data collection, then a simplified procedure could be developed for research studies and for use in developing a priority ranking of crossings for the installation of active control devices. The procedure could be used at all crossings, not just those with severe sight distance restrictions or with the hidden observers.

CHAPTER VIII

LITERATURE REVIEW FOR INVESTIGATION OF ADVISORY SPEEDS FOR GRADE CROSSINGS

I. THE NEED FOR ADVISORY SPEED SIGNING AT GRADE CROSSINGS

As drivers approach a passive grade crossing marked in accordance with the Manual on Uniform Traffic Control Devices (MUTCD) (15), they are warned by signs, and perhaps pavement markings, that there is a crossing ahead. However, they will not know the speed of the trains using the crossing. The sight distance available along the track when viewed from various locations on the approach is also unknown to the approaching drivers. However, the driver is expected to adjust driving behavior to allow for train speed and track sight distance in order to perform safely.

As demonstrated in Appendices F and G, the drivers at the two crossings studied who manifested a desire, by their head movements, to perform safely were not making their visual observations at the proper points from the crossing. This indicates that the true hazard related to the restricted sight distance and train speed was not apparent to the drivers.

II. CURRENT PRACTICE FOR ADVISORY SPEED SIGNING

The MUTCD (15) sets forth the standards for traffic control devices in the United States. The MUTCD allows the use of an advisory speed

plate to communicate to drivers the need to adjust their speed.

Section 2C-35 of the MUTCD (15) indicates that an advisory speed plate ". . . .may be used in conjunction with any standard yellow warning sign to indicate the maximum recommended speed around a curve or through a hazardous location." This section further states that an advisory speed plate shall not be erected until the recommended speed has been determined by traffic engineering procedures. The manual also calls for the locations to be periodically checked to see if the advisory speed needs to be modified. The standard railroad advance warning sign meets the criteria for use of supplemental advisory speed signing. Chapter 8 of the MUTCD, dealing with grade crossing devices, does not clearly state that the advisory speed plate may be used with the railroad advance warning sign. As discussed earlier, track sight distance and train speed are important variables affecting safe driver performance at grade crossings. However, these two items are not apparent to a driver as the vehicle approaches a grade crossing. If an improper speed is maintained when approaching a crossing, the driver may not be able to safely react to the presence of a train near or at the crossing.

Advisory speed signing is commonly used for roadway curves with safe operating speeds below that of the remainder of the highway. Advisory speed signing is also used for approaches to crossroads where engineering studies indicate that sight distance on the approach is insufficient to allow the major road traffic to travel at the speed limit. In other words, the major road traffic must be slowed down to allow cross road traffic to safely traverse the crossing.

The use of an advisory speed sign in conjunction with the railroad advance warning signing appears to be an inexpensive countermeasure for passive crossings. The Railroad-Highway Grade Crossing Handbook (2) indicates that:

> An advisory speed sign (W13-1 in MUTCD) should be used in conjunction with advance warning signs when site or geometric conditions are such that ample time cannot be provided for the driver to correctly maneuver his vehicle through the railroad-highway intersection (i.e., the minimum sight triangle is not obtainable for highway speed.) The advisory speed sign should reduce the driver's speed to no less than 15 mph (24 km/hr), preferably 20 mph (32 km/hr), to allow the driver time to safely respond to conditions at the crossing. The sign is usually placed on the same support as the advance warning sign.

The next chapter will discuss a procedure for establishing an advisory speed for grade crossings. A procedure for locating the railroad advance warning sign and advisory speed plate assembly will also be presented.

A mandatory speed signing system would also be a candidate countermeasure. However, Lyles (41), in his evaluation of five signing systems for reducing speeds on horizontal curves, found that none of the systems were consistently more effective. The systems studied included advisory and mandatory speed signing. These results could be expected to carry over to grade crossings, and they would indicate that mandatory speed signing at grade crossings would produce no additional benefits over the standard advisory speed signing.

CHAPTER IX

METHODOLOGY FOR INVESTIGATION OF ADVISORY SPEEDS FOR GRADE CROSSINGS

I. ESTABLISHING AN ADVISORY SPEED FOR GRADE CROSSINGS

As discussed earlier, the determination of a safe approach speed is based on stopping distance considerations and track clearance before the arrival of a train. In order to make a safe crossing the driver must make a "go" or "no go" decision far enough from the crossing, commensurate with the vehicle's speed, to allow the vehicle to stop short of the crossing if a train is detected, or to clear the tracks before the arrival of a train, in the event that a train was just beyond the limits of the track sight distance from the point where the "go" decision was made.

The proper advisory speed may be determined by evaluating the available track sight distance at several points from the crossing. As suggested earlier, these points should be based on perception and stopping distances for various approach speeds. These approach speeds should cover the entire range of expected approach speeds in 5 mph increments. At each of the evaluation points, the question needs to be asked, "If a driver were travelling at the approach speed associated with this point, would the vehicle be able to traverse the tracks safely before a train could arrive at the crossing?" The assumption must

be made that the train is barely out of view at the shortest track sight distance measurement (right or left) from the evaluation point.

The train would be assumed to be travelling at the maximum allowable speed for the crossing under consideration. For example, if a vehicle is travelling at 30 mph, a distance from the crossing equal to the perception-braking distance associated with 30 mph speed (203 feet), and the track sight distance and train's speed are such that the automobile could clear the crossing before the arrival of the train, then 30 mph is a candidate advisory speed for the crossing. If the driver can safely traverse the crossing at the speed limit, then no advisory speed signing is needed. If not, however, the crossing should then be assigned an advisory speed sign. The highest safe speed (in 5 mph increments) should be used for the crossing.

II. ILLUSTRATION OF PROCEDURE FOR ESTABLISHING ADVISORY SPEEDS

As an illustration of this procedure, the advisory speed for Crossing Number One, from the field study, was determined. Using the sight distance data in Table 7, p. 68, the data in Table 15 was developed assuming a train speed of 25 mph, 2.5 second perception-reaction time and dry pavement.

From the data in Table 15, it is apparent that speeds of 15 through 40 mph, except for 25 mph, would be candidate advisory speeds for this site. This is due to the fact that the time for the vehicle to clear the track is less than the time for a train to arrive. This

TABLE 15

CANDIDATE ADVISORY SPEEDS-CROSSING NUMBER ONE

STOPPING DISTANCE FOR SPEED SHOWN	SPEED FROM WHICH CAR COULD STOP	TIME TRAVEL TO CLEAR CROSSING AT THAT SPEED	MINIMUM TRACK SIGHT DISTANCE	TIME FOR TRAIN TO TRAVEL TO
20	Stop	0 sec.	311	8.5 sec.
39	5	5.3	204	5.6
62	10	4.2	177	4.8
87	15	4.0	156	4.3
114	20	3.9	156	4.3
145	25	4.0	122	3.3
178	30	4.1	197	5.4
215	35	4.2	204	5.6
256	40	4.4	179	4.9
299	45	4.5	158	4.3
347	50	4.7	133	3.6
399	55	4.9	108	2.9
454	60	5.2	65	1.8

is for "go" decisions made at the roadway distances associated with each approach speed.

The speed limit in the vicinity of the crossing was 40 mph. Therefore, one view might be that no advisory speed signing is needed, since at the stopping distance associated with 40 mph (256 feet) the driver has sufficient track sight distance to allow clearance of the crossing prior to the arrival of a train travelling 25 mph, which was just beyond the available sight distance. However, in establishing an advisory speed, as in the selection and design of all traffic control devices, engineering judgment must be carefully applied. The approach is on a curve which requires the driver's attention to negotiate. Therefore, the driver may be concentrating on negotiating the curve and not on looking for trains at the 256 foot point.

However, the location associated with the 20 mph speed (114 feet) is close enough to the crossing and the roadway alignment is such that effective looking for trains can be expected. Therefore, it is recommended that an advisory speed limit of 20 mph be established for this crossing and the advance warning sign and advisory speed assembly be located 114 feet from the crossing.

If drivers are educated to the purpose and basis of this signing, then their speeds should be closer grouped to the speed desired at a particular location. If no advisory speed is established, the assumption is made by default that the drivers will be travelling at 40 mph, 256 feet from the crossing. However, this neglects to consider the fact that speeds are distributed with, hopefully, the 85th percentile being

40 mph. Because of this, it would appear reasonable to always consider an advisory speed to narrow the speeds to a small range, unless the approach to the crossing is very open and the alignment will allow drivers to give attention to trains. This means that engineering judgment must be used when applying this technique with each site being considered for its unique features.

Similar calculations for crossing Number Two yields the computations shown in Table 16.

A mandatory stop or active protection should be considered at crossing Number Two, since the sight distance is so limited that the train would always reach the crossing before the highway vehicle, when judgments are made from each of the 13 locations.

The illustrative calculations in Table 16 were based on dry pavement because this was the pavement condition at the time of the field study. However, to be consistent with the design assumptions made for other elements of the roadway, such as stopping sight distances and maximum horizontal curvature, it is recommended that wet pavement conditions be assumed in establishing advisory speeds at grade crossings. This will result in the distances shown in Table 17 being used in association with each assumed approach speed. For instance, when evaluating 20 mph as a candidate advisory speed, track sight distance should be measured when viewed from a point on the approach roadway 126 feet from the crossing. The candidate advisory speed should then be evaluated to see if a train travelling at the maximum speed for the site would travel from the limits of sight distance to the crossing at

TABLE 16

CANDIDATE ADVISORY SPEEDS-CROSSING NUMBER TWO

ROADWAY DISTANCE TO CROSSING	SPEED FROM WHICH COULD STOP	TIME TRAVEL TO CROSSING AT THAT SPEED	MINIMUM TRACK SIGHT DISTANCE	TIME FOR TRAIN TO TRAVEL TO CROSSING
20	Stop	---	225	6.1
39	5	5.3	115	3.1
62	10	4.2	64	1.7
87	15	4.0	77	2.1
114	20	3.9	16	0.4
145	25	4.0	16	0.4
178	30	4.1	18	0.5
215	35	4.2	18	0.5
256	40	4.4	0	0
299	45	4.5	0	0
347	50	4.7	0	0
399	55	4.9	0	0
454	60	5.2	0	0

TABLE 17

STOPPING SIGHT DISTANCE REQUIREMENTS ASSUMING WET PAVEMENT CONDITIONS

V SPEED MPH	f WET[1]	PERCEPTION DISTANCE @2.5 SEC.	S BRAKING DISTANCE[2]	REQUIRED PERCEPTION AND BRAKING DISTANCE +20'[3]
5	.40	18	2	40
10	.40	37	8	65
15	.40	55	19	94
20	.40	73	33	126
25	.38	92	55	167
30	.36	100	83	203
35	.35	128	117	265
40	.33	147	162	329
45	.32	165	211	396
50	.31	183	269	462
55	.31	202	325	547
60	.30	220	401	641
65	.30	238	470	728
70	.29	257	564	841

[1]Coefficient of friction from 1964 AASHO Policy on Geometric Design of Rural Highways. (38)

[2]Based on $S = \frac{V^2}{2(f)\ 32.2}$ where V is in fps.

[3]Minimum legal clearance for stopped vehicle of 15 feet, plus 5 feet from driver's head to front bumper.

a lesser time that it would take the highway vehicle travelling at 20 mph to reach the crossing. If the highway vehicle could clear the crossing before the train arrives, then 20 mph would be a reasonable advisory speed. Again, the highest advisory speed that works should be used.

A further refinement on determining the time for the highway vehicle to clear the crossing would be to conduct test runs on the approach. For instance, in order to check out the 20 mph advisory speed, a car should travel past the 126 foot approach point at 20 mph. The actual time that it would take a driver to clear the crossing should be recorded. This would compensate for a driver having to slow down due to a rough crossing or other reasons. The actual time to clear the crossing should be done for all approach points and their associated speeds, including both approaches to the crossing and then compared with train arrival times from the outer limits of track sight distance from each point.

Due to decreased likelihood of driver conformance to an extremely low speed, the advisory speed should not be less than 15 mph. If the crossing sight distance and train speed are such that a driver will not be safe driving at 15 mph, then consideration should be given to the use of the mandatory stop sign or active protection at the crossing, providing the hazard (train-vehicle exposure) is sufficient to warrant this action. On the other hand, if an extremely high approach speed is the only speed that will result in a safe crossing then a stop sign or active protection should also be considered.

Using this procedure, a driver will be given sufficient information to allow compensation for both a lack of knowledge concerning the sight distance at the crossing being approached and the maximum speed of the trains using that crossing. This would be comparable to the standard practice of providing advisory speed for restricted horizontal and vertical geometrics.

Throughout this discussion, the term advisory speed has been used. It is not intended to limit the consideration of ways to convey advisory speed information to drivers to only the standard advisory speed plate. It may be that future research may indicate that a regulatory sign or a new type of sign would better convey the concept of an advisory speed for safe looking on the approach to passive crossings.

III. LOCATION OF ADVISORY SPEED SIGNS FOR GRADE CROSSINGS

Section 8B-3 of the MUTCD (15) covers the placement of the railroad advance warning sign. That section states:

> Placement of the sign shall be in accordance with Section 2C-3 and Sections 2A-21 to 2A-27, normally 750 feet or more in advance of the crossing in rural areas and 250 feet in advance of the crossing in urban areas, except that in a residential or business district, where low speeds are prevalent, the sign may be placed a minimum distance of 100 feet from the crossing.

This section of the MUTCD has been generally interpreted in a manner which results in the railroad advance warning sign for rural passive crossings being located a uniform 750 feet from the crossing. However, if the preceding procedure for establishing an advisory speed is used,

the advisory speed plate may actually need to be at a location other than 750 feet from the crossing. If the advisory speed plate were placed 750 feet from the crossing and it advised the driver to approach the crossing at 30 mph, then the driver could reduce the vehicle speed to 30 mph and begin looking for a train 750 feet from the crossing. It may be that looking for a train that far from the crossing would be useless since the track sight distance may be very short when the crossing is viewed from 750 feet away. With a short track sight distance, the car travelling at 30 mph could easily be beaten to the crossing by a train.

The preferred location for the advance signing with the advisory speed plate would be at the critical point used for the advisory speed determination. For example, if the advisory speed was 30 mph, then the speed plate assembly should be placed at a "safe" distance from the crossing associated with that speed or 203 feet. The "safe" distance would be based on the perception-braking distance for the speed. If the track sight distance at that point was adequate to allow clearance, then a driver travelling 30 mph and looking for a train at the point of the 30 mph sign assembly will be assured of a safe crossing. The driver can stop if a train is in the sight triangle. The vehicle can also clear the tracks if a train is just beyond his sight triangle. With this system, the driver is told how fast to drive to be safe and where on the approach the driver needs to be travelling at that speed and looking for a train. Consideration should be given supplemental

educational efforts to encourage looking for trains at the desired point. This may require a clear message to drivers as to where they should look for trains.

The MUTCD, in Section 2A-25, states that, "Warning signs should be placed in advance of the condition to which it calls attention," While making a general recommendation of 750 feet for rural areas, Section 2C-3 goes on to state that, "The actual advance warning distance will be determined by two factors, the prevailing speed and the prevailing conditions. These bear respectively on the time available to the driver to comprehend and react to the message, and the time needed to perform any necessary maneuver." These statements appear to give adequate latitude for the location of the rural advance warning sign at distances other than 750 feet. Locating these signs at the appropriate effective looking distance associated with the advisory speed will give the driver enough information to make a safe crossing.

For illustrative purposes, the advisory speed sign for crossing Number One, which was previously computed as 20 mph, should be located 130 feet in advance of the crossing. If a driver passes the sign travelling at 20 mph and is looking for a train, the driver will make a safe crossing or the vehicle can come to a safe stop if a train is detected.

Here again, it is not the intent to limit the actual sign considerations to the standard advisory speed plate. Regulatory signing or a new sign may be determined to better convey the message of where a look should take place and at what speed should the vehicle be travelling.

CHAPTER X

RESULTS AND CONCLUSIONS FROM INVESTIGATION OF ADVISORY SPEEDS FOR GRADE CROSSINGS

I. RESULTS

The current advisory speed signing practices were examined in Chapter VIII. A methodology for establishing advisory speeds for railroad crossings was developed and set forth in Chapter IX. A procedure for locating the advisory speed sign at the location where effective looking for trains can take place was also developed and is documented in Chapter IX.

II. FINDINGS AND RECOMMENDATIONS

1. Finding - Drivers were observed approaching grade crossings who manifested their desire to perform safely by making head movements. However, the head movements were not made while the vehicle's speed or location was such that a safe reaction to the presence of a train could take place.

Recommendation - The advisory speed sign is a countermeasure for consideration at passive crossings with restricted sight distance. The technique described in Chapter IX will allow the establishment of the advisory speed for a crossing and the determination of the location for the railroad advance warning sign with an appropriate advisory speed plate. Passive railroad crossings with restructed sight distances

should have advisory speed signing. The speed determination should be as described in Chapter IX. The warning signing should be located at the location where effective looking can take place based on the advisory speed. The MUTCD should state the criteria for advisory speed signing for railroad crossings. Public education efforts should be undertaken to explain how drivers can use this sign in order to guarantee a safe crossing, since the advisory speed is not applicable downstream from the sign, as is the case for horizontal curves. The advisory speed would be applicable at the point of the advance sign at which point effective "looking" can take place. Of course, the site should be monitored for changes in sight distance or train speeds which would affect the advisory speed.

CHAPTER XI

LITERATURE REVIEW FOR INVESTIGATION OF PRIORITY PROCEDURES FOR GRADE CROSSING IMPROVEMENTS

I. EVALUATION OF DRIVER PERFORMANCE AT PASSIVE CROSSINGS

As a part of this research methods of accounting for the effect of sight distance on safe driving behavior were considered. Detailed sight distance measurements were made at two grade crossing sites. As the sites were studied, it became apparent that at every point along the approach roadway, there is a window of safe speeds bounded by upper and lower limits. The upper limit for the safe approach speed window is the maximum speed from which the driver could perceive the train and safely come to a stop within the distance remaining from which the evaluation was made. The lower would be the speed at which the driver could safely clear the crossing ahead of a train in the event a train was just beyond the track sight distance at the point from which the judgment was made to proceed through the crossing. In other words, the lower speed limit must be slow enough to stop, but not so slow as to allow a train to reach the crossing at the same time or before the vehicle, thus resulting in a car-train collision. The "go" or "no go" decision can be made at any point along the approach roadway if the driver is operating within the window of safe speed. After making a

"go" decision, the driver need only maintain the current speed to cross the tracks safely.

This concept of a window could be useful in research on countermeasures and for comparing the hazards of crossings for use in setting priorities for the installation of active protection. The procedures currently being used to evaluate driver performance and crossings are discussed in the following sections.

II. IMPORTANCE OF SIGHT DISTANCE

In the design of roadway elements, sight distance plays a large role. Stopping sight distance is considered on vertical crests in profile design. Sight distance from the minor road is considered in the design of intersections. Sight distance is also important at passive railroad grade crossings. To operate safely, the driver must be able to see if a train is coming. If the driver cannot see down the track an adequate distance, relative to the vehicle's operating speed, then the driver and vehicle are being expected to perform beyond their physical limitations. If a driver overdrives the sight distance by travelling faster than is commensurate for a safe stop at the crossing, and if a train were detected within the available sight distance, then there is a high potential for an accident. Sight distance limitations can be corrected by clearing the quadrant or installing active protection. The driver can also be advised of the need for operating at a reduced speed at the crossing.

The number of crossings with sight distance limitations is not known on a national scale. However, Schoppert and Hoyt (22) measured sight distances at 31 passive crossings. Only one of the 31 crossings had all four quadrants with adequate sight distance for the roadway speed limit. Only 20% of the 124 quadrants were actually adequate. The following section discusses present methods being used to evaluate crossings for sight distance deficiencies.

III. CURRENT MEASURES OF EFFECTIVENESS FOR EVALUATING DRIVER PERFORMANCE

Sight distance at railroad grade crossings has been used in the safety evaluation of crossings. Many priority and warrant formulae for grade crossing improvement use sight distance as an independent variable.

In 1973, Sanders (9), in a study for the Federal Railroad Administration and the National Highway Traffic Safety Administration, developed procedures for evaluating countermeasures at grade crossings. If, for example, a public authority was contemplating a change in standard signing, procedures would be needed to evaluate the benefits, if any, of the change. Sanders' evaluating measures consisted of:

1. Looking behavior within 200 feet of a crossing with restricted sight distance.
2. Speed measurements 500 feet and 10 feet from the crossing.

The increase in looking behavior and an increase in the ratio of speed reduction (speed decrease from 500 feet to 10 feet from the

crossing divided by the entering speed) were suggested as independent variables. As changes were made to the traffic control devices, changes in these variables could be tested for statistical significance.

The procedure used by Sanders required hidden observers and sites with severe sight distance restriction, such that obvious head movements would be necessary. The measurements taken were actually an indirect evaluation of the manner in which the driver was coping with the limited sight distance.

Dommasch, et al. (12) studied experimental passive signs at railroad grade crossings in New Jersey. The following measures were used to evaluate the effectiveness of the experimental signs.

1. Standard deviation of the spot speeds on the crossing.
2. Head movements.
3. Brake light applications.
4. Motorist interviews.

This study found that an increase in awareness, as quantified through the above variables, was associated with the experimental signs. The increases were generally statistically significant.

In early 1972, Russell et al. (42) studied a high accident grade crossing to evaluate the effectiveness of improvements. The measure used to evaluate the changes was a speed profile developed from spot speeds taken at eight locations along the approach roadway. The spot speeds were developed from photographic records of the vehicles crossing through speed traps.

In 1978, Sanders et al. (16) evaluated the use of STOP signs at railroad crossings. Measures used to evaluate the driver performance at representative STOP signs were:

1. Accident analysis.
2. Driver stopping behavior.
3. Driver looking behavior.
4. Speed profiles for approaching vehicles.
5. Individual vehicle delay.

In a study for the United States Department of Transportation, Koziol and Mengert (10) evaluated three experimental passive signing systems at 18 sites. The measures considered in evaluating driver behavior to these systems were:

1. Head movement.
2. Speed profile.
3. Root mean square deceleration.
4. Headway reduction ratio.
5. Time in hazard zone.
6. Number of vehicles stopping at the crossing.
7. Speed reduction (speed 800 feet from crossing minus speed at 200 feet from the crossing).
8. Exit speed (speed at 200 feet from the crossing.

Only head movement, speed reduction, and exit speed were finally used in the evaluation of the signing systems.

In 1978, the North Carolina Department of Transportation conducted a study of all of the 4,369 passive railroad grade crossings in that

state. (43) This study made a complete sight distance inventory of the crossings. The sight distance measured was as follows:

1. Highway Approach Sight Distance-the distance the driver is from the tracks when the crossing or crossbucks first become clearly visible to him. These were compared with the posted and 85th percentile speed safe stopping sight distances.
2. Right and left sight distances were measured along the tracks from the point where a train could be seen when viewed at the safe stopping sight distance from the crossing. This is based on both the posted and real speeds along the approach roadway. These measurements were compared with the distance from the crossing at which the driver should actually see the train in order to make a safe "go" or "no go" decision. This determination was based on train speed, vehicle speed, length of vehicle, length of railroad crossing, and the required safe stopping sight distance for the posted and real speeds.
3. The last sight distance measured was the right and left sight distance for a vehicle stopped at the crossing. This was evaluated to determine if a vehicle, such as a C-50 truck, could safely clear the crossing from a stopped position after a "go" decision was made. The method of evaluation was to compare the actual distance with the required sight distance for a safe crossing from a stopped position.

All of the North Carolina sight distance measurements were then evaluated to rank crossings in order of sight distance deficiencies.

The ratio of actual sight distance available to required sight distance for each of the eight sight distance measures was determined. For example, if the distance at which the driver could actually see the crossing was less than the safe stopping sight distance for the roadway, a ratio was developed of actual divided by required. This ratio was then subtracted from one. This results in a site with a deficiency in some sight distance measurement having a rating of less than one. The greater the deficiency, the lower the rating.

All of the ratings were combined into one overall sight distance rating for the crossing, using the Delphi Method, where the weight of each deficiency rating was determined by a panel of professionals. The overall sight distance deficiency formula is shown as follows:

$$12\left(1 - \frac{ASD}{PSD}\right) + 32\left(1 - \frac{ASD}{RSD}\right) + 6\left(1 - \frac{PSD\text{-}L}{DCDST}\right)$$
$$+ 6\left(1 - \frac{PSD\text{-}R}{DCDST}\right) + 14\left(1 + \frac{RSD\text{-}L}{DCDST}\right) + 14\left(1 - \frac{RSD\text{-}R}{DCDST}\right)$$
$$+ 8\left(1 - \frac{VSD\text{-}L}{DCDST}\right) + 8\left(1 - \frac{VSD\text{-}R}{DCDST}\right) =$$

Total deficiency value for a particular approach of a crossing where:

ASD = Highway Approach Sight Distance to Crossing or Crossbucks

PSD = Posted Speed Sight Distance Required for Safe Stopping

RSD = Real Speed Sight Distance Required for Safe Stopping

PSD-L = Track Sight Distance to the Left from the PSD

PSD-R = Track Sight Distance to the Right from the PSD

DCDST = Necessary Track Distance from the Crossing the Driver must be Able to See to Cross Safely

RSD-L = Track Sight Distance to the Left from the RSD

RSD-R = Track Sight Distance to the Right from the RSD

VSD-L = Vehicle at Stopbar Distance-Left Track Sight Distance

VSD-R = Vehicle at Stopbar Distance-Right Track Sight Distance.

The North Carolina Study did not develop a method of tying the sight distance deficiency rating into an overall priority formula, including car-train exposure. Other agencies have developed formulae with many variables, including sight distance. These are discussed in the next section.

IV. PROCEDURES CURRENTLY USED TO DEVELOP PRIORITIES

All states have procedures to guide management in determining which passive crossings should be upgraded to active protection. These procedures may be simply a method of setting priorities for the use of available grade crossing protection funds or they may be actual numerical warrants to be applied to specific situations. There is no nationally recognized formula or warrant for providing active protection. In 1977, Sanford reviewed the criteria used by the states. (32) This review indicated that the majority of the states were using one or more of the following formulae for setting priorities for grade crossing improvement:

1. Hazard formula from NCHRP 50 (22) is used by ten states.

   Formulation EA per year = A x B x Trains/day

   Where EA = expected accidents

   A = factor for vehicles/day

   B = factor for existing warning device at crossing

   The values for A and B are selected from NCHRP 50. (22)

2. The New Hampshire formula (39) is used by seven states.

   Formulation HI = VTP = Hazard Index

   V = ADT on road

   T = number of trains per day

   P = warning factor

   gates = 0.1

   flashing lights = 0.6

   signs only = 1.0

3. The Peabody-Dimmick formula (21) is used by six states.

   Formulation

$$\text{Expected Accidents/ 5 years} = 1.28\frac{(\text{Daily Highway Traffic})^{0.170} \times (\text{Daily Train Traffic})^{0.151}}{(\text{Warning Coefficient})^{0.171}} +$$

   Additional Parameter

   The warning coefficient for various protective systems is listed in the publication.

These formulae only consider the volume of highway and train traffic in conjunction with the present protection being provided. At

least one of the above three formulae is used by 23 states. It should be noted that sight distance is not input into the priority setting procedure. The NCHRP Report No. 50 procedure does allow adjustments for approach gradient number of lanes, and angle of crossing.

V. PRIORITY PROCEDURES USED BY THE STATES

A short discussion of the procedures used by those states which Sanford noted as including sight distance in priority setting or warrants follows. Sanford reported that 15 states and the District of Columbia used view and site conditions as parameters in priority formulae, and/or in warrant formulae. The actual formulae are included in Appendix H.

Arizona

Arizona uses a benefit cost ratio approach for warrants. Stopping sight deficiency is also considered in the form of engineering judgment for individual crossings. Priorities for grade crossing improvements include consideration of crossings with stopping sight distance deficiencies. Therefore, Arizona considers sight distance in their procedures, only subjectively, without an analytical process.

Arkansas

Arkansas utilizes a hazard index formula for both warrants and priorities. The hazard rating includes a factor for road and train volume along with a factor for accident record, local conditions, and number of tracks. The local condition factor includes a judgment rating

as to whether the local conditions are Good, Fair, Medium, Bad, or Hazardous. In this judgment rating, sight distance is one of the factors included.

District of Columbia

The District of Columbia uses a factored version of the NCHRP 50 formula. The NCHRP 50 formula is used to compute the expected accidents. A rating of 1, 2, or 3 is given to the crossing, based on the expected accidents. Similar ratings of 1, 2, or 3 (3 being the most severe case) are given for ADT, trains per day, warning devices, sight distance, number of tracks, number of approach lanes, crossing angle, and approach train speed. Each of these variables is weighed and their products totaled and divided by the maximum possible score. The higher the rating the more hazardous the crossing. Limits are set for defining crossings as very hazardous, hazardous, and nominal, based on numerical ratings. The sight distance at the crossing is considered by relating sight distance to tables from NCHRP Report No. 50. The poorest rating, "3," is assigned to a crossing that does not have sight distance meeting the sight distance table associated with dry pavement and a one second perception-reaction time from the NCHRP Report. A "2" is assigned if the crossing meets the minimum table but does not meet the design values table requirements based on trucks, wet pavement, and a two second perception-reaction time. A "1" is assigned if the design values table is met. This rating is then weighted by two. This means the sight distance is weighted at only two of the total of 21 weighting points assigned to all of the variables.

Florida

Florida uses a hazard index formula to predict the number of accidents in a four year period based on the maximum speed of trains, train volumes, ADT, highway speed limit, and sight distance. Sight distance is entered into the calculation by finding the ratio of the actual minimum stopping sight distance, along the highway, to the required stopping sight distance on wet pavement. The summation of the four clear quadrant sight distance values measured from the required stopping sight distance point is also divided by the required stopping sight distance. These two ratios are factored and included in the summation of the other factored components of the crossing system under consideration. Warrants are developed based on a safety index derived from the hazard index formula. Priorities are based on the safety index, available funds, benefit-cost ratios, and accident history.

Iowa

Iowa uses a crossing rating which is a summation of a rating for all four quadrants of the crossing. Each quadrant is assigned a rating based on highway traffic, train volume, train speed, sight distance, alignment consideration, angle of crossing, and safe stopping sight distance. Sight distance is measured along a track from a point on the roadway approach 500 feet away. Sight distance enters the formula as a divisor for the product of train volume and train speed. Priorities and warrants are based on the formula.

Kansas

Kansas uses a hazard index formula which includes ADT, train volume, sight distance, angle of crossing, and number of tracks as variables. Sight distance enters the computation as an additive factor with the angle of crossing. The factor used for sight distance is based on the ratio of 8,000 divided by the quadrant sight distance measurements from all four quadrants and the number of tracks. Warrants are based on exposure factors (ADT x train volume). Priorities are based on the hazard index formula.

Louisiana

Louisiana includes sight distance and speeds in their hazard index ratings. These are supplemental considerations, along with the Peabody-Dimmick ratings, and they are applied in a subjective manner.

Massachusetts

Massachusetts has inventoried sight distance at all of its crossings. Priority rankings are based on subjective ratings derived from inventory data.

Mississippi

Mississippi considers sight distance in a subjective manner along with exposure, existing protective devices, and recommendations from a diagnostic team. The diagnostic team considers sight distance in its recommendations.

Montana

Montana utilizes a hazard index formula which includes ADT, train volume, type of train movements, number of tracks, sight distance,

approach angle, highway alignment, number of lanes, vertical sight distance, crossing width, and local intersections. Sight distance is evaluated at each quadrant and a value of "1" is assigned if it is totally restricted. A value of "0" is assigned if it is unrestricted. The sum of the judgmental ratings for the four quadrants (maximum value is "4") is added to the other factors. This sum is divided by 100. The maximum sight distance rating of "4" is overshadowed by the first factor which is the car-train product, expressed in units of vehicle-trains. Therefore, it has little impact on the setting of priorities or warant considerations which are based on this index.

Nebraska

Nebraska uses a sight distance factor as an additive factor to area factor, train speed, highway speed, track rating, roadway surface, and crossing grade factors. The summation of these factors are applied to the car-train product.

North Carolina

North Carolina uses a hazard index based on car-train product. As stated earlier, all crossings have been inventoried for sight distance. A procedure has been developed to establish priorities for improving sight distance. However, the relation of sight distance deficiencies to exposure has not been developed as yet.

North Dakota

North Dakota uses a rating system which defines a standard adequate crossing as one that has a par rating of 100. This rating is made up of the four major categories of railroad conditions, highway conditions,

exposure factor, and visibility factor. Thirty-six of the par points are assigned to the visibility factor. Less points are alloted, based on the number of quadrants that are deficient in sight distance. The determination of a deficiency in sight distance is based on tabular values for car and train speeds compared with the available sight distance. Therefore, sight distance could affect the ratings by as much as 36%.

South Dakota

South Dakota uses a hazard index based on exposure multiplied by the summation of factors related to train speed, sight distance, angle of crossing, number of tracks, highway alignment, and vehicle accidents. The factor for sight distance is based on track sight distance available from the roadway 300 feet from the crossing and ranges from 0 to 1, with "1" being the factor assigned for track sight distance under 500 feet. This factor makes up one-ninth of the maximum additive factors, unless accidents have occurred at the crossing. If accidents have occurred at the crossing, the relative weighting value of the sight distance factor is effectively reduced. Warrants are based on the hazard index. Priorities are based on recommendations from the diagnostic team.

Wisconsin and Wyoming

Wisconsin and Wyoming use a hazard index based on car-train exposure. The priority setting procedure includes sight distance as one of the subjective evaluations by the diagnostic team.

CHAPTER XII

METHODOLOGY FOR INVESTIGATION OF PRIORITY PROCEDURES FOR GRADE CROSSING IMPROVEMENTS

I. INCORPORATION OF DRIVER PERFORMANCE INTO PRIORITY PROCEDURES

As discussed in the preceding chapter, none of the procedures currently available for use in establishing priorities in a program for upgrading passive grade crossings to active crossings actually considers driver behavior at the passive sites. Various measures are used as input into models which endeavor to rank the probability of train-vehicle collisions during a certain time period. However, the current driver behavior at the crossings under consideration is a meaningful independent variable which can and should be used in establishing priorities.

The probability of a train-vehicle collision is related to the exposure of unsafe drivers to trains. Unsafe drivers are those who are operating their vehicles in such a manner that they could not avoid an accident if a train was in the vicinity of the crossing while they are approaching that crossing. The probability of conflict is related to the probability of train arrival during the time that a driver is approaching the crossing in an unsafe manner.

In order to approximate the probability of this conflict, an estimation of the unsafe drivers using the approach to the crossings

under consideration must be determined. Here again, the window concept can be used and a new procedure is described in the following section.

II. NEW METHOD FOR DEVELOPING PRIORITIES

As discussed earlier, the design of the field studies resulted in the concept of a window of speeds at each point along an approach roadway where a safe "go" or "no go" decision could be made by the driver. The current literature indicates that related sight distance measurement procedures are based on measurements of track sight distance taken at one or two locations along the approach roadway. However, the very nature of sight obstructions and the possibility of vehicles approaching the crossing at varying speeds can allow good sight distance at one point on the highway and poor sight distance at a point within the next ten feet. Therefore, measurement from a standard point on the highway does not provide a true measure of the influence of sight distance on the safety of the crossing. Sight distance is "site specific" as related to safety and the establishment of advisory speeds.

As discussed in the preceding section, methods used by the states to evaluate grade crossings for priority ratings or warrants either overlook sight distance, or include a judgment or factor adjustments to ratings. The sight distance factors used by the states are empirical factors based on judgment of the developers of the formulae. This is apparent since no studies have been able to correlate sight distance and accidents. (22) This lack of correlation is based on the lack of uniform recording of sight distance information and the lack of

inclusion of quadrant involvement in car-train accident records. In other words, there is no data base to correlate the two variables.

The Sanders' Study (9) procedure did not allow an analytical determination of safe vehicle operation, only the changes in the dependent variables for each different treatment could be measured. The North Carolina study did not relate actual driver operation to the sites studied.

The procedure which follows has the potential of providing a direct index of the effect of sight distance on the safety of a crossing. The procedure consists of the following steps:

1. Measure the track sight distance from many locations on the two highway approaches.
2. Using the FHWA's traffic analyzer, or a similar technique, measure the speed of each vehicle as it crosses each point from which track sight distances were determined.
3. Evaluate the speed data and determine the proportion of drivers who at some point on their approach to the crossing were operating at a speed where they could make a safe "go" decision (could stop safely and also could clear the crossing before a train just beyond sight triangle would arrive). Figure 6 is a flow chart showing the stops in applying this procedure.

The proportion of safe drivers could be used to evaluate countermeasures through before and after measurements. The proportion of unsafe drivers could also be used as input into a priority procedure

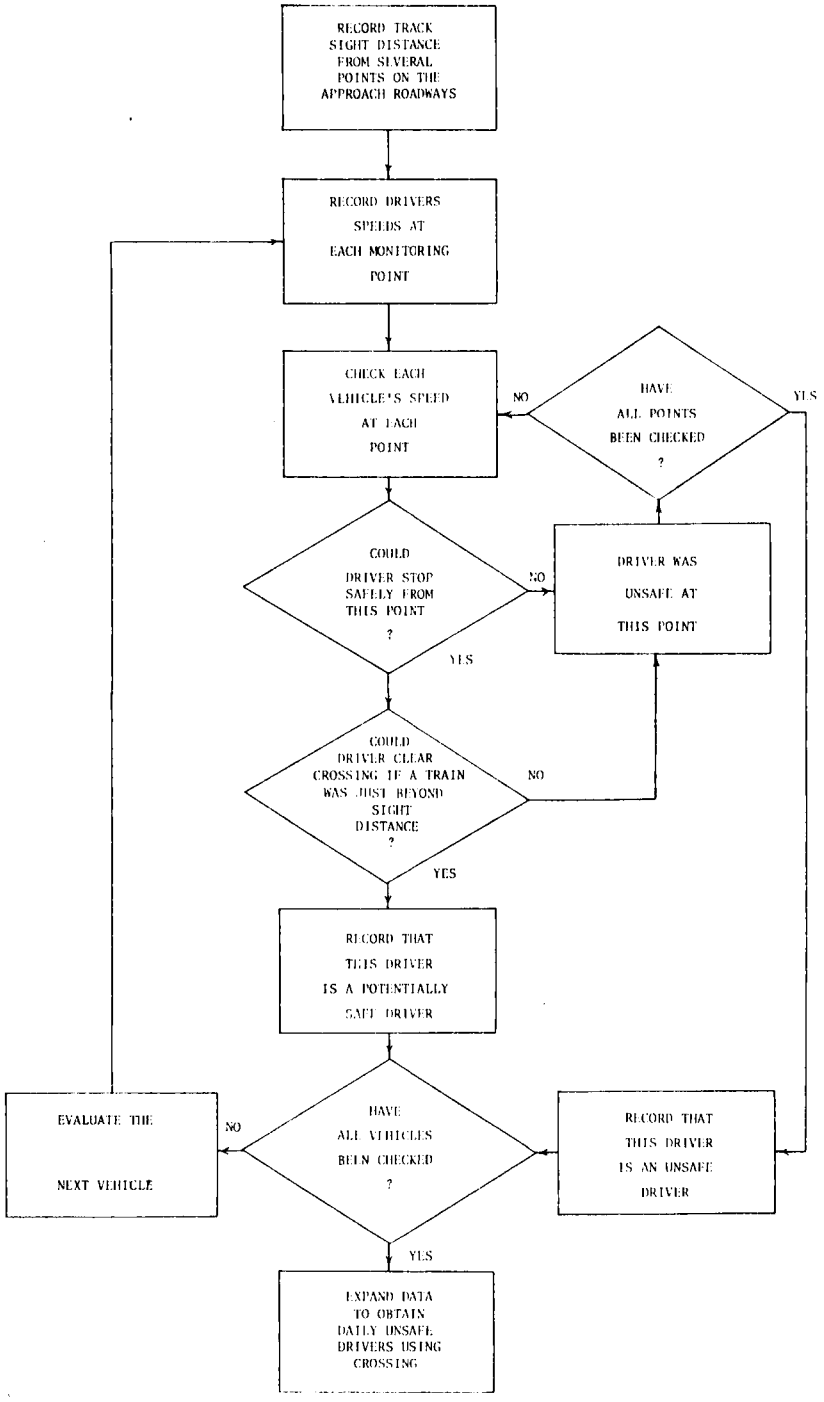


Figure 6. Flow chart for data collection to determine number of unsafe drivers using a grade crossing.

by factoring the ADT to arrive at the expected number of drivers who are using the crossing in an unsafe manner.

The FHWA's traffic analyzer is suggested as a data collection tool for this procedure since it is a device that can be used to record vehicle speeds and placement at many locations. Vehicles are detected by means of tape contact switches placed on the pavement. Previous applications of this data collection instrument indicate that the switches on the pavement do not appear to cause drivers to alter their behavior.

This instrument detects vehicle speeds by placing two tape switches at a known distance apart. The instrument uses elapsed time between the switches to compute and record vehicle speeds. The pairs of tape switches could easily be used to instrument approaches to grade crossings to develop approach speed profiles for use in unsafe driver determination in accordance with the procedure proposed by the present research.

A variation on this procedure would be to use hidden observers to watch head movements in the same manner as the field studies reported in Chapter VI. The number of drivers who "look" in the proper zone commensurate with their speed would be classed as "safe" drivers. The percentage of safe drivers could then be used in a priority procedure as discussed earlier.

The choice of methods would be at the option of the state. However, either method would yield a direct indicator of the effect of sight distance on the drivers using the crossing.

The basic procedure can be utilized at all crossings since no hidden observers are necessary. It can also be used at night since head movements are not recorded. It could be used on a sampling basis for each approach; for use in expanding to the 24 hour traffic. The data collected would give direct consideration to measures currently being utilized in empirical formulae by the states. Such items as vehicle speed, train speed, crossing angle, highway alignment, and approach grades are considered by the driver along with sight distance, as the vehicle goes through the crossing. The real question is, "Could the driver stop if a train suddenly appeared, and could the vehicle clear the crossing after making a "go" decision?" This would be a direct evaluation of a crossing's safety. If two crossings have the same car-train exposure, the one that is being operated with a higher product of unsafe drivers and trains should be given higher priority for grade crossing improvement. The concept of dealing with unsafe drivers could have application to any ranking process by deleting the factors that are being evaluated directly, such as speeds, sight distance, etc.

A possible objection to the use of this procedure is that the assumption must be made that the driver is always alert and watchful for a train if the driver is labeled "safe" because the vehicle was travelling at the appropriate speed. This objection is removed if the "safe" driver is viewed as a potentially safe driver. In other words, if this procedure indicated that 50% of the drivers using a crossing were travelling at an appropriate speed to make a safe "go" decision, then 50% would be the absolute upper limit of "safe" drivers. It may

be that the attentive drivers who had proper speeds would be less than 50%, but one could be certain that 50% were "unsafe" since they could not have made a safe judgment due to their speeds. This would allow the procedure to be used for comparative purposes assuming that the matter of interest is the relative number of unsafe drivers for input into countermeasure evaluation or priority procedures.

The real advantage of this procedure is that a human factors type measure of how a driver evaluates a crossing is obtained. If the driver evaluates it incorrectly, the vehicle speed profile will be an indicator of the wrong evaluation. If the drivers are not perceiving the restricted sight distance or train speed, the use of advisory speed signing should be considered and the site restudied. If the site continues to remain high in the priority listings, the installation of active protection should definitely be considered.

The Federal Railroad Administration has recently issued a notice of proposed rulemaking which would require all train locomotives be equipped with flashing stobe lights. If this is finally implemented, the train will be much more conspicuous. The assumption of the approach speeds being related to safe performance is more reasonable since the drivers' attention is more likely to be directed to an approaching train. Also, if a driver has a direct line of sight to a locomotive, then the train's horn may also attract his attention and allow a safe stop, if the vehicle is travelling at an appropriate speed for the distance from the crossing.

The recommended procedure is to develop for the approaches of each crossing under consideration an estimation of the number of drivers who approach the crossing in an unsafe manner each day. In other words, "How many drivers approach the crossing each day at such a speed that they could not avoid a train collision under a possible train arrival condition?" The three step procedure described above should be used to make this determination. The probability of a train arriving during the time that one of the "unsafe" drivers is approaching must then be determined.

The probability of an accident is related to the probability of an unsafe driver approaching the crossing multiplied by the probability that a train will also be in the vicinity of the crossing. Schoppert et al. (22) state that one second is fairly representative of the time during which a vehicle occupies the crossing. However, at normal speeds, Schoppert found that it takes the average driver approximately two to three seconds to travel from the point where the vehicle was last able to stop to the point where he is clear of the crossing. Schoppert reasons that the probability of train arrivals in greater than one second increments is not a concern because each additional second added to the time of train arrival would give the highway vehicles, within that time of the crossing, exactly that amount of time to beat the train. If the train arrival increment were increased, it would be necessary to extend the vehicle arrival increment by the same amount. However, Schoppert further states that during the two to three seconds the driver still has the alternative of evasive actions, even though

the vehicle cannot stop. He can run off of the road, or he can hit an object other than the train. He can also accelerate and possibly beat the train. For purposes of Schoppert's investigation, a highway risk time of one second was used.

The problem then becomes one of determining the probability that a train will arrive during a one second time period and the probability that a driver will approach the crossing in an unsafe manner during a one second period. A poisson distribution can be assumed for both trains and vehicles unless specific knowledge of the site will allow more accurate assumptions.

The probability of having at least one arrival in a randomly chosen second is:

$$P_T(\geq 1) = 1 - e^{-V_T/T} .$$

Where

$P_T(\geq 1)$ = Probability of arrival of at least one train in a second

T = Number of seconds in a day

V_T = Volume of daily trains

This equation can be modified to cover vehicle arrivals during a one second period:

$$P_V(\geq 1) = 1 - e^{-V_V/T}$$

$P_V(\geq 1)$ = Probability of arrival of at least one vehicle in a one second period

T = Number of one second periods in a day

V_V = Volume of unsafe drivers using the approach under consideration.

The expected number of accidents at the crossing would be:

$$P_A = \text{(Number of Seconds in a Year)}\ [P_V(\geq 1)][P_T(\geq 1)] \quad .$$

This is computed for each approach since the approaches may have different characteristics.

This procedure is used to rank passive crossings by expected accidents per year. The crossings with a higher expected number of accidents should be upgraded to active protection first. Of course, an over riding assumption is that the passive crossings under consideration are already signed and marked in accordance with the MUTCD. More sophisticated probability procedures can be used if one knows about the hourly distribution of train and vehicle traffic (peak hour). The above procedure could be used for each hour in the day and the probabilities of conflict during each hour of the 24 hours summed up to arrive at a total probability of conflict during the 24 hour period. This would account for crossings with no night train movements or nonrandom distributions.

However, for simplicity and due to possible changes in train schedules, it is recommended that the above probabilities be approximated by utilizing the exposure of trains to unsafe performing drivers for each approach in terms of a train-unsafe driver product. As may be noted from the probability formulae, as vehicle volume increases the

probability of vehicle arrival increases. As train volume goes up, the probability of train arrival also goes up. Likewise, as vehicle or train volume goes up, their product increases. Since relative priority is the questions at hand, a simple train-vehicle product could be used and is hereby recommended. A site with ten trains per day and 400 vehicles approaching the crossing in an unsafe manner (both approaches) would have an exposure of 4,000 train-unsafe vehicles. If this were compared with a site with eight trains and 600 unsafe drivers, the exposure of 4,800 would indicate that this site should be considered for active protection before the site with an exposure of 4,000.

III. ILLUSTRATION OF NEW PRIORITY PROCEDURE

In order to illustrate the new driver behavior oriented procedure, hereafter, termed The University of Tennessee (UT) priority procedure, and to compare its results with two of the currently used procedures, the following hypothetical crossings will be ranked using the UT procedure, the New Hampshire formula, and the procedure from NCHRP 50 (22).

The ten sites shown in Table 18 will be ranked by each method. All of the sites are passive grade crossings and are signed and marked in accordance with the MUTCD. The objective is to rank the crossings for upgrading to active protection in order to obtain the maximum safety benefit for the funds invested in grade crossing improvement.

The proportion of unsafe drivers would be determined by using the three step procedure discussed in this chapter. Based on the sample for each approach, the percentage of unsafe drivers was expanded to the

TABLE 18

ILLUSTRATIVE DATA FOR USE IN PRIORITY PROCEDURES

SITE	ADT	UNSAFE DRIVERS	TRAINS/DAY
1	1000	200	9
2	2000	2000	2
3	1200	1100	3
4	800	700	4
5	400	200	11
6	1400	200	12
7	1800	500	6
8	500	100	8
9	1600	100	10
10	400	400	20

ADT by multiplying the percent of unsafe drivers for each approach by the directional ADT. This yields the approximate number of unsafe drivers using both approaches.

The New Hampshite formula is used by seven states. It has the formulation:

$$HI = VTP \quad .$$

Where

HI = Hazard Index

V = ADT on road

T = Number of trains per day

P = Warning factor, for signs only P = 1.0.

The New Hampshire formula results in the ranking are shown in Table 19.

The formula developed and reported in NCHPR Report No. 50 (22) is used by nine states and the District of Columbia. The formula is as follows:

$$EA \text{ Per Year} = A \times B \times \text{Trains Per Day} \quad .$$

Where

EA Per Year = Expected accidents per year

A = Factor from Table of Highway Volumes

B = Protection Factor (B = 3.03 for crossbucks) .

TABLE 19

RESULTS OF ILLUSTRATIVE RANKING USING
NEW HAMPSHIRE FORMULA

RANK	SITE	HI = VTP
1	6	16,800
2	9	16,000
3	7	10,800
4	1	9,000
5	10	8,000
6	5	4,400
7	8	4,000
8	2	4,000
9	3	3,600
10	4	3,200

The NCHRP 50 formula results in the rankings are shown in Table 20.

The UT priority ranking procedure developed by this research ranks passive crossing by the exposure of drivers performing unsafely to trains. The formula is:

$$RAE = VT \quad .$$

Where

RAE = Relative Accident Exposure

V = Number of Drivers Approaching the Crossing in an Unsafe Manner Each Day

T = Trains Per Day .

The value for V (Unsafe Drivers) is determined from field studies of sample traffic on each approach to the crossing. These field studies will enable an approximation to be made of the number of drivers who approach the crossing in an unsafe manner each day. Using the UT Method results in the rankings shown in Table 21.

The results from ranking these ten crossings by the three formulae are as shown in Table 22.

The choice of ranking procedures becomes extremely important when there are only a limited amount of funds available for improving grade crossings. Assume that the ten crossings under consideration were within a governmental jurisdiction that had funds to improve only three passive crossings. Using the New Hampshire Method, crossings Number 6, 9, and 7 would be improved. With the NCHRP 50 Method, crossings

TABLE 20

RESULTS OF ILLUSTRATIVE RANKING USING NCHRP 50 FORMULA

RANK	SITE	ADT	A FACTOR[1]	TRAINS/ DAY	EA=AxBxTRAINS/DAY =Ax3.03xTRAINS/DAY
1	6	1,400	0.001877	12	0.06825
2	9	1,600	0.002127	10	0.06444
3	7	1,800	0.002377	6	0.04321
4	1	1,000	0.001377	9	0.03755
5	10	400	0.000486	20	0.02945
6	8	500	0.000694	8	0.01682
7	5	400	0.000486	11	0.01620
8	2	2,000	0.002627	2	0.01592
9	3	1,200	0.001627	3	0.01479
10	4	800	0.001104	4	0.01388

[1]From Figure 24 NCHRP 50.

TABLE 21

RESULTS OF ILLUSTRATIVE RANKING USING NEW PROCEDURE

RANK	SITE	ADT	V UNSAFE DRIVERS	T TRAINS/ DAY	RAE = VT
1	10	400	400	20	8000
2	2	2000	2000	2	4000
3	3	1200	1100	3	3300
4	7	1800	500	6	3000
5	4	800	700	4	2800
6	6	1400	200	12	2400
7	5	400	200	11	2200
8	1	1000	200	9	1800
9	9	1600	100	10	1000
10	8	500	100	8	800

TABLE 22

COMPARISON OF ILLUSTRATIVE RANKING OF TEN GRADE CROSSINGS BY THREE METHODS

SITE	RANK BY NEW HAMPSHIRE	RANK BY NCHRP 50	RANK BY (UT) NEW PROCEDURE
1	4	4	8
2	8	8	2
3	9	9	3
4	10	10	5
5	6	7	7
6	1	1	6
7	3	3	4
8	7	6	10
9	2	2	9
10	5	5	1

6, 9, and 7 would also be improved. Using either of these two formulae will result in similar rankings if one neglects to consider how drivers are presently using the crossings.

When the UT Method rankings are examined, crossings 6, 9, and 7 are actually ranked as numbers 6, 9, and 4, when driver behavior and sight distance are considered.

This comparison of the three methods illustrates the deficiency in the existing priority procedures. Using the existing procedures, the passive crossings at which drivers are performing safely are given the same weight as those where almost all of the drivers are not performing safely. For example, crossing number 6 was ranked as top priority by the existing formulas, mainly due to its high ADT. However, only 200 of the 1400 vehicles using the crossing each day are performing in an "unsafe" manner. On the other hand, all 400 vehicles per day using crossing number 10 are performing in an "unsafe" manner due to their poor perception of the hazard at the crossing (sight distance and train speed).

The cost effective management strategy would be to improve the three crossings which have the highest exposure of unsafe behavior to trains. This would be sites 10, 2, and 3, all of which are rated fairly low by the two other formulae.

CHAPTER XIII

RESULTS AND CONCLUSIONS FROM INVESTIGATION OF PRIORITY PROCEDURES FOR GRADE CROSSING IMPROVEMENTS

I. RESULTS

Chapter XII presented the results of an investigation into methods for evaluating driver behavior at passive crossings and establishing priorities for grade crossing improvements. An improved procedure was developed and set forth in Chapter XII.

II. FINDINGS AND RECOMMENDATIONS

Finding - The current procedures for evaluating the effect of sight distance restrictions on grade crossings do not yield a clear evaluation of the effect of restricted visibility on the accident potential at grade crossings. The procedure described in Chapter XII will yield an estimation of the number of drivers who are not traversing a crossing in a safe manner.

Recommendation - Consideration should be given to utilizing the technique described in Chapter XII for evaluating countermeasures.

Finding - The University of Tennessee Method for establishing priorities for improving passive crossings will result in a more cost effective use of public funds than the procedures currently available.

Recommendation - The University of Tennessee formula should be utilized by public authorities responsible for managing a grade crossing improvement program.

Future research in this area should consider correlating passive sites with high exposure of unsafe drivers to trains with car-train accident experience at those sites. This would tend to substantiate the need for driver behavior considerations in priority procedures. The low accident rates at grade crossings may make such a correlation study very difficult.

CHAPTER XIV

CONCLUSIONS

I. SUMMARY

This research investigated driver perception of hazard and risk at grade crossings. Driver knowledge and its relationship to performance was studied. Methods for communicating the hazard of individual grade crossings were also studied. Finally, an improved method for establishing priorities for improvements of passive grade crossings was developed. This method is based upon existing driver behavior at the crossings under consideration. The recommendations from this effort are stated in the next section.

II. OVERALL FINDINGS AND RECOMMENDATIONS

In order to facilitate the communication of the findings and recommendations from each phase of the research effort, these have been presented at the conclusion of each chapter covering a particular phase. For summary purposes, the findings and recommendations from each phase are listed below. The appropriate chapters should be consulted for details on the individual findings and recommendations.

A. Questionnaire Phase (Chapter II)

1. The use of a questionnaire at a drivers' license examining station is a workable method of data collection regarding driver knowledge.

2. A substantial segment of the driving population is apparently unaware that not all grade crossings have active protection. Countermeasures would be to include this message in any grade crossing safety campaign. Different advance warning signs to distinguish between passive and active grade crossings should be investigated.
3. Drivers appear to be aware of the stopping distance relation between trains and vehicles and the scope of grade crossing fatalities in the United States. Therefore, these two messages would not be productive in a safety campaign.
4. A high proportion of drivers believed that they should stop at all grade crossings. Public education efforts should emphasize the requirement for approaching a grade crossing with caution. The misconception of a required stop may actually be contributing to a disregard of grade crossings if drivers see this as an unreasonable requirement.
5. Enforcement action associated with grade crossings is apparently almost nonexistent. This may be a motivation force for improved performance.
6. A fairly high proportion of drivers did not properly identify the location where the standard grade crossing signing is placed. Information on standard signing should be a part of any railroad safety campaign.

7. A substantial portion of the drivers displayed a lack of faith in active devices as manifested by their indication that they should look for trains as well as checking to see if a signal has been activated. Improved signal reliability would improve signal credibility and perhaps cause more respect for the device when activated.

B. Knowledge Related to Performance (Chapter III)

1. Very few of the observed drivers could be classified as performing safely. Several made head movements at inappropriate locations. Advisory speed signing may be useful at grade crossings.
2. Knowledge and driving behavior were not statistically related.
3. A high proportion of drivers questioned near the grade crossing sites believed that they were supposed to stop at a passive crossing. As discussed earlier, under item A-4, this perception may contribute to disregard of grade crossings.
4. The field study technique is workable, but it could be improved if the hidden observers could be deleted from the procedure. This would require that vehicle speed at various locations from the crossing be used as an indicator of "safe-unsafe" performance.

C. Advisory Speed Signing for Grade Crossings (Chapter IV)

Passive grade crossings with restricted sight distances should be evaluated for the use of advance advisory speed signing. The techniques for establishing the advisory speed and locating the warning sign developed in this research should be used. The MUTCD should call for this type of signing for appropriate grade crossings.

D. Driver Performance at Passive Grade Crossings (Chapter V)

The current procedures for evaluating the effect of sight distance restrictions on grade crossings do not yield a clear evaluation of the effect of restricted visibility on the accident potential at grade crossings. The method developed as a part of this research should be used to evaluate countermeasures and to establish priorities for improving passive crossings.

E. The Incorporation of Driver Performance into Priority Establishing Procedures (Chapter VI)

The optimum safety benefits from an expenditure of construction funds for upgrading grade crossings are related to a meaningful priority method for selecting grade crossings for improvement. The use of the technique developed in this study will allow the priority improvement of those crossings which have the highest probability of a conflict between a train and a driver performing unsafely. The management of a state's grade crossing program would be improved if the technique described herein were utilized.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Rail-Highway Grade Crossing Accidents/Incidents Bulletin-1976. Federal Railroad Administration, U. S. Department of Transportation, Washington, D. C., 1977.

2. Railroad-Highway Grade Crossing Handbook. Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., April, 1978.

3. 1978 Annual Report Highway Safety Improvement Programs. Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., 1978.

4. Rail Crossing Safety--At What Price. Report to Congress by U. S. General Accounting Office, Washington, D. C., April 25, 1978.

5. Railroad-Highway Grade Crossings-Bibliography. Transportation Research Board Bulletin 57, Washington, D. C., 1976.

6. Summary of Railroad-Highway Grade Crossing Research Activity. Transportation Research Board Circular No. 190, Washington, D. C., January, 1978.

7. Railroad-Highway Grade Crossings. Federally Coordinated Research Programs Task 1-0-1, Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., October, 1977.

8. Rail-Highway Grade Crossing Safety. Highway Research Information Service Selection, Transportation Research Board, Washington, D. C., April, 1977.

9. Human Factors Countermeasures to Improve Highway-Railway Intersection Safety. Biotechnology, Inc., For Federal Railroad Administration and National Highway Traffic Safety Administration, U. S. Department of Transportation, Washington, D. C., July, 1973.

10. Koziol, Joseph S. and Peter H. Mengert. Railroad Grade Crossing Passive Signing Study. Transportation Systems Center, U. S. Department of Transportation, Cambridge, Massachusetts, August, 1978.

11. Maine Facility Research Summary, Results 1973-1976. U. S. Department of Transportation, Cambridge, Massachusetts, May, 1977.

12. Dommasch, I. N., R. L. Hollinger, and E. F. Reilly. Passive Control at Rail-Highway Crossings. New Jersey Department of Transportation, Trenton, New Jersey, May, 1977.

13. Manual on Uniform Traffic Control Devices for Streets and Highways --Official Rulings on Requests for Interpretations, Changes, and Experimentations. Federal Highway Administration, U. S. Department of Transportation, Vol. VIII, December, 1977.

14. Berg, William D. Experimental Design for Evaluating the Safety Benefits of Railroad Advance Warning Signing. Federal Highway Administration, Washington, D. C., April, 1979.

15. Manual on Uniform Traffic Control Devices. Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., 1971.

16. Safety Features of Stop Signs at Rail-Highway Grade Crossings. Biotechnology, Inc. for Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., April, 1978.

17. Standby Power for Railroad-Highway Grade Crossing Warning Systems, University of Lowell Research Foundation for Federal Railroad Administration, U. S. Department of Transportation, Washington, D. C., September, 1976.

18. Innovative Concepts and Technology for Railroad-Highway Grade Crossing Motorist Warning Systems. Cincinnati Electronics Corporation for Federal Railroad Administration, U. S. Department of Transportation, Washington, D. C., September, 1977.

19. Potential Means of Cost Reduction in Grade Crossing Automatic Gate Systems, Transportation Systems Center for Federal Railroad Administration, U. S. Department of Transportation, Washington, D. C., February, 1977.

20. Grade Crossing Activated Advance Warning Signals-Interium Report. JEM and Associates for Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., December, 1978.

21. Peabody, L. E., and T. B. Dimmick. "Accident Hazards at Grade Crossings," Public Roads Magazine, Vol. 22, No. 6, Washington, D. C., 1941.

22. Factors Influencing Safety of Highway-Railroad Crossings, NCHRP Report 50, Transportation Research Board, Washington, D. C., 1968.

23. Coleman, Janet and Gerald Stewart, "Investigation of Accident Data for Railroad Grade Crossings," Transportation Research Board Record 611, Washington, D. C., 1976.

24. Butcher, Thomas A. "Evaluation of Safety Improvements at Highway-Railway Crossings," Indiana State Highway Department, Indianapolis, Indiana, February, 1973.

25. "The Effectiveness of Automatic Protection in Reducing Accident Frequency and Severity at Public Grade Crossings in California," California Public Utilities Commission, San Francisco, California, August, 1975.

26. McCarthy, E. Jerome, Basic Marketing, Richard D. Irwin, Inc., Homewood, Illinois, 1978.

27. Churchill, Gilbert A., Marketing Research, The Dryden Press, Hillsdale, Illinois, 1976.

28. Motor Vehicle Laws-State of Tennessee, Tennessee Department of Safety, Nashville, Tennessee, 1971.

29. Uniform Vehicle Code, National Committee on Uniform Traffic Laws and Ordinances, Washington, D. C., 1972.

30. Kearney, Edward F., Drivers' Duties at Railroad Crossings, National Highway Traffic Safety Administration, U. S. Department of Transportation, Washington, D. C., January, 1979.

31. National Highway Safety Standards, U. S. Department of Transportation, Washington, D. C., 1967.

32. Sanford, J. L., "Criteria Used by State Highway Agencies to Determine Warrants and Priorities for Warning Devices at Rail-Highway Crossings," Highway Traffic Safety Center, Urbana, Illinois, April, 1977.

33. "Study of Motor Vehicle Codes and Drivers Licensing Practices," Proceedings American Railway Engineering Association, Vol. 73, 1972.

34. Tennessee Driver's Handbook, Tennessee Department of Safety, Nashville, Tennessee, 1977.

35. Operation Life Saver-Program Guide, National Highway Safety Council and Association of American Railroads, Chicago, Illinois, 1979.

36. Heathington, K. W. and T. Urbanik, "Driver Information Systems for Highway-Railway Grade Crossings," Highway Research Record 414, Transportation Research Board, Washington, D. C., 1972.

37. Stoke, C. B., "The Effectiveness of Written Driver Knowledge Tests," Preprint 1980 Transportation Research Board, Washington, D. C., January, 1980.

38. Richards, H. A. and G. S. Bridges, "Railroad Grade Crossings," Traffic Control and Roadway Elements-Their Relationship to Highway Safety, Chapter 1, Automotive Safety Foundation, Washington, D. C., 1968.

39. Voorhees, A., Factors Influencing Safety at Highway Rail Grade Crossings, NCHRP Project 3-8, Highway Research Board, Washington, D. C., January, 1967.

40. A Policy on Geometric Design of Rural Highways, American Association of State Highway and Transportation Officials, Washington, D. C., 1965.

41. Lyles, Richard W., "An Evaluation of Warning and Regulatory Signs for Curves on Rural Roads," University of Maine, Orono, Maine, December, 1979.

42. Russell, E. R., H. L. Michael, and T. H. Butcher, "Driver Reaction to Improved Warning Devices at a Rural Grade Crossing," Transportation Research Record, Number 611, Transportation Research Board, Washington, D. C., 1976.

43. "Railroad-Highway Grade Crossing Sight Distance Study," North Carolina Department of Transportation, Raleigh, North Carolina, October, 1978.

APPENDICES

APPENDIX A

DEFICIENCIES IN STATE LAWS REGARDING GRADE CROSSINGS

DEFICIENCIES IN STATE LAWS REGARDING GRADE CROSSINGS

From National Highway Traffic Safety Administration Study-Drivers' Duties at Railroad Crossings (31)

SUMMARY AND OBSERVATIONS

1. Thirty-one states specifically require drivers to proceed at a safe and appropriate speed at railroad grade crossings. The remaining states should amend their basic speed rules to conform with UVC 11-801 and Tennessee should adopt this important UVC section.

2. The three states with a 15 mph limit at crossings where the view is obstructed should repeal that limit, adopt UVC 11-801, and post any reduced specific speed limit under provisions relating to speed zones (see UVC 11-802 and 11-803).

3. While most states restrict passing at railroad grade crossings in conformity with the Code, four states do not. These four states should adopt UVC 11-306 or amend their laws to conform with that section.

4. Forty-nine states have laws requiring drivers to stop when electric or mechanical signals warn of the approach of a railroad train at a railroad grade crossing. While virtually all of these laws probably are in substantial agreement, the wording of a few of these laws should be reexamined to make certain that they apply to all drivers as well as to all crossings with automatic signals. The two states without such laws should adopt UVC 11-701.

5. Forty-five states require stopping when a crossing gate is lowered at a grade crossing. The other six states should adopt UVC 11-701 or update existing laws using UVC 11-701. Thirty-six states also ban driving through, around or under a gate at the crossing but one state allows it when safe and fourteen do not have comparable express prohibitions.

6. Forty-six states have laws requiring drivers to stop for a flagman giving a signal indicating the approach of a train. However, there is disagreement as to whether a driver must remain stopped. The five states without this requirement should adopt it if flagmen are ever used at grade crossings.

7. Thirty-six states have laws requiring drivers to stop for a train giving a signal but fifteen do not. The fifteen states should adopt UVC 11-701 (a) (3).

8. Thirty-six states have laws requiring drivers to stop for a train that is dangerously close to a railroad grade crossing. Thirteen states do not have this rule and two laws are not applicable to all grade crossings. Unless every grade crossing has automatic signals, it is incomprehensible that any state would fail to require drivers to stop for a train.

9. One state-South Carolina-has not adopted any portion of UVC 11-701 and thus does not require drivers to stop for trains nor for signals indicating the approach of a train.

10. As to where drivers should stop and when they may proceed, several state laws are silent. Some laws allow stopping ten feet from the nearest rail though the Uniform Vehicle Code and federal regulations have long specified fifteen feet. Several states do not indicate a maximum distance for stopping (such as within fifty feet from the nearest rail) so that drivers could claim they complied with the law by stopping substantial distances away from the grade crossing.

11. Though the Uniform Vehicle Code and laws in twelve jurisdictions do not provide for the use and meaning of stop signs at grade crossings, thirty-nine states do. One state requires stop signs at most grade crossings even though the National Committee found they should not be used except in very unique situations.

12. Forty-nine states have laws requiring buses and vehicles transporting dangerous cargoes to stop at grade crossings and two jurisdictions do not. The two jurisdictions should adopt UVC 11-703. Eight states have more than one law and, unfortunately, laws in several states prescribe different rules for the same driver. It is unnecessary and undesirable to have more than one law covering the same traffic situation.

13. Drivers of school buses and vehicles transporting hazardous cargoes are required to stop at railroad grade crossings in forty-six states. However, laws in five states do not require these drivers to stop at all grade crossings as would the Uniform Vehicle Code and laws in the other forty-six states.

14. As to exceptions from the duty of certain drivers to stop at railroad grade crossings, many states have not yet adopted all the exceptions provided by the Uniform Vehicle Code. The most controversial of these exceptions involves a crossing equipped with crossing gates or alternately-flashing lights. The Uniform Vehicle Code and laws in thirteen states have this exception while the Bureau of Motor Carrier Safety Regulations and laws in thirty-six states do not have it. If a state law excepts such crossings and the federal regulations do not, drivers subject to the federal regulations must stop at these crossings while drivers who are not subject to the federal rules need not stop. Any conflict between federal and state rules is not desirable because it causes confusion and nonuniformity.

15. The Uniform Vehicle Code and laws in forty states impose special duties at grade crossings on persons driving or moving vehicles and structures that are very low or very slow. Eleven states do not have such requirements in their vehicle codes.

16. Since 1971, the Uniform Vehicle Code would prohibit driving onto a railroad grade crossing when there is no space on the other side to permit clearing the crossing. Ten states have this rule and forty-one do not. The forty-one states should adopt it.

17. Fifteen states have the Uniform Vehicle Code restriction against unnecessary stops on railroad grade crossings. The thirty-six states without this rule should update their laws using UVC 11-1003.

18. Unless there is a steady red light, a "Don't Walk" signal, or a gate, the Uniform Vehicle Code and state laws specify no duties for pedestrians at railroad grade crossings and only thirteen states have adopted the Uniform Vehicle Code rule against entry onto the crossing when a gate or barrier is in operation.

APPENDIX B

DRIVERS' TRAINING MATERIAL RELATIVE TO RAILROAD CROSSINGS

PURPOSE: To enable the student to safely cross railroad crossings and to respond to possible dangers at such crossings.

CATEGORY	CRITICALITY				
	HIGH	MODERATELY HIGH	MODERATE	MODERATELY LOW	LOW
General		The student will watch for advanced circular warning signs along the roadway, road markings, or other physical indications that a railroad crossing is immediately ahead. He will: • Slow down and prepare to stop at the crossing unless a clear view of the tracks is available. • Prepare to stop if following a school bus, commercial passenger vehicle, or tank truck.			
Approaching and Stopping	The student will bring the car to a complete stop when approaching a signalized railroad crossing if the signal is activated. When stopped at the crossing he will: • Remain stopped until the signal indicates the track is clear.	When approaching a railroad crossing with no signal, the student will look in both directions quickly and if a train is approaching he will stop the car within 50 feet but not less than 15 feet from the nearest rail.	When approaching a railroad crossing with no signal, the student will look in both directions quickly and if visibility is clear and no trains are in sight he will maintain speed and cross immediately. When stopped at a multi-track, no-signal railroad crossing, the student will: • Cross the tracks if no trains are approaching. • If waiting for an approaching train, remain stopped until the first train has completely cleared the crossing and the view is clear in both directions on the other tracks. • Remain stopped if other trains are approaching. When approaching a signalized railroad crossing in which the signal is not activated the student: • Will listen for the sound of an approaching train and look in both directions before crossing the tracks.	The student will proceed to cross the tracks at a crossing without a signal only after the train has completely cleared the roadway.	

	• Proceed across tracks only after obtaining a clear view of all tracks in both directions. • Proceed across the tracks in spite of activated signal after checking both directions of all tracks if no train is approaching or if a single train is approaching at a slow rate of speed at some distance.	When stopped at a signalized crossing the student will proceed across the tracks if a flagman motions him to do so.	• May proceed without stopping if no train is coming, the train is stopped at a distance, or the train is moving slowly at some distance.		
Crossing Tracks			When crossing railroad tracks, the student will not stop on the tracks or between separated tracks. He will not enter the crossing until sufficient space on the other side of the tracks exists for a car to stop completely clear of the tracks. He will take preventive action against possible stalling and avoid abrupt or jerky movement of the car when crossing tracks at a low speed. In doing so he will: • Start across tracks in low enough gear in a manual transmission car to decrease the chance of stalling. • Maintain a steady pressure on the accelerator pedal. If a flashing signal or an automatic gate is activated while the car is crossing the tracks, he will continue through the crossing as quickly as possible without stopping.	The student will not attempt to shift gears until completely beyond the crossing area.	
Stalled Car on Tracks			If the car stalls on the tracks while crossing, the student will: If time permits, • Attempt to start the car. • Use the starter in a manual transmission car as a last resort in an attempt to move the car off the tracks. If the train is close and rapidly approaching, • Instruct passengers to leave the car immediately and to clear the area.		

PURPOSE: To enable the student to safely cross railroad crossings and to respond to possible dangers at such crossings. *(Continued)*

CATEGORY	CRITICALITY				
	HIGH	MODERATELY HIGH	MODERATE	MODERATELY LOW	LOW
Stalled Car on Tracks *(Continued)*			• Immediately leave the car and seek a safe area away from tracks and car.	If the car stalls on the tracks while crossing and will not restart, the student will push the car off the tracks manually, if possible, when no imminent danger exists.	

KNOWLEDGES

The student should know the hazards involved in crossing railroads.

Accident statistics:

Approximately 1,600 persons were killed and 4,000 persons were injured at railroad crossings in 1968.

One-third of car-train accidents involve the car striking the locomotive or part of the train behind it.

Sixty percent of car-train accidents happen in daylight usually at a familiar crossing.

State laws generally require school buses, tank trucks carrying explosives or flammable liquids, and commercial carriers to stop for railroad crossings except under certain specified conditions.

Approximately 180,000, or 80% of the nation's railway grade crossings have only signs to mark the grade locations and do not have additional protection devices to warn the motorist of an approaching train.

Railroad crossing signals should not be trusted entirely because they can malfunction.

The first train on a multitrack railroad crossing may screen another train coming from the opposite direction and its sound may drown out the noise of the other train.

Killing or stalling the engine can be especially hazardous when crossing railroad tracks.

Accelerating smoothly will reduce the chances of stalling the engine when crossing the railroad tracks.

Shifting gears is especially dangerous when crossing railroad tracks because shifting gears increases the danger of stalling.

The car engine should be thoroughly warmed up before attempting to cross railroad tracks.

APPENDIX C

DERIVATION OF EQUATION USED TO DETERMINE DISTANCE AND SPEED AT THE TIME OF HEAD MOVEMENT

DERIVATION OF EQUATION USED TO DETERMINE

DISTANCE AND SPEED AT THE TIME OF

HEAD MOVEMENT

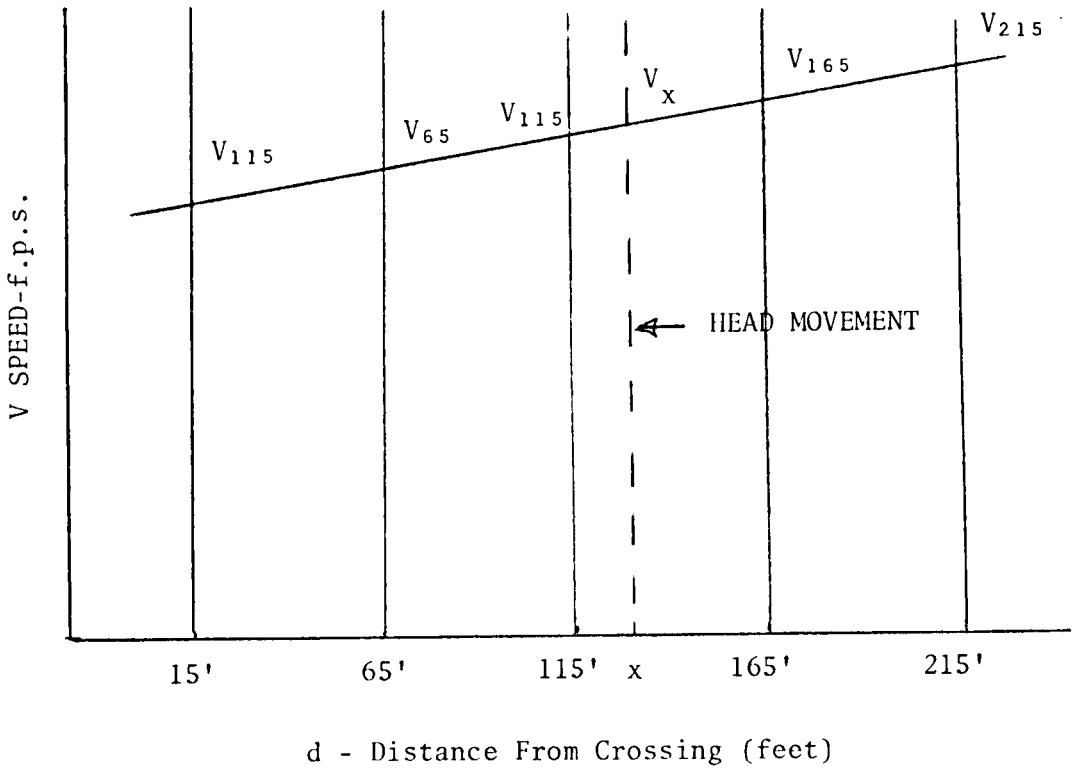


Figure 7. Approach speed profile used to determine distance and speed at time of head movement.

Known: V_{15}, V_{115}, V_{215} -- Speed at 15', 115', 215' from crossing

Time (t) for vehicle to travel from the point of the head movement to a trap mark (found by scalling from the two traces).

Desired: Distance X and speed V_x associated with the instance the head movement was made.

If $\overline{V}$ = mean speed between V_{65} (determined from speed profile plot) and point of head movement, V_x the $\overline{V}\ t = X$

If linear relationships are assumed between known speed points an equation can be developed as follows to solve for X.

$$V_x = V_{65} + \left(\frac{V_{165} - V_{65}}{100} \right) x$$

If $\overline{V} = \frac{V_{65} + V_x}{2}$

Then

$$\overline{V} = \frac{V_{65} + V_{65} + \left(\frac{V_{165} - V_{65}}{100} \right) x}{2}$$

and if $\overline{V}t = x$

then

$$x = \left[\frac{V_{65} + V_{65} + \left(\frac{V_{165} - V_{65}}{100} \right) x}{2} \right] t$$

$$x = \left[\frac{2V_{65} + \left(\frac{V_{165} - V_{65}}{100} \right) x}{2} \right] t$$

$$x = \left[V_{65} + \left(\frac{V_{165} - V_{65}}{200} \right) x \right] t$$

$$x = V_{65}\, t + \left(\frac{V_{165} - V_{65}}{200} \right) xt$$

$$x - \left(\frac{V_{165} - V_{65}}{200} \right) xt = V_{65}\, t$$

$$x \left[1 - \left(\frac{V_{165} - V_{65}}{200} \right) t \right] = V_{65}\, t$$

$$x = \frac{V_{65}\, t}{1 - \left(\frac{V_{165} - V_{65}}{200} \right) t}$$

V_{65}, V_{165} in fps

t in sec.

APPENDIX D

RESPONSES TO QUESTIONNAIRE ADMINISTERED AT SITE ONE

TABLE 23

RESPONSES TO QUESTIONNAIRE ADMINISTERED AT SITE ONE

VEHICLE	RESPONSE TO QUESTION 1	2	3	4
572	B	?	D	E
393	C	A	C	E
046 (2)	B	A	B	E
321	C	A	D	E
443	B	C	E	E
440 (2)	B	C	E	E
658	B	C	E	E
669	B	C	D	E
231	B	C	E	E
187	B	C	B	E
485	B	C	E	E
368	B	A	E	E
26H	C	B	E	C
161	B	C	D	E
36H	C	B	E	C
985T	B	C	D	B
466	B	C	D	C
128	C	A	E	C
212	B	C	D	E
707	B	C	D	E
547	B	C	D	E
383 (2)	B	C	D	E
205	B	C	E	E
467	B	A	D	E
PPT (2)	C	B	E	C
307	C	A	A	E
013	C	A	E	C
819	B	C	D	C
662	C	A	B	C
674	B	C	E	E
A75	C	A	B	E
223	B	C	A	C
795	B	C	E	C
477	C	A	D	C
488	B	C	D	C
156	C	?	E	E
312	B	D	A	C
426	C	A	A	C

APPENDIX E

RESPONSES TO QUESTIONNAIRE ADMINISTERED AT SITE TWO

TABLE 24

RESPONSES TO QUESTIONNAIRE ADMINISTERED AT SITE TWO

VEHICLE	RESPONSE TO QUESTION 1	2	3	4
735	B	C	E	E
722	B	C	E	E
291	B	?	B	E
690	B	?	E	E
658	B	?	D	E
911	B	C	D	C
175	B	A	D	E
14C (2)	C	A	E	C
375	B	C	A	C
771	B	A	D	C
675 (3)	B	C	?	C
463	B	E	D	E
955	B	A	E	E
784	B	C	E	E
441	B	A	E	E
547	B	A	D	E
688	B	C	D	E
641	B	C	E	E
875	B	C	E	E
593	B	C	D	B
171	C	B	E	E
651	C	B	E	E
651	B	C	E	C
775	B	A	B	E
331	B	A	D	C
633 (2)	C	A	E	E
662	B	A	D	E
247	B	A	D	E
612	B	A	E	E
880	B	C	A	C
670	B	C	E	C
654	C	A	A	E
979	B	C	D	E
215	B	A	E	E
810	B	A	D	E
023	B	C	D	C

TABLE 24 (continued)

VEHICLE	RESPONSE TO QUESTION			
	1	2	3	4
777	B	C	D	E
95-F	B	A	D	C
752	C	A	A	E
832	B	C	D	E
369	B	B	D	E
353	C	B	D	E
379	C	A	E	E
23-E	B	A	D	E

APPENDIX F

OBSERVED DRIVER BEHAVIOR AT SITE ONE

TABLE 25

OBSERVED DRIVER BEHAVIOR AT SITE ONE

VEHICLE	SPEED (MPH) AT DISTANCES FROM CROSSING 15'	115'	215'	315'	LOOKED	DISTANCE (FT) AT LOOK	SPEED (MPH) AT LOOK	STOP	SPEED SLOPE
572	31	34	36	32					0.0250
046	15	36	43	40	Yes	38	22	Yes	0.1450
443	26	30	36	32					0.0600
819	40	52	52	52					0.1950
440	28	26	26	24					0.0000
658	45	52	52	40					0.0350
440	45	45	45	45					0.0000
669	22	31	28	28	Yes	65	27		0.0300
231	38	45	45	38	Yes	-12	40		0.0350
187	19	28	38	34	Yes	65	23		0.1050
046	15	32	40	38	Yes	65	23	Yes	0.1250
485	16	31	36	23					0.1000
368	34	34	32	30					0.0000
161	26	34	36	34					0.0500
819	32	40	38	32	Yes	81	37		0.0300
985T	15	34	38	34	Yes	65	24		0.1200
674	32	40	45	34					0.0600
466	34	49	45	38					0.0600
A75	40	45	43	38					0.0150
223	31	43	43	38					0.0600
795	16	27	34	32					0.0900
383	38	45	43	36					0.0250
212	43	57	45	40					0.0100
707	31	43	45	36	Yes	65	37		0.0750
547	18	32	43	38	Yes	80	27		0.1250

TABLE 25 (continued)

VEHICLE	SPEED (MPH) AT DISTANCES FROM CROSSING 15'	115'	215'	315'	LOOKED	DISTANCE (FT) AT LOOK	SPEED (MPH) AT LOOK	STOP	SPEED SLOPE
488	17	17	49	43					0.1600
383	36	40	40	34					0.0200
205	30	43	40	38					0.0500
312	27	52	57	57	Yes	56	38		0.1500
467	30	52	57	49					0.1300
PPT	17	28	32	30	Yes	44	21		0.0750
393	--	--	43	38	Yes	--	--		------
321	38	40	40	34					0.0100
307	25	34	38	34	Yes	69	30		0.0650
013	38	40	32	38					0.0000
PPT	31	34	38	34					0.0450
26H	27	34	40	31					0.0650
36H	34	45	40	38					0.0300
662	19	35	35	35	Yes	102	29		0.0750
128	30	40	43	38					0.0650
477	27	32	31	31	Yes	91	31		0.0200
156	43	43	40	36					0.0000
426	40	52	57	45					0.0850

APPENDIX G

OBSERVED DRIVER BEHAVIOR AT SITE TWO

TABLE 26

OBSERVED DRIVER BEHAVIOR AT SITE TWO

VEHICLE	SPEED (MPH) AT DISTANCES FROM CROSSING 15'	115'	215'	315'	LOOKED	DISTANCE (FT) AT LOOK	SPEED (MPH) AT LOOK	STOP	SPEED SLOPE
379	20	25	30	34	Yes	21	21		0.0500
14C	45	45	52	45	Yes	28	44		0.0550
353	24	36	43	34					0.0950
654	52	45	45	49					0.0000
752	57	52	52	45					0.0000
633	19	31	30	30					0.0550
14C	38	38	43	32	Yes	- 8	36		0.0450
633	24	30	30	30					0.0300
171	49	57	57	52					0.0400
547	49	52	57	45					0.0400
23E	49	32	40	40					0.0000
441	27	36	45	38	Yes	-12	27		0.0900
291	31	38	40	38					0.0450
369	28	36	32	40					0.0200
832	12	24	26	25	Yes	43	16	Yes	0.0700
784	38	45	40	27					0.0100
777	49	45	43	40					0.0000
023	27	38	45	45					0.0900
95F	30	32	34	40	Yes	5	30		0.0200
955	19	34	38	38	Yes	17	22	Yes	0.0950
880	34	30	32	32					0.0000
810	18	32	43	43	Yes	49	23		0.1250
771	27	31	38	36	Yes	- 2	27		0.0550
375	27	43	45	38					0.0900

TABLE 26 (continued)

VEHICLE	SPEED (MPH) AT DISTANCES FROM CROSSING 15'	115'	215'	315'	LOOKED	DISTANCE (FT) AT LOOK	SPEED (MPH) AT LOOK	STOP	SPEED SLOPE
463	23	38	45	38	Yes	42	28		0.1100
215	34	38	38	43	Yes	41	36		0.0200
651	36	36	36	34					0.0000
979	34	34	38	36					0.0200
670	28	32	38	36					0.0500
675	31	40	43	36					0.0600
675	27	38	38	45					0.0550
612	19	32	30	38	Yes	43	24		0.0550
247	34	38	25	45	Yes	18	36		0.0000
662	23	38	38	43	Yes	50	30		0.0750
675	18	26	26	32	Yes	33	21		0.0400
331	24	28	32	--					0.0400
775	9	26	30	32	Yes	65	17	Yes	0.1050
175	57	52	52	45	Yes	5	54		0.0000
911	31	40	40	40	Yes	35	34		0.0450
658	30	43	43	40	Yes	5	33		0.0650
593	43	45	38	43					0.0000
690	12	25	31	28	Yes	52	17		0.0950
875	16	31	38	38	Yes	57	23		0.1100
641	30	31	31	31	Yes	1	31		0.0000
735	49	43	49	45					0.0000
722	62	52	52	45					0.0000
688	45	43	52	43					0.0350

APPENDIX H

FORMULAE AND WARRANTS USED BY STATES WHICH CONSIDER SIGHT DISTANCE (1977)

Hazard Index formula

Hazard Rating of Crossing = (Highway Traffic Points) x (Railway Traffic Points) x (Accident Record and Local Conditions Points)

(Points from chart, p. 33)

Warrants

Hazard Rating	Warning
1 through 10	Signs
11 through 25	Flashing lights and bells Short arm gates for double tracks*
26 through 50	Grade separation where feasible, or short arm gates
51 through 125	Grade separation if possible, or most feasible treatment

*Except where not more than one train occupies the crossing at a time or train speeds are below 70 mph.

Priorities

Based on hazard ratings of crossings considering:

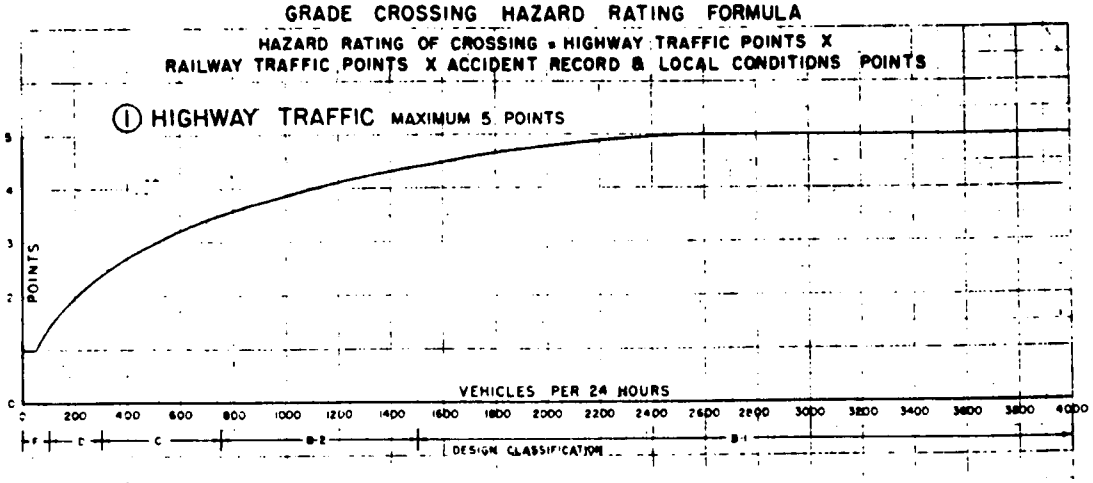
1. Highway and rail traffic
2. Number and type of tracks
3. Accident record
4. Local conditions of: geometrics and sight conditions

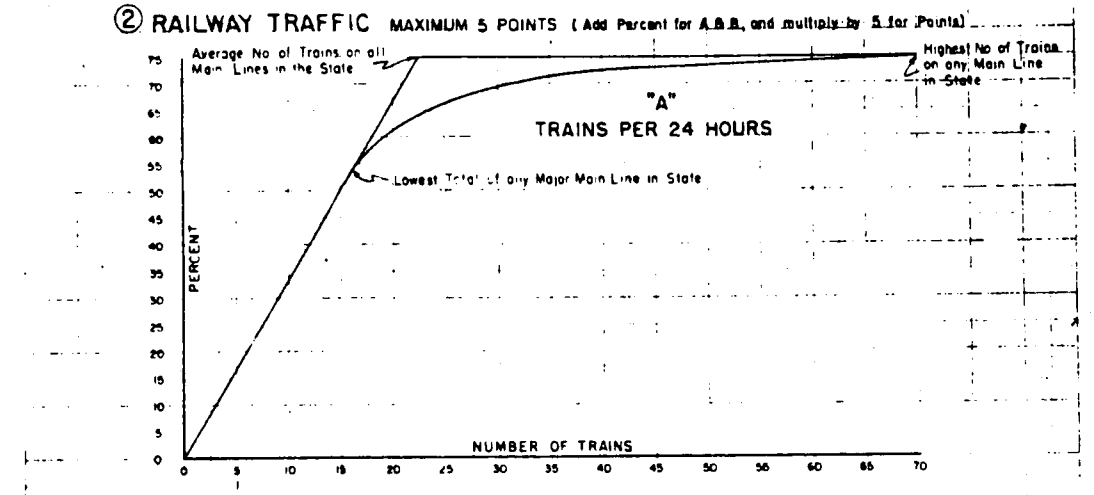
Reporting personnel

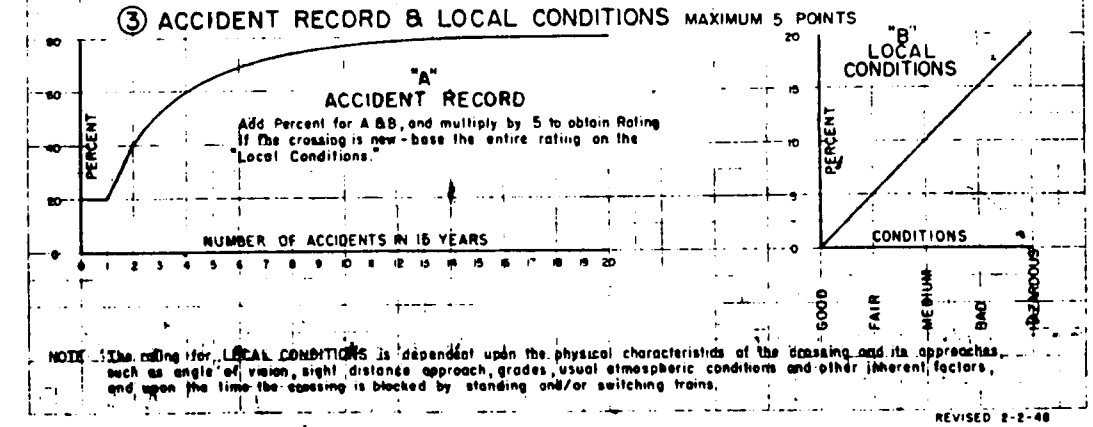
Howard Snow, Assistant and Head
Current Planning Section
Arkansas Highway Department
9500 New Benton Highway
Little Rock, Arkansas 72209

ARKANSAS STATE HIGHWAY DEPARTMENT
GRADE CROSSING HAZARD RATING FORMULA

HAZARD RATING OF CROSSING = HIGHWAY TRAFFIC POINTS X RAILWAY TRAFFIC POINTS X ACCIDENT RECORD & LOCAL CONDITIONS POINTS







NOTE: The rating for LOCAL CONDITIONS is dependent upon the physical characteristics of the crossing and its approaches, such as angle of vision, sight distance approach, grades, usual atmospheric conditions and other inherent factors, and upon the time the crossing is blocked by standing and/or switching trains.

REVISED 2-2-48

District of Columbia

Hazard Index Formula

Elements:

			RATING	X	WEIGHT	=	INDEX POINTS	MAX. POSSIBLE PTS.
1.	(A)	Expected accidents per year (NCHRP Report 50)						
		Train involved accidents EA = BAT B and A are values from figure 24 T = Trains per day EA = _____X_____X_____=_____						
	(B)	Nontrain involved accidents (1) With automatic gates $EA = \frac{ADT}{100}(0.00866+0.00036T)$ EA = _____(0.00866+0.00036___) = _____						
		(2) All other protection types $EA = \frac{ADT}{100}(0.00499+0.00036T)$ EA = _____(0.00499+0.00036___) = _____						
	(C)	Total Expected Accidents Per Year (A) + (B) = _____						
	(D)	Rating — Value EA ≥ 1.20 — 3 1.20 > EA > 0.40 — 2 EA ≤ 0.40 — 1	___	x	5	=	____	(15)
2.	ADT: Average daily highway traffic (V)							
	(A)	Greater than 10,000 — 3						
	(B)	6,000 to 10,000 — 2						
	(C)	Less than 6,000 — 1	___	x	3	=	____	(9)
3.	Trains per day (TV)							
	(A)	Greater than 20 — 3						
	(B)	10 to 20 — 2						
	(C)	Less than 10 — 1	___	x	3	=	____	(9)

Hazard Index formula: Elements (con't)	Value	RATING	X	WEIGHT	=	INDEX POINTS	MAX. POSSIBLE PTS.
4. Warning Device (PD, PDNEW)							
(A) No warning at all	4						
(B) Crossbuck, stop sign, advance warning only, or far side traffic signals	3						
(C) Crossbuck, or stop sign with advance warning signs, and pavement markings, or flashing lights only, near side signals only	2						
(D) Flashing Lights or traffic signals with advance warning sign and pavement markings	1	___	x	3	=	___	(12)
5. Sight distance (VIS, VISN)							
(A) Less than that shown in Table 22 (NCHRPR 50)	3						
(B) Between that shown in Table 22 and 20 (NCHRPR 50)	2						
(C) Greater than that shown in Table 20 (NCHRPR 50)	1	___	x	2	=	___	(6)
6. Number of train tracks (TK)							
(A) More than 3	3						
(B) 2 or 3	2						
(C) 1	1	___	x	2	=	___	(6)
7. Number of lanes on each approach (ELAP)							
(A) Three or more	2						
(B) 2 or 1	1	___	x	1	=	___	(2)
8. Crossing angle (acute angle between axes of track and roadway) (ELAA, ELAAN)							
(A) $A \geq 70°$	3						
(B) $70° > A > 40°$	2						
(C) $A \leq 40°$	1	___	x	1	=	___	(3)

Hazard Index formula: Elements (con't)

		Value	RATING	X	WEIGHT	=	INDEX POINTS	MAX. POSSIBLE PTS.
9.	Approach speed of trains							
	(A) $V \geq 50$ MPH	3						
	(B) 50 MPH > V > 30 MPH	2						
	(C) $V \leq 30$ MPH	1						
			___	x	1	=	___	(3)

Comprehensiveness:

A. $\frac{\text{Total of maximum possible points for items evaluated}}{\text{Total maximum possible score}} = \frac{\quad}{65} = C$

C = _____

C = Comprehensive factor, if all factors evaluated,

C = 1.0 - C will approach 0 as fewer and fewer items are evaluated. The smaller the "C" value, the less comprehensive the evaluation.

Hazardousness Rating:

A. $\frac{\text{Total Index Points}}{\text{Total Maximum possible points for items evaluated}} = \frac{\quad}{\quad} = R$

R = _____

$R \geq 0.90$	Very Hazardous
$0.90 > R > 0.60$	Hazardous
$R \leq 0.60$	Nominal

The closer the R value is to 1.0, the higher the number of negative safety aspects at crossings. As "R" approaches "0" the expected hazardousness will decrease.

Benefit-Cost formula

A. $[(EA-EA2) \times \$20,165 + (EA1-EAN) \times \$1,655] \times (Y)$ Where:

EA = Expected train involved accidents per year under existing conditions

EA2= Expected train involved accidents per year with proposed conditions

Benefit-Cost formula (con't)

EA1= Expected nontrain - involved accidents per year under existing conditions

EAN= Expected nontrain - involved accidents per year with proposed conditions

$20,165= Average cost per train-involved accidents

1,655= Average cost per nontrain-involved accidents

Y= Number of years device is expected to function

Cost of Improvements (CT)

Where flashers are being installed

Initial Cost = $24,000

Maintenance per year = $1,300

Expected Life = 35 years

Salvage Value = $2,400

Where Traffic signals are being installed

Initial Cost = $15,000

Maintenance per year = $200

Expected Life = 50 years

Salvage value = $25.00

Where signs are being installed

Initial Cost = $100

Expected LIfe = 20 years

Where Pavement Markings are placed

Initial Cost = $250/lane

Expected Life = 5 years

Single Unit Flashers

Initial Cost = $4,000

Maintenance Per year = $250

Expected LIfe = 35 years

$$\text{Benefit-Cost-Ratio} = \frac{\text{Benefits for X years}}{\text{Costs for X years}}$$

Warrants

Flashing light signals:

ADT = 5000+

Priorities

1. Existing warning devices
2. Hazardousness Index
3. Benefit-Cost Ratio
4. Budget constraints within a fiscal year

Reporting personnel

Suat Barsaran, Chief
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Highway and Traffic
415 Twelfth Street, N.W.
Washington, D. C. 20004

Florida

Hazard Index formula

1. $t_p = -8.075 + .318 \ln S_t + .484 \ln T + .437 \ln A + .387 \ln V_v +$

$[.28 - .028 (\frac{MASD}{RSSD})]^{**} + [.33 - 1.23(\frac{MCSD^*}{RSSD})] + .15$ (if no crossbucks)

1a. $y = (e^{.968 t_p + 1.109}) \div 4$

2. $t_a = -8.075 + .318 \ln S_t + .166 \ln T + .293 \ln A + .387 \ln V_v +$

$[.28 - .028 (\frac{MASD}{RSSD})]^{**} + .225(L-2)^{***} - .233$ (if gates)

2a. $y = (e^{.968 t_a + 1.109}) \div 4$

Where:

A = vehicles per day or annual average daily traffic

L = number of lanes

MASD = the actual minimum stopping sight distance along roadway

MCSD = the clear sight distance (ability to see approaching train along the roadway recorded for the four quadrants established by the intersection of the railroad tracks and road)

RSSD = the required stopping sight distance on wet pavement

S_t = the maximum speed of the train

T = the yearly average of the number of trains per day

t_a = $\ln^+$ of the predicted number of accidents in 4 year period at crossings with active protection

t_p = $\ln^+$ of the predicted number of accidents in a 4 year period at crossings with passive warning

V_v = the posted vehicle speed limit unless geometrics dictate a lower speed

y = predicted number of accidents per year at a crossing

$^+$ln = Napierian Logarithm

*This variable omitted if the crossing is protected by flagmen or the calculation is less than zero.

**This variable omitted if sight restriction is due to a parallel road.

***This variable omitted when gates are present.

Warrants

Safety index = R = $(1 - \sqrt{y^1})$ 90

y = from hazard index formula

$y^1 = y \sqrt{(H/y)\ (P)}$

H = six year accident history

P = number years of accident history

Flashing light signals, mast mounted:

a. R < 70, and

b. ADT < 5000, and

c. adequate stopping site distance, and

d. shoulders < 6^1, and

e. street not collector or arterial, and

f. no undue distraction from neon signs.

Flashing light signals, cantilever mounted:

a. R < 70, and

b. Highway design speed > 70, or

c. 4 lanes or more, or

d. shoulders > 6, or

e. background distraction.

Flashing light signals and gate arms:

a. Train speed > 80 mph, or

b. R < 70, and

c. multiple tracks, or

d. 4 lanes or more, or

e. ADT > 5000, or

f. Crossing is used by school buses for more than two trips per day, or

g. Continued accidents with flashing light signals, or

h. Crossing within 50 feet of highway intersection.

Install crossing illumination:

a. Safety index below 70, and

b. An ADT of more than 400, and

c. Posted highway speed less than 40 mph, and

d. An average of at least two trains per night with speeds less than 30 mph, and

e. Sufficient electrical power.

Include train speed measuring equipment:

a. Train speeds greater than 80 mph, or

b. Minimum train speeds one-half or less than maximum speeds, and,

c. ADP greater than 4000, or

d. Arterial or collector highway.

Grade separation structure:

a. ADT of over 10,000, and

b. Highway design speed above 60 mph, and

c. Train speeds above 30 mph, and

d. 10 trains per day, and

e. Benefit to cost ratio over one and fund availability.

Priorities

1. Safety index.

2. Available funds.

3. Benefit/cost studies

4. Accident history

Hazard Index formula

Crossing rating = Q1 + Q2 + Q3 + Q4

QN = 0.0103 (highway traffic/2) x (sum of trains speeds/sight distance) + 1.3393 (AL.F/5 + 90/DEG. + K/100)

Where:

Q = Quadrant rating

AL.F. = Alignment factor (Table 1)

DEG. = Angle of highway approach to railroad

K = Safe stopping sight distance (Table 2)

Highway Traffic = That half involved with each quadrant

Sum of Train Speeds = Number of trains x speed (from one direction only)

Sight distance = Distance along track from a point on roadway approach 500 feet away

Table 1
Alignment Factor

The alignment factor rating is based on the distance from the crossing that the crossbuck becomes visible to the motor vehicle operator.

Rating	Visibility of Crossbuck (Feet)
10	300 feet or less
9	300-400
8	400-500
7	500-600
6	600-700
5	700-800
4	800-900
3	900-1000
2	1000-1100
1	1100 feet or more

Table 2
"K" Factor

Primary System	Assumed Speed	Stopping Distance (K)
Paved	60 mph +	500 feet
	55	430
	50	360
	45	310
	40	260
	35	220
	30	180
	25	140
	20	100
Gravel	50 mph +	380 feet
	45	320
	40	270
	35	220
	30	180

Guidelines

Flashing light signals:

Sight distance

3000 exposure factor (daily trains x daily vehicles)

Single track

Flashing light signals and gate arms:

Multiple tracks

3000 exposure factor (daily trains x daily vehicles)

Rail-Highway grade separation structure:

Angle of crossing

Train speed

Rail-Highway grade separation structure: (con't)

10,000 exposure factor (daily trains x daily vehicles)

Type of highway system

Priorities

Iowa Crossing Rating Formula (Above Hazard Index Formula)

Reporting personnel

Leslie D. Chelsvig
Railroad Negotiator
Office of Development Support
Iowa Department of Transportation
Highway Division
Ames, Iowa 50010

Kansas

Hazard Index formula

EF = Exposure Factor = Highway Traffic x Train Traffic

3000 EF used normally to consider improvements.

Other factors considered:

1. Sight distance limitations
2. Angle of crossing (tracks and highway)
3. Speed of trains
4. Speed of highway traffic
5. Design Formula Rating:

$$\text{Rating} = A^{\frac{(B + C + D)}{4}}$$

$$A = \frac{[\text{Highway Traffic}]\ [(2\text{x No. of Fast Trains}) + (\text{No. of Slow Trains})]}{400}$$

$$B = 2\sqrt[3]{\frac{8000}{\text{Sum of Sight distance 4 ways}}}\ (2000' \text{ max. for one way})$$

$$C = \sqrt{\frac{90}{\text{Angle of Intersection}}}$$

D = 1.0 for one main track; 1.5 for two main tracks; 1.8 for three main tracks; or 2.0 for four or more main tracks.

6. BPR Formula Rating:

$$I = 1.28\ \frac{H^{0.170} \times T^{0.151}}{P^{0.171}} + K$$

H = Highway traffic - average number of vehicles

T = Train traffic - number of trains per day

P = Warning type coefficient

K = Additional parameter (smoothing factor)

Warrants

Flashing light signals:

EF = 3000

Single track

Flashing light signals and gate arms:

EF = 3000

Multiple tracks

Single track with train speed of 70 mph

Grade separation structures:

EF = 10,000

Crossing conditions

Priorities

Kansas Hazard Index Formula listed above.

Reporting personnel

Ralph W. Carroll
Coordinating Engineer
Kansas State Highway Commission
State Office Building
Topeka, Kansas 66612

Louisiana

Hazard Index formula

Peabody-Dimmick (BPR) Formula (present use)

Exposure factor (Product of rail and highway daily counts)

Sight distance and speeds

New Hampshire Formula (future use)

Warrants

1000+ ADT requires concrete or rubberized surfaces

Priorities

Peabody-Dimmick hazard rating (present use)

Annual accident reports

Benefit/cost studies (future use)

New Hampshire Formula (future use)

Reporting personnel

Turner S. Lux, Jr.
Agreements Engineer
Louisiana Department of Highways
P.O. Box 44245, Capitol Station
Baton Rouge, Louisiana 70804

Massachusetts

Massachusetts is in the process of upgrading all crossings throughout the state and provide as minimum protection advanced signing and pavement markings. There are approximately 1350 grade crossings in the 14 counties of Massachusetts. Ten (10) of these counties have had an inventory of their crossings completed. The inventory provides the following:

1. Sight distance and geometry of approaches.
2. Existing controls, such as gates, signs, signals, and pavement markings.
3. Structural condition of the pavement at the crossing.

Even before this inventory is completed, improvements at the crossings will be made in the following order of priority:

1. Pavement markings and warning signs in accordance with the 1973 edition of the Manual on Uniform Traffic Control Devices will be installed as a minimum treatment for all railroad crossings.
2. Improvements will be made to the pavement at crossings where it is identified as necessary in the inventory.
3. Installation of wig-wag signals, bells, gates, and highway lighting.

Reporting personnel

L. T. Perkins
Traffic Engineer
Massachusetts Department of Public Works
100 Nashua Street
Boston, Massachusetts 02114

Mississippi

Warrants

Flashing light signals:

Train movements and speeds

Vehicle movements and speeds

Sight distance and restrictions

Exposure

Number of accidents

Highway width

Flashing light signals and gate arms:

Multiple tracks

Grade separation structure:

Grades are separated wherever possible on all high-speed, high-volume, primary highways crossing main line railroads.

Priorities

Traffic engineering studies.

Reporting personnel

A. M. White
Assistant Chief Engineer
Traffic & Safety
Mississippi State Highway Department
P. O. Box 1850
Jackson, Mississippi 39205

Montana

Hazard Index formula

$$HI = (ADHT) \times (ADTT) \times F_1 + F_2 + F_3 + ---F_{10}) \div 100$$

HI = Hazard Index

(ADHT) = estimated average daily highway traffic for the design year

(ADTT) = estimated average daily train traffic to be encountered during the design year.

When the guidelines are utilized to analyze what type of crossing warning should be provided at a crossing on a proposed construction project, the design year is usually twenty years in the future. However, when the guidelines are utilized to analyze an existing situation, or compare crossings, the design year might be the current year.

$(F_1 + F_2 + F_3 ---F_{10})$ is a factor which attempts to give certain values to and summarizes the various physical conditions encountered or anticipated at a crossing site. As currently used, this factor has a maximum value of 12.2.

The product of the above three factors is then divided by 100 to obtain a more workable range of Hazard Index values.

The makeup of the $(F_1 + F_2 + F_3 ---F_{10})$ factor is further described as follows:

F_1 = Type of train movements - maximum value 4.0

Use 4.0 for passenger trains over 50 mph

Use 3.0 for freight trains over 50 mph

Use 2.0 for passenger or freight trains under 50 mph

Use 1.0 for switching movements only

F_2 = Trackage - maximum value 0.8

Use 0.8 for two mainline tracks plus other tracks

Use 0.6 for two mainline tracks

Use 0.2 for one mainline track and one or more side tracks

Use 0.1 for a single track

F_3 = Sight Distance - maximum value 4.0

Each quadrant ranges in value from 1.0 to 0.0 as the sight distance varies from totally restricted to unlimited.

F_4 = Approach Angle - maximum value 1.6

The value ranges from 1.6 to 00.0 as the crossing angle varies from very flat to a right or nearly right angle.

Use 1.6 for 0-20°

Use 1.2 for 21°-40°

Use 0.8 for 41°-60°

Use 0.4 for 61°-80°

Use 0.0 for 81°-90°

F_5 = Highway Alignment - maximum value 0.6

Use 0.6 if both approaching roadways are on curves over 7°30'

Use 0.5 if both approaching roadways are on curves under 7°30'

Use 0.4 if one approach roadway is tangent and the other is on a curve over 7°30'

Use 0.3 if one approach roadway is tangent and the other is on a curve under 7°30'

Use 0.1 if both approach roadways are tangent

F_6 = Number of Lanes - maximum value 0.2

Use 0.2 for 4 or more lanes

Use 0.1 for 2 lanes

Warrants

Urban Guidelines

Computed Hazard Index	Needed Warning
Under 2,000	Crossbucks
2,000 - 10,000	Flashing Lights
10,000 - 20,000	Gates
over 70,000	Separation

Rural Guidelines

Hazard Index	Warning
Under 200	Crossbucks
700-- 1,000	Flashing Lights
1,000 - 7,000	Gates
over 7,000	Separation

Priorities

Computed Hazard Index

Need

Public Demand

Reporting personnel

Alex G. Zbitnoff
Manager, Traffic Unit
Montana Department of Highways
6th and Roberts Streets
Helena, Montana 59601

Hazard Index formula

HI with no warning = VT (F1 + F2 + F3 + F4 + F5 + F6)

V = Function of average daily traffic

T = Function of number of trains per day

F1 = Area factor

F2 = Sight distance factor

F3 = Train and vehicle speed factor

F4 = Track rating factor

F5 = Roadway surface type factor

F6 = Crossing grade factor

HI with warning = $\frac{HI}{p}$

p = warning type factor

Warrants

On-site inspections by road, railroad, and local officials to determine warning devices warranted by traffic and on-site conditions. If the number of trains per day times average daily traffic for the design year exceeds 25,000, a viaduct will probably be constructed and if this product exceeds 50,000, a viaduct is definitely called for.

Priorities

City and county requests

Hazard Index formula

Reporting personnel

Glen E. Stoddard
Railroad Liaison Engineer
Nebraska Department of Roads
P.O. Box 94759
Lincoln, Nebraska 68509

North Carolina

Hazard Index formula

$$HI = \frac{(ADT_h \times ADT_{rr})}{100}\left(1 + \frac{N}{Y}\right)$$

HI = Hazard Index

ADT_h = Average Daily Traffic on the Highway

ADT_{rr} = Average Daily Traffic on the Railroad

Y = The Number of Years in the Study Period

N = The Number of Train-Vehicle Accidents in Y years

Warrants

Flashing light signals, post mount:

one lane of approach traffic

Flashing light signals, cantilever mount:

two or more lanes of approach traffic

Flashing light signals and gate arms:

simultaneous operations on two or more tracks or train speeds over 70 mph

Grade separation:

Where terrain or geometrics dictate or where volumes of traffic and trains are high

Priorities

Because actual train-vehicle accidents do not occur with great frequency (only about 200-300 annually in North Carolina on over 6,000 crossings) difficulty is met in producing a strong priority listing based solely on known accident histories. For this reason, we have used three

basic criteria, two of which express accident potential, for determining the priority rating of locations on the list. These criteria are:

1. Accident Frequency - Crossings showing an accident frequency of 0.25 accidents per year or above.

2. Main Line Crossings - These are multiple-track, high-speed, high-volume crossings on the main or through lines of the major railroads. Crossings with approximately 20 trains per day are considered high-volume.

3. Hazard Index --Crossings with HI of 300 or above. The formula is listed above.

All crossings on the list were tested according to this criteria. All crossings meeting all three criteria were listed first; those meeting the various combinations of two criteria, 1 & 2, 1 & 3, 2 & 3, were listed next, in that order; all meeting only one criteria, 1, 2, or 3, were listed third, in that order; and all meeting none of these criteria were listed last. Within each group priority is determined by Hazard Index.

Reporting personnel

W. J. Brown
Railway Signal Engineer
North Carolina Department of Transportation
Raleigh, North Carolina 27611

North Dakota

Warrants

Flashing light signals:

High exposure factor

Restricted sight distances

Flashing light signals and gate arms:

Where there is a possibility of more than one train on a crossing at the same time.

Priorities

Based on:

1) Number of tracks
2) Track skew angle
3) Type of railroad warning
4) Alignment
5) Approach grades
6) Crossing smoothness
7) Exposure factor of train and vehicle volumes
8) Deficient sight conditions
9) Stopping sight distances
10) Speeds

The North Dakota rating system defines a standard adequate crossing as one that has a par rating of 100, which is made up of four major categories:

1) Railroad conditions Par 21

2) Highway conditions Par 13

3) Exposure factor Par 30

4) Visibility factor Par 36

Par 100

1) Railroad conditions (Par 21) are defined as follows:

a) Number of tracks (Par 12)

Single main track	12
Main and one industry	8
Main and one passing	5
Two main	0

For each additional passing or industry track subtract one point.

b) Track skew (Par 9)

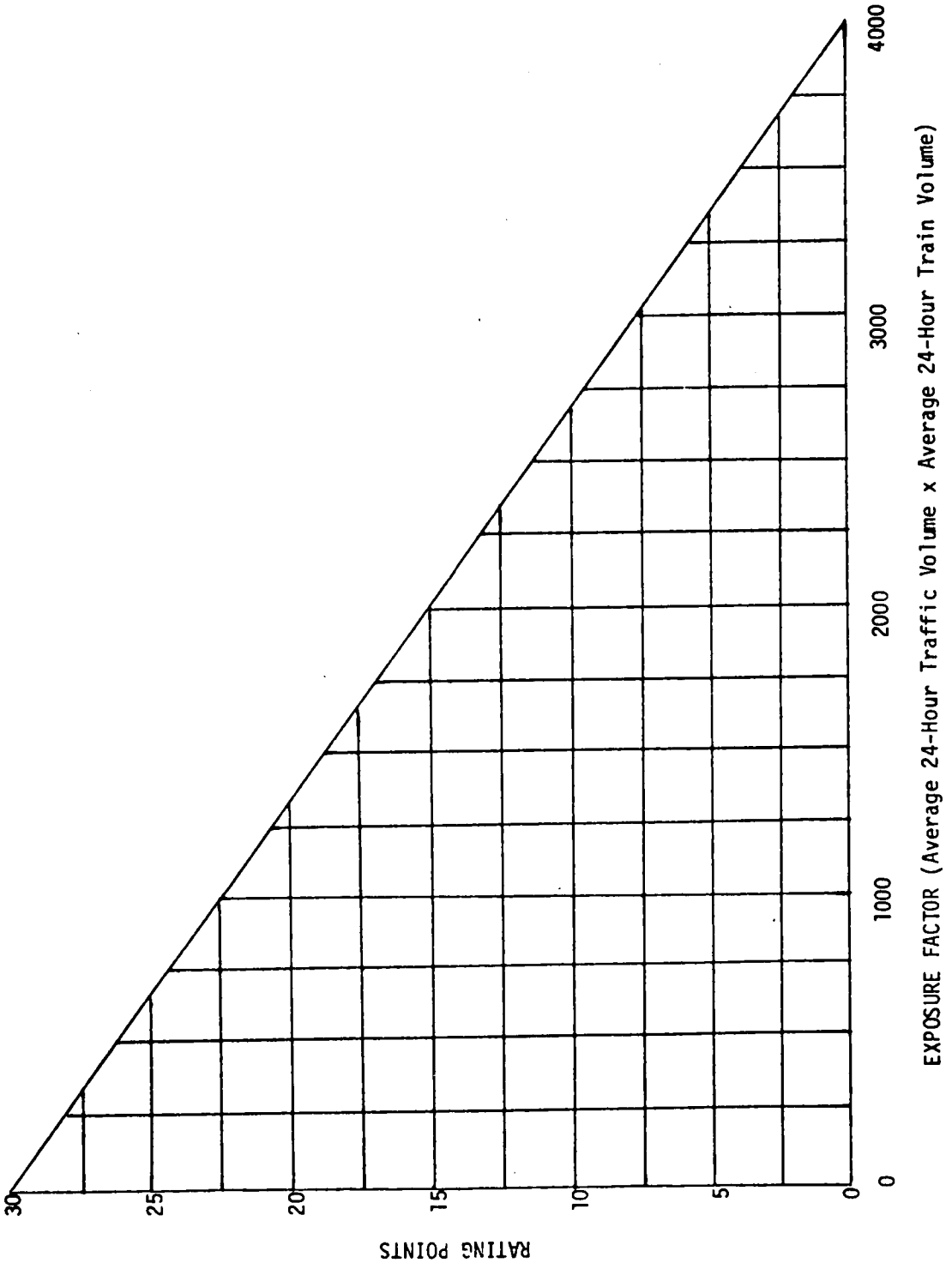
90° - 81°	9
80° - 71°	8
70° - 61°	7
60° - 51°	6
50° - 41°	4
40° - 31°	2
30° - 21°	1
20° or less	0

2) Highway conditions (Par 13) are defined as follows:

a) Type of warning (Par 4)

Reflectorized advance warning sign and crossbucks or better----------4
Reflectorized crossbucks only to above--3
Plain crossbucks only----------2
Anything less----------0

NORTH DAKOTA RATING SYSTEM
EXPOSURE FACTOR CHART



used to determine stopping distances:

Design Speed of Highway, MPH	Minimum Stopping Sight Distance, FT.
15	80
25	160
30	200
35	240
40	275
50	350

The distance traveled by the train during the time interval required to stop a vehicle is computed from the following table:

Train Speed MPH	Highway Design Speed, MPH				
	15	25	30	35	40
20	120	160	180	200	220
30	180	240	270	300	330
40	240	320	360	400	440
50	300	400	450	500	550
60	360	480	540	600	660
70	420	560	630	700	770
80	480	640	720	800	880

In order for a quadrant to be considered open, the driver has to have sufficient sight distance to avoid a collision. Where truck traffic is heavy, the North Dakota rating system takes into consideration the time interval required by the stopped commercial vehicle to cross the track safely.

Reporting personnel

D. J. Laschkewhsch
Senior Manager
North Dakota State Highway Department
Bismarck, North Dakota 58501

South Dakota

Hazard Index Formula

HI = VT [T1 + S + A + N + C + (A1 - 1)]

V = Vehicular traffic in 100's

T = Trains per day

T1 = Train speed (under 60 mph = 1, over 60 mph = 2)

S = View factor--clear sight distance right and left at approach distance 300 feet (inclements of 500 ft. = 2000 = 0; 1500 = .25; 1000 = .50; 500 = .75; less than 500 = 1)

A = Intersection angle; 90 = 2, 45 = 1, less than 45 = 2

N = Number of tracks; 1 = 0, 2 to 4 = 1, over 4 = 2

C = Highway alignment; straight = 0, curve or hill on one side = 1, curve or hill on two sides = 2

A1-1 = Vehicle accidents minus 1.

Warrants

Flashing light signals:

3000 + = exposure rate
60 mph vehicle speed (rural)
30-40 mph vehicle speed (urban)
50 mph train speed (rural)
15 mph train speed (urban)

Grade separation structure:

20,000 + = exposure factor

Traffic patterns

Illumination:

Sight distances, 10 day climatic conditions, two accidents/year, foreign light interference

Priorities

Railroad crossing diagnostic team

Establishing procedures

Reporting personnel

Larry Synder, Manager
Utilities and Railroad Program
Division of Highways
Pierre, South Dakota 57501

Wisconsin

Hazard Index Formula

Traffic Volume Factor = product of ADT and train traffic

Priorities

Traffic Volumes

Sight Distances

Accident Record

Speeds

Geometrics

Diagnostic team review

Reporting personnel

J. M. Horsall
Supervising Development Engineer
Division of Highways
4802 Sheboygan Avenue
Madison, Wisconsin 53702

Wyoming

Warrants

Flashing light signals:

3000 exposure factor, rural

5000 exposure factor, urban

Flashing light signals and gate arms:

15,000 exposure factor, rural 2 or more mainline tracks high hazard rating

20,000-30,000 exposure factor, urban depends on type of street

Grade separation structure:

75,000 exposure factor

Hazard Index Formula

Exposure factor is the product of the average annual daily traffic (design year) times the greatest number of trains per day.

Priorities

General hazard rating formula calculated by field inventory and railroad company data which includes the following:

1. Highway traffic (ADT)
2. Number and speed of trains
3. Sight distances
4. Culture and sight obstructions
5. Type of advance warning
6. Number and type of tracks
7. Alignment of road and tracks
8. Highway speed

VITA

John Edward Tidwell, Jr. is a native of Nashville, Tennessee. He was born on October 2, 1940. He graduated from Nashville's Central High School in 1958.

He studied civil engineering at Vanderbilt University, and received the Bachelor of Engineering degree in 1962.

Upon graduation, he entered the United States Bureau of Public Roads' 3-year Highway Engineer Training Program. This training program included training assignments at several locations throughout the country. After completion of the training program, he was assigned to the Tennessee Division Office of the Bureau of Public Roads in Nashville, Tennessee. He bagan work on his Master of Science degree in civil engineering under a Transportation Option in 1967. He received his Master of Science degree in 1969.

He has since held various engineering positions with the Bureau of Public Roads and its successor, the Federal Highway Administration. He has been assigned to the Tennessee, Mississippi, and North Carolina Divisions. He is currently the Planning and Research Engineer in the North Carolina Division located in Raleigh, North Carolina.

In 1968, he was assigned to an academic year of full time graduate study at The University of Tennessee under the Federal Highway Administration's Graduate Studies Program. He has completed the requirements for the Doctor of Philosophy degree with a major in civil engineering and received the degree in 1980.

He is also an ordained minister in the Primitive Baptist Church and serves as Pastor of the Gift Primitive Baptist Church in Coats, North Carolina.

He is a licensed Professional Engineer in the states of Tennessee and Mississippi.

He is married to the former Janet Elizabeth Malone of Nashville, Tennessee and they have two daughters.