NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **50**

FACTORS INFLUENCING SAFETY AT HIGHWAY-RAIL GRADE CROSSINGS

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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REPORT 50

FACTORS INFLUENCING SAFETY AT HIGHWAY-RAIL GRADE CROSSINGS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

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FOREWORD

By Staff

Highway Research Board

This report will be of interest to traffic, utility, and design engineers, and public officials responsible for the design and operation of safe highway-rail grade crossings. The research presents a method of forecasting the likelihood of accidents at highway-rail grade crossings and includes recommended warrants for the improvement of crossings based on the predicted accident savings. An extensive review of human factor considerations has been conducted to develop improved protection devices. Experimental signs have been studied and specific recommendations are made for improved crossing protection.

In 1961 motor vehicle accidents at highway-rail grade crossings numbered 2,931. In these accidents, 1,173 people were killed and 3,031 people were injured. The highway fatality rate at highway-rail grade crossings is disproportionately high when compared to the national total. Furthermore, almost one-third of the accidents occurred at crossings protected by audible and/or visible signals, 56 occurred despite lowered gates, and 88 occurred in the presence of trainmen or watchmen. It was with these thoughts in mind that this project was initiated by action of a joint committee of the American Association of State Highway Officials and the Association of American Railroads meeting in Miami, Florida, on December 6, 1962.

Alan M. Voorhees & Associates in this comprehensive and well-documented study have directed their efforts toward the interpretation and analysis of currently available highway-rail grade crossing data in the United States. Experimental and conventional signs for crossing protection were designed, installed, and tested in the field. A motion picture of the signs installed in the field was made and a group of engineers subjectively rated the experimental signs.

Research findings include the development of a mathematical model for predicting accidents. The model was based on accident data obtained from a wide variety of private sources, state highway departments, and regulatory agencies. From the Interstate Commerce Commission the investigators obtained more than 15,000 accident reports spanning a five-year period.

Warrants and criteria for the improvement of railroad crossings are presented in a graphic form. By applying the warrants developed, a jurisdiction may determine priorities for improvements based on installation, maintenance, and accident costs. The priorities are assigned by using a benefit-cost technique. The research also includes an analysis of accidents that did not involve trains, presents a method for determining the adequacy of crossing sight distance, considers the requirements that certain vehicles must stop at all crossings, and indicates the number of crossing accidents involving trucks.

This research presents the most comprehensive analysis of highway-rail grade crossing accidents known to date and provides the engineer with useful information that can be applied to increase the safety aspects of highway-rail grade crossings. Future research could involve the further testing of the experimental control devices, controlled studies of train visibility, development of less expensive automatic devices, and a review of the legal requirements that certain vehicles must stop at all crossings.

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ACKNOWLEDGMENTS

The research reported herein was conducted by Alan M. Voorhees & Associates, with David W. Schoppert, Associate, and Dan W. Hoyt, Engineer, as co-principal investigators. Other research agency personnel providing assistance were: Stephen G. Petersen, who participated in the studies of speed characteristics and the improvement of devices; Joann Harris, who wrote the computer programs necessary to the study; Robert Colenutt, who participated in the qualitative analysis; J. Royce Ginn, who participated in the development of the accident model; and Jerry L. Currier and Merritt Edson, who prepared the graphics.

Slade F. Hulbert and Albert Burg, of Planning and Engineering Sciences, Inc., served as human factors consultants to the project, and co-authored Appendix B.

John Quigley served as a special consultant assisting in development of the accident model.

The authors also extend thanks to the several railroads, public agencies, and individuals listed in Appendix F, whose cooperation in supplying data made this study possible.

FACTORS INFLUENCING SAFETY AT HIGHWAY-RAIL GRADE CROSSINGS

SUMMARY

Accidents at railroad crossings have been a matter of public concern for many years. Although they account for less than 0.1 percent of all motor vehicle accidents, the number of people killed and injured in each accident is high. This is illustrated by the fact that each year approximately 2.5 percent of all motor vehicle deaths have occurred at railroad crossings.

Flashing lights and gates have been shown to reduce materially the numbers of accidents that occur at railroad crossings. However, the installation and maintenance cost for this type of protection is high. This makes it extremely important that the locations selected for improvement be chosen with regard to the anticipated benefits. It should also be made certain that a greater improvement in safety could not be obtained through improvement of other highway locations with the same funds.

This problem is complicated by the low rate of accidents occurring at crossings. The 7,500 crossings analyzed by this study had an average accident rate of less than one accident every ten years. The low incidence of accidents on a crossing basis indicates that a program to provide protection should not, except in very rare cases, be based on an individual crossing's accident experience. This point is illustrated more clearly by the following hypothetical example, which represents the expected distribution of accidents at 60 identical crossings during a five-year period:

Number of accidents	0	1	2
Number of crossings	55	5	–

That the same five crossings would have an accident in the following five-year period is highly unlikely. The probability that any of the crossings would have two accidents is only 0.02. This does not mean that no crossings would have two accidents, but rather that if a crossing did have two accidents, two would not be expected in every five-year period.

Warrants for Crossing Protection

This study has developed a procedure, based on a statistical analysis, that permits calculation of a probable accident rate for a railroad grade crossing. This procedure (summarized in Fig. 24) takes into consideration number of trains, traffic volume, type of protection, environment (urban or rural), and, for certain types of protection, gradient, number of traffic lanes and angle of crossing. The method by which day and night train arrivals and the hourly variation of highway traffic can be considered in the predictive equations is illustrated under "Use of the Model" in Chapter Six.

By combining this information with assumptions concerning the costs of accidents and the costs of providing various types of protection, a simple procedure of determining economic warrants for improvements can be developed. Such a procedure is graphically presented in Figure 25, in which the implicit cost assumptions are: cost per accident, \$8,000; cost of flashing lights, \$13,000; cost of gates,

$26,000; cost to upgrade flashing lights to gates, $13,000; cost of grade separation, $100,000; and economic life of improvements, 10 years.

The probability factor which serves as a base to Figure 25 is the product of the number of trains and the *A* factor shown in Figure 24. As indicated on the charts, installation of flashing lights in rural areas is warranted—i.e., there is a benefit/cost ratio greater than 1.9—when the probability factor exceeds 0.06. Likewise, gates are warranted at a probability factor of 0.10. Grade separation is not warranted at any level of probability shown on the chart. It should be pointed out that the only costs considered by these charts are those associated with accidents. To make a complete economic evaluation for grade separations, travel delay costs would also have to be considered.

The procedure presented in Figure 25, when combined with information on available budgets, allows development of a rational railroad crossing improvement program that will maximize benefits subject to budget constraints.

Nontrain-Involved Accidents at Crossings

From a sample of 3,627 accidents that occurred at railroad crossings, those involving trains accounted for only about one-third. The other two-thirds were almost evenly distributed between accidents which occurred when the train was present but not involved, and those which occurred when the train was not even present.

Accidents at crossings which did not involve trains were found to be primarily a function of highway vehicles, number of trains, and the presence of automatic gates. The resulting equations are as follows:

With automatic gates

$$\text{EA} = \frac{V}{100}\,(0.00866 + 0.00036T)$$

All other protection types

$$\text{EA} = \frac{V}{100}\,(0.00499 + 0.00036T)$$

in which EA is the number of expected nontrain-involved accidents per year, V is the number of vehicles per day, and T is the number of trains per day.

Because a large number of single-vehicle accidents occur in the vicinity of railroad crossings, it is recommended that sign supports and bases of devices be designed to reduce the severity of injuries to vehicle occupants. Other objects along the roadside should be removed when feasible.

Crossings were found to have a turbulent effect on the traffic stream. Comparison of the distribution of vehicle speeds at the crossing and prior to the influence of the crossing indicated a definite reduction in average speeds and fewer vehicles within a 10-mph pace. These conditions are believed to contribute significantly to multiple-vehicle accidents at crossings.

This study also found that vehicles that are required to stop at all railroad crossings account for approximately 13.3 percent of the accidents which occur when a train is not present.

The requirement that certain types of vehicles stop at all railroad crossings needs to be reviewed. Some areas have declared certain crossings to be exempt from this requirement. This should be done on a nationwide basis. It is recommended that this class of vehicle should not be required to stop (1) at crossings equipped with devices which warn of a train's approach, (2) at crossings on high-volume streets and highways that have an extremely small amount of train traffic, and (3) at crossings that have been abandoned by rail traffic. The requirement as it would apply to the remaining locations should be critically reviewed to determine whether the desired amount of trade-off between vehicle-vehicle and vehicle-train accidents is being obtained.

Sight Distance

Analysis of the accident data indicates that the major safety problem is caused by trains which appear on the crossing after the driver has passed his final opportunity to stop. A review of field conditions at crossings indicates that the driver traveling at the normal approach speed generally cannot see approaching trains before he reaches the point on the highway at which he must make his decision to stop. Improvement of this situation is dependent on two things: (1) educating the driver to the fact that he must look to his right and left for approaching trains and (2) providing clear quadrants which allow a driver to see approaching trains when he does look.

A method has been developed by this study for determining the adequacy of sight distance at railroad crossings. The method proposed is based on criteria used for normal highway design purposes, but in addition incorporates the speed of the trains as a factor.

The basic assumption made is that the driver at all points on his approach must be able to see a train in time to stop or proceed across the crossing ahead of the train. Recommended sight distances for various combinations of railroad and highway vehicle speeds are given in Table 20. Where the recommended distances cannot be provided and automatic devices are not warranted, every effort should be made to reduce the highway approach speed, the train speed, or both.

Improved Passive Protection

Although it may be possible to make some advances in automatic devices which operate the signals, it is clear that some device less expensive than lights or gates and more effective than existing warning signs must be found for a very large number of crossings.

As a result of an intensive study of signing, specific recommendations are made regarding the adoption of proposed new signs for use at railroad crossings. The signs proposed are the result of a study of human factors, accident research, economics, and observations of actual test signs erected at typical locations. Additionally, an opinion survey was conducted to determine the reaction to the signs by an impartial audience.

Each of the signs was designed to provide the driver, through sign shape and message, at least one of the following types of information to aid his safe negotiation of the crossings:

1. Inform him prior to the crossing exactly what his obligation will be (i.e., should he observe an automatic device which will inform him of a train's approach or is it his complete responsibility to look for approaching trains).

2. Emphasize at the crossing, when automatic devices are *not* present, that his responsibility is to determine the existence of trains in such proximity to the crossing as to constitute a hazard.

3. Provide him with additional information necessary for his safe negotiation of the crossing. For example, when sight distance is restricted and requires a reduction in highway approach speed, post advisory speed signs. When the driver cannot see an approaching train sufficiently far in advance of the crossing, post

reduced advisory highway speeds and tell him where and when on the approach to look.

4. Provide him with no information when no hazard exists. If the crossing has been abandoned or is used only infrequently by rail traffic, do not use signs which the driver associates with trains. If other types of hazards exist, use signs which the motorist can associate with the hazard (such as "Bump," "Dip," or "Road Narrows").

Alternative shapes, colors, and messages were studied. Because of the results of human factors studies, one color studied was brilliant yellow-green (Bureau of Standards color No. 116). Although it is not one of the colors recommended for use at railroad crossings, it was observed to be a good color for highway signs. Because of the value of this sign for both day and night conditions, it is recommended that its use be reserved for locations which generally do not have street lighting or illumination and which are problems during poor visibility conditions.

General

Accidents normalized for highway volume occur more frequently during nighttime than during daytime hours. Approximately 42 percent of the accidents involving trains are at night; however, only about 25 percent of the highway traffic is at night and rail traffic is relatively constant throughout a 24-hr period. In addition, 93 percent of the 561 accidents which involved a vehicle running into the side of a stopped train occurred at night. Also, 78 percent of the accidents involving vehicles which ran into trains traveling less than 10 mph occurred at night. These findings indicate that crossings which are frequently blocked or used by slow moving trains during nighttime hours should be lighted.

The statistics indicate that there is considerable variation in accident rate during darkness. Although the accident rate between 6:00 P.M. and midnight is approximately twice as high as the daytime rate, a peak hazard occurs between 2:00 A.M. and 4:00 A.M. During this peak, the accident rate is six to eight times as high as the daytime rate.

Driver fatigue may be an important factor; however, it is noted that relative humidity generally peaks during the same time period and that a rise in relative humidity also corresponds to a higher winter accident rate, even in states which do not have ice or snow. Poor visibility, frosting and misting of windshields, and wet pavements, which accompany high relative humidities, may play an important part in creating this period of peak accident rate. Further study of this hypothesis is certainly warranted.

CHAPTER ONE

INTRODUCTION

Attempts to reduce accidents at railroad crossings have a long history dating from the earliest days of motoring. Train-actuated warning devices, especially gates and to a lesser extent flashing lights, have been shown to materially reduce accidents. However, the problem of selecting those crossings where special signals will do the most good is a persistent one. The existing and future resources of the United States will not allow the installation of automatic devices at all crossings because of their high installation and maintenance costs.

There are approximately 220,000 highway-rail grade crossings in the United States. Approximately 44,000 have been provided with special protection of some sort; gates, flashing lights, flagmen, traffic signals, or bells. The remaining 176,000 have no special protection except signs.

Approximately 3,200 accidents per year involve trains. Accidents involving trains have much greater severity than other types of traffic accidents, resulting in approximately 1,200 deaths and 3,400 persons injured each year. The fact that vehicle-train accidents are so severe (the number killed in each accident is almost directly related to the number of car occupants) has caused a great amount of attention to be focused on them, both by researchers and by the public. Traffic accidents at railroad crossings number approximately 10,000 per year, resulting in 1,300 deaths and 11,300 injuries.

On the average, there is one traffic accident per crossing every 22 years and one accident per crossing involving a train every 69 years. Expressed in another way, one of every 22 crossings will have an accident each year, and one of every 69 crossings will have an accident involving a train each year. Very few crossings will have more than one accident per year involving a train. This is not to suggest that safety improvements should not be made at railroad crossings, but rather that the crossings to be improved should be selected with care.

Previous research generally falls into four main categories, as follows:

1. Development of hazard indices, which are based principally on judgment.
2. Development of accident models using regression techniques.
3. Before-and-after accident studies.
4. Others, including observance studies, economic studies, studies of sight distance, and miscellaneous studies.

General agreement has been reached by previous researchers concerning the relative hazard-reducing potential of protection devices and the fact that there is a strong correlation between accidents and rail and highway volumes.

This report represents an operations research approach to studying the factors influencing safety at railroad crossings and developing improved warning for the driver, warrants for improved protection, and assignment of priority for a group of crossings warranting improvement. The analyses of the problems and solutions presented are the result of combined analyses by psychologists, mathematicians, economists, geographers, and traffic and safety engineers. It is believed that the reader will find much of the information contained in this report to be applicable to other areas of traffic and highway safety as well as to railroad crossings.

CHAPTER TWO

QUALITATIVE ANALYSIS OF FACTORS INFLUENCING SAFETY

PRINCIPAL FACTORS

Three principal factors influence safety at highway-rail grade crossings. They are (1) the driver, (2) the vehicles, and (3) the physical conditions. These factors are interrelated and are all affected by other less important ones such as weather, driver age, and light condition.

Each of the three principal factors has had certain controls placed upon it. Driver licensing has helped to establish a definable minimum level of driver ability, maturity, and physical capabilities. Beyond that there is little control over the driver. There remains a great deal of work to be done in this area. The application of human factors knowledge to highway safety represents a virtually untapped tool. The driver is without doubt the factor which is most variable.

The vehicles themselves are definable for all practical purposes. They are required to meet certain legal requirements in all States, and in some a vehicle inspection is required periodically. Several types of vehicles influence safety at rail-highway grade crossings. The most important are the train, the truck, the bus, and the automobile.

Virtually nothing has any influence on the train. Because of its size, its deceleration and acceleration are relatively nil. Its travel path is limited to the rails. Only one control exists, and that is its speed.

Trucks, buses, and automobiles are more controllable. They can be stopped, slowed, speeded up, or turned in reasonable distances. The truck and the bus have much poorer performance capability than the automobile. Given identical initial speeds, an average auto can accelerate at 3 to 17 times the rate of the average large truck and can decelerate at about twice the rate of the average large truck (*3*).

Vehicle characteristics vary greatly among and between the different types of vehicles. Visibility from the vehicles is another variable. In terms of glass area and vehicle obstructions, trucks generally provide the driver with poorer visibility. Although trucks are generally equipped with good rear-view mirrors, these mirrors are of little value in spotting a train. The driver does sit at a higher elevation in trucks than in autos, thus allowing him to see over features which would obstruct an auto driver's view. On the other hand, trucks have a higher noise level than autos, making it more difficult for the truck driver to detect an audible warning.

The traveled way, which includes the highway, the railroad, signs, buildings, terrain, and other features on the approach to the intersection, is perhaps the most controllable of the three principal factors. Safety improvements made in this area are entirely dependent on the state of the art.

The interaction of these three principal variables creates unsafe conditions, but it is believed that the interaction can also be used to advantage in improving safety.

During the course of this study, police and driver reports were made available on about 500 accidents at crossings. Descriptions of these accidents relate directly to the three principal factors. Additional data were made available by the Interstate Commerce Commission and various States, cities and counties.

The Driver

That the driver is a creature of habit is illustrated by the lady who abandoned her stalled auto as the train approached but returned to close the door and was hit by the train. The hypnotic effect which the train has on the driver is demonstrated by those who release their pressure on the brake and either creep or roll into the side of the train. The determination of a driver to stick to his first decision even though it is wrong is illustrated by the driver who, upon spotting the approaching train, applied brakes and skidded 70 feet to a stop on the tracks, to be subsequently hit broadside by the train. If he had changed his decision and decided to beat the train across he would have been successful.

Examples of following too close, inattention, and drunk driving were frequent. Less frequent situations were drivers who misinterpreted a watchman's signal, and drivers who had their attention diverted from the train indication by an intersection traffic signal or other control device not pertinent to the railroad crossing. Other drivers, whose attention was diverted from the highway by the flashing light signals, were involved in rear-end collisions with other highway vehicles.

A few situations were found where the driver drove in front of a second train after waiting for the first to pass. It appears that it is common for drivers stalled on the tracks and under the stress of an approaching train to attempt to start the vehicle while it is in gear. It is obvious that the driver's decision and reaction time, as well as his ability to judge train speed and observe a multitude of events at one time, are all important factors.

Information concerning drivers involved in accidents was provided by the Illinois Division of Highways on punch cards which represented all accidents involving trains during a three-year period, 1962-1964. There were 816 such accidents. This information was compared with that for drivers involved in all types of motor vehicle accidents in Illinois during 1965.

Table 1 compares the distributions of driver age for vehicle-train accidents and all types of accidents. The conclusion to be drawn from this table is that drivers over 65 represent a greater portion of the drivers involved in vehicle-train accidents than in all types of motor vehicle accidents.

Table 2 is a comparison of driver residence distributions. There appears to be no significant difference. As with all types of accidents, nearly 80 percent of the drivers involved reside within 25 miles of the accident scene.

Table 3 compares driver sex distributions. Again there appears to be no significant difference.

The Vehicle

The characteristics of the vehicle were shown to be a factor in many of the accidents studied. Vehicle stalling, brake failure, car radios, inadequate defrosters, and response to acceleration and deceleration were all evident as factors contributing to accidents. The tendency for a vehicle to stall is much greater when it is changing speed; i.e., accelerating or decelerating. When it is accelerating from a stopped position, this tendency becomes even greater. Circumstances requiring a change in speed, or stop, occur frequently in areas surrounding grade crossings. Several drivers stated in their accident report that they stalled on the crossing after just pulling out of a curb parking space, turning from a road which parallels the railroad, or exiting from an off-street parking facility adjacent to the railroad. The fact that the vehicles had been parked indicates that the engine probably was cold, thus having a greater tendency to stall. This presents a strong argument for access control and prohibition of parking in the vicinity of crossings.

The ability of the vehicle to respond to braking and acceleration is shown as a factor in several ways. Of 256

TABLE 1

COMPARATIVE DISTRIBUTION OF AGE OF DRIVER IN MOTOR VEHICLE AND VEHICLE-TRAIN ACCIDENTS[a]

DRIVER AGE	DISTRIBUTION (%) MOTOR VEHICLE ACCIDENTS[b]	VEHICLE-TRAIN ACCIDENTS[c]
15 & Younger	0.3	0.2
16	1.2	1.5
17	2.8	2.9
18 to 19	7.5	7.9
20 to 24	15.2	13.9
25 to 34	22.2	17.5
35 to 44	20.0	20.6
45 to 54	15.9	16.4
55 to 64	9.8	9.6
65 to 74	4.1	8.3
75 & Older	1.0	1.2
All	100.0	100.0

[a] Source: Illinois Division of Highways.
[b] All motor vehicle accidents, 1965.
[c] 1962, 1963, and 1964.

TABLE 2

COMPARATIVE DISTRIBUTION OF RESIDENCE OF DRIVER IN MOTOR VEHICLE AND VEHICLE-TRAIN ACCIDENTS[a]

DRIVER RESIDENCE	DISTRIBUTION (%) MOTOR VEHICLE ACCIDENTS	VEHICLE-TRAIN ACCIDENTS
Local resident	79.5	78.3
Residing elsewhere in State	15.7	17.3
Nonresident of State	4.8	4.4
All	100.0	100.0

[a] See Table 1 for notes.

TABLE 3

COMPARATIVE DISTRIBUTION OF SEX OF DRIVER IN MOTOR VEHICLE AND VEHICLE-TRAIN ACCIDENTS[a]

DRIVER SEX	DISTRIBUTION (%) MOTOR VEHICLE ACCIDENTS	VEHICLE-TRAIN ACCIDENT
Male	79.4	81.6
Female	20.6	18.4
All	100.0	100.0

[a] See Table 1 for notes.

reports of accidents at railroad crossings which were studied in detail, 18 involved automatic gates but no trains. Thirteen of the 18 vehicles involved were trucks.

Of the 15,589 accidents involving trains reported to the Interstate Commerce Commission during a five-year period, 20.5 percent involved trucks

Table 4 gives the percentage of trucks involved in accidents at crossings with various types of protection. As the level of protection decreases, the percentage of accidents involving trucks increases. Trucks account for approximately 18 percent of the miles driven and about 16 percent of the vehicle registration (*3*). Trucks account for approximately 11 percent of the vehicles involved in all types of motor vehicle accidents (*16*).

Table 4 indicates that the truck accident record at crossings protected by gates is only slightly higher than that in other types of highway situations. For lower levels of protection this record steadily worsens to the point where, at very low levels of protection, it is more than twice the truck record at other highway locations, and in fact is poorer than the passenger car record.

It is easy to see that the situation at crossings which do not provide warning of an approaching train can present the driver with a complicated, sometimes impossible, situation quite different from the normal highway hazard. Such situations require a combination of good driver and vehicle performance.

It would seem that crossings with a visual signal, such as flashing lights which warn of a train's approach, should approximate the normal highway situation. However, the data show that on a percentage basis trucks are involved in nearly as many accidents at these crossings as at crossings having no automatic protection.

Table 5 indicates that part of the high truck involvement may be attributable to their greater length, and the fact that they occupy the crossing longer (only 14.6 percent of the vehicles which struck the train were trucks, whereas 24.0 percent of the vehicles struck by the train were trucks). This could also be due to the fact that truck braking ability is more comparable to passenger cars than acceleration ability.

The Physical Conditions

The roadway, its geometrics, and its surroundings can readily be related to accidents. As with the driver and the vehicle, many of the factors associated with the traveled way must be accepted as part of the American way of life. However, previous research has demonstrated the effectiveness of improved protection in reducing accidents. Other roadway elements, such as sight obstructions, changes in grade, parking, access control, and fixed objects along the roadside, were evident as factors in several accident reports studied.

Accident distributions by vehicle speed, train speed, part of train involved, manner of collision, and light condition provide much insight concerning the importance of sight distance.

Many statistics have separated train accidents into two types— vehicle hits train and train hits vehicle. Approxi-

TABLE 4

TRUCK ACCIDENTS AS A PERCENTAGE OF THE TOTAL, BY PROTECTION TYPE[a]

PROTECTION TYPE	ACCIDENTS (NO.) TRUCK	TOTAL	PER-CENT
Automatic gates	42	338	12.4
Manual gates	23	172	13.3
Watchman	10	133	7.5
Other employee	246	1,517	16.2
Aud. and vis. signal	282	1,629	17.3
Audible signal	287	1,454	19.7
Visual signal	262	1,246	21.1
Crossbuck	732	3,453	21.2
Advance warning sign	135	598	22.6
Unprotected	1,162	5,039	23.1
All	3,181	15,580	20.5

[a] Source· Interstate Commerce Commission, 1960-1964 nationwide data

mately two-thirds of the accidents have resulted from the train hitting the vehicle and one-third from the vehicle striking the train. The general conclusion has been that there is not much that can be done about the one-third that strike the train because these drivers would have to be completely oblivious to the driving task. The situation confronting the driver is much too complicated for such a simple conclusion. The simple form in which the statistics are presented is misleading. Because of sight distance, speed, cone of peripheral vision, reaction time, and other factors, further analysis was made.

The Interstate Commerce Commission had data on the numbers of accidents involved with various parts of the train (Table 6). Nearly 90 percent of the vehicles were hit by the train or hit the engine or head end of the train. The data regarding length from the front of train are given only in quarters except for head end and last unit. The average length of trains involved in accidents can be approximated, knowing the number of cars in each train and the approximate length of a car. Based on these figures, the average length of train is 2,130 ft.

Considering the time required for a highway vehicle to stop at different speeds and the distance which a train travels in this time at various speeds, it can be seen that a negligible percentage of the accidents are caused by a driver's not being aware of the presence of a train on the crossing (see Table 7). At 40 mph it takes a driver approximately 8 sec to stop his vehicle; at 60 mph, it takes approximately 11.6 sec to stop.

More generally, the driver is simply not seeing the train soon enough before it reaches the crossing. After the train occupies the crossing, it is very unlikely that the driver does not see the train; but by then it is simply too late for him to take preventive action. The important accident contributing factors include peripheral vision and quadrant sight obstructions.

The following tables and graphs illustrate how accident type changes with vehicle speed and train speed. Table 8 and Figure 1 show that as vehicle speed increases, the percentage of vehicles striking the train increases. As train speed increases, the percentage of vehicles striking the train decreases, as shown in Table 9 and Figure 2.

These basic data concerning speeds of trains and highway vehicles and parts of trains involved were found to be so intriguing that a more detailed analysis was performed.

Knowing (1) the part of the train involved in an accident, (2) the speed of the train, (3) the number of cars in the train, and (4) the speed of the highway vehicle, it was possible to determine the approximate location of the front of the train when the driver was at his design decision point. (For a more thorough discussion of the design decision point concept, see Chapter Four.) Design values for stopping distance and time to proceed were utilized. Table 10 gives the actual maximum distance trains were from the crossing when the driver was at his design decision point. Table 11 gives the numbers of accidents by distance of train from the crossing. Excluded from this analysis were all accidents in which the highway vehicle or train was stopped, or their speed was unknown, or the length of the train was unknown. However, including those accidents in which the train was stopped on the crossing, it appears that the train was on the crossing when the driver was at his decision point in

TABLE 5

DISTRIBUTION OF TRAIN-INVOLVED CROSSING ACCIDENTS, BY ACCIDENT TYPE AND VEHICLE TYPE

VEHICLE TYPE	DISTRIBUTION OF ACCIDENTS: TRAIN HIT MOVING VEHICLE (NO.)	(%)	TRAIN HIT STALLED VEHICLE (NO.)	(%)	TRAIN HIT STOPPED VEHICLE (NO.)	(%)	MOVING VEHICLE HIT TRAIN (NO.)	(%)	TOTAL (NO.)	(%)
Auto	6,251	75.5	661	78.9	705	76.1	4,631	83.6	12,248	78.7
Bus	26	0.3	1	0.1	5	0.6	6	0.1	38	0.2
Truck	1,983	24.0	175	20.9	214	23.1	808	14.6	3,181	20.4
Motorcycle	16	0.2	1	0.1	2	0.2	93	1.7	112	0.7

TABLE 6

PARTS OF TRAINS INVOLVED IN ACCIDENTS IN THE UNITED STATES, 1960-1964 [a]

ACCIDENT TYPE	ACCIDENTS (NO.)	ACCIDENTS (%)	TRAIN SECTION LENGTH (FT)	CUM. ACCIDENTS (%)	CUM. TRAIN LENGTH (FT)
Hit by train	10.047	64.6	—	64.6	—
Hit 1st unit	3,670	23.6	50	88.2	50
Hit 1st quarter [b]	710	4.6	482	92.8	532
Hit 2nd quarter	388	2.5	532	95.3	1064
Hit 3rd quarter	279	1.8	532	97.1	1596
Hit 4th quarter [c]	317	2.0	482	99.1	2078
Hit last unit	143	0.9	50	100.0	2130
All	15,554	100.0	2130		

[a] Source: Interstate Commerce Commission.
[b] Of longer train; or second, third, or fourth unit of train with less than five units.
[c] But not last unit.

TABLE 7

DISTANCE TRAVELED BY TRAIN DURING HIGHWAY VEHICLE'S STOPPING TIME

	DISTANCE TRAVELED FOR HIGHWAY VEHICLE SPEED OF			
	40 MPH		60 MPH	
TRAIN SPEED (MPH)	DIST./8 SEC (FT)	% OF AVG. TRAIN LENGTH	DIST./11.6 SEC (FT)	% OF AVG. TRAIN LENGTH
80	937	44.0	1,360	63.8
70	822	38.6	1,190	55.8
60	704	33.1	1,020	47.8
50	587	27.5	850	39.9
40	469	22.0	680	31.9
30	352	16.5	510	23.9

less than 13 percent of the accidents. Looking further at those accidents in which the train was on the crossing when the driver was at his decision point (see Table 12), it is observed that in 76 percent of them, the train speed was less than 10 mph.

Further insight can be gained by looking at the day-night aspect of accidents in which train speed was under 10 mph and the highway vehicle hit the train. This is seen in Table 13, which shows that trains moving at higher speeds provide better cues to the driver at night than do slower-moving trains.

This analysis demonstrates that trains which occupy the crossing when the driver is at his design decision point do not constitute a major portion of the highway-rail crossing problem.

The analysis does indicate the importance of the following:

1. Stressing to the driver that he must (a) obey the signals at crossings when they are present and (b) look for trains when there are no signals.

2. Providing a quadrant sight distance, where signals do not exist, such that the driver can see a train if he does look.

3. Lighting crossings that are frequently occupied by slow-moving trains during hours of darkness.

TABLE 8

VEHICLE-TRAIN ACCIDENTS BY LIGHT CONDITION, ACCIDENT TYPE, AND HIGHWAY SPEED

	NO. OF ACCIDENTS							
	DAYLIGHT				DARK			
MOTOR VEHICLE SPEED (MPH)	STRUCK BY TRAIN	RAN INTO TRAIN	TOTAL	% AT SPEED RUNNING INTO TRAIN	STRUCK BY TRAIN	RAN INTO TRAIN	TOTAL	% AT SPEED RUNNING INTO TRAIN
Standing	1,247	—	1,247	0	518	1	519	0.2
1 – 9	785	93	878	10.6	313	83	396	21.0
10 – 19	1,407	202	1,609	12.6	571	228	779	28.6
20 – 29	1,246	364	1,610	22.6	659	536	1,195	44.8
30 – 39	745	422	1,167	36.1	433	609	1,042	58.5
40 – 49	361	334	695	48.0	187	436	623	70.0
50 – 59	203	263	466	56.4	89	359	448	80.0
60 and over	110	259	369	70.2	45	280	325	86.1
High speed	24	42	66	63.6	16	65	81	80.2
Not reported	745	324	1,069	30.3	343	642	985	65.2
All	6,873	2,303	9,176	25.1	3,174	3,239	6,413	50.5

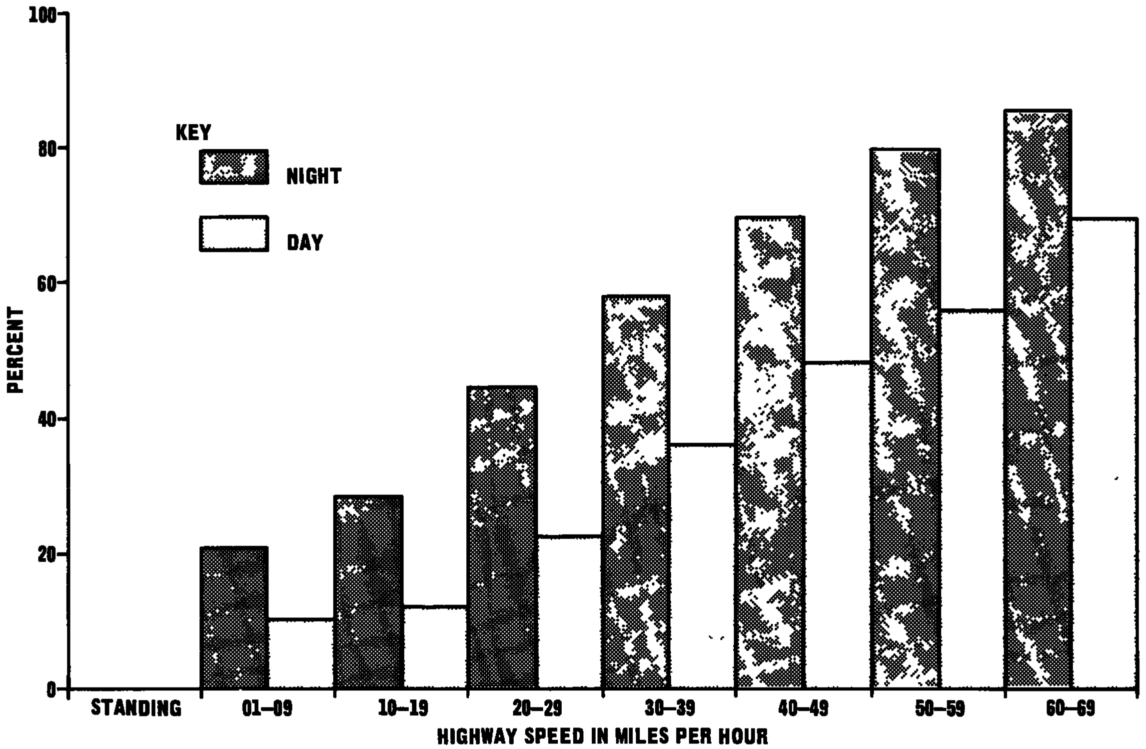

Figure 1. Relationship of highway vehicle speed to accidents in which vehicles struck trains.

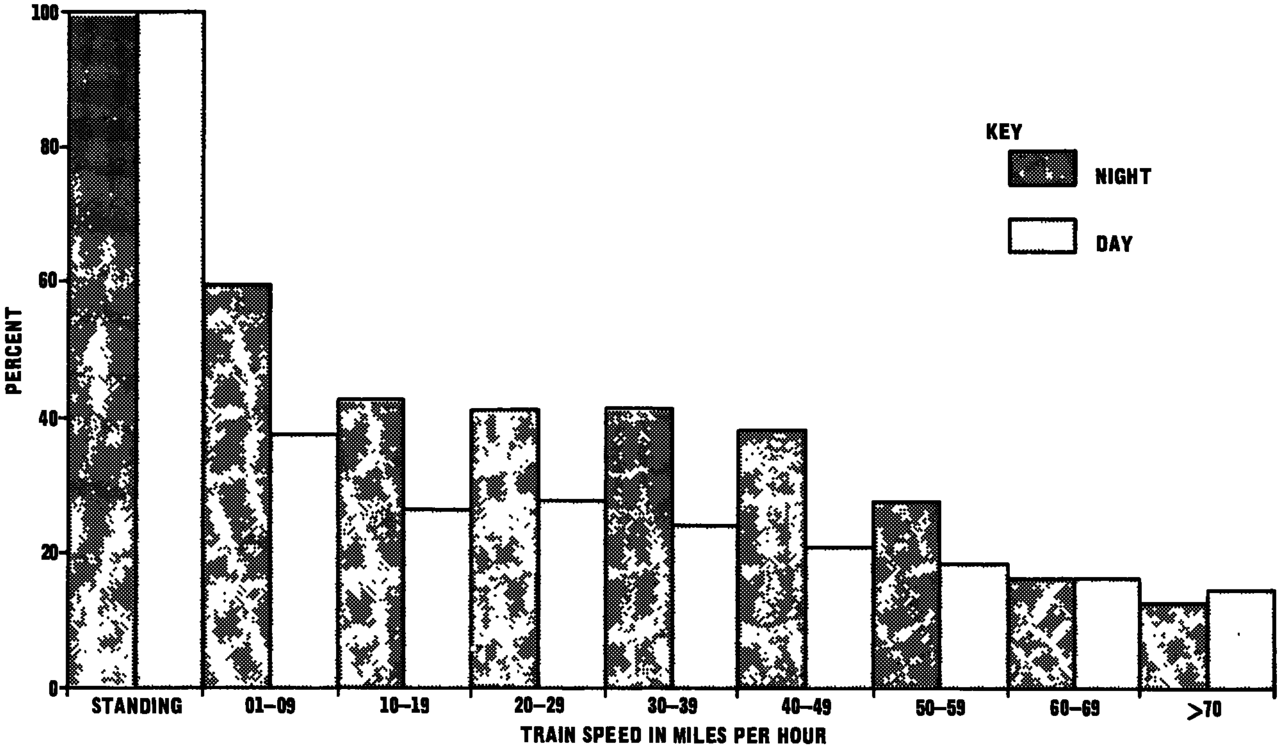

Figure 2. Relationship of train speed to accidents in which vehicles struck trains.

TABLE 9

VEHICLE-TRAIN ACCIDENTS BY LIGHT CONDITION, ACCIDENT TYPE, AND TRAIN SPEED

TRAIN SPEED (MPH)	NO. OF ACCIDENTS							
	DAYLIGHT				DARK			
	STRUCK BY TRAIN	RAN INTO TRAIN	TOTAL	% AT SPEED RUNNING INTO TRAIN	STRUCK BY TRAIN	RAN INTO TRAIN	TOTAL	% AT SPEED RUNNING INTO TRAIN
Standing	—	41	41	100	—	520	520	100
1 – 9	542	330	872	37.8	696	1,170	1,866	62.6
10 – 19	1,407	202	1,609	12.6	571	228	799	28.6
20 – 29	1,280	501	1,781	28.1	530	385	915	42.0
30 – 39	1,207	394	1,601	24.6	362	261	623	41.9
40 – 49	1,085	298	1,383	21.5	321	203	504	38.7
50 – 59	715	170	885	19.2	219	84	303	27.7
60 – 69	448	90	538	16.7	148	29	177	16.4
70 and over	570	99	669	14.8	167	26	193	13.5
Not reported	4	—	4	0	—	7	7	100
All	6,873	2,303	9,176	25.1	3,174	3,239	6,413	50.5

Other Factors

The combinations of driver, vehicle, roadway, and the multitude of other factors result in accident trends.

For example, accident rates at railroad crossings show considerable seasonal and diurnal variation. The incidence of vehicle-train accidents is twice as high in winter months as in the summer. This seasonal change is shown in Figure 3, where the accident index represents a standardized score obtained by dividing actual monthly accidents by monthly fuel consumption. In this way, the incidence of accidents is not biased by seasonal vehicle use. No similar adjustment is made for train traffic, because flow is relatively constant throughout the year.

There appears to be no simple explanation for the high rate of accidents in winter, although part of the yearly distribution of accidents may be explained by several seasonal, climatic and meteorological factors. Included are:

1. Cold weather factors, such as ice, snow, and low temperatures, all causing difficult driving conditions and rolled up windows.
2. Yearly distribution of daylight and darkness.
3. Yearly and diurnal differences in relative humidity.

The effects of cold weather can be examined by comparing the accident distribution for southern States, where winters are relatively mild, and northern States, where winters are quite severe. Eleven southern and 26 northern States were chosen, because they could be accurately classified; but 11 other States were not considered because they were neither distinctively northern nor southern. Figure 4 indicates that winter crossing accident rates are much higher than summer rates even in the extreme

TABLE 10

MAXIMUM DISTANCE OF ACCIDENT-INVOLVED TRAINS FROM CROSSING WHEN HIGHWAY VEHICLES WERE AT THEIR DESIGN DECISION POINT

TRAIN SPEED (MPH)	DISTANCE OF TRAIN FROM CROSSING (FT) FOR HIGHWAY SPEED OF							
	1 – 9 MPH	10 – 19 MPH	20 – 29 MPH	30 – 39 MPH	40 – 49 MPH	50 – 59 MPH	≥60 MPH	HIGH NOT STATED
1 – 9	30	40	40	40	50	100	100	100
10 – 19	100	100	100	150	150	200	200	200
20 – 29	150	200	200	200	250	300	300	350
30 – 39	150	250	250	300	350	400	450	500
40 – 49	200	300	300	350	450	500	550	600
50 – 59	250	400	400	450	500	600	650	750
60 – 69	300	450	450	550	600	700	800	850
≥ 70	350	500	500	600	700	800	900	1000

TABLE 11

NUMBERS OF ACCIDENTS INVOLVING TRAINS BY DISTANCE OF TRAIN FROM CROSSING AT DRIVER'S DECISION POINT

Train's Distance From Crossing (ft.)	Highway Speed (MPH) 1-9	10-19	20-29	30-39	40-49	50-59	60 +	High Unknown	Total	Per Cent	Train Speed (MPH) By Max. Distance
< 20	90	179	355	412	296	129	118	25	1604	13.8	
20-29	184	0	0	3	1	85	0	0	273	2.4	
30-39	17	317	257	162	2	1	82	25	863	7.4	
40-49	0	0	0	2	56	0	2	0	60	0.5	
50-99	207	496	542	122	3	39	20	2	1431	12.3	1-9
100-149	379	54	119	241	203	67	51	0	1114	9.6	
150-199	197	347	436	330	85	40	24	21	1480	12.7	10-19
200-249	113	320	329	99	102	73	2	0	1038	8.9	
250-299	89	272	291	239	72	62	87	6	1118	9.6	
300-349	101	12	27	212	82	62	2	9	507	4.4	20-29
350-399		218	155	0	63	54	57	3	550	4.7	
400-449		123	126	125	118	51	26	8	577	5.0	
450-499		161	146	23	73	58	38	6	505	4.4	30-39
500-549				49	0	31	29	0	109	0.9	
550-599				83	44	39	1	12	179	1.5	40-49
600-649					12	8	41	0	61	0.5	
650-699					39	17	1	4	61	0.5	
700-749						8	13	5	26	0.2	50-59
750-799						23	15	0	38	0.3	
800-849							14	6	20	0.2	60-69
850-899							18	1	19	0.2	
900-1000								4	4	0.0	70 +
Total	1377	2499	2783	2102	1251	847	641	137	11637	100.0	
Per Cent	11.8	21.5	23.9	18.0	10.8	7.3	5.5	1.2	100.0		
Driver's Distance From Crossing (ft.)	45	95	165	270	395	560	745	965			

Legend
MAXIMUM DISTANCES FOR TRAIN SPEEDS

Speed of Train

1-9
10-19
20-29
30-39
40-49
50-59
60-69
70 +

TABLE 12

ACCIDENTS INVOLVING TRAINS WHICH WERE ON THE CROSSING WHEN THE MOTORIST WAS AT HIS DECISION POINT

TRAIN SPEED (MPH)	ACCIDENTS NO.	%
Stopped	561	25.9
1 – 9	1082	50.0
10 – 19	170	7.9
20 – 29	136	6.3
30 – 39	103	4.7
40 – 49	76	3.5
50 – 59	29	1.3
60 – 69	8	0.4
70 and over	0	0.0
All	2165	100.0

TABLE 13

ACCIDENTS IN WHICH THE VEHICLE STRUCK THE TRAIN, BY LIGHT CONDITION

TRAIN SPEED (MPH)	ACCIDENTS DAY NO.	DAY %	NIGHT NO.	NIGHT %	TOTAL NO.	TOTAL %
Stopped	41	7.3	520	92.7	561	100.0
1 – 9	330	22.0	1170	78.0	1500	100.0
All	2303	41.5	3239	58.5	5542	100.0

southern States, where winters are comparatively mild. In fact, the annual variation of accident rate in the extreme south does not appear significantly different from that in the extreme north.

This is rather surprising, because in the northern States there is a relationship between low temperatures and accident rates. In California this relationship seems to hold at night, but breaks down during the day when temperatures generally are above 60 F (Fig. 5). Thus, low temperatures appear to be a contributing factor in some States, but do not explain the higher incidence of winter accidents in the relatively mild South.

It is possible, therefore, that higher winter accident rates are a function of several other factors, one of which might be the number of hours of darkness, with which low winter temperatures are associated. Figure 6 shows that Chicago, Ill., assumed to be representative of the northern States, has more hours of darkness in winter than Houston, Tex., representing the southern States.

Although only about 25 percent of the annual traffic in the United States is at night, both in the North and South darkness extends into the morning and evening rush hours. During the winter some areas have more than one-half of their travel during darkness. In Chicago, for about 3½ months, sunset is before 5:00 PM, whereas in Houston it is never dark before 5:00 PM. However, Figure 7 and Table 14 show quite clearly that the distribution of accidents throughout the year at any hour is about the same, so that even at 2:00 PM, when it is always light, there is a greater incidence of vehicle-train accidents in the winter months. In other words, neither temperature, nor darkness, nor snow or ice, are predominant causes of seasonal accident differentials. Some other factor or combination of factors must be causing or controlling the distribution.

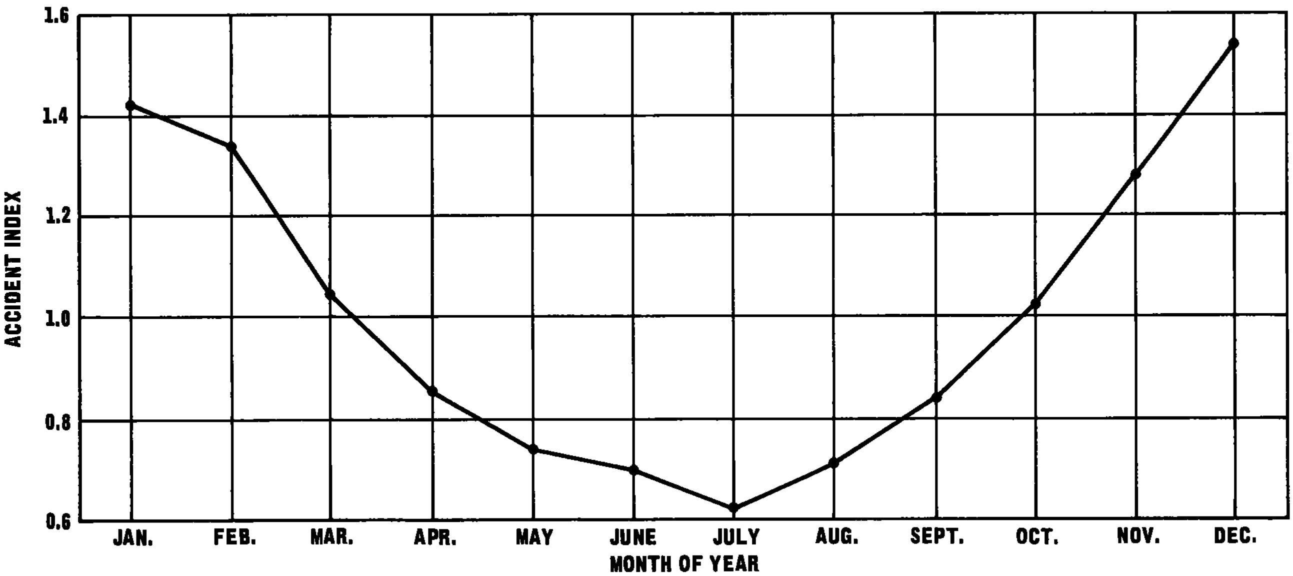

Figure 3. Accident index by month.

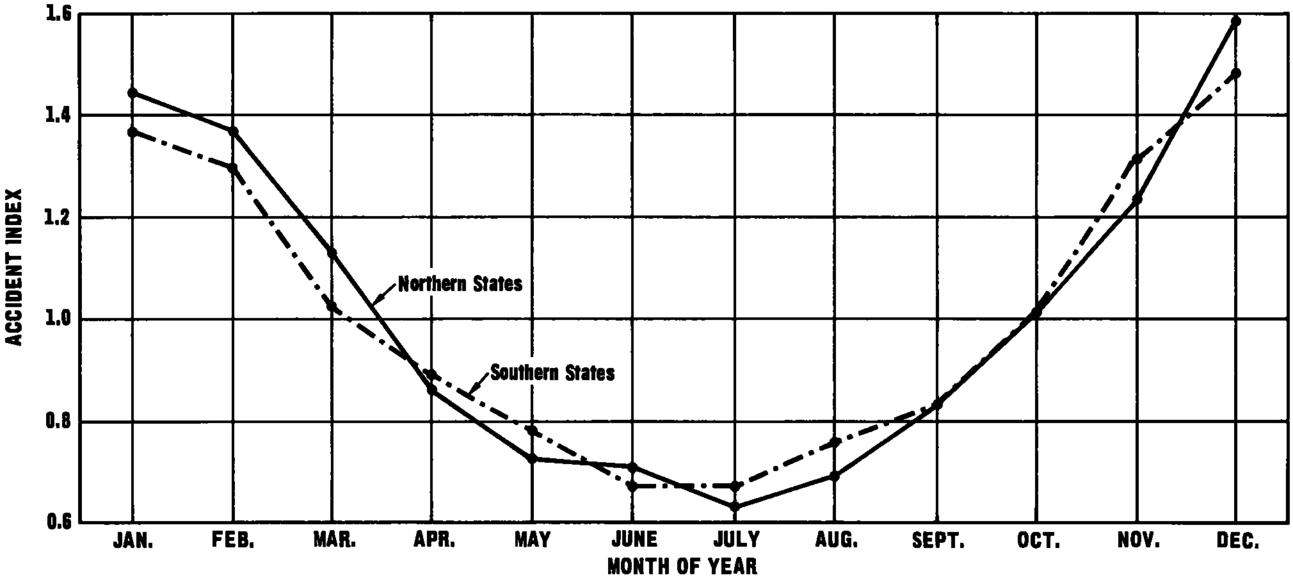

Figure 4. Monthly accident index for northern and southern states.

It is possible that relative humidity may be a contributing factor, because relative humidity figures in the probability of windshields misting or fogging up, thus limiting the visibility of drivers. Relative humidity is defined as the ratio between the amount of water vapor a given unit of air is holding at a certain temperature (absolute hu-

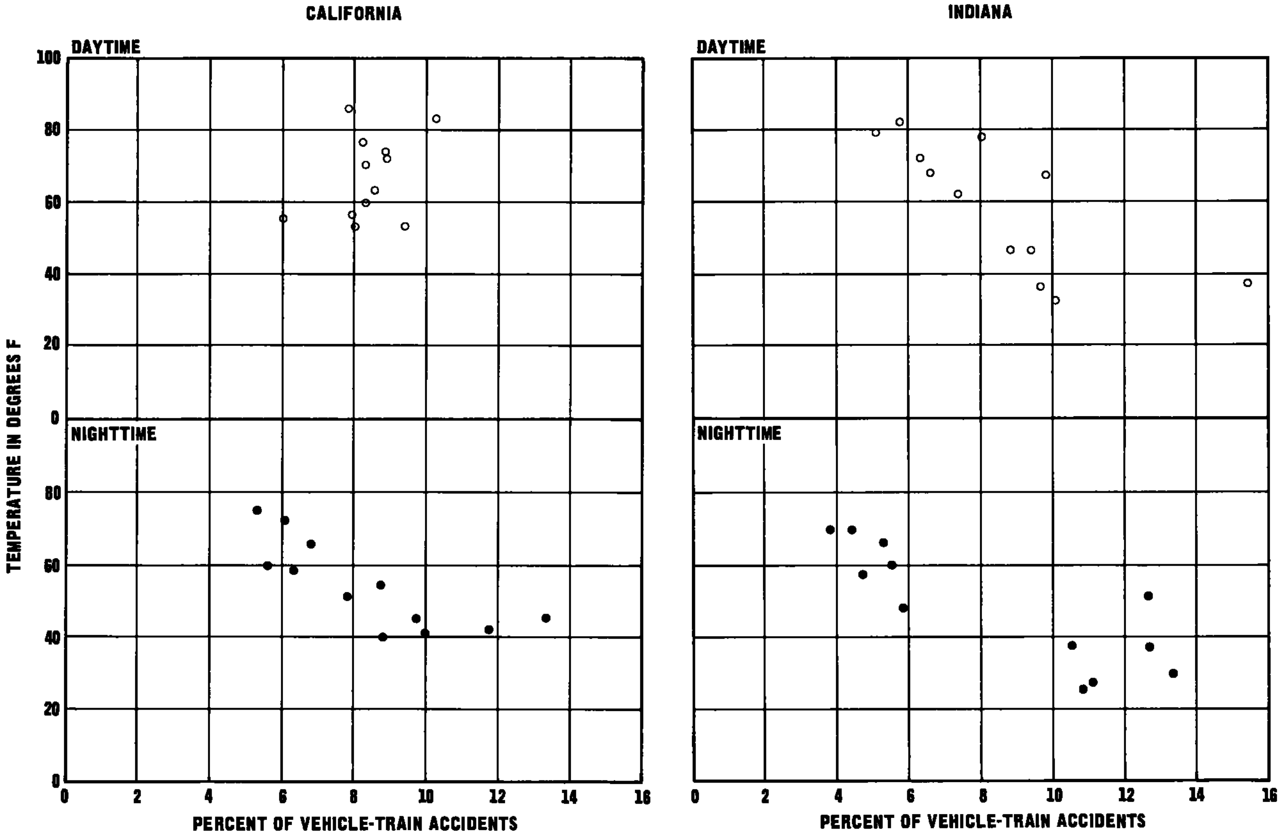

Figure 5. Relationship of temperature to vehicle-train accidents.

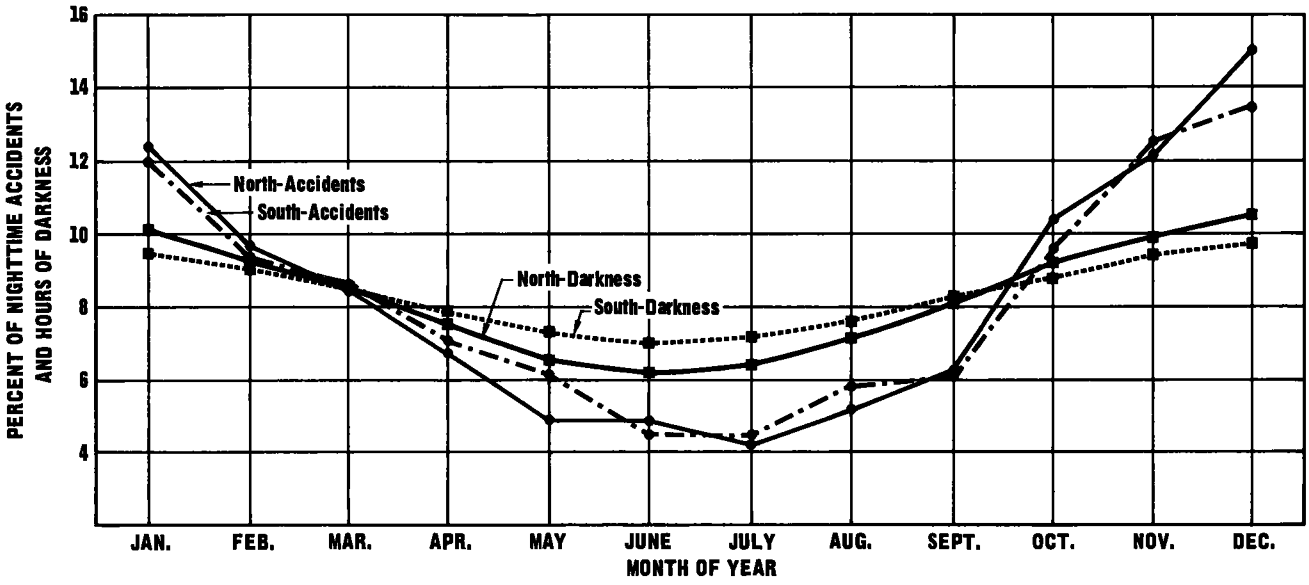

Figure 6. Monthly variation of hours of darkness and nighttime accidents.

midity) and the amount of water vapor it is capable of holding at that temperature. It is usually expressed as a percentage, so that if the air is saturated the relative humidity is 100 percent (*9*).

The water vapor capacity of air is a direct function of temperature, inasmuch as air is capable of holding increasingly larger amounts of water as temperature increases. The shape of this function can be seen in Figure 8; it is important to notice that when temperatures are low only a small increase in water vapor will lead to

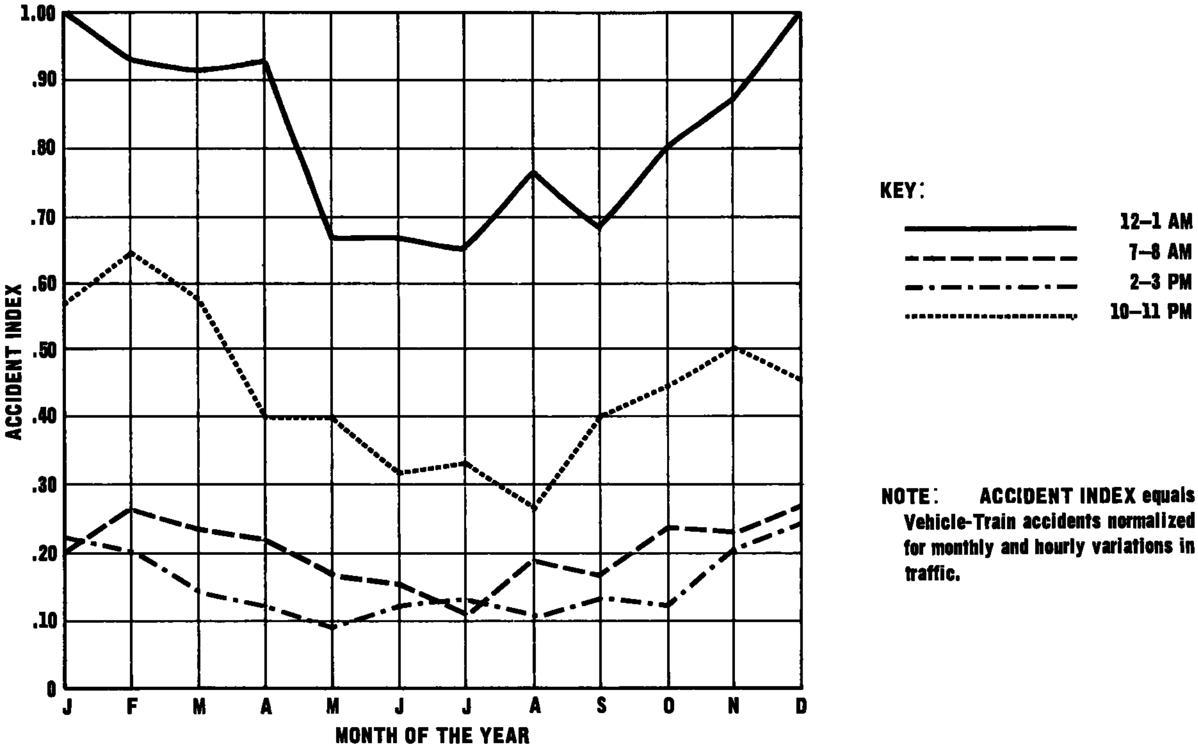

Figure 7. Monthly accident index for selected hours.

TABLE 14

TOTAL ACCIDENTS INVOLVING TRAINS, 1960-1964, BY MONTH AND HOUR OF THE DAY

HOUR OF DAY	ACCIDENTS JAN. NO.	JAN. %	FEB. NO.	FEB. %	MAR. NO.	MAR. %	APR. NO.	APR. %	MAY NO.	MAY %	JUNE NO.	JUNE %	JULY NO.	JULY %	AUG. NO.	AUG. %	SEPT. NO.	SEPT. %	OCT. NO.	OCT. %	NOV. NO.	NOV. %	DEC. NO.	DEC. %	TOTAL NO.	TOTAL %
12 M	53	9.84	43	7.98	45	8.35	47	8.71	36	6.67	36	6.67	36	6.67	43	7.98	35	6.50	50	9.26	56	10.38	59	10.92	539	100
1 AM	45	9.60	37	7.89	41	8.74	41	8.74	34	7.25	35	7.46	16	3.41	32	6.82	38	8.10	45	9.60	60	12.79	45	9.60	469	100
2	36	8.30	37	8.52	36	8.30	27	6.24	30	6.91	23	5.30	27	6.22	29	6.69	20	4.62	53	12.20	50	11.52	66	15.31	434	100
3	18	6.87	22	8.41	18	6.87	23	8.79	17	6.50	29	11.10	17	6.50	18	6.87	13	4.97	21	8.03	27	10.31	39	14.90	262	100
4	20	9.25	12	5.55	19	8.80	24	11.00	14	6.48	21	9.72	15	6.95	14	6.48	16	7.41	27	12.50	18	8.34	18	8.34	218	100
5	33	10.22	37	11.49	23	7.14	19	5.89	16	4.96	20	6.20	22	6.82	28	8.68	29	8.99	36	11.18	27	8.38	33	10.22	323	100
6	62	10.21	46	7.57	45	7.41	36	5.93	45	7.41	40	6.59	37	6.09	55	9.05	43	7.08	59	9.71	69	11.38	71	11.70	608	100
7	60	8.29	67	9.25	61	8.42	63	8.70	48	6.63	46	6.35	33	4.56	58	8.00	50	6.90	85	11.73	65	8.97	89	12.30	725	100
8	73	9.71	57	7.59	75	9.98	51	6.78	57	7.58	46	6.12	42	5.29	53	7.05	53	7.05	66	8.78	78	10.38	101	13.42	752	100
9	72	9.49	75	9.88	73	9.62	46	6.06	44	5.79	41	5.40	46	6.06	49	6.46	54	7.11	68	8.95	78	10.28	114	15.00	760	100
10	93	12.40	92	12.28	71	9.46	45	6.00	46	6.14	41	5.46	39	5.20	51	6.80	37	4.94	58	7.74	64	8.53	113	15.09	750	100
11	98	12.20	97	12.09	65	8.10	51	6.35	50	6.22	46	5.73	51	6.35	59	7.35	43	5.35	67	8.34	73	9.09	105	13.08	805	100
12 N	104	14.17	59	8.31	58	8.16	44	6.20	38	5.35	41	5.78	34	4.80	47	6.66	41	5.78	42	5.92	84	11.85	118	16.62	710	100
1 PM	88	11.28	78	10.00	67	8.59	39	5.00	47	6.02	47	6.02	50	6.41	46	5.89	59	7.55	61	7.81	81	10.39	118	15.12	781	100
2	96	11.90	77	9.55	57	7.06	52	6.45	40	4.96	52	6.45	55	6.82	52	6.45	57	7.06	63	7.82	78	9.66	128	15.89	807	100
3	88	10.84	87	10.72	51	6.29	48	5.92	52	6.40	50	6.16	52	6.40	58	7.15	64	7.89	69	8.50	78	9.61	113	13.92	810	100
4	95	11.35	82	9.80	66	7.89	61	7.29	62	7.41	49	5.86	51	6.09	60	7.17	60	7.17	74	8.84	76	9.08	102	12.19	838	100
5	97	11.92	85	10.48	51	6.28	49	6.03	41	5.05	54	6.75	50	6.16	47	5.79	55	6.77	58	7.14	102	12.57	123	15.15	812	100
6	117	14.25	60	7.30	66	8.02	38	4.62	43	5.23	36	4.37	36	4.37	33	4.01	52	6.34	106	12.89	111	13.50	116	14.10	824	100
7	122	15.50	86	10.92	60	7.64	64	8.14	26	3.31	29	3.68	38	4.83	30	3.81	61	7.75	66	8.40	107	13.60	98	12.47	787	100
8	62	10.15	49	8.03	64	10.49	58	9.50	45	7.36	35	5.73	33	5.40	40	6.55	39	6.39	61	9.99	53	8.69	72	11.80	611	100
9	52	7.68	60	8.86	79	11.69	55	8.13	49	7.25	43	6.35	39	5.76	44	6.50	55	8.14	50	7.38	59	8.72	92	13.60	677	100
10	68	10.65	68	10.65	65	10.19	46	7.21	48	7.52	37	5.80	42	6.58	34	5.34	49	7.68	61	9.56	59	9.25	61	9.56	638	100
11	65	10.18	68	10.62	55	8.60	59	9.23	55	8.60	36	5.63	31	4.85	44	6.88	40	6.25	63	9.85	60	9.38	64	10.00	640	100
All	1,727		1,481		1,311		1,086		983		933		892		1,024		1,063		1,409		1,613		2,058		15,490	100

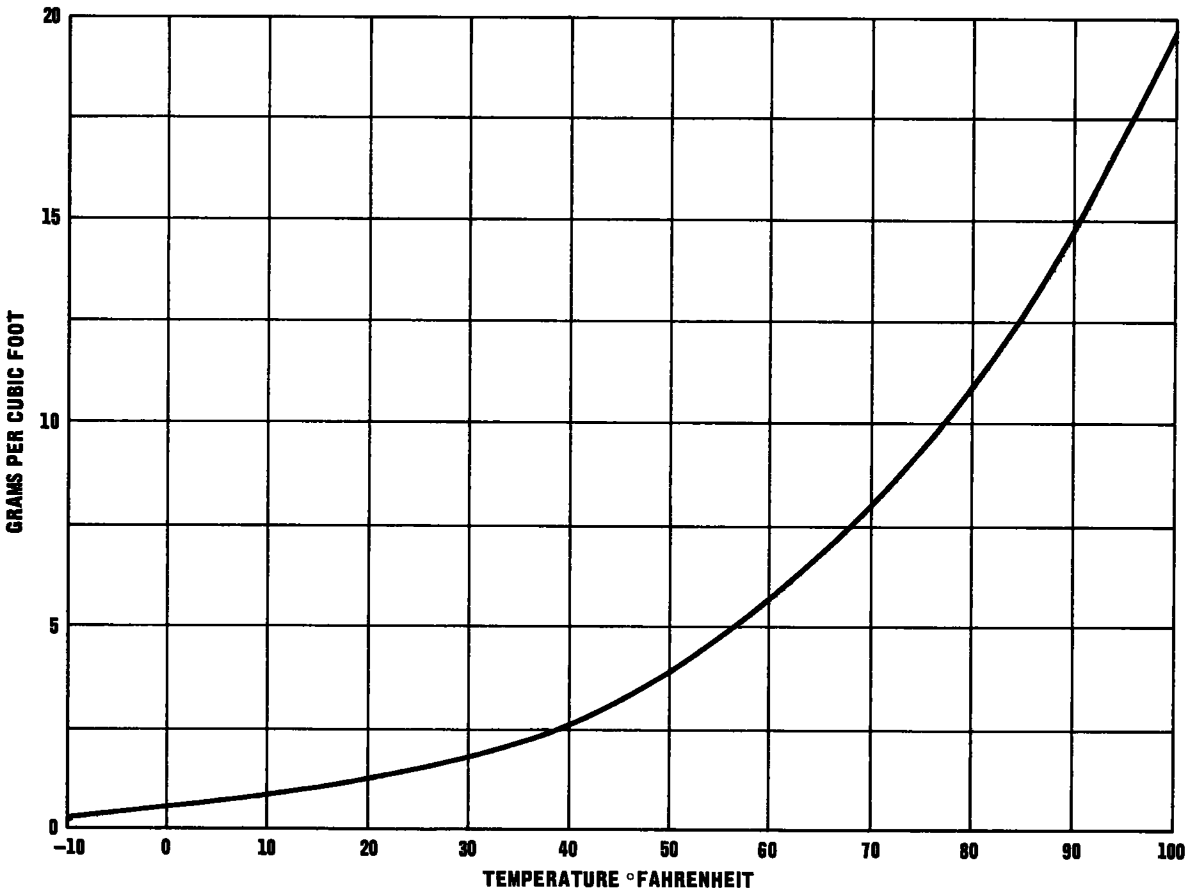

Figure 8. Water vapor holding capacity of air related to temperature.

condensation (i.e., release of moisture by the air when the relative humidity is 100 percent), whereas at high temperatures a large addition of moisture is necessary to cause condensation.

Misting up of windshields is therefore most likely to take place when relative humidities are high, and particularly when temperatures are quite low. Under these conditions only a small addition of water vapor will lead to condensation taking place on windshields. Under these conditions the water vapor released by breathing is frequently sufficient to cause misting in a car and thereby create a driving hazard. Several pieces of evidence support and substantiate this hypothesis. In addition, hours and months characterized by high relative humidities are more likely to produce adverse weather conditions, which in turn produce poor visibility and wet pavements.

As Figures 3, 4, 6, and 7 show, more vehicle-train accidents occur during the winter months. This is true for any hour of the day (Table 14). During these months, relative humidities are consistently high (Fig. 9) and temperatures relatively low. But equally important is the fact that the highest accident rate on an hourly basis occurs between 2:00 and 4:00 AM, when relative humidity reaches its diurnal peak (Fig. 10). Not only are relative humidities high at these hours, but temperatures also are at their 24-hr low, thus creating ideal conditions for misting. The misting of side windows would be particularly important in obstructing the drivers' view of trains at railroad crossings. It is these side windows which are lèast effectively cleared by heaters and defrosters. Moreover, because 78 percent of accidents involving trains occur within 25 miles of the driver's residence, heaters and defrosters are not fully effective for much of the travel time.

None of this evidence is conclusive, nor does it suggest that misting is the only reason for the distribution of accidents, but it certainly might be a contributing factor explaining at least some part of the total variation. If humidity is a significant variable, it would be possible to determine the range of temperature and humidity conditions at which misting is most likely to occur. A probability index could be devised with adequate data. An example of the calculation of the time taken for misting to occur follows.

Let it be assumed that at a given temperature the absolute humidity of the air is 9.8 grams per cubic meter. From wet-bulb thermometer readings it is known that at this temperature the water vapor capacity of the air is 10 gm per cu m. Thus, relative humidity is $9.8/10 = 98$ percent.

Now a certain automobile has an interior volume of 22 cu m and the relative humidity in the car without the

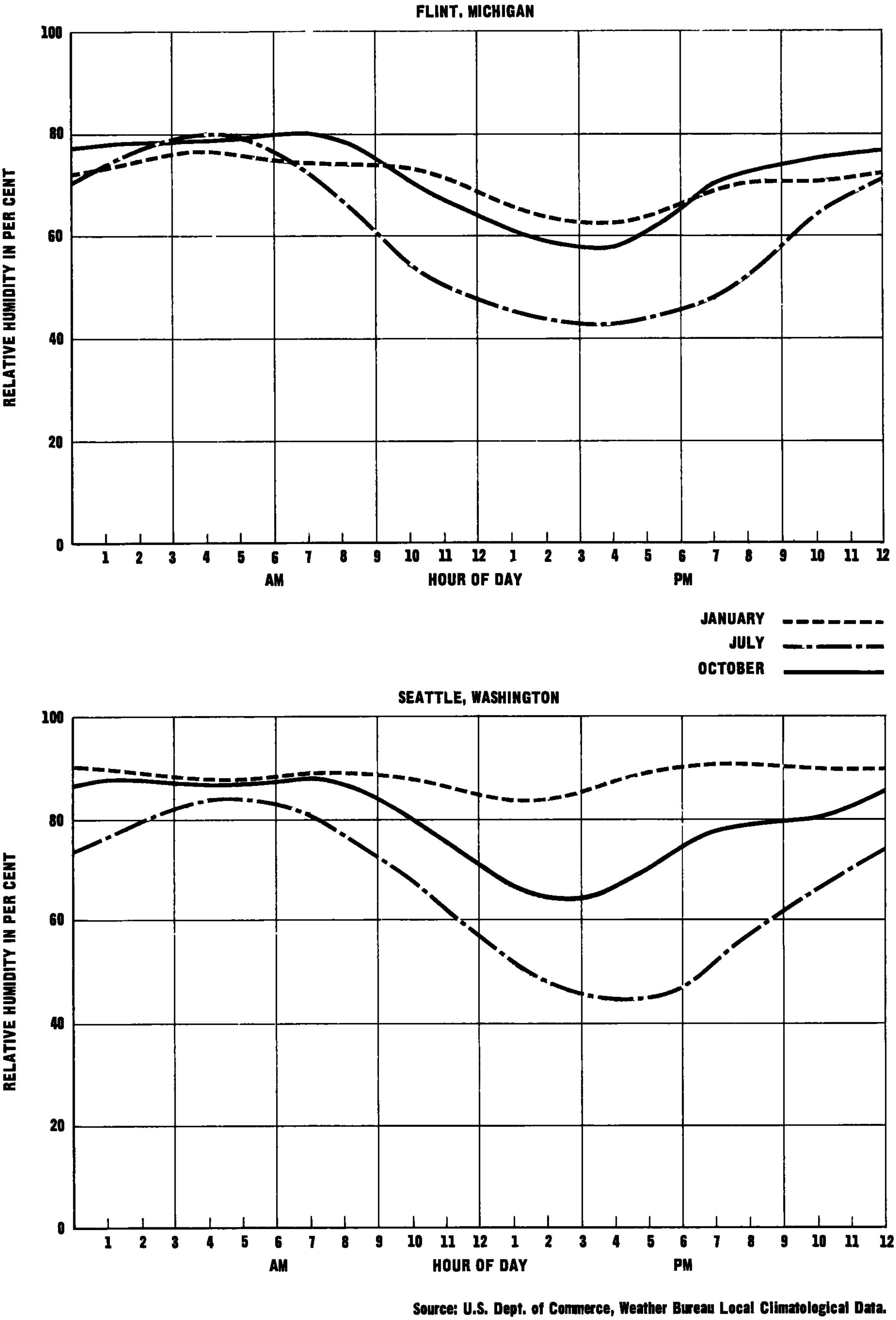

Figure 9. Relative humidity by hour of day for January, July and October, 1965.

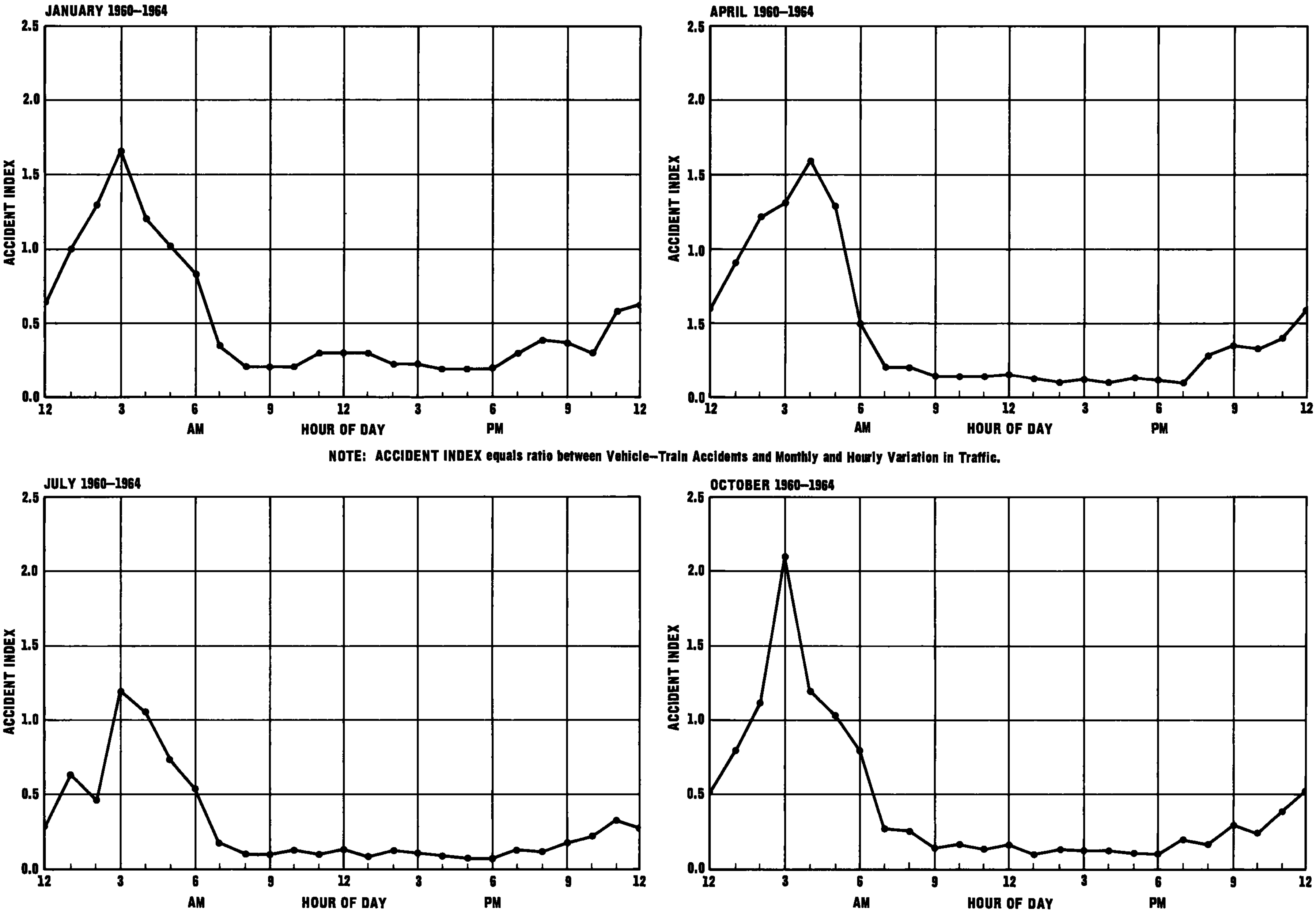

Figure 10. Accident index by hour for selected months.

driver is 98 percent. The capacity of the car saturation point will be 220 gm, but at present it only holds 215.6 gm. In other words, at the given temperature, 4.4 gm of moisture must be added to the air inside the car to cause any condensation.

It is known that a normal, resting, healthy male expires moisture at the rate of 0.5 ml for each respiration (*6*). Therefore, at an average frequency of 12 respirations per minute he expires 6 ml per min, or 6 gm per min. When the driver steps into his car he immediately adds moisture to the air, probably at a higher rate than 6 gm per min, but this figure is used here for illustrative purposes. If the temperature within the car does not change (and frequently the heater may not be effective for 5 min), the driver will add moisture to the air in the car, thus raising the relative humidity nearer to saturation. At 6 gm per min saturation would take place in less than 1 min. In fact, only a small part or area of the car may have to reach 100 percent relative humidity for misting to occur, and in this case the effective volume of air to be saturated will be much less and misting will take place more rapidly.

This example assumes an empty car initially, but it is not difficult to conceive of situations in which relative humidities are lower and the car is being driven and the heater is functioning. Even then misting can and does occur. Naturally, at 3:00 AM other factors, such as fatigue, alcohol, and darkness, are important; but evidence suggests that humidity may be an important factor, which, moreover, can be measured and isolated.

However, future research on the causes of accident rates is necessary. The humidity factor requires more intensive study, which should include small area studies of accidents and weather conditions and a more precise definition and tabulation of the respiratory rate and expired volume of water vapor of drivers. A formula may be available to help calculate the temperature and humidity range most likely to cause misting (*6*). Finally, more data need to be collected on the spatial variation of accidents and local weather in the United States so that correlations can be made and relationships defined more precisely.

TABLE 15

PERCENTAGE OF CROSSING ACCIDENTS WHICH INVOLVED TRAINS [a]

STATE	NO. OF YEARS	NUMBER OF ACCIDENTS: AT CROSSINGS	NUMBER OF ACCIDENTS: INVOLVING TRAINS	%
Ariz.	4	44	15	34.1
Colo.	3.5	166	53	31.9
Conn.	6	94	0	0
Ill.	2.5	452	97	21.5
Ohio	5	1028	191	18.6
Vt.	5	108	19	17.6
Total		1892	375	19.8

[a] Source: State highway departments of reporting states, covering primarily accidents at crossings of State highways.

THE NONTRAIN-INVOLVED ACCIDENT AT CROSSING

The bulk of available crossing accident data consists of statistics on the numbers of accidents involving trains. Consequently, previous research has focused on vehicle-train accidents and ways of preventing them. Little publicity has been given to the fact that many accidents which occur at railroad crossings do not involve trains, and that train accidents are actually rather infrequent.

Data covering all accidents at railroad crossings were made available by six State highway departments. Table 15 gives the numbers of accidents and percentages involving trains. The variation between States could be due to any number of factors. The level of accident reporting and other factors, such as the frequency of rail and highway traffic, are undoubtedly significant.

Additional data were tabulated by the Illinois Division of Highways for a special study. The effect of lower highway volumes (and possibly lower types of protection) is shown by the fact that 55 percent of the accidents at crossings on county and local roads involve trains. Another interesting tabulation (Table 16) indicates whether or not a train was present at the time of the accident. The fact that one-third of the accidents occur when a train is not present indicates that railroad crossings are quite hazardous independently of train operation. Also of interest is the distribution of these accidents by type and manner of collision (Tables 17 and 18).

No data were discovered during the course of this study which indicate the number of accidents that occur annually at railroad crossings. Because, however, the Illinois summary includes 2½ years of Statewide data, both urban and rural, for 16,000 crossings, it is assumed to be representative of the nation. Based on this assumption, it is possible to estimate the number of accidents, deaths, and injuries which occur per year nationwide, as follows:

$$\frac{\text{Annual crossing accidents}}{\text{Annual train accidents}} = \frac{\text{Illinois crossing accidents}}{\text{Illinois train accidents}}$$

$$\frac{\text{Annual crossing accidents}}{3{,}200} = \frac{3{,}627}{1{,}113}$$

$$\text{Annual crossing accidents} = 10{,}000$$

TABLE 16

DISTRIBUTION OF ACCIDENTS AT CROSSINGS BY PRESENCE AND INVOLVEMENT OF TRAIN [a]

TRAIN INVOLVEMENT	ACCIDENTS: NO.	ACCIDENTS: %
Involved	1113	30.7
Present, not involved	1339	36.9
Not present	1175	32.4
Total	3627	100.0

[a] Source: Illinois Division of Highways, covering State highways, county roads, and city streets in entire State.

TABLE 17

TYPES OF ACCIDENTS AT RAILROAD CROSSINGS[a]

TYPE OF ACCIDENT	ACCIDENTS: TRAIN INVOLVED NO.	%	TRAIN PRESENT[b] NO.	%	TRAIN NOT PRESENT NO.	%	TOTAL NO.	%
Ran off roadway	4	0.4	29	2.2	63	5.4	96	2.6
Overturned in roadway		—	5	0.4	17	1.4	22	0.6
Pedestrian		—	3	0.2	6	0.5	9	0.2
Motor vehicle in traffic	15	1.3	1213	90.6	784	66.7	2012	55.5
Parked motor vehicle		—	1	0.1	1	0.1	2	0.0
Railroad train	1091	98.0	6	0.4	2	0.2	1099	30.4
Bicyclist		—		—	1	0.1	1	0.0
Fixed object	3	0.3	67	5.0	216	18.4	286	7.9
Other object		—	13	1.0	25	2.1	38	1.1
Other non-collision		—	2	0.1	60	5.1	62	1.7
All	1113	100.0	1339	100.0	1175	100.0	3627	100.0

[a] Source: Illinois Division of Highways.
[b] But not involved.

TABLE 18

ACCIDENTS AT CROSSINGS BY MANNER OF COLLISION[a]

MANNER OF COLLISION	ACCIDENTS: TRAIN INVOLVED NO.	%	TRAIN PRESENT[b] NO.	%	TRAIN NOT PRESENT NO.	%	TOTAL NO.	%
Rear-end or sideswipe, same direction	15	1.3	1169	87.3	621	51.8	1805	4.7
Head-on or sideswipe, opposite direction		—	31	2.3	140	11.9	171	4.7
Angle collision		—	15	1.1	24	2.1	39	1.1
Collision with pedestrian		—	3	0.2	6	0.5	9	0.2
Other collision	1094	98.3	71	5.3	234	19.9	1399	38.6
Non-collision	4	0.4	49	3.7	141	12.0	194	5.4
Others and not known		—	1	0.1	9	0.8	10	0.3
All	1113	100.0	1339	100.0	1175	100.0	3627	100.0

[a] Source: Illinois Division of Highways.
[b] But not involved.

$$\frac{\text{Annual deaths at crossings}}{\text{Deaths with trains}} = \frac{\text{Illinois deaths at crossings}}{\text{Illinois deaths with trains}}$$

$$\frac{\text{Annual deaths at crossings}}{1{,}200} = \frac{315}{290}$$

$$\text{Annual deaths at crossings} = 1{,}305$$

$$\frac{\text{Annual injuries at crossings}}{\text{Annual injuries with trains}} = \frac{\text{Illinois injuries at crossings}}{\text{Illinois injuries with trains}}$$

$$\frac{\text{Annual injuries at crossings}}{3{,}400} = \frac{2{,}445}{738}$$

$$\text{Annual injuries at crossings} = 11{,}280$$

The magnitude of the highway-rail crossing problem takes on new dimensions when it is realized that more is at stake than simply the deaths, injuries, and property damage associated with the 3,200 annual accidents which involve trains.

Concern with only those accidents involving trains does not put the highway-rail crossing problem in proper perspective. The fact that rear-end accidents, when the train is not even present, account for 17 percent of all accidents at crossings suggests that the disruption of the traffic stream by the crossing could be an important factor in crossing accidents. This concept is discussed in more detail in Chapter Three. In Illinois, very few crossings have

STOP-sign "protection". Nevertheless, a multitude of rear-end-type accidents still occur. Installation of STOP signs would have the effect of creating further disruption to traffic and increasing the number of rear-end accidents by large amounts. There is some evidence which indicates that accidents involving trains are reduced by the installation of STOP signs. However, there is also evidence that obedience of the driving population to STOP signs at railroad crossings is poor (*4*). Additionally, STOP signs have the disadvantage of "crying wolf" to the driver when the actual likelihood of a train is very small. This practice is generally recognized as breeding contempt for the control device.

The individuals responsible for protection at crossings should study carefully the trade-off between vehicle-vehicle and vehicle-train accidents to determine if STOP signs would really provide the desired result. It is suggested that STOP signs not be used at crossings on roadways which have traffic consisting of large trucks or which have significant volumes of passenger cars.

A report by the Colorado Department of Highways (*5*) indicates that 25 percent of the accidents which occur at railroad crossings involve vehicles that are reqnired by law to stop and occur when a train is not even present. During a 2½-year period Illinois had 156 accidents of this type, of which 5 resulted in deaths and 59 resulted in injuries. This only represents 4.3 perceut of the accidents at crossings in Illinois, but it represents 13.3 percent of the crossing accidents that occur when a train is not present. Vehicles required by law to stop certainly do not account for nearly 13.3 percent of the miles driven.

Many railroad crossings have been abandoned and are never used by trains. Others are used by trains only during certain seasons of the year. Still others are used regularly but infrequently, such as once or twice per month. There is certainly no need to stop any group of vehicles at crossings of this type.

Other crossings have visual devices that clearly indicate the approach of a train to the motorist. Great care has been taken to insure failsafe operation of these devices. Their failure rate is, in fact, very low. In this case, also, it is recommended that no group of vehicles be required to stop when the device does not indicate the approach of a train.

Crossings that have automatic protection and crossings having extremely low volumes of trains should be declared exempt from this requirement.

CHAPTER THREE

SPEED CHARACTERISTICS

During the course of the field studies it was observed that there was a distinct slowing of traffic at a railroad grade crossing. In addition, general observation of traffic conditions indicated that drivers as a group have developed a reflex reaction which causes them to slow upon approaching a crossing. Thns, the questions were what causes them to slow down and how great is the differential between the speed at the crossing and that at a point beyond the influence of the crossing.

Six crossings in Maryland and Virginia were chosen to represent a cross-section of protection types ranging from passive crossbucks to active devices such as flashing lights, flashing lights with gates, and crossbucks with standard traffic control signals.

Another criterion for selecting the study sites was crossings of equal driving quality. Unfortonately, it was not possible to find crossings representing the cross-section of protective devices which were also equally smooth. The result of this difficulty in selecting sites was that the possible differential effect of various protection types appears to be masked by the quality of the crossing. Nevertheless, the spot speed checks which were made produced valuable insight into the magnitude of the speed reduction at the average grade crossing.

Two speed checks were made for each crossing. The first check was at a point ranging from 300 ft to several thousand feet from the crossing where normal roadway speeds prevailed. The second check was made at the crossing. The two checks were not made simultaneously, bnt the experience of other researchers in using speed data indicates that this is not a serious problem. Whenever possible the checks were made on the same day, or at most over two successive days.

The locations selected are all in the urban area except for the study at Limekiln, Md., which is distinctly rnral in character.

Table 19 sets forth several characteristic measures of the speeds which were found at the study locations. The

TABLE 19

COMPARISON OF SPEEDS AT SELECTED RAILROAD CROSSINGS WITH THOSE IN ADVANCE OF THE CROSSING INFLUENCE [a]

CROSSING LOCATION	TRAFFIC DIREC-TION	CROSSING PROTEC-TION [b]	MEAN SPEED (MPH)				85%ILE SPEED (MPH)			15-85%ILE RANGE (MPH)			% IN 10-MPH PACE		
			BEFORE	AT	DIFF.	95% LEVEL	BEFORE	AT	DIFF.	BEFORE	AT	DIFF.	Before	At	Diff.
Park St., Vienna, Va.	E	XB	25.94	24.74	1.20	> 0.96	30	29	1	8	9	1	81	76	5
Carlyn Spr. Rd., Arlington, Va.	N	XB	30.29	25.27	5.02	> 1.02	35	30	5	9	10	1	82	76	6
Columbia Pike, Arlington, Va.	E	FLS	32.29	30.96	1.33	> 1.10	38	35	3	10	8	2 [c]	74	76	2 [c]
U.S. 15, Limekiln, Md.	S	FLS	47.22	30.28	16.94	> 2.32	52	37	15	10	12	2	73	64	9
	N		40.60	29.61	10.99	> 3.20	47	35	12	12	11	1 [c]	68	68	—
Randolph Rd., Montgomery Co., Md.	E	FLSG	27.06	17.99	9.07	> 1.06	31	23	8	7	10	3	84	71	13
G. Washington Pkwy., Alexandria, Va.	S	XBTS	36.12	33.62	2.50	> 1.12	40	38	2	9	10	1	75	74	1

[a] Speed observations conducted in early September 1966.
[b] Protection code: XB = crossbuck; FLS = flashing light signals; FLSG = flashing light signals and gate; XBTS = Crossbuck with traffic control signals.
[c] Value contrary to trend found at other locations.

first characteristic studied was the mean speed. In every case, the mean speed at the crossing was lower than the speed prior to entering the influence of the crossing. Furthermore, a check of the standard error of the means showed that all of these differences were significant at the 95 percent confidence level and that 5 of the 7 were significant at the 99 percent level. The differences ranged from almost 17 mph at the rural location to just over 1 mph at two others.

Another measure of the speed characteristics was the 85th percentile speed observed. Again, each study location showed a drop from the normal speed to that at the crossing. As with the mean speed, there is a substantial range, depending on the location and characteristics of the crossing.

Of particular interest in the study of speed characteristics was the spread of the speeds observed. Two measures of this spread were evaluated. The first measure was the range in miles per hour from the speed at the 15th percentile to that at the 85th. In five of the seven study situations, the range increased at the crossing. For the other two, the reverse trend was observed; however, plausible explanations based on the field conditions are available.

At the Columbia Pike study site, the observations in advance of the crossing were made adjacent to a signalized intersection. Thus, even thuugh only the vehicles passing through on the green were observed, the signalized intersection apparently still had a substantial effect insofar as compressing the speed range.

At the Limekiln location, where both directions of travel were studied, the difference between the characteristics in the two directions is readily apparent. Immediately south of the crossing is a cluster of homes which comprise the town of Limekiln. The speed limit through the town is 40 mph, unchanged from the route speed, which gives an indication of the rural character of the community. However, it appears that the town has a disruptive influence, causing both a reduction in speed and a spreading of the observed range.

The effects of outside influence at these two locations appear again in a tabulation of the percentage of traffic in the 10-mph pace. In each case, except for Columbia Pike and US 15 northbound, the pace contains fewer vehicles at the crossing than it does in advance of the crossing.

Each of the four measures developed indicates conclusively that the traffic stream flow is less homogeneous at grade crossings thau it is at other locations on the highway away from the crossiug influence. Figure 11 shows typical speed differences and distributions. The significance of this finding can be compared with the findings in the study by the U.S. Bureau of Public Roads entitled "Accidents on Main Rural Highways" (*22*).

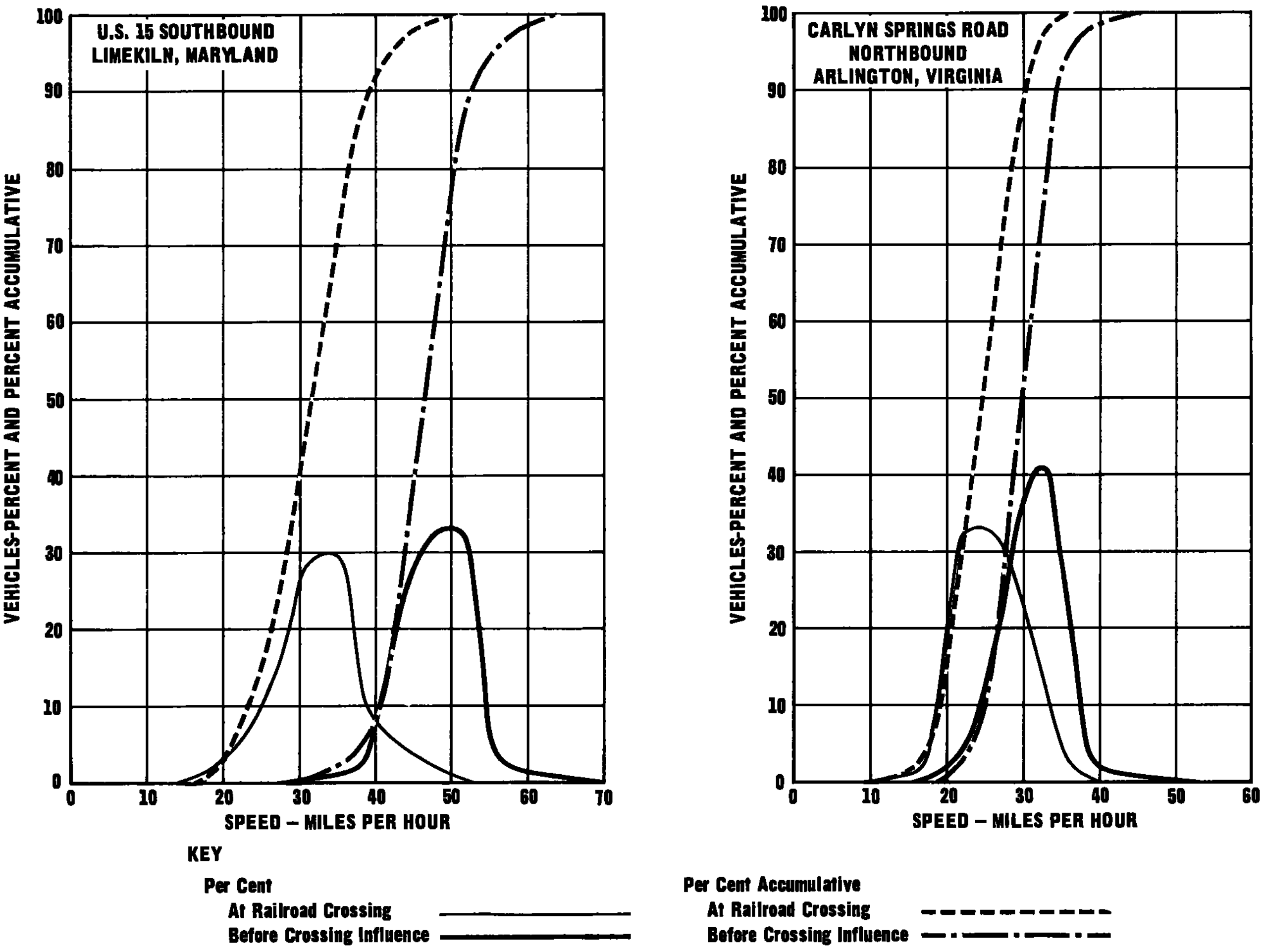

Figure 11. Vehicle speed distributions at two study crossings.

One of the facets investigated in the BPR study was the effect of the speed differential between successive vehicles on accident experience. As the differential increases, accident experience was found to increase at a much faster rate than the percentage of vehicles in the traffic stream with the same observed speed differential. However, as discussed in Chapter Two, the large numbers of accidents which occur at railroad crossings when a train is not even present (large in terms of their numbers being greatly higher than normal spot locations on a highway, such as 1,500 ft from the crossing) support the findings of the BPR study (*22*). Thus, the indications of this limited study of speeds at railroad crossings are that there is a potential for greater accident experience, although an attempt to obtain accident information for these locations failed.

CHAPTER FOUR

SIGHT DISTANCE

In the process of collecting data for this study, it was noted that sight distance is recorded in many different ways.

Although the influence of sight distance upon hazards at a crossing is controversial, common sense indicates that there is a minimum value which should be provided at all crossings. Highway engineers consider sight distance to be an important factor in the design and improvement of highway facilities. There is no reason why it should be any less important at railroad grade crossings.

In order to understand the issue, it is necessary to discuss precisely what is meant by sight distance. There are actually three sight distances which are important to the driver as he approaches a grade crossing. The first distance which a driver needs is the visibility of the crossing itself. In other words, at what distance in advance can the driver actually see the crossing? If a driver traveling at the speed limit cannot make a safe stop, due to vertical and horizontal highway alignment and landscape, the visibility is inadequate. The value of automatic protection is directly dependent on this distance. If the visibility is inadequate in advance of an existing crossing, and cannot feasibly be improved, standard traffic engineering aids such as advisory speed signs and better advance warning must be employed.

The second type of sight distance which the driver finds necessary to safely negotiate a crossing is the quadrant visibility. After a driver becomes aware that he is approaching a crossing, he must then be able to observe the approach of a train in the two quadrants to his right and left. If a train is approaching, he must be able to make a safe stop prior to reaching the crossing. Many times the driver's view of the railroad approach will be at least partially obscured.

Occasionally a driver is forced to stop at a crossing. The crossing may be blocked by a train, it may be controlled by stop signs, or the vehicle itself may be required by law to stop. In these cases, the driver must be able to see a sufficient distance along the track to allow him to judge if it is safe to proceed. This is the third sight distance which the driver finds important to his safe negotiation of the crossing.

METHOD OF DETERMINING ADEQUATE DESIGN SIGHT DISTANCE

The three sight distances discussed in the foregoing are shown in Figure 12. Required sight distance 1 is dependent on the highway speed limit. The maximum reasonable speed which the highway vehicles travel is the determining factor.

Required sight distance 3 is dependent on the train speed. Like automobiles, the trains do not all travel at the same speed. Therefore, the maximum train speed should be used.

Required sight distance 2 is dependent on both train and highway speeds.

Knowing the highway speed and the train speed, the required sight distances can be determined from Table 20, which is based on the following assumptions:

1. Safe stopping sight distance from *A Policy on Geometric Design of Rural Highways* (*1*).
2. A 50-ft design vehicle.
3. Ten feet of clearance, both in advance and beyond the crossing, plus 15-ft length of crossing, for a total crossing width of 35 ft.
4. Due to possible rough conditions and limited acceleration capabilities of C 50 vehicles, a maximum speed of 10 mph or an average speed of 5 mph. (At this average speed it takes 11 sec for a 50-ft truck to pass over the crossing and clear the other side by 10 ft.)

Table 21 gives values associated with required sight distance. Sample calculations are shown in Appendix E. The assumptions made for these calculations presumably include the worst possible conditions. The assumed highway vehicle is a large truck, the pavement condition is wet, and the perception-reaction time is sufficiently large to include 85 percent of the drivers. The required sight distances given in Table 20 are based on accepted values for highway design purposes and should contain a factor of safety for conditions encountered under unusual driving conditions. A measure of the magnitude of the difference can be seen by comparing the values in Table 20 with the minimum values, given in Table 22.

ADEQUATE SIGHT DISTANCE FOR USUAL DRIVING CONDITIONS

The values in Table 22 were developed on the basis of the following assumptions:

1. Perception-reaction time of 1 sec.
2. Dry pavement.
3. Passenger car (making length of vehicle plus clearance 40 ft instead of 85).
4. Normal acceleration ability of a passenger car.

The values thus produced are 22 to 48 percent of those in Table 20, and are thus more liberal in judging the adequacy of existing conditions. However, it is extremely important to realize that these conditions are not created by fixed groups of drivers, crossing features, and vehicles. For example, a driver who might be found through tests to have normal perception-decision-reaction time, may have abnormally high perception-decision-reaction time on another day or in another situation. Thus,

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The values thus produced are 22 to 48 percent of those in Table 20, and are thus more liberal in judging the adequacy of existing conditions. However, it is extremely important to realize that these conditions are not created by fixed groups of drivers, crossing features, and vehicles. For example, a driver who might be found through tests to have normal perception-decision-reaction time, may have abnormally high perception-decision-reaction time on another day or in another situation. Thus,

TABLE 20

REQUIRED DESIGN SIGHT DISTANCES FOR COMBINATIONS OF TRAIN AND HIGHWAY VEHICLE SPEEDS[a]

TRAIN SPEED (MPH)	DESIGN SIGHT DISTANCE FOR HIGHWAY SPEED OF 0 MPH	10 MPH	15 MPH	20 MPH	25 MPH	30 MPH	35 MPH	40 MPH	45 MPH	50 MPH	55 MPH	60 MPH	65 MPH	70 MPH	75 MPH
10	162	126	104	94	91	94	96	99	101	107	113	118	125	129	138
15	242	189	156	141	137	141	143	147	152	161	169	176	187	194	207
20	323	252	208	188	182	188	191	197	203	214	226	235	250	258	276
25	404	315	260	235	227	235	238	246	253	267	282	293	312	322	344
30	484	378	312	281	273	281	286	295	303	321	339	352	374	387	414
35	565	441	364	328	318	328	333	342	354	375	395	411	436	452	483
40	645	504	416	376	364	376	382	394	406	428	452	470	500	516	552
45	725	567	468	422	409	422	429	442	455	482	508	528	561	580	620
50	807	630	520	470	454	470	476	492	506	534	564	586	624	644	688
55	886	694	573	516	500	516	524	540	556	588	621	645	685	710	758
60	967	756	624	562	546	562	572	590	606	642	678	704	748	774	828
65	1049	819	676	610	591	610	619	638	657	695	734	762	810	837	895
70	1129	882	728	656	636	656	666	684	708	750	790	822	872	904	986
75	1210	945	780	704	681	704	714	737	758	803	847	879	935	967	1035
80	1290	1008	832	752	728	752	764	788	812	856	904	940	1000	1032	1104
85	1370	1070	885	799	774	779	812	835	861	910	960	998	1059	1097	1172
90	1450	1134	936	844	818	844	858	884	910	964	1016	1056	1122	1160	1240
95	1533	1200	990	890	865	890	910	935	960	1020	1070	1115	1190	1225	1310
DISTANCE ON HIGHWAY FROM CROSSING (FT)	20	65	95	125	165	215	270	330	395	470	560	640	745	840	965

[a] For one track, and level gradient.

the values in Table 22 must be recognized as minimum and used with care.

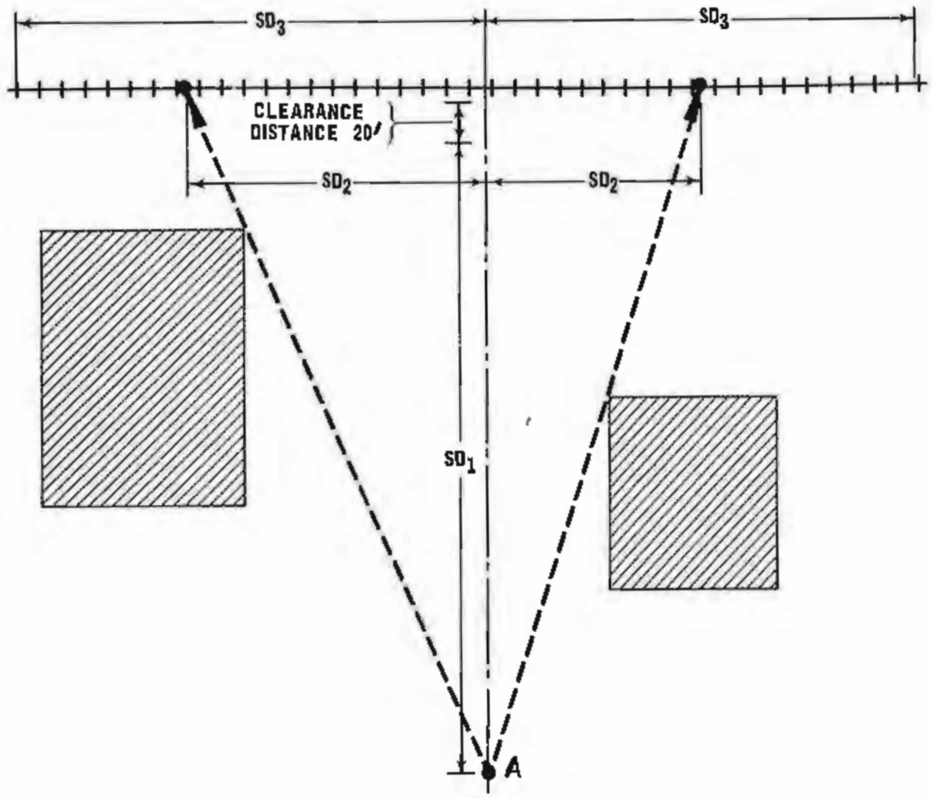
One use for Table 20 is to evaluate existing conditions at a crossing. It is often unrealistic to expect an existing crossing to have been designed under the design assumptions specified previously. However, the question arises: Can we economically justify clear sight quadrants as large as required by Table 20? The driver has neither

TABLE 21

VALUES OF VARIOUS ELEMENTS ASSOCIATED WITH HIGHWAY STOPPING AND PROCEEDING TIMES AND DISTANCES AT RAILROAD CROSSINGS

SPEED (MPH)	PERCEPTION-REACTION DISTANCE (FT)	BRAKING DIST. (FT)	BRAKING TIME (SEC)	SAFE STOPPING DIST.[a] (FT)	SAFE STOPPING TIME (SEC)	CLEARANCE + SSD (FT)	TIME TO PROCEED (SEC)
10	37	8	1.1	45(45)	3.6	65	4.5
15	55	18	1.6	73(75)	4.1	95	4.4
20	73	33	2.3	106(105)	4.8	125	4.3
25	92	55	3.0	147(145)	5.5	165	4.5
30	110	83	3.8	193(195)	6.3	215	4.9
35	128	120	4.7	248(250)	7.2	270	5.3
40	148	162	5.5	310(310)	8.0	330	5.7
45	165	212	6.4	377(375)	8.9	395	6.1
50	183	269	7.4	452(450)	9.9	470	6.5
55	202	337	8.4	539(540)	10.9	560	7.0
60	220	400	9.1	620(620)	11.6	640	7.3
65	238	487	10.2	725(725)	12.7	745	7.9
70	258	563	11.0	821(820)	13.5	840	8.3
75	275	670	12.2	945(945)	14.7	965	8.8

[a] Numbers in parentheses are rounded values.



SD1=SAFE STOPPING SIGHT DISTANCE
SD2=DISTANCE ALONG TRACK SUCH THAT VEHICLES TRAVELING AT SPEED LIMIT CAN BEAT TRAIN FROM POINT A OR STOP
SD3=DISTANCE DOWN TRACK SUCH THAT TRAIN CANNOT ARRIVE IN LESS THAN 11.0 SECONDS

Figure 12. Illustration of sight distance.

the knowledge nor the time to visually survey the crossing and determine whether the sight distance is adequate for the combination of his speed and the train's speed. Additionally, he is not aware of the danger, because all similar decisions are made for him in the normal highway situation; e.g., at the majority of highway intersections.

The fact that trucks are involved in accidents with trains relatively more frequently than other highway vehicles is a very strong argument for using design values for sight distance (Table 20). The larger sight triangle required for trucks is shown in Figure 13, which is based on the following assumptions and calculated values (*3*) given a 60-mph train speed and a 50-mph highway speed:

1. Deceleration rate from 50 mph: passenger car, 26 ft/sec^2; truck, 13 ft/sec^2.
2. Reaction-decision time (stopping and accelerating): car and truck, 2 sec.
3. Clearance for stopping: car and truck, 10 ft.
4. Total distance required to stop: passenger car, 251 ft; truck, 354 ft.
5. Uniform acceleration rate from 50 mph: passenger car, 5.13 ft/sec^2; truck, 0.29 ft/sec^2.
6. Clearance for accelerating: passenger car, 23 ft; truck, 70 ft.
7. Total distance to beat train: passenger car, 292 ft; truck, 442 ft.

Figure 13 shows the magnitude of the differences between car and truck performance. The decision which the designer must face is the degree of importance of trucks in the traffic stream at the locations under consideration based on the amount of truck traffic. When trucks are a factor, every effort needs to be made to use Table 20 for design purposes.

SIGHT DISTANCE AS A VARIABLE

Although sight distance is one of the more common variables found in crossing inventory data and an attempt was made in the development of most of the accident predictive equations to test sight distance for its significance, it has never been shown as a strong variable.

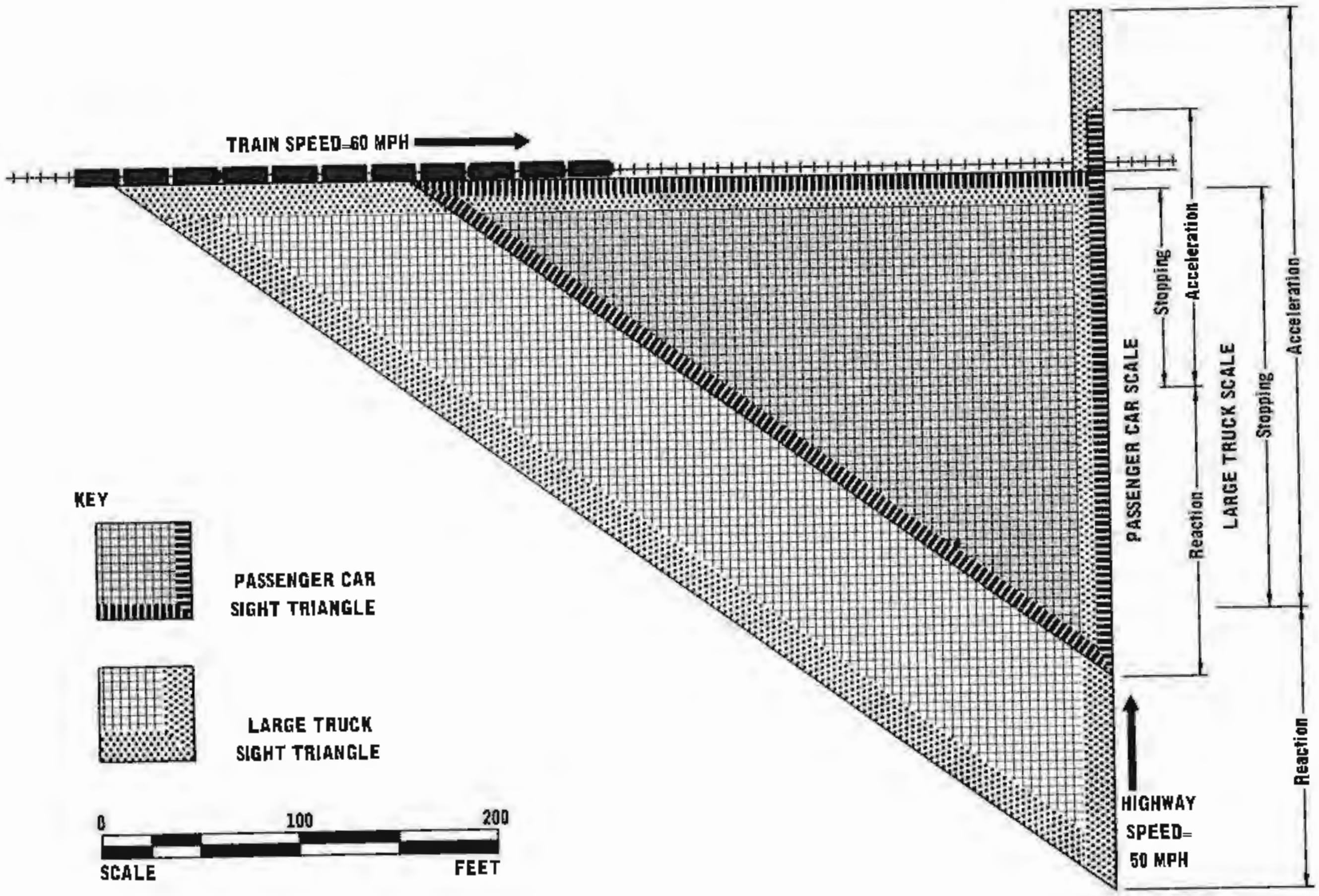


Figure 13. Passenger car and large truck sight triangles.

TABLE 22

MINIMUM SIGHT DISTANCE REQUIREMENTS FOR "NORMAL" CONDITIONS

TRAIN SPEED (MPH)	MINIMUM SIGHT DISTANCE (FT) REQUIRED FOR HIGHWAY SPEED OF														
	0 MPH	10 MPH	15 MPH	20 MPH	25 MPH	30 MPH	35 MPH	40 MPH	45 MPH	50 MPH	55 MPH	60 MPH	65 MPH	70 MPH	75 MPH
10	36	34	32	32	32	34	35	37	39	42	46	51	57	62	62
15	53	50	48	48	48	50	52	55	58	64	69	77	86	93	93
20	71	67	64	63	64	67	70	73	78	85	92	103	114	124	124
25	89	84	80	79	81	84	87	91	97	106	116	128	143	155	155
30	106	101	95	95	97	100	105	110	117	127	139	154	171	186	186
35	124	117	111	111	113	117	122	128	136	148	162	180	200	217	216
40	142	134	127	127	129	134	140	146	156	170	185	205	228	248	248
45	160	151	143	143	145	150	157	164	175	190	208	231	257	279	279
50	177	168	159	158	161	167	174	183	194	212	231	257	285	310	309
55	195	185	175	174	178	184	192	201	214	233	254	282	314	341	341
60	213	202	190	190	194	201	209	219	233	254	277	308	342	372	371
65	231	218	207	206	210	217	227	237	253	275	300	334	371	403	402
70	249	235	223	222	226	234	244	256	272	297	324	359	400	434	433
75	266	252	239	238	242	251	262	274	292	318	347	385	428	465	464
80	284	269	255	253	258	267	279	292	311	339	369	411	456	496	495
85	302	286	271	269	274	284	297	311	330	360	383	436	485	527	526
90	319	302	286	285	290	301	314	329	350	381	416	462	513	558	557
95	337	319	302	301	306	318	332	347	369	403	439	488	542	589	588
	DISTANCE ON HIGHWAY FROM CROSSING (FT)														
	15	20	35	50	70	90	115	145	175	210	250	300	350	405	465

This does not seem logical; sight distance should be one of the most important variables. If the driver cannot see the crossing and down the track an adequate distance, then he and his vehicle are being expected to perform beyond their physical limitations. Such crossings do exist —and in considerable numbers. Because of this, most hazard indices have included sight distance.

It is believed that there is a logical explanation for the nonexistence, or existence as a very minor variable, of sight distance in predictive equations. The explanation reverts back to:

1. The type of sight distance information collected.
2. The manner in which it was collected.
3. The manner in which it was recorded for analysis.
4. The fact that it is a difficult feature to measure and even more difficult to record for meaningful analysis.

The distances which a driver can see along the railroad to his right and left are generally measured from an arbitrary fixed distance on the highway from the crossing. The distance on the highway should not be a fixed distance from the crossing, but should be a function of highway vehicle speed.

The distances used are generally 300, 400, 500, or 600 ft. These distances correspond to design speeds of approximately 37, 45, 52, and 57 mph. In only one political jurisdiction throughout the data collection portion of this study did it appear that an effort had been made to incorporate vehicle speed in this distance. In that case, measurements were taken at 300 ft in urban environments, and 500 ft in rural environments.

The very nature of sight obstructions can allow good sight distance at one point on the highway and inadequate sight distance at a point on the highway 10 ft away. Therefore, measurement from a fixed point on the highway does not provide a true measure of the influence of sight distance on safety.

Sometimes when data are assembled for punch cards the minimum or average value of the four distances is used. This even further reduces the value of the measurements as an indication of the effect of sight distance on safety. Finally, if an accident does occur at a crossing the data collected do not include the quadrant which was involved.

FIELD SURVEY OF EXISTING SIGHT DISTANCE CONDITIONS

Because it was not possible to find satisfactory data on sight distance, field measurements were taken at selected crossings. Two two-man field crews were assembled. Each crew was given written and oral instructions, as well as an actual field demonstration of the procedures. A copy of the instructions and the form used are given in Appendix D.

Crossings having a large number of accidents during a 10-year period were selected. Crossings with fewer accidents and the same approximate average daily traffic, trains per day, number of tracks, and protection type were then selected. Complete data were gathered on 52 crossings, of which 21 had flashing light signal protection and 31 had crossbucks. Two determinations of sight distance adequacy were made. One was based on design conditions; the second, on normal conditions. Drivers traveling at the legal speed limit on the 42 approaches to the signalized crossings could see the signals far enough in advance to provide a design stopping distance in 95 percent of the cases. In every case the sight distance required by a passenger vehicle in good operating condition was available.

Because neither quadrant sight distance nor visibility along the tracks is an important factor at crossings which have automatic protection, this feature was not studied at crossings so protected.

At the 31 crossings protected with crossbucks, drivers traveling at the legal speed limit could see the crossing or a train occupying the crossing sufficiently far in advance to allow a design stopping distance at 88 percent of the locations and a passenger vehicle stopping distance at 97 percent of the locations.

A study of the design requirement with respect to available quadrant sight distance yielded the following results. Only 1 of the 31 crossings had all four quadrants sufficiently clear to allow a driver traveling at the speed limit to see an approaching train prior to the time at which he would have to make his decision to stop or proceed. In fact, only 20 percent of the 124 quadrants and 10 percent of the 62 approaches were adequate in this respect.

Performing the same analysis of available quadrant visibility using the less rigid passenger car sight distance requirements produced only slightly better results. At 9 of the 31 crossings all four quadrants allow the average driver, in a properly maintained vehicle, to see an approaching train in time to stop if all other conditions are favorable. When these more liberal criteria are used, 61 percent of the quadrants and 47 percent of the approaches are adequate.

No correlation was found between accidents and either of the sight distance criteria. This can probably be explained by the fact that (1) almost all of the crossings had bad sight distance and (2) none had a really bad accident record. The crossings with the highest numbers of accidents in this sample only averaged 0.5 accidents per year over a 10-year period. Although statistical analyses were not meaningful, it is clear from this sample that the normal crossing does not have adequate sight distance.

CHAPTER FIVE

IMPROVEMENT OF DEVICES

MODEL OF THE DRIVING PROCESS

As an aid to the analysis of factors influencing safety at highway-rail grade crossings, a model of the driving process was constructed (Fig. 14). It is an adaptation of a general diagram of the driving process presented by Platt (*20*) and has been altered to relate more specifically to traffic situations at railroad grade crossings.

The driving process as shown in Figure 14 is composed of events, observations, decisions, and actions, which result in errors and correct actions. Errors may in turn lead to collisions, whereas correct actions will lead to safe driving.

Events are elements of the environment. They include continuous and discrete events. Examples of continuous events are temperature, pavement width, light condition, and condition of driver. Discrete events are signs, trees, pedestrians, grade crossings, intersections, trains, sounds emanating from within or from outside the vehicle, and others. The number of events that may be present in a situation wonld vary from driver to driver and with time at the same location.

All events are not related to the driving task. Individnals "observe" events through sensory perception while carrying out the driving task. The events are observed through the senses of seeing, smelling, hearing, or feeling.

The Model Related to Driver Limitations

The number of events a driver is able to observe in a given time is limited. He cannot be expected to observe all events and of those which he does observe some are unrelated to the driving task. Different levels of motivation influence the number of events which he observes.

For each event observed, a decision must be made concerning whether or not action is required. An event such as the sound made by wind meeting a truck might require no action and could be forgotten immediately. An event such as an advance railroad grade crossing warning sign might require no immediate action, but the information shonld be retained for possible later action. Retaining this information will improve the chances of the driver observing the related events, such as the grade crossing or train, and also will improve his chances of making the correct decision quickly enough to take the correct action and resnlt in safe driving.

As indicated by Platt (*20*), approximately one time in every 40 decisions the average driver will make the wrong decision. Fnrthermore, approximately 20 percent of the events which are not observed result in chance errors. Both of these situations result in incorrect actions. The driver may realize the impending hazard caused by his incorrect action and make the correct decision, but not have time to carry out the correct action.

Thns, depending on the circumstances at the instant of driver failure, in the form of actions not taken and incorrect actions, the resnlt can be:

1. A collision.
2. A near collision.
3. No dangerous results.

The driving task may end with a collision. If no collision resolts, the driving process continues as new events are observed and decisions must be made.

An estimate of the driver's limitations to make observations was made by Platt (*20*) based on information available from tests. According to data, the driver is limited to 16 visual observations per second. Continuous events result in an estimated 37 potential discrete visual observations per mile.

To illustrate the effect of these limitations, the following two conditions are assumed:

1. Rural area, 60-mph vehicle speed;
   37 potential discrete observations per min;
   0.62 potential discrete observations per sec of continuous events;
   700-ft stopping distance or critical approach distance.
2. Urban area, 30-mph vehicle speed;
   18 potential discrete observations per min;
   0.30 potential discrete observations per sec of continuous events;
   300-ft stopping distance or critical approach distance.

Using Platt's techniques, Table 23 was prepared to estimate in a hypothetical situation the number of events and observations which a driver could expect to encounter under the two conditions. It should he noted that an event may reqnire several observations.

Platt also indicates that the driver does not make all potential observations. He estimates that out of 110 potential visual observations, 80 (or about 73 percent) are made (*20*). It is believed that the percentage of observations would increase as potential observations decrease, but factual evidence has not been developed. Therefore, applying the ratio of completed to uncompleted observations to the totals in Table 23 indicates that the driver makes 49 observations in a rnral situation and 127 in an urban situation.

Because, as stated previously, the driver is limited to only 16 observations per second, approximately 3 sec of observation time wonld be necessary in a rural location and approximately 8 sec in an urban location.

Increasing the observation-decision-reaction time in intensively developed areas would not be a practical solution, because with each increase in time there would be a corresponding increase in events. This analysis points np the

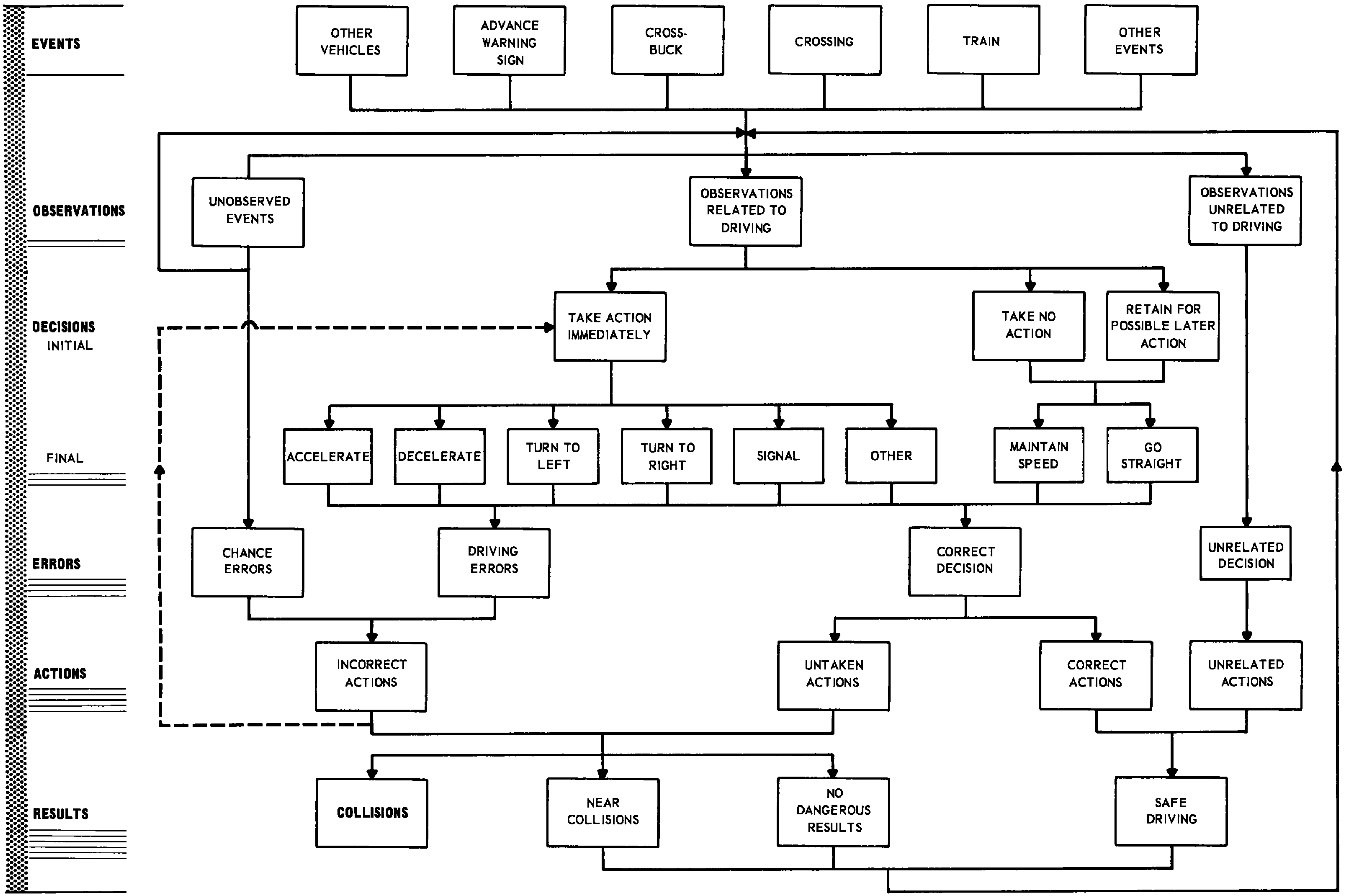


Figure 14. Basic order of traffic situations at railroad grade crossings.

TABLE 23

ESTIMATE OF DRIVER'S VISUAL OBSERVATIONS

EVENT	60-MPH RURAL CONDITIONS [a] NO. EST.	VIS. OBS.	30-MPH URBAN CONDITIONS [b] NO. EST.	VIS. OBS.
Highway geometrics				
Horizontal & vertical curves	1	2	—	—
Surface hazards (tracks)	1	2	1	2
Crossbucks & railroad	1	3	1	2
Advance warning signs	1	2	1	2
Other signs & no passing markings	2	4	3	6
Lane, centerline & edgeline	1	2	2	4
Driveways and sideroads	1	3	4	12
Guardrails and posts	3	3	3	3
Visual obstructions	2	2	4	4
Total		23		35
Environment				
(Weather, road surface, light conditions)	—	16	—	16
Stationary objects				
Parked vehicles	—	—	24	72
Trees, abutments and advertising signs	16	16	20	20
Total		16		92
Moving objects				
Other vehicles	3	9	5	15
Train	1	3	1	3
Pedestrians	—	—	3	6
Animals	—	—	1	2
Cyclists	—	—	1	2
Total		12		28
All		67		174

[a] Within 700 ft in advance of crossing. [b] Within 300 ft in advance of crossing

need for careful treatment of the urban situation and justifies providing events associated with the grade crossing which will be effective in attracting the driver's attention.

Data presented in Chapter Six indicate that other factors compensate for the large number of distractions found in urban areas. Accidents involving trains normalized for highway and rail volumes are approximately three times higher in rural areas. Probable compensating factors would be low train and highway speeds, street lighting, and a greater level of driver alertness and attentiveness to the driving task.

The Decision Process at Railroad Grade Crossings

The driving process just described can be directly related to the events at railroad grade crossings.

The first event related to the crossing which should be observed by the driver as he approaches is the advance warning sign. He must then make a decision based on his observation. Experience from past observations may be reflected in his decision. For example, he may be aware that this particular crossing is rough or he may be aware that many crossings are rough but not know about the condition of this particular one. If he is familiar with the crossing, he may know exactly where the bumps are located and how to traverse the crossing in a manner such that some of them may be avoided. Thus, these earlier observations, which were retained as experience, will play an important part in his decision.

The normal decision would be one of the following:

1. Take immediate action and decelerate.
2. Take no immediate action, but retain the information for possible action later; maintain speed.

The decision may be made with no thought given to the possibility of a collision with a train. When the driver has reached the point in his approach where he may observe protective devices at the crossing or the crossing itself there may be:

1. A train occupying the crossing.
2. A train approaching the crossing.
3. No train in the vicinity of the crossing.

Observation of the first situation should cause the driver to make the decision to take immediate action. He should decide that the correct action is to decelerate and stop before reaching the crossing. Due to the driver's lack of attention, inadequate sight distance, or excessive speed, there may not be sufficient time to stop. The driver may observe his impending hazard and decide to take corrective action, such as turning to the right or left to avoid the train. Highway engineers are concerned with minimizing the possibility of this situation. To do this, it should be made certain that a driver, reasonably attentive to his driving task and traveling at a reasonable speed, under normal conditions can see a train on the crossing in ample time. If it is not economically feasible to provide this distance on an existing facility, the speed should be reduced.

If no train occupies the crossing, but a train is approaching the crossing, one must look further at the events related to the crossing, the driver's observations, decisions, and actions. The most important event, the approaching train, is less likely to be observed than a train which occupies the crossing, because it may be outside the driver's periphery of vision. At crossings where automatic protection has been installed, the normal driver does not look for an approaching train. Instead he relies on the automatic protection. At crossings without automatic protection, an attempt has been made, through education, to cause the driver to associate the events, such as a crossbuck, the crossing, and the advance warning sign, with the possible approach of a train. Upon observing these events the normal driver is expected to look for the train.

The driver has two reasonable decisions to make as he observes a train approaching the crossing:

1. He may decide to stop before reaching the crossing.
2. He may decide to maintain his speed or accelerate to beat the train to the crossing.

His decision should be based on his judgment of several observations. These would include train speed and distance from the crossing, his own speed and distance from the crossing, and others. In order to determine the correct decision, a mathematical solution is necessary. In some circumstances one of the two decisions would be correct, but not the other. In other circumstances both decisions would be correct. In still others, neither would be correct. In other words, there are cases where a reasonably alert driver when confronted with an approaching train will find it impossible to reach an intelligent decision using the information now provided.

There are several reasons why a driver may choose to stop at a crossing, as follows:

1. The vehicle may be required by law to stop.
2. The immediately preceding driver has stopped and is blocking the moving traffic lane.
3. A train may be blocking the crossing.
4. Automatic protection may be in operation.

In making the decision to proceed from a stopped position, the driver considers his observation of events. If one of these observations was not an approaching train, the driver can be expected to proceed.

The preceding describes very simply the normal decision processes which a driver would use during his approach to a crossing. Many other unique situations are encountered by drivers at crossings, but they are too numerous and varied for discussion.

INFORMING THE MOTORIST

Preceding information has explained in detail the explorations into the problems which confront the motorist at railroad grade crossings. In this section these problems are related to measures which can be instituted to provide the motorist with information that he can use to make intelligent decisions.

At a crossing where there is a flashing signal, wig-wag, gate, or some other active device, the motorist's obligation is to observe and respond to the device upon its actuation by an approaching train. The accident statistics previously reported show that when the motorist's decision-making process is reduced to a simple response to a signal that experience and training have taught him means "stop," accident experience at grade crossings is substantially improved.

If every grade crossing could be protected with an active device the problems experienced could be reduced to minimum levels. Unfortunately, administrators at all levels, both government and private, are dealing with a limited resource—money. This resource must be allocated to the improvements which will provide the greatest benefit or rate of return on investment. Thus, it becomes necessary to protect many grade crossings with devices that only inform the motorist of hazard and place upon him the responsibility for a decision of whether or not it is safe to proceed. As a result, it is believed that the greatest immediate opportunity for the improvement of the motorist's decision-making process is in the area of passive protection of grade crossings. There will always be a need for a family of passive devices which can be tailored to meet the range of situations which it will not be economically feasible to treat with active devices. Further, greater definition of the situations to be treated with passive devices leads logically to the definition of limits which can be of value to the administrator in deciding which crossings should be actively protected.

The Basic Problems

From the motorist's point of view the problem he faces at a grade crossing can be divided in two categories, as follows:

1. To know there is a train on the crossing.
2. To know there is a train approaching the crossing which can constitute a hazard.

Each of these categories has a day-night condition which must also be considered.

Once a train is on the crossing, the motorist's only problem is to see it in time to react and stop. In daytime, under good visibility conditions, approaching a crossing which is visible from at least the stopping sight distance for the prevailing highway speed, the train itself provides all the evidence which the motorist needs to make a decision to act. His responsibility is to halt his vehicle in advance of the crossing and wait for the train to clear. If an active crossing device is present, it is overshadowed by the train and merely supplements the obvious.

If the view of the crossing is restricted by darkness or poor visibility conditions, the problem confronting the motorist becomes more difficult. In this case, he may not see a train passing over a crossing which has only passive protection in time to stop. This, therefore, is a distinct problem where the motorist needs supplemental information to enable him to make a proper decision. The recommendations for resolving this problem, as well as the others identified in this section, are discussed later.

Another element which can restrict the motorist's view of a train passing over a crossing is the alignment of the highway. Vertical and horizontal curvature can reduce his view of a train or of a crossing signal to the point where he does not have enough sight distance at the prevailing highway speed to avoid a collision. Thus, highway alignment defines another problem area.

At a crossing with passive protection, the motorist not only must be able to see the crossing, but also have a sight triangle which is large enough to see an approaching train and decide whether he must stop or can proceed safely prior to the train's arrival at the crossing. A special case of this situation is a crossing which has sight restrictions on either side which so limit the view that a motorist stopped at the crossing cannot see an approaching train far enough away to allow him to cross the track without being hit. A more complete discussion of sight distance and its effect on the motorist's safe negotiation of the crossing is given in Chapter Four.

The decision-making process at a crossing with passive protection becomes even more difficult in poor visibility conditions or darkness. In this case, the only clue to a train as it approaches a crossing is its headlight and any marker lights which may be mounted on the locomotive. This is a difficult clue for the motorist to observe when the sight triangle is unobstructed, and becomes even more so when his view is blocked or when the crossing is not at right angles to the road.

Thus, in summary, there are four basic problems which confront the motorist approaching a railroad crossing, as follows:

1. The effect of darkness or poor visibility when a crossing is occupied by a train.
2. The effect of vertical or horizontal alignment on stopping sight distance.
3. The effect of the sight triangle on stopping distance at a passively protected crossing.
4. The effect of darkness or poor visibility conditions at a passively protected crossing.

Exploration of Ways to Inform the Motorist

HUMAN FACTORS RESEARCH

Two approaches were taken to explore various means by which the motorist could better cope with the problems just delineated. One approach took the form of an investigation of human factors research which have application to the design of warning devices. This effort, reported in Appendix B, resulted in general principles (Table 24) which should be followed in developing warning systems. These principles, together with other information gathered in the human factors study, were then evolved into the following specific recommendations:

1. Make greater use of color and shape coding than has previously been the case.
2. When possible, provide adequate illumination for each crossing.
3. Provide adequate advance warning for every crossing.
4. Make use of cross-modality stimulation; specifically, investigate the feasibility of rumble strips (tactual and auditory stimulation), horns (auditory stimulation), and so on.
5. Provide redundant information, both by repetition of the message and by cross-modality stimulation.
6. Utilize the intermittent stimulation principle for all automatic signals.
7. Utilize automatic signals whenever possible; when not possible, provide unique nonautomatic warnings with greater impact than the standard nonautomatic warnings. That is, crossings without activated signals should be marked quite differently from those with activated signals, so that the driver, upon approaching them, is made aware of the fact that it is his responsibility to determine whether or not a train is approaching.
8. Insure a minimum amount of distracting or irrelevant information by removing all extraneous messages from the immediate vicinity of the crossing.
9. Use warning devices of greater impact for isolated crossings.
10. Investigate the feasibility of providing the driver with prior information about crossing density and train traffic volume.
11. Incorporate some features of existing warning systems into any new and novel systems developed, to prevent adverse effects from negative transfer of old habits.
12. Provide the traffic engineer with warrants for crossing protection devices that are sufficiently flexible to permit him to utilize unique warning "packages" for unique crossing situations. A set of such warning packages, graded according to impact or attention value, should be part of the traffic engineer's arsenal.

INTERVIEWS AND MEETINGS

The second approach used was interviewing persons of long experience in the installation of grade crossing protection and meeting with traffic engineers who have had to deal with a wide variety of situations involving the motorist.

The highlights from these discussions are presented in the following paragraphs. The ideas generated in these discussions related primarily to devices. It was recognized that a simple, inexpensive active device would solve many of the problems previously described by decreasing costs and therefore allowing them to be installed at a greater number of crossings.

The first group of ideas dealt with existing active devices. It was brought out by one of the persons experienced in grade crossing installations that at low train volumes existing devices are not failsafe. Train volumes below two per day cannot be depended on to maintain a bright rail, which is essential for automatic operation. Unless special measures are taken, the rail becomes dull or corroded and the flashing light signals and gates may not function automatically and will require some other form of activation. Several methods have been tried to overcome this problem, but none has been completely successful.

There were numerous indications that the present state of electronic technology could be applied to train detection and subsequent actuation of a crossing protection device that would be less expensive and as reliable as the present track circuit. Possibly, detection devices used for traffic signals could be adapted for railroad use, or radio control directly from the engine cab may be practical.

Another group of suggestions was aimed at the protection device itself. At present, flashing light signal lampheads are fixed to the standards with provisions for vertical as well as horizontal adjustment. Some of them are attached to the standards with a ball-joint socket. The latter are particularly difficult to adjust for proper indication and have a tendency to lose the proper adjustment due to loosening of the locking nut by vibrations caused by passing trains and vehicular traffic. Because the red light emanating from the lamphead often has a wide horizontal and a very narrow vertical angle, it is essential that it be carefully adjusted and locked into position for it to give a proper indication to the approaching highway traffic. There were indications that considerable improvements could be made to existing devices through the design of new lenses and new mountings. In addition, where gates are used there is a need to use colors which will be brilliant both by day and by night and which will not blend with the background.

The whole discussion of active crossing devices raised a question about how railroad crossings are different from other intermittent hazards which the motorist is likely to encounter, such as firehouses, lift bridges, and special pedestrian crossings. In each of the other cases, attempts have been made to adapt standard traffic control signals. Although there is little uniformity today, these attempts suggest an in-depth study of the need for a special device which would have application to a whole family of intermittent hazards, including railroads. More research than can be undertaken in the present project is required to determine the feasibility of such a device or family of devices.

In addition to visual devices, there were suggestions for devices which utilized other senses of the driver. These included various devices to amplify the sound of the train for broadcast on the car radio, bells and klaxons to accompany the flashing signals, or a recorded message broadcast from a roadside transmitter. (Bells are already used at some crossings, but these comments were aimed at devices which would overcome the internal sounds in an automobile or truck with the windows closed.) Roughening of the pavement to produce a change in both sound and the "feel" of the road also was suggested.

One group of comments was aimed at preparing the motorist for the crossing when his view of it was restricted. This included flashing signals in advance of the crossing, to be actuated by an approaching train, and traffic signals which flashed all the time but turned red as a car approached so that speed would be reduced. This set of ideas generated emphatic comments that devices which present the same aspect whether or not a train is present will in time generate complacency and subsequent nonperformance on the part of the motorist.

With the realization that there was also a need for improvements in passive devices, suggestions were made for signs which could catch a train headlight and reflect it down the highway, thus acting as a cue to the motorist at night. Another suggestion was for a reflectorized panel which would be mounted on the far side of the tracks so that a train breaking a vehicle's headlight beam would produce a flashing effect, thus alerting the driver to its presence. Additional pavement markings were suggested as a means of attracting driver attention and causing him to slow down through such tricks as converging longitudinal paint lines or transverse lines with progressively decreased spacing on the pavement. Finally, there were expressions that more information on the advance signing (such as track angle and where to look for a train) would be a material aid to the driver.

Based on the general findings of human factors studies and interviews, a series of alternative signs was devised and tested.

TABLE 24

GENERAL PRINCIPLES FOR DEVELOPMENT OF WARNING SYSTEMS

A. Take into account the full range of human characteristics; i.e., do not use only the "normal" or "average" driver in specifying design requirements.
B. Minimize uncertainty in decision-making by making alternative courses of action as few and as simple as possible.
C. Provide the driver with prior warning of the responses he will be asked to make; this warning should be far enough in advance to allow ample time to detect the warning signal and to make the appropriate responses, but not so far in advance as to fall victim to man's relatively short-term memory.
D. Avoid the presentation of any extraneous or irrelevant information that could interfere with attention to the important cues.
E. Maximize the detectability (target value), legibility, and clarity of meaning of the warning devices (signs, signals, or markings), following the principles set forth in this report. Use simple, direct, specific warnings.
F. Design the warning systems to include redundancy. This redundancy may take two forms; i.e., repetition of the message by means of several signs, signals, or markings, and the use of multi-channel stimulation (e.g., rumble strips in addition to signs).
G. Use uniformity as a basic principle of signing; however, develop unique warning systems for unique situations. The principle of uniformity is upheld if these unique systems are reserved for use only in unique situations, such as the isolated or unprotected crossing. With regard to unprotected crossings, it should be pointed out that present warning systems offer very few cues for the motorist to distinguish between a crossing that has some signal protection and one that does not.
H. Where the hazard (i.e., highway-rail grade crossing) occurs infrequently (that is, where the hazard is an isolated one), provide warning devices with maximum detectability, and utilize the principles of redundancy and uniqueness (F and G, above).
I. Avoid false or unnecessary warnings, because a warning followed by a zero change in conditions distracts the driver's attention to no useful purpose, and it is possible that other perceptually similar signs that are of value in aiding the driver may subsequently be ignored due to a generalization process.

Alternative Signs

The devices which were developed for testing took into account the study of accidents, their distributions and relationships to other factors, principles and recommendations of human factors studies, and the comments and suggestions obtained in the interviews.

The signs represent a conscious effort to provide a sequence of signing for grade crossings which meets the following objectives:

1. To identify a unique hazard, which is a railroad crossing.
2. To inform the motorist of his obligations at the crossing; i.e.,
   (a) Watch for a signal which would indicate the approach of a train, or
   (b) Look for the train and determine for himself if it is safe to cross.
3. If it is necessary for the motorist to look to his right and left for trains, to inform him where on his approach he should look for them.

The signs and the sequences tested are shown in Figures 15 through 22. Figure 15 shows both the recommended sign for use at passively protected crossings and a similar alternate. Both signs retain the internationally recognized crossbuck symbol, but have a background which lessens the chance of the symbol blending into a light background, such as a white building, the sky, or a white or grey pavement surface. The particular background shown was selected because of the similarity in the motorist's obligation at railroad-highway intersections and at highway intersections controlled by a YIELD sign. The Uniform Vehicle Code (*10*) states that "Whenever any person driving a vehicle approaches a railroad grade crossing . . . the driver of such vehicle shall stop within 50 feet but not less than 15 feet from the nearest rail of such railroad, and shall not proceed until he can do so safely . . . if [sic] . . . a railroad train approaching within approximately 1,500 feet of the highway crossing emits a signal audible from such distance and such railroad train, by reason of its speed or nearness to such crossing is an immediate hazard; an approaching railroad train is plainly visible and is in hazardous proximity to such crossing."

With respect to the YIELD sign, "The driver of a vehicle approaching a yield sign if required for safety to stop shall stop before entering the crosswalk on the near side of the intersection or, in the event there is no crosswalk, at a clearly marked stop line, but if none, then at the point nearest the intersecting roadway where the driver has a view of approaching traffic on the intersecting roadway."

Not only is the use of the YIELD shape at railroad crossings consistent with the meaning applied to it in the uniform code, but it also provides a regulatory device which passively protected crossings do not presently have (crossbucks are not mentioned in the uniform code). The recommended sign was chosen over its alternate shown in the same figure because of its unique shape.

The recommended advance warning for passively protected crossings is shown in Figure 16. This sign (the track angle sign) was designed to provide an advance warning distinct from that used at crossings with active devices. In addition to telling the motorist that the obligation is his, the sign also tells him where to look by giving the angle in 45° increments (three positions). This sign should be placed a distance from the crossing dependent on the highway approach speed.

The second sign shown in Figure 16 (LOOK FOR TRAINS) should be used only when the combinations of highway and railroad approach speeds and quadrant sight distances do not allow the motorist to see approaching trains from the location of the advance warning sign. There are many crossings where this situation exists (see Table 20). This sign would be supplemented by advisory speed plates and would be placed at the location where the motorist traveling at the advised speed could see approaching trains in time to stop.

Figure 17 shows the recommended advance warning sign for crossings equipped with, flashing lights, gates, traffic signals, or wigwags. This sign was selected to be distinct from the advance warning recommended for crossings not equipped with automatic devices so that the motorist would be aware of the different obligation. The recommended sign is a combination of words and symbol. Three alternates which were studied are also shown in Figure 17.

Figure 18 shows a series of signs studied for use at crossings with passive protection. All of the signs shown in this figure are symbolic. The recommended advance warning sign can be compared with the same sign having a black roadway. The black roadway was judged to be less desirable because it detracts from the most important item on the sign—the tracks. The roadway is shown only to provide a reference to indicate the approximate angle. The third sign shown in Figure 18 is a symbolic alternate to the LOOK FOR TRAINS sign. This sign, although attention getting, was judged to be too unusual. An extensive education campaign would be necessary before the majority of motorists would fully understand its meaning.

Figure 19 shows six additional signs which were studied for use *at* the crossing. In varying degrees, they all provide a background for the crossbuck. These signs were judged to be inferior to those shown in Figure 15. It was found that motorists have a strong tendency to associate yellow diamond and rectangular shapes as advance warnings and not as marking the hazard, which is the intent of these signs.

Figure 20 shows a series of advance warning signs composed entirely of word messages for use at crossings with passive protection. TRAIN CROSSING was judged to be inferior to the track angle sign and offers no real advantages over the standard round R-X-R. REDUCE SPEED and VIEW OF TRAINS LIMITED are presented to supplement the LOOK FOR TRAINS sign. There may be cases where sight distance is extremely poor and these signs can be used to advantage. They should not be taken as a substitute for the advisory speed plate, however.

Figure 21 shows the same series of signs supplemented with advisory speed plates used as delineators. They were spaced progressively closer together and closer to the pavement edge to present to the motorist the illusion of traveling faster. This arrangement was found to be very effective. It is recommended that the delineators be terminated at the LOOK FOR TRAINS sign.

Figure 22 illustrates the use of brilliant yellow-green as a color for the installation at the crossing. Human factors studies indicate that this color provides maximum target and visibility distance for objects under low illumination levels. At the same time, it is a different color than the yellow associated with the advance warning and would distinguish the advance warning from the actual crossing. Preliminary evaluation indicated that the average driver associates both rectangular and diamond-shaped yellow signs with a warning of an approaching hazard and very definitely as not marking the point of hazard. The particular signs shown are an effort to provide a hazard marker. Two signs with the message TRAINS CROSS HERE and a white arrow on a black background pointing down were erected on the near side of the crossing (right and left). END OF XING was erected on the far right and left. The purpose of four signs was to indicate the angle of crossing. It was not entirely effective.

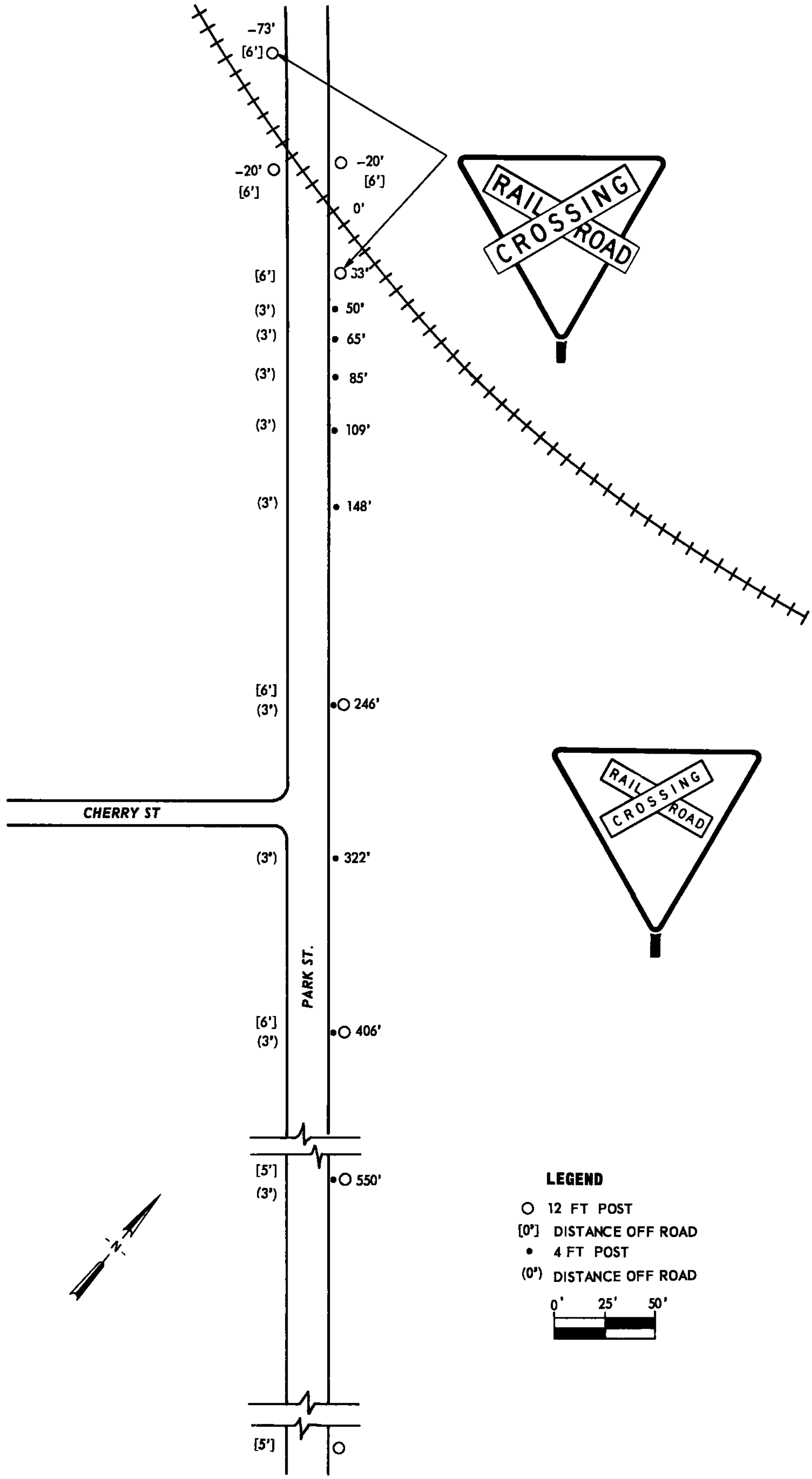


Figure 15. Passive protection at the crossing, Alternate A.

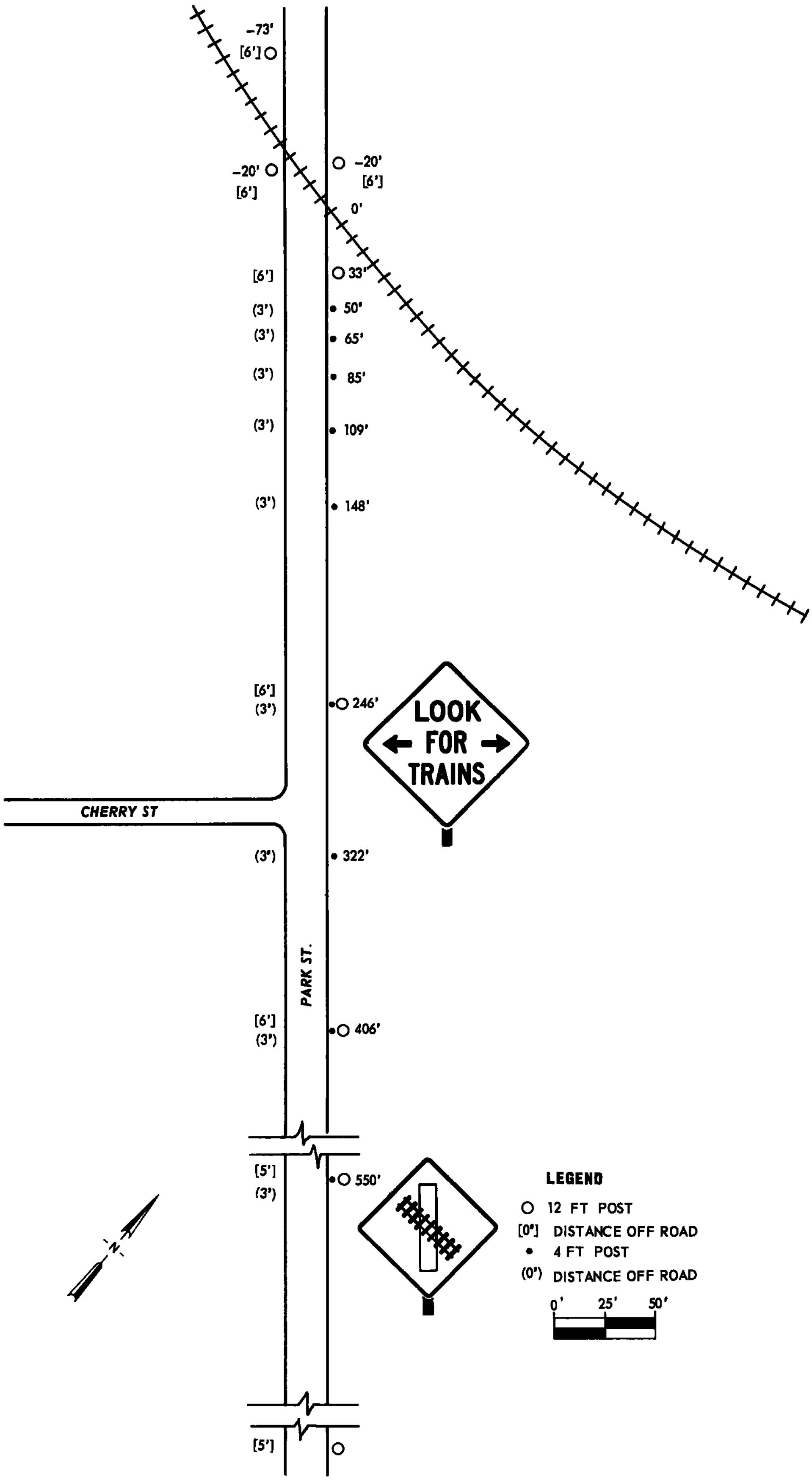


Figure 16. Passive protection advance warning, Alternate A.

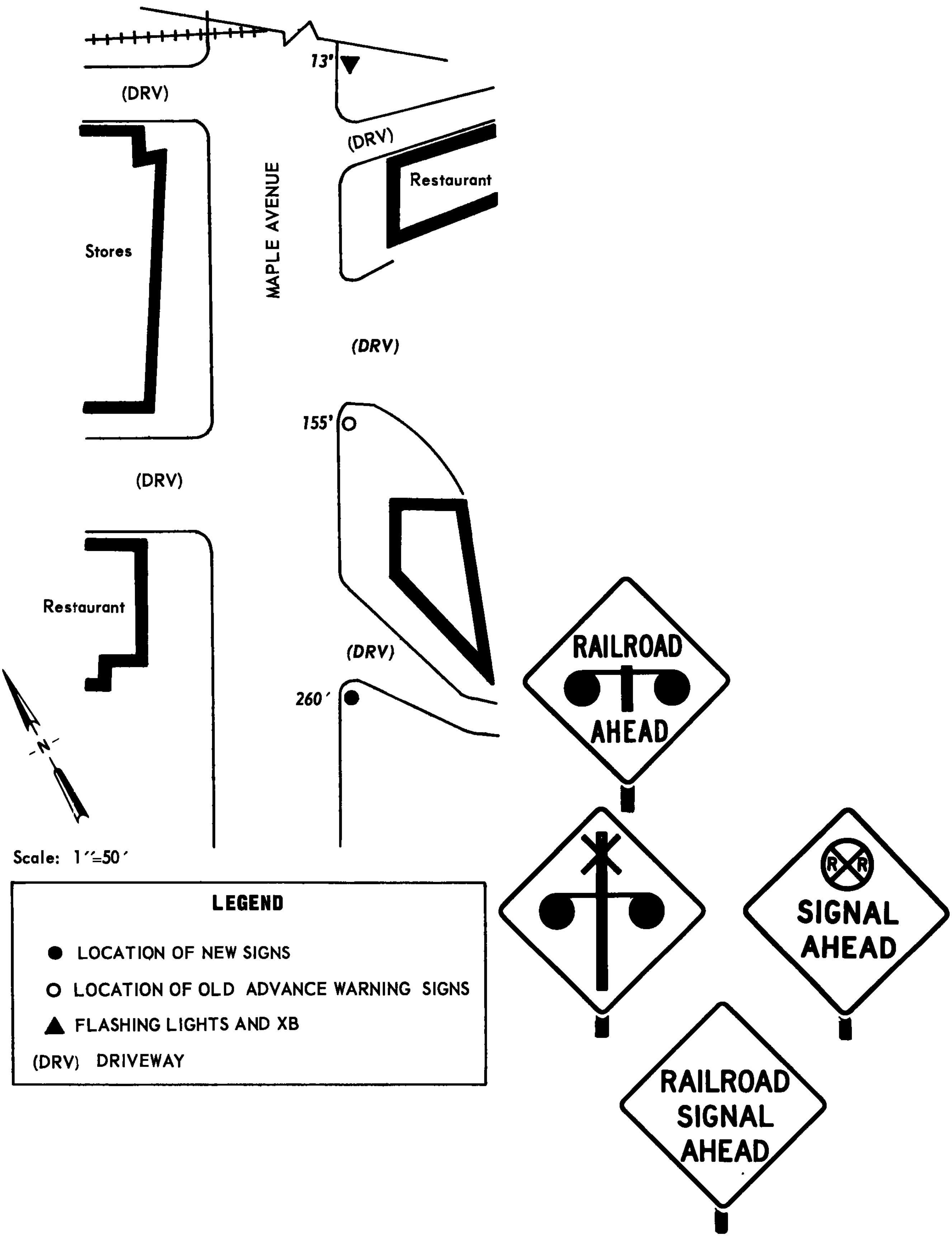


Figure 17. Active protection advance warning.

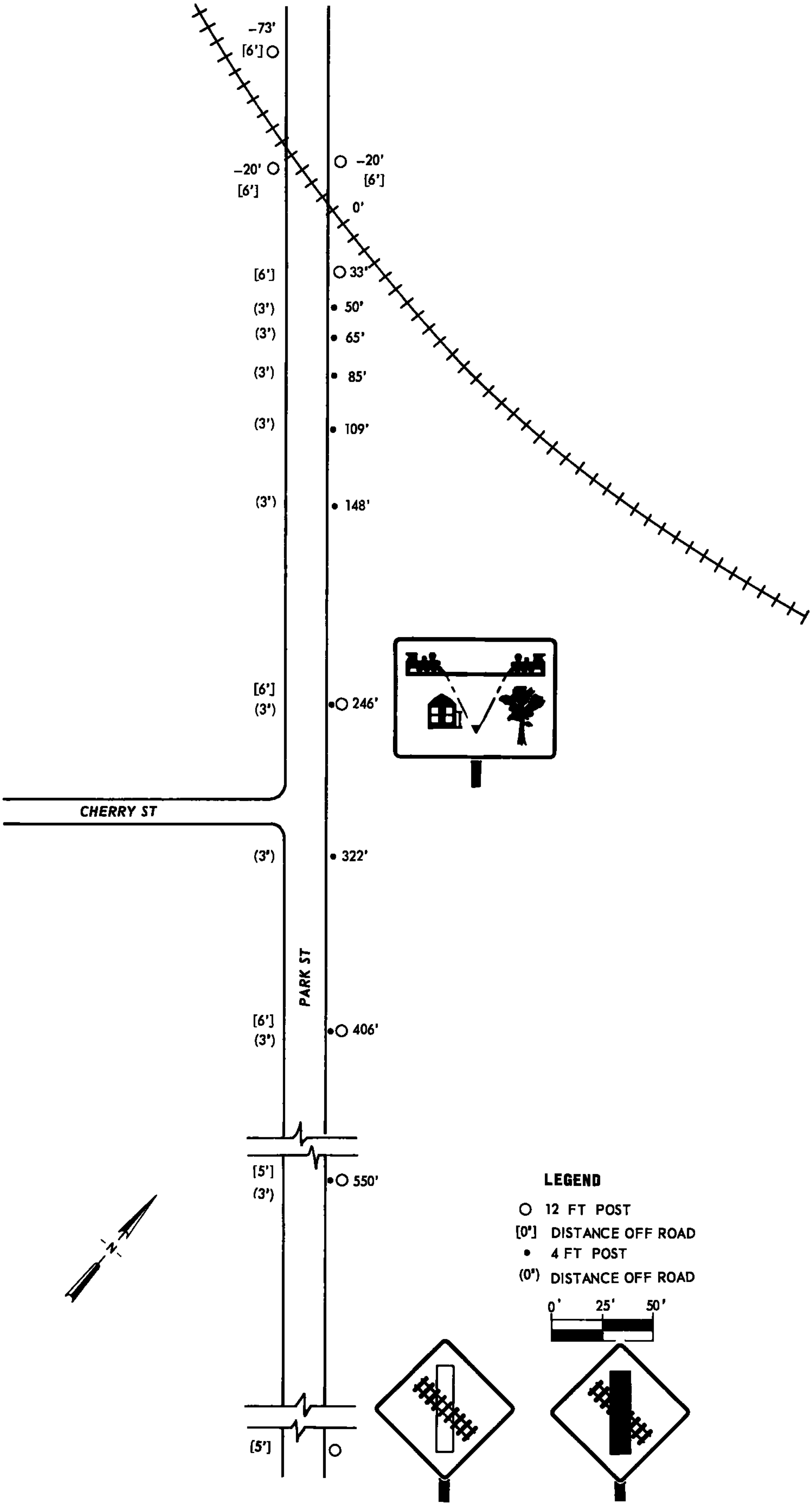


Figure 18. Passive protection advance warning, Alternate B.

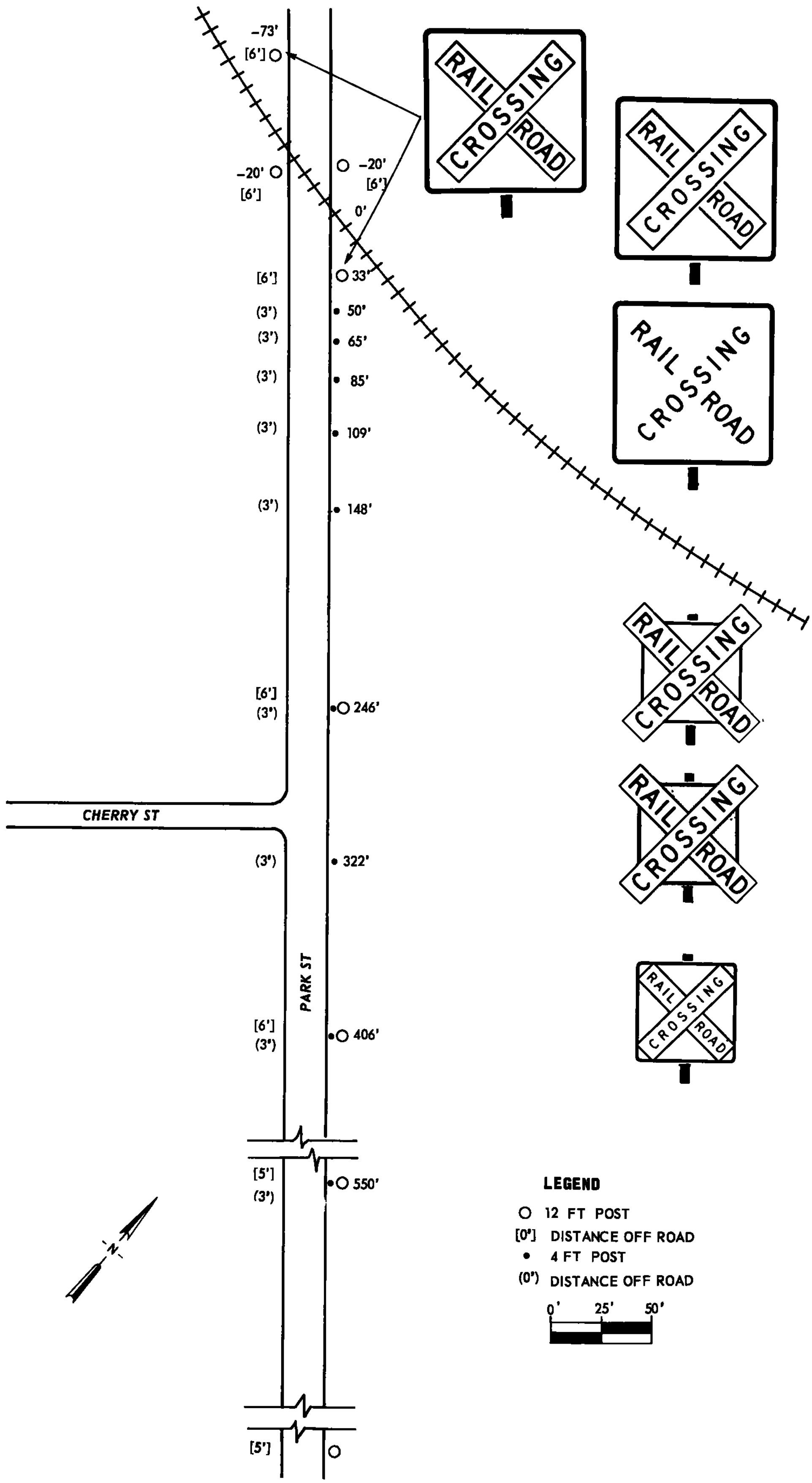


Figure 19. Passive protection at the crossing, Alternate B.

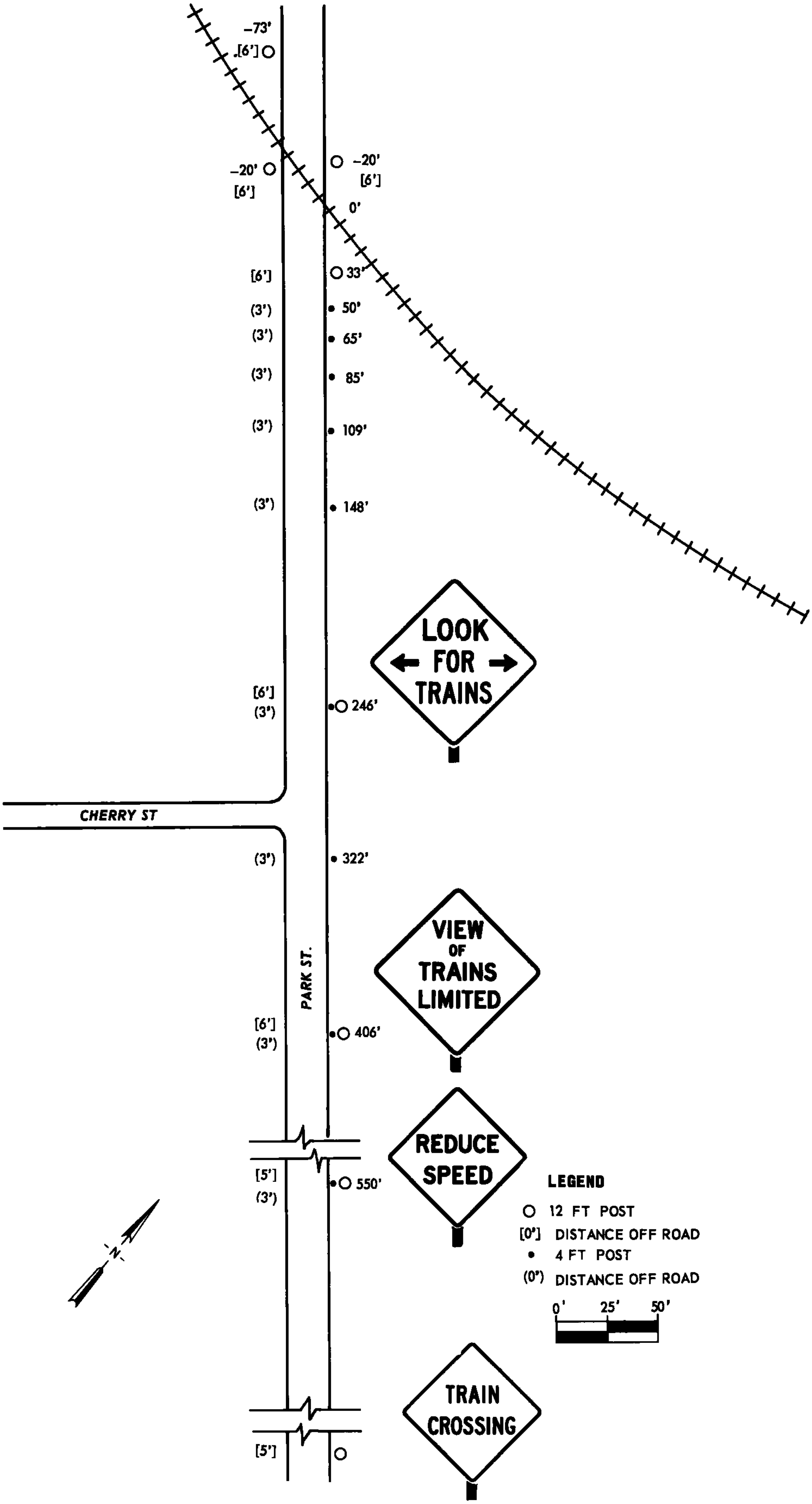


Figure 20. Passive protection advance warning, Alternate C.

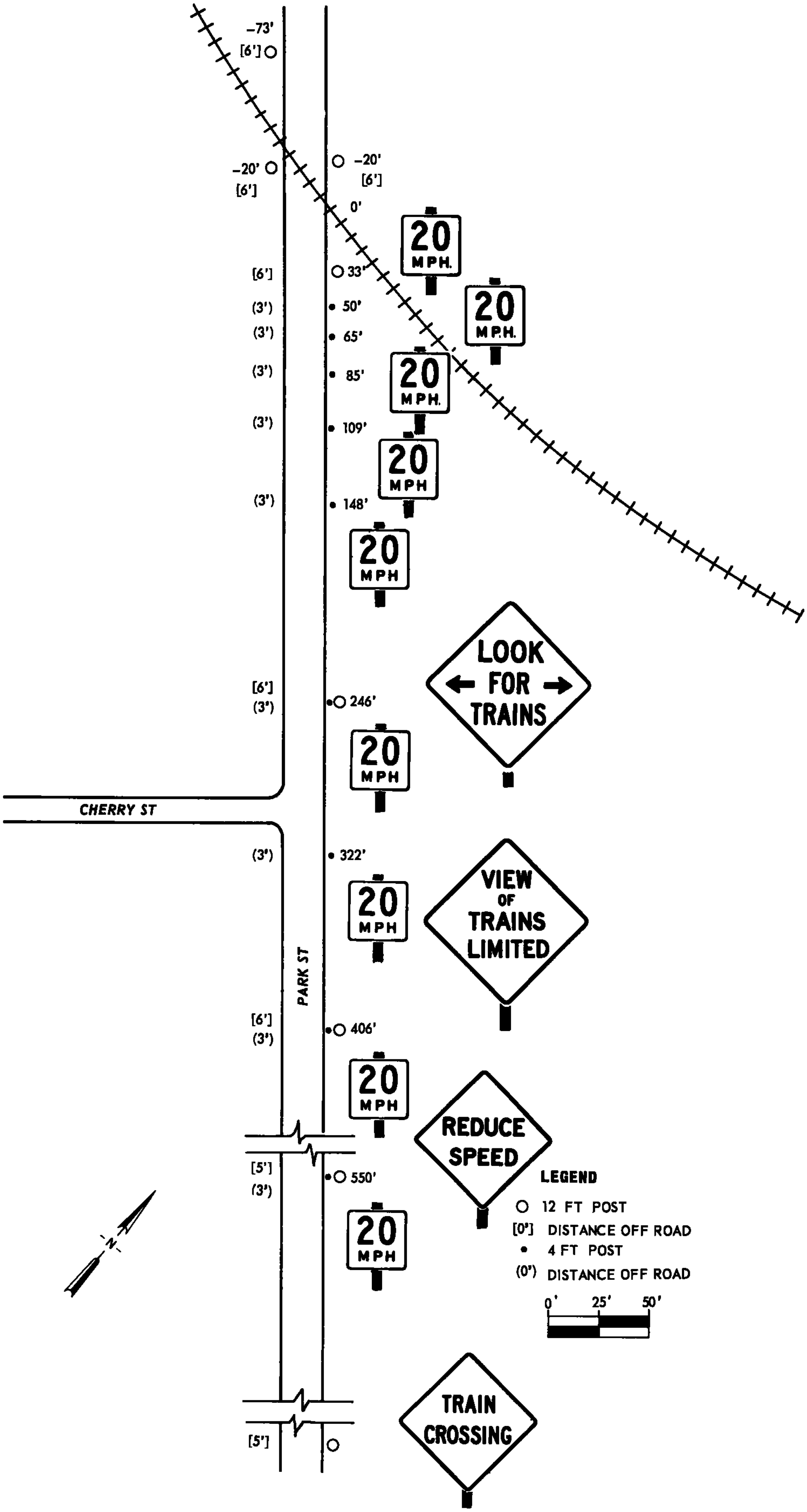


Figure 21. Passive protection delineator effect.

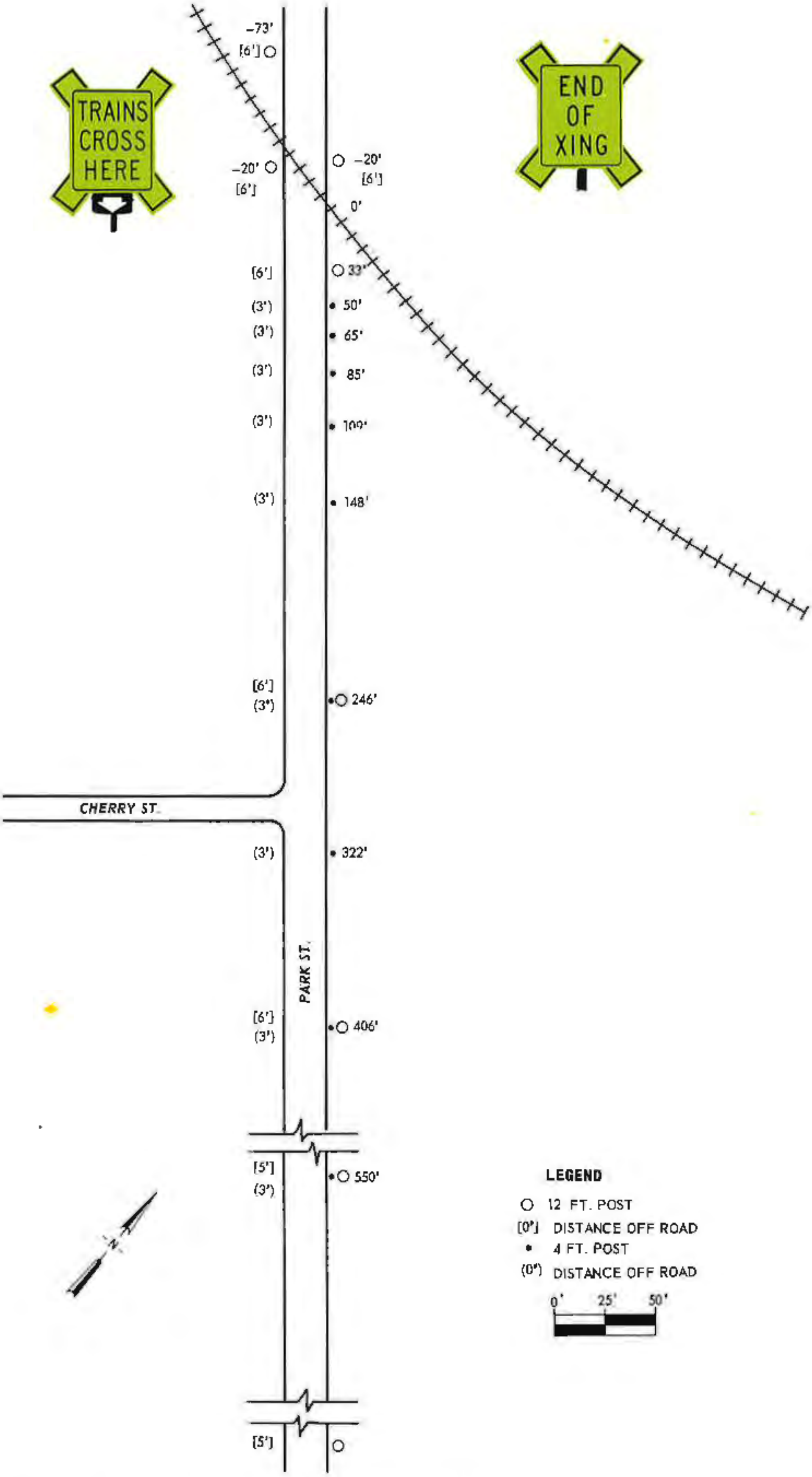


Figure 22. Passive protection at the crossing, Alternate C.

TESTING

Each series of experimental signs was erected at two typical crossings in the town of Vienna, Va. One crossing had flashing light signals, the other unreflectorized crossbucks. Each series was photographed on movie film from a moving car and slides were made in daylight and simulated darkness.

An audience of 23 employees of the contractor was assembled for an opinion survey of the signs. Most of the individuals are professionals in the firm. A 20-min presentation of the background information, the goals and objectives of the signs was given in such a way as to avoid prejudicing the audience. The opinion survey consisted of two parts. Eighteen sequences of signs from the movie were observed by the audience during Part I. As each sign was passed in the movie, a slide was flashed on the screen beside the image of the movie. The audience was requested to rate each sign within each series as to like, dislike, or no opinion.

Part II consisted of viewing slides of specific alternative signs rather than approach scenes. The audience was asked to rank each alternative sign in order of preference. In addition, they were also asked to judge specific signs as useful or not useful and to express their preference for color.

The results of Part I represent the initial reaction to each sign within a series. Part II indicates how the individuals ranked specific signs which might be used for the same purpose. The results of the survey are given in Appendix C.

The sign which received the most favorable response was the triangular shape with large crossbucks (Fig. 15), with 17 individuals indicating that they liked the sign and only 1 expressing dislike. Other signs to which the initial reactions were favorable included:

Track angle with white roadway (Fig. 16).
LOOK FOR TRAINS (Fig. 16).
RAILROAD (symbol) AHEAD (Fig. 17).

Signs which received an unfavorable reaction from many of the participating individuals were:

R-X-R SIGNAL AHEAD (Fig. 17).
RAILROAD SIGNAL AHEAD (Fig. 17).
The "look" symbol (Fig. 18).
Small square target with large crossbuck Fig. 19).
TRAIN CROSSING (Fig. 20).
Track angle with black roadway (Fig. 18).
Small square target with small crossbuck (Fig. 19).

The delineator effect, shown in Figure 21, received an even distribution between like, dislike, and no opinion.

The results of Part II indicate that the group prefers the following signs over their alternatives and over their applicable existing counterparts (i.e., the round R-X-R and the crossbuck):

RAILROAD (symbol) AHEAD (Fig. 17).
Track angle with white roadway (Fig. 16).
LOOK FOR TRAINS (Fig. 16).
Triangular target with large crossbuck (Fig. 15).

The majority of individuals expressed the opinion that the signs which advise REDUCE SPEED and VIEW OF TRAINS LIMITED (Fig. 20) would be useful under some circumstances.

Preference of individuals for yellow or brilliant yellow-green was fairly evenly split.

FINDINGS

This jury rating, plus the observations of the study staff, determined the signs to be recommended. In general, the end result of combining these findings is the replacement of the present standard round railroad advance warning sign (W10-1) with two different signs which are keyed to the type of protection. At the crossing itself the crossbuck is retained, but in the case of a crossing without some form of active protection the installation is given much greater target value.

With regard to reflectorization, members of the study staff made the following observations. Reflectorized white is generally a duller white than nonreflectorized, being more of a silver color under daylight conditions. Comparisons were made between the white reflectorized material used in the test signs and the white of the existing crossbuck. The existing crossbuck gave an obviously superior indication to the motorist during daylight conditions. Under nighttime conditions the reverse was true. This comparison was also made at another installation, where both a reflectorized and a nonreflectorized crossbuck had been installed. Consequently, it is strongly recommended that nonreflectorized materials be used at crossings which have only daytime train operation.

Although brilliant yellow-green (Bureau of Standards color No. 116) was tested and appeared to be a good color for highway signing (Fig. 22), it was the opinion of the study staff that it could probably be put to better use at another location. Because it is a good color for day-night visibility, its use should be reserved for a problem area which exists in rural locations, or locations which generally do not have street lighting.

With regard to the placement of devices, it is recommended that a maximum distance from the pavement edge be specified for the location of reference markers (crossbucks, flashing lights, etc.) This distance should be not more than 12 ft. Generally, the signs should be close enough to the roadway edge to allow the driver to have maximum opportunity to view them on his approach. In urban areas, at crossings which have nighttime train operation and drivers with low-beam headlights, the height of the sign should generally be no more than 5 ft to allow maximum effectiveness of the reflectorization.

Application of Findings

CROSSINGS WITH NO PROTECTION

As a beginning point, consider a crossing which has an extremely low train volume. The most obvious examples are crossings of abandoned rail lines, seldom used yard sidings, and spurs. Throughout the country many such crossings exist. In keeping with the general principle of avoiding unnecessary warnings, all signs pertaining to the crossing, both at the crossing and on the approach, should be removed. If there is a hazard at the crossing which it is not economically feasible to eliminate (such as a bump, dip, narrowing of pavement, or other feature), the motorist should be informed through standard highway signs, which have been designed for such conditions. This signing technique would have the effect of informing the motorist of train scheduling (i.e., no signs, no trains), reducing the hazard created by drivers slowing to observe nonexistent trains, and increasing the impact of devices at crossings which are used by trains.

The same principle can be utilized at crossings where train operations are seasonal, such as lines which serve some mining and farming areas. Such crossings should be protected only during those times of the year when they are used by trains. During the remainder of the year the signs should be removed.

CROSSINGS WITH PASSIVE PROTECTION

The next level would include crossings which are used regularly by trains, have two clear sight triangles on each highway approach of appropriate dimensions for the prevailing highway speed and the highest train speed, have no train activity at night, and have a low accident probability with a passive device.

The minimum passive protection for such a grade crossing would be:

1. A reference marker at the crossing.
2. An advance warning sign installed at the point where the driver must look to see a train and decide to stop or proceed.

The recommended reference marker for the stated conditions is shown in Figure 15. It should be noted, however, that the recommended sign has been assigned a function by virtue of shape in addition to simply marking the crossing. In Section 11-701 of the "Uniform Vehicle Code," which pertains to obedience to signals indicating the approach of a train, it is stated that a vehicle will stop under certain conditions involving the approach or presence of a train. Thus, a railroad crossbuck with a background in the shape of a YIELD sign can perform the additional function of transmitting the motorist's obligations at a railroad crossing; that is, to give way to a train which is so close as to constitute a hazard.

The recommended advance warning sign, shown in Figure 16, provides more useful information than the present standard round R-X-R. In addition to showing a track crossing the road, the approximate angle can also be indicated. Three standard signs—45° left, 45° right, and 90° angles—should cover most situations in enough detail to alert the motorist to the directions in which he must look for a train. Under the stated conditions for this situation, this sign would be located at a point determined from highway speeds (see Table 20).

As the situation becomes more complex, additional treatment is required to provide the motorist with the information he needs to arrive at his stop or proceed decision. Possible complicating conditions are listed in the following, with the sequence of steps that should be taken to raise the level of effectiveness of the passive protection:

A. Trains passing over the crossing in darkness and/or poor visibility conditions:
   1. Reflectorize the basic devices.
   2. Add a white reflective panel on the far side of the crossing to indicate the presence of a train if the track crosses the road between an angle of 80°-110° and if train speed normally exceeds 30 mph. (This speed will produce about 50 flashes per minute, equivalent to a flashing signal.)
   3. Light the crossing to show the presence of a train.
   4. Add an oscillating headlight to the locomotive.
   5. Add illumination to the locomotive exterior to improve its visibility.

B. A sight triangle which is restricted:
   1. Determine the cost of clearing and maintaining the sight triangle versus the installation of more complex devices, considering the possibility of active devices being required in the extreme case.
   2. Reduce the prevailing highway speed and/or reduce train speed.
   3. In addition to the basic advance warning sign, install a second sign at the point where the motorist should look for the train. The recommended sign (LOOK FOR TRAINS) for use at this location is shown in Figure 16. It would be located at the point where a motorist can first see a train. Because sight conditions are restricted, this sign would be accompanied by an advisory speed calculated from the sight distance available. The advance warning (track angle symbol, Fig. 15) would be located in advance of this sign, a distance equal to that required for deceleration without braking from the prevailing highway speed to the advisory speed. An advisory speed plate would also be mounted below this advance warning sign.
   4. If the reduction in train and highway speeds decrease below practical levels:
      (a) Install an active device.
      (b) Accept the calculated risk of a predictable number of accidents over an extended period of time.

Alternative (b) in item B4 represents a decision which must be made by the administrator based on all the available information. A methodology developed by this project, and presented under "Use of the Model" in Chapter Six, provides a means of predicting probable accident rates. This must be balanced against the cost of installing and maintaining an active device. As indicated previously, there are limits below which presently used active devices can not be relied on for consistent operation and thus may not be operable even if installed. Such a decision is not an easy one to make, but in balancing the benefits to be achieved against the cost and the money available for allocation to such a project, the alternative of accepting a certain number of accidents must be faced.

C. Unusual conditions of highway and railroad alignment, speeds, or other circumstances which require emphasizing the previously installed devices:

1. Install a series of rumble strips at the point where the motorist should reduce speed.
2. Increase the size of the advance warning signs.
3. Install advance signs on both sides of the road.
4. Add pavement markings or barrier effects along the roadside which trick the driver into slowing down. Large-size delineators can be effectively used on two-lane roads to achieve a speed reducing effect by making the spacing progressively less as the motorist approaches the decision point.

One of the factors which established the basic condition was a low accident probability when a passive device was used. As the volumes of trains and motor vehicles increase, the probability of an accident occurring with passive protection will increase, thus providing an opportunity to establish a cut-off point above which a passive device will be considered inadequate and an active device will be installed.

The exact level of cut-off will vary, depending on such factors as the number of crossings to be protected and the amount of money available for highway safety purposes. Thus, it is possible to establish a hierachy of devices for installation at protected grade crossings.

CROSSINGS WITH ACTIVE PROTECTION

The basic equipment for protection of a crossing with an active device is outlined in the following. It should be noted that in addition to the established cut-off point on the probability of an accident occurring, special circumstances occurring at passively protected crossings may warrant treatment with active devices.

At the Crossing.—An active device at the crossing in the form of flashing lights and/or gates or a new form which would make railroad crossings a part of the family of hazards described previously.

On the Approach to the Crossing.—The recommended advance warning sign is shown in Figure 17. Instead of merely indicating to the motorist that there is a railroad ahead, this sign tells him that the crossing ahead is protected with a device which will be activated by a train and that his obligation will be to stop if the device so indicates. Where the crossing device is not visible at the stopping sight distance for prevailing highway speeds, the advance warning should be supplemented with a reduced highway speed equivalent to the stopping sight distance available.

If special conditions of highway alignment require it, or if experience shows that the basic equipment must be supplemented for added emphasis, the following steps should be considered:

1. Install a series of rumble strips at the point where the speed reduction must begin.
2. Increase the size of the advance warning signs.
3. Install advance warning signs on both sides of the road.
4. Install special "red signals ahead" signs interconnected with the grade crossing signals.
5. Add auditory stimuli, such as a spoken warning on induction radio or a warning bell interconnected with the crossing signals (at such time as these techniques are fully perfected).

The Recommendations vs the Problems, A Summary

In summary, the study has developed devices which meet basic principles for marking hazardous locations. Existing devices do not fulfill all these principles and this led to the recommendation of new devices.

Previous discussion identified four basic problems which confront motorists approaching grade crossings which do not have ideal conditions. The purpose of this section is to summarize the problems and identify the elements in the recommendations which help to solve these problems.

PROBLEM 1—THE VISIBILITY OF A TRAIN OCCUPYING A PASSIVELY PROTECTED CROSSING IN DARKNESS OR UNDER POOR VISIBILITY CONDITIONS

The solution to this problem takes two forms, dependent on the train speeds and frequencies. In areas where trains stop on the crossing or pass very slowly, lighting which will illuminate the train is recommended. Where train speeds are higher (30 mph or greater) and where the highway and railroad cross at nearly right angles, a reflectorized panel can be used on the far side of the crossing to create a flashing effect as the train passes. However, if the smaller angle of the highway-railroad intersection is less than 80°, the flashing effect will be blocked by the train, thus leaving illumination as the best approach.

PROBLEM 2—RESTRICTED SIGHT TRIANGLE ON THE APPROACH TO A PASSIVELY PROTECTED CROSSING

The first alternative to be investigated is the feasibility of clearing the sight obstructions so that trains will be visible within the sight triangle determined from the prevailing highway speed and the highest train speed. Other alternatives then become reducing highway speed and/or train speed, adding additional signs and increasing their size, and, in the extreme case, installing active protection to reduce the situation to that described in Problem 4.

PROBLEM 3—A RESTRICTED SIGHT TRIANGLE ON THE APPROACH TO A PASSIVELY PROTECTED CROSSING WITH TRAIN ACTIVITY AT NIGHT OR UNDER REDUCED VISIBILITY CONDITIONS

This is a more serious amplification of Problem 2, because of the difficulty in identifying the train. It has been suggested that at such a crossing an arrangement of mirrors may be used to reflect a train's headlight beam towards the driver. This suggestion would be applicable only when train speed and railroad alignment would allow a continuous beam of light to strike the mirrors for at least 12 sec prior to the passage of the train over the crossing. Another approach, and one that would be beneficial at all crossings, would be to illuminate the locomotive so that it could be detected at some distance from the crossing. Previous discussion pointed out that the night accident rate for passenger trains more nearly approximates the day rate than does the night rate for freight trains. The primary variable appears to be the illuminated string of cars in the passenger train. If illuminated panels were added to each side of the locomotive, the effect created by a passenger train would be evident for all trains at the crucial point—the front of the train. As previously noted, 93 percent of the accidents involve the front one-fourth of the train. A reflectorized panel would be effective when the locomotive is on the crossing, but an internally illuminated panel along the length of it would be visible at great distances from the crossing and would provide a cue that the motorist could track over an extended time period. In addition, an oscillating head lamp would be more quickly detected than the fixed headlight. Without such measures the only alternative is to install at the crossing active devices which will be actuated by an approaching train.

PROBLEM 4—RESTRICTED SIGHT DISTANCE ALONG THE HIGHWAY ON THE APPROACH TO A CROSSING

This problem is a restricted case of Problem 2, because it only applies when the driver's decision has been reduced to a stop or proceed situation. Either the driver must be informed, through an interconnected device such as a signal or audible message, that a train is about to pass over the crossing, which he cannot see, or a highway speed reduction equivalent to the stopping sight distance must be accomplished through signs, pavement markings, and other psychological tricks. The exact package of devices must be tailored to the individual situation.

CHAPTER SIX

THE QUANTITATIVE EVALUATION OF HAZARD

The ultimate in hazard prediction techniques would be an equation which accurately explained the frequencies of accidents at railroad grade crossings by taking into account all of the variables which have some effect. From a practical point of view, such an equation would be too large and clumsy to be of any value. Accidents depend on such factors as driver skill and perception, etc., which would be impossible to quantify in any consistent way. It is obvious also that many accidents occur from essentially random causes and so any predictive equation is bound to "explain" less than 100 percent of accident behavior, even in the very long run. However, even an equation which made use of only the criteria which had major effects would still be quite useful.

Those who have studied accidents at railroad crossings are aware that they occur very infrequently. However, they are also aware that accidents involving trains, although they occur even less frequently, are very severe. For example, the mean number of accidents involving trains per year per crossing for the nation is approximately 0.015. The mean number of accidents per crossing is three to five times those involving trains. Those familiar with the hazards at railroad crossings have also observed crossings that from all appearances are identical, yet have experienced different numbers of accidents during the same time period.

It becomes obvious that an equation cannot be expected to predict the exact number of accidents which will occur at a given crossing during a given time period. At best, it can only predict the mean number of expected accidents at a crossing during an extended time period. However, the expected value should be a better indication of the number of accidents which will occur at a location than even that location's past history. In that respect, it is a very useful tool.

DEVELOPMENT OF THE MODEL

The simplest approach—one frequently found in presentations of crossing accident statistics—is accidents per crossing. This approach can be misleading, because it does not take into account the probability of an accident occurring, based on the number of vehicles and trains.

Table 25 indicates that accidents per crossing increase as protection type increases. This phenomenon has been observed in many previous studies. However, as would be expected, and as previous studies have shown, accidents per crossing decrease as protection type increases when normalized for vehicle and train volumes.

The best method by which to normalize has long been a subject of discussion. Highway intersection accidents are usually normalized by summing all of the vehicles which pass through the intersection. The rate is then expressed as accidents per number of vehicles. A similar approach has been taken at railroad crossings by expressing the rate as accidents per number of highway vehicles per train. This function reduces to Accidents/(Vehicles × Trains), in which the denominator is commonly called the "V-T Index."

The study staff was particularly intrigued with the approach taken by Contra Costa County, Calif., which was based on Poisson arrival of vehicles and the probability of simultaneous vehicle and train arrivals. This was a very logical approach to a hazard index.

The most basic investigation of the distribution of accident frequencies at crossings with a given type of warning device is to hypothesize that the process is completely random with an average equal to the observed average. The resulting "expected distribution" is a Poisson distribution.

The comparison between these "expected distributions" and the observed distributions is given in Table 26, which indicates that the distributions do not compare well enough

TABLE 25

SUMMARY OF DATA, BY PROTECTION TYPE

PROTECTION TYPE	NO. OF CROSSINGS	NUMBER OF ACCIDENTS PER YEAR	ACCIDENTS PER CROSSING PER YEAR	PROBABILITY $\times 10^{-6}$ PER CROSSING	ACCIDENTS PER CROSSING PER YEAR PER PROBABILITY
Crossbucks	5541	231	0.0417	0.406	0.103
STOP signs	728	68	0.0935	1.552	0.060
Wigwags	303	124	0.4100	11.690	0.035
Flashing lights	795	186	0.2340	11.110	0.021
Gates	128	33	0.2580	22.900	0.011

TABLE 26

COMPARISON OF EXPECTED AND OBSERVED DISTRIBUTION OF ACCIDENTS

		DISTR. OF ACCIDENTS FOR CROSSINGS HAVING					
TYPE OF PROTECTION	TYPE OF DISTRIBUTION	0 ACC.	1 ACC.	2 ACC.	3 ACC.	4 ACC.	5 ACC.
No protection	Expected	366	3	+	+	+	+
	Observed	367	1	1	0	0	0
Passive protection, one side only	Expected	1385	40	1	+	+	+
	Observed	1385	41	0	0	0	0
Passive protection, both sides	Expected	3723	284	1	+	+	+
	Observed	3773	207	29	4	5	0
STOP sign protection, one side	Expected	91	7	1	+	+	+
	Observed	91	8	0	0	0	0
STOP sign protection, both sides	Expected	536	80	6	1	+	+
	Observed	545	65	11	2	0	0
Active warning devices	Expected	313	91	13	+	+	+
	Observed	319	84	9	5	1	0

to accept the hypothesis that is required by the "expected distribution." That is, the accidents do not occur in a random process, or perhaps the tendency toward accidents is not equal for every crossing within the group. The last portion of the hypothesis would be expected to be violated under normal conditions. Different traffic volumes, different train volumes, and different geometrics would all seem to have an effect on the tendency to have accidents.

For demonstration purposes, assume that the last group is made up of two types of crossings with different accident means. Further, suppose that 80 percent of the crossings have a mean accident expectancy of 0.1809 per five years, and the other 20 percent have a mean accident expectancy of 0.7236. This combination has the same expectancy (0.2895) as the observed group; however, the combined distribution histograms are somewhat different from the original Poisson with that mean, as follows:

Expected	320	80	15	3	+	+
Observed	319	84	9	5	1	0

This fit is considerably better than the previous one. It is reasonable to expect that with greater knowledge of the various crossings an even better fit could be obtained. There is no implication that the assumed values are representative of the actual conditions. The demonstration was employed only to point out that the assumption of randomness is not necessarily the basic point violated, and also to indicate that a fruitful investigation of the tendencies toward accidents is desirable even under the conditions of randomness.

It was with this in mind that the following model to determine the probability of an accident was developed:

$$P = R(K + p) \qquad (1)$$

in which

$P =$ the probability of an accident;
$K =$ the probability of a vehicle arriving at the grade crossing occupied by a train;
$p =$ the probability of a train arriving at the grade crossing occupied by a vehicle; and
$R =$ the risk that a driver will be unaware of his surroundings, hence will not (or perhaps will be unable to) take the necessary evasive action to avoid a pending collision. $R = 1$ implies total risk (unswerving drivers who completely ignore on-rushing trains or are completely oblivious to an obstacle in their path), and $R = 0$ implies perfect information and complete awareness, hence no risk.

Eq. 1 says that the probability of an accident occurring, if total risk is involved, is equal to the probability of a vehicle arriving at a crossing occupied by a train plus the probablity of a train arriving at a crossing occupied by a vehicle. If perfect information and complete awareness are present, the risk will drop to zero and no accident will occur.

The "risk" as defined in the foregoing can be expected to be decidedly different when a train occupies the crossing than when a train is approaching the crossing. Therefore, it is logical that Eq. 1 be reduced to

$$P = rK + Rp \qquad (2)$$

in which r and R are the corresponding risks for the two situations. Furthermore, the "risk" would also be expected to be a function of warning devices. This would reduce Eq. 2 to

$$P = C(rK + Rp) \qquad (3)$$

in which C is a coefficient depending on the type of protection at the crossing.

Accident statistics indicate that accidents which could be predicted by the function CrK account for 35 percent of the accidents involving trains. However, analysis of mass statistical data in Chapter Two indicates that unless the crossing is used by extremely slow-moving trains at night, the value of r drops so low when a train occupies the crossing prior to the motorist's final opportunity to stop that it is negligible.

This allows further simplification of the foregoing model. One second is fairly representative of the time during which a vehicle occupies the crossing, unless the driver stalls, stops, or is unaware of the approach of a train. However, at normal speeds it takes the average vehicle approximately 2 to 3 sec to travel from the point where the driver was last able to stop to the point where he is clear of the crossing. This time includes the time during which he occupies the crossing and is a function of vehicle speed only if the driver is totally unaware of his surroundings.

The probability of train arrivals in greater than a 1-sec increment 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. It can be assumed that during the 2 to 3 sec in the vicinity of the crossing, the driver's level of awareness would be the same. This simplifies the equation to

$$P = CRp \qquad (4)$$

in which C and R have already been defined, and p is the probability of a train arriving in a given second of time and a vehicle arriving in a given 2 to 3 sec. Therefore,

$$p = ab \qquad (5)$$

in which a is the probability of a train arriving in a given second and b is the probability of a vehicle arriving in a given 2 to 3 sec.

Although the logic of a 2- to 3-sec arrival interval seems to be good, the statistics do not entirely support it. For example, 2.5 times as many accidents occur in the 1-sec interval (moving train hits a moving car) as occur in the 2- to 3-sec interval (moving train appears on the crossing after the driver has gone beyond his final opportunity to stop). During the 2 to 3 sec, the driver still has alternatives of evasive action, even though he cannot stop. He can run off the road or he can hit an object other than the train. He can also accelerate and possibly beat the train. For purposes of the accident model, a highway risk time of 1 sec was used.

Risk can also be expected to be a function of the physical features at the crossing. Features such as angle of crossing, highway speed, train speed, sight distance, visibility, number of lanes, and others could be expected to alter the risk.

Probability of an Arrival

The flow of traffic throughout the day has a rather regular pattern, which is a function of the time of day. Therefore, it is possible to estimate with some reasonableness the flow of traffic which occurs in a given hour. However, there is a high degree of randomness within any hour.

If it is given that V_h is the volume of traffic in the hth hour, but randomness within that hour is assumed, the probability that no vehicle crosses a predetermined point on a roadway in a randomly chosen second of time is e^{-V_h/T_h}, in which T_h is the number of seconds in an hour. Therefore, the probability of having at least one arrival in a randomly chosen second is $1 - e^{-V_h/T_h}$. Due to the low daily volumes of trains, the approximation Z_t/T_t (in which Z_t is the number of trains in the time period, and T_t is the number of seconds in the time period) is valid for almost any sophisticated distribution which may be devised. The time period may be virtually of any length which can be supported by information. Generally, the best information available for this study was simply the number of trains per day, or perhaps the day-night division of daily volumes. Then

$$b_h = 1 - e^{-V_h/3600} \qquad (6)$$

and

$$a_h = Z_t/T_t \qquad (7)$$

in which the time period, t, covers the h hour.

The term ab is then determined as follows:

$$ab = \sum_{h=1}^{24} a_h b_h \qquad (8)$$

If it is known that one train arrives in a day, and further that the train arrives in the 16th hour, then $a_{16} = 1/3{,}600$, and all other $a_j = 0$. If the knowledge of the arrival is unsure within a 2-hr period, $a_h = 1/7{,}200$ for each of those two hours, and $a_h = 0$ for the others. If no knowledge of the scheduling is available, the train can be assumed to be equally likely to arrive in any hour of the day, and appropriately reflected by making each $a_h = 1/(24 \times 3600)$.

Aggregation of Two Types of Risk

In earlier investigations, it was seen that the effects of darkness are considerable when compared to the risk of an accident in the daylight hours. The major portion of information for this study does not distinguish between daylight and dark arrivals of trains, nor are the corresponding accidents coded in this manner. Hence, the problem was one of having only the total number of accidents which occurred under both conditions, making the separation of the effects impossible to reflect in the model. There is also the possibility that the summation of accidents from these two separate categories may cause some bias in the results. It is therefore necessary to investigate the conditions of the model and the possible effects due to this aggregation.

To begin, the model basically expresses a binomial distribution. It is expected to determine the probability of an accident occurring for each second of time, and there will be a finite number of seconds to be considered no matter how long a practical study lasts.

Let P_1 be the probability of night accidents occurring in a fixed time span of N seconds, and P_2 be the probability of day accidents occurring in the same period. Assume that y_1 night accidents have occurred, and y_2 day accidents have occurred. The measure $y = y_1 + y_2$ is available in the study data. The question being asked here is: What is the distribution of the variable, y, which is the sum of two random variables, y_1 and y_2? The answer is, of course, that the distribution is the convolution of the two separate frequency functions of the random variables. That is,

$$P(y = y_1 + y_2) = \left\{\binom{N}{y_1}(P_1)^{y_1}(1-P_1)^{N-y_1}\right\} * \left\{\binom{N}{y_2}(P_2)^{y_2}(1-P_2)^{N-y_2}\right\} \quad (9)$$

The mathematics of the situation is simplified considerably by the fact that the binomial distribution is quite accurately approximated by the Poisson distribution when P is small, N is large, and $N P$ is less than 5. Considering the fact that three or four accidents are rarely observed in a 5-year period (indicating that $N P$ is probably less than 1), and that N (the number of seconds) = 31,500,000 + for a single year's observations, a high degree of accuracy can be expected from a Poisson distribution with the parameter $N P$. And it is easily shown that

$$P(y) = N^y \frac{(P_1 + P_2)^y e^{-(P_1+P_2)N}}{y!} \quad (10)$$

This indicates that the convolution is closely approximated by a single Poisson distribution whose parameter $N P$ is equal to $N P_1 + N P_2$, the sum of the probabilities of the independent distributions. That is,

$$N P = N P_1 + N P_2 = C\,[N(R_d\, a_d\, b_d) + N(R_n\, a_n\, b_n)] \quad (11a)$$

or

$$P = C\,[R_d\, a_d\, b_d + R_n\, a_n\, b_n] \quad (11b)$$

and if lack of information requires that $a_d\, b_d = a_n\, b_n = a\, b$,

$$P = C\,(R_d + R_n)\, a\, b \quad (11c)$$

Eq. 11c simply says that the effects of night and day can be approximated if the day and night spilts of vehicle volumes and train volumes are known, otherwise the model will be measuring the combined effects of day and night situations. Neither approach is disruptive to the model.

Formulation of the Risk Equation

The risk equation (represented by R in the preceding discussions) is expected to be dependent on the roadway geometrics.

Inasmuch as it is quite possible that the effect of some particular geometric is radically different for two types of warning devices, R should actually be thought of as representing a matrix of equations, one for each warning device group. Under this concept, the probability of an accident in the Jth group of devices with a known $a\, b$ is

$$P_j = C\,(1 - K_{0j} \pm \epsilon_j - K_{1j}\, X_1 - K_{2j}\, X_2 \;.\;.\;.)\; a\, b \quad (12)$$

in which K_0 is the "basic awareness"; ϵ is the "error" representing the variability in the "basic awareness"; K_1, K_2 . . . are the coefficients which indicate the effects of geometric numbers 1, 2 . . . as measured by X_1, X_2 . . ., respectively; and $a\, b$ is defined by Eq. 5. For theoretical reasons, the expression within the parentheses should never exceed 1 nor be less than 0.

The frequency function of accidents for a single crossing under a specified set of conditions will be

$$P(y) = \binom{N}{y}(P)^y(1-P)^{N-y} \quad (13a)$$

or can be accurately approximated by

$$P(y) = \frac{(N\,P)^y\, e^{-N\,P}}{y!} \quad (13b)$$

in which y is the number of accidents and N is the number of seconds in the study period.

If 1,000 grade crossings identical with respect to traffic, trains, and geometrics (for demonstration purposes it was assumed that $P = 4 \times 10^{-9}$, the raw mean observed in the Oregon data) were studied for various lengths of time, the expected results would be the distributions shown in Figure 23. This concept is quite important. It suggests that some crossings, which are just as safe as some 900 other crossings, can have two accidents in the first year of the study while the other 900 have none.

At this point, it is reasonable to point out that very long study periods are necessary to obtain reliable data. It would also be necessary to hold traffic and train volumes constant, as well as foregoing any alterations in the warning devices. Such requirements are absurd in the real world. Obviously hazardous conditions are changed as soon as the hazard becomes known. Thus, it is not possible to locate data which could represent the conditions.

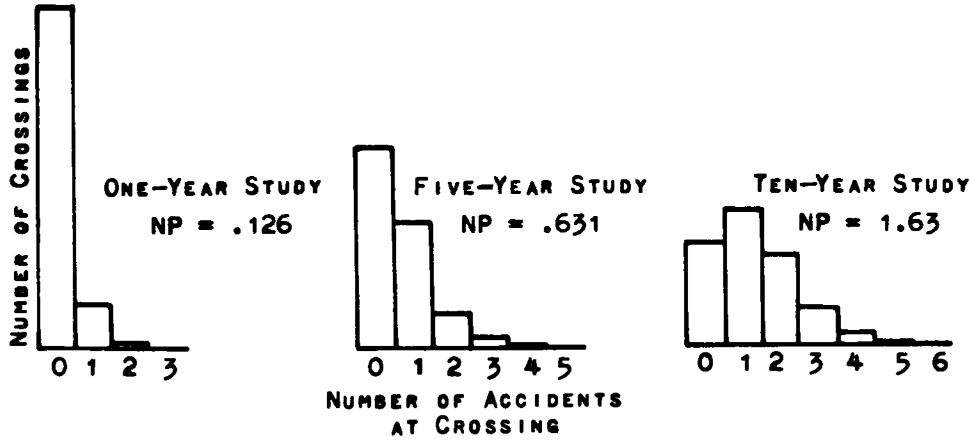


Figure 23. Hypothetical study of 1,000 identical crossings.

Estimating Coefficients in the Risk Equation

In estimating the effects of different types of warning devices and geometrics one is faced with two categories of variables. Some variables are continuous variables which vary from zero up to some practical limit; others are Bernoulli variables having only two values, zero or one. These 0/1 variables are used to indicate the presence or absence of a particular situation or device. It is possible that a mix of these types of variables could cause some complications in an attempt to estimate the coefficients of their effects. There is also the problem of warning device changes having been made during the study period so that there are different time spans under which conditions were relatively constant.

It is appropriate that the model be theoretically investigated under these conditions to establish its validity as a method for estimating the coefficients.

Suppose that there are several observations of each of three categories of situations. Define X as a 0/1 variable which is 1 when advanced warning signs are present, 0 when they are not. The three situations are as follows:

1. Has advanced warning signs and a roadway width of 22 ft; probability of an accident in this situation is P_1; has N_1 trials or seconds in which an accident could conceivably occur, and y_1 accidents.
2. Has advanced warning signs and a roadway width of 36 ft; probability of an accident in this situation is P_2; has N_2 trials, y_2 accidents.
3. Has a roadway width of 24 ft; no advanced warning signs (but the variable, X, is included, realizing that it will be zero when this situation occurs); probability of an accident in this situation is P_3; has N_3 trials, y_3 accidents.

The likelihood function of observing each of the y_j totals in the N_j trials, all in the same group of data, is given by

$$L = \binom{N_1}{y_1}(P_1)^{y_1}(1-P_1)^{N_1-y_1} \binom{N_2}{y_2}(P_2)^{y_2}(1-P_2)^{N_2-y_2} \binom{N_3}{y_3}(P_3)^{y_3}(1-P_3)^{N_3-y_3} \quad (14)$$

Inasmuch as the logarithm of a function is monotonic with respect to the function, the function can be maximized by maximizing its logarithm. The logarithm of the likelihood function, letting $C_j = \binom{N_j}{y_j}$, is

$$\begin{aligned} \ln L &= \Sigma_j [\ln C_j + y_j \ln P_j + (N_j - y_j) \ln (1 - P_j)] \\ &= \Sigma_j [\ln C_j + y_j \ln (a_j + b X) + (N_j - y_j) \ln (1 - a_j - b X)] \quad (15) \end{aligned}$$

Taking the derivative with respect to b (i.e., estimating b such that the likelihood will be maximum),

$$\frac{d \ln L}{db} = \sum_j \left(0 + \frac{y_j X}{(a_j + b X)} - \frac{(N_j - y_j) X}{(1 - a_j - b X)} \right) = 0 \quad (16)$$

Taking the second derivative gives all negative terms, hence defining a maximum, not a minimum. Rearranging the terms under the summation sign gives

$$\begin{aligned} \frac{d \ln L}{db} &= \sum_j \frac{X (y_j - N_j a_j - N_j b X)}{(a_j + b X)(1 - a_j - b X)} = 0 \\ &= \sum_j \frac{N_j X (y_j/N_j - a_j - b X)}{(a_j + b X)(1 - a_j - b X)} = 0 \quad (17) \end{aligned}$$

At this point it is important to realize that A_j is made up of some constant plus some effect due to the presence of other warning devices plus some error term, or

$$A_j = A_0 + G_j + e_j \quad (18)$$

Then letting

$$y_j/N_j = A_0 + G_j + b X + e_j \quad (19)$$

will satisfy the summation term by term, in those cases where $X = 1$. For the situation under category 3, where

$X = 0$ (i.e., advanced warning signs do not exist), the X term outside of the parentheses will cause the term to be zero, hence satisfying the equation in that case also.

It is also important to point out that the technique holds only when $A_j + b\,X$ is not equal to zero nor equal to one. That is, if the risk is independent of the variables being employed ($A_j + b\,X = 0$), or if no accidents occurred in this category ($A_j + b\,X = y_j/N_j = 0$ for all observations), the left-hand term in the denominator of Eq. 17 will cause the equation to explode. Such a situation would also occur if $a\,b = 0$.

Likewise, if the situation were saturated with accidents (one occurring every second, so that $A_j + b\,X = y_j/N_j = 1$), the right-hand term in the denominator would have the same effect.

The condition where $a\,b = 0$ is not interesting to this study, and the condition of saturation has never been known to occur. However, the condition of zero accidents could cause problems. If any variable has its non-zero values completely associated with no accidents in such a manner that the combined effects of the other variables are negatively correlated to the variable in question, the results would be invalidated. Although this event is highly unlikely, it does point out the need for fairly large sample sizes.

Otherwise, there is justification for expanding the number of categories, and indeed calling each grade crossing a category, so long as each variable has some non-zero value associated with at least one accident at some crossing in the data.

Regression techniques can then be used to estimate the coefficients, because the regression equation is precisely

$$y_j/N_j = A_0 + G_j + b\,X_j + e_j \tag{20}$$

or, in actual form,

$$y_j/N_j = (1 - K_0 - K_1\,G_j - K_2\,X_j \pm \epsilon_j)\;a_j\,b_j \tag{21}$$

Previous discussion has proposed a purely mathematical model for testing. It appears that the use of Poisson arrivals might be an unnecessary bit of added mathematical sophistication. However, when this hypothesis was tested on groups of actual data which contained higher volume crossings it was found to be a better predictor of accidents than the assumption of random arrivals.

By substituting $K'_0 = 1 - K_0$ in Eq. 21, the predictive equation,

$$\left(\frac{y/N}{a\,b}\right) = K'_0 - K_i\,X_i - K_2\,X_2 - K_m\,X_m \tag{22}$$

in which

X_i = geometric conditions or independent variables
$i = 1, m$; and
m = number of independent variables exerting a significant effect on accident behavior,

can be estimated directly by least squares.

It is to be remembered that this form of the equation is based on the assumption that other factors influence the expected value of y/N by adding to the "natural" value of A_0 (see Eqs. 18 and 20). It is not altogether clear whether the influence of other factors is additive at a given y/N and a given $a\,b$. This suggests, among other things, a possible model of the form

$$\left(\frac{y/N}{a\,b}\right) = K'_0\,X_1\,K'_1\,X_2\,K'_2\,\ldots\,X_m\,K'_m \tag{23}$$

Although this model is linear in logarithms, conventional least squares techniques break down when the value of any of the independent variables is zero or when the number of accidents is zero. Because it was desirable to examine all crossings, whether or not accidents had occurred, this form was not investigated further.

Before discussing specific variables and equations, it should be noted that by normalizing the dependent variable in the regression equation (that is, dividing accidents per common time period by the Poisson-distributed expected risk of collision, a joint function of highway and train volumes), the resulting estimate will naturally explain a much smaller percentage of the remaining variance. Virtually all other studies have shown that the most important predictors in estimating accident frequency are highway volumes and train volumes. The effect of using these normalized dependent variables in the regression model is that the regression explains some portion of the residual variance after highway and train volumes together have explained what is generally a significant portion of accident frequency. It is not expected that the equation will explain a large amount of the variance in the risk coefficient, but rather that the coefficient be tested to see whether the geometrics and crossing conditions affect it significantly.

Some Observations on Relation of the Model to Previous Studies

Peabody and Dimmick (*19*) used $V\,T$ as the basic variable in a hazard index. There are certain similarities between this term and the $a\,b$ term.

For the time being, assume that traffic is uniformly distributed throughout the day. In this case, each $V_h = V/24$, and likewise $Z_h = Z/24$. Hence,

$$b = 1 - e^{-V/(24 \times 3{,}600)} \tag{24}$$

For matters of presentation, let

$$X = V/(24 \times 3{,}600) = V/86{,}400 \tag{25}$$

Now the series expansions become

$$e^{-X} = 1 - X + \frac{X^2}{2!} - \frac{X^3}{3!} + \frac{X^4}{4!} - \ldots \tag{26}$$

and

$$(1 - e^{-X}) = X - \frac{X^2}{2!} + \frac{X^3}{3!} - \frac{X^4}{4!} + \ldots \tag{27}$$

Using only the first term of the series expansion as an approximation, it is acceptable with less than 1 percent error so long as X is less than 0.02 (or V is less than 1,728 vehicles per day). It is acceptable with less than 10 percent error when X is less than 0.19 (or V is less than 16,400 vpd). Therefore, it can be seen that the earlier model is not at variance with the model being presented, at least where this variable is presented. There is a basic difference in the approaches, in that the earlier study concerned itself only with crossings which had had accidents, which is to say that a "conditional distribution" was involved, and the parameters of such a distribution can be solved only by iterative methods. If one were to assume that the mean of the conditional distribution were the mean of the real distribution, the results would have a regular error term and be biased toward overestimation. This phenomenon was observable in the earlier model and is seen in the *K*-factor in the formulation given in a previous section of this report.

In 1954 the Oregon State Highway Commission published a report (*18*) in which $0.40 + 7.53 \times 10^{-5} V - 8.72 \times 10^{-11} V^2$ is a strong factor. If one allows $X = 2.32 \times 10^{-6} V$, the equation reduces to

$$0.40 + 32.5\left(X - \frac{X^2}{2!}\right)$$

Although the value of X is approximately 12 times V/86,400, the form of the equation is extremely interesting. The term in parentheses is the first two terms of the expansion. It is probably significant that the Oregon data involved higher volumes of traffic than the Peabody-Dimmick data.

CALIBRATING THE MODEL

Train-Involved Accident Model

DISCUSSION OF DATA

As mentioned previously, the data were collected from a wide variety of State highway and regulatory agencies and from academic sources. In addition to peculiarities in data collection, presentation, and quality control, and in geographic and regional differences, the varying time lengths of the individual analyses presented certain problems. Within the universal sample of the study the length of the individual studies varied from 1 year to 15 years. This presented two problems when using the information as a data base.

First, even when the number of accidents is converted to a common time frame, it is to be expected that variance of accident rates about the mean value differs depending on whether the individual study had been conducted on a short-run or a long-run basis. For example, if the mean accident rate at a given type of protection and for given values of the independent variables is 0.5 per year for a study of 1-year duration, one would expect that there would be large numbers of crossings with histories of zero and one accident per year. On the other hand, if the study was of 10-year duration, one would expect that the individual values of accidents per year would be more clustered around the 0.5 level and the frequency of crossings with accident rates of zero or one would be greatly reduced.

Second, as the length of the individual study increased, it is to be expected that the reliability of the highway and rail volume estimates is reduced, because in many cases volumes were estimated at only one or two points in time.

For virtually all of the data, train and highway volumes were measured on a daily basis and it was therefore assumed that vehicle and train arrivals were random within a 24-hr period. That is,

$$(ab)_{24\ \mathrm{hr}} = \sum_{h=1}^{24} (a_h\, b_h) \qquad (28)$$

For those few observations which reported volumes on a day-night or 12-hr basis, a separate analysis was conducted.

Each of the observations was categorized into one of five groups, depending on the most active type of protection at the crossing. The groups are: (1) crossbucks, (2) STOP signs, (3) wigwags, (4) flashing lights, and (5) gates.

As a further subdivision, each crossing within each of these groups was classified according to whether it was situated in an urban or a rural environment and the urban and rural crossings were analyzed separately. There are a number of reasons for this approach. In addition to differences in vehicle and highway volumes associated with urban and rural environments, there are significant differences in highway speed limits and, in particular, differences in train speeds. Because not enough compatible data existed in the sample to include these two variables and no data were available on the multitude of other factors which are the result of urban and rural characteristics, it was decided to stratify by urban/rural to correct, as much as possible, for lack of this information.

For each of the groups, the number of crossings with compatible data and the type of data which was compatible differed. The data associated with the various groups are discussed in the following:

VARIABLE NUMBER	DESCRIPTION
1	Accidents: number of vehicle-train accidents times 100, expressed on a per-year basis.
2	ADT: average daily highway traffic.
3	Average number of trains per day.
4	Sight distance: minimum of the four quadrants measured 300 to 500 ft from the railroad on the highway approach.
5	Angle: acute angle of intersection of tracks and roadway.
6	Number of lanes in both directions.
7	Maximum approach gradient: generally an average of the area within 100 ft from the crossing measured as a percent.
8	Number of tracks: number of mainline (but occasionally including spur and switch) tracks.
9	Train speed: the approximate maximum speed of the approaching trains, as determined from the rules and regulations of the operating railroads or as determined from time records.

It is clear from these definitions that the data were not completely compatible; nevertheless, aggregations had to be made, simply because no uniform method of collection presently exists and the technique used by previous researchers has included so many different definitions. When it is noted, for example, that for some 10 to 15 percent of the crossing sample, even ADT data were not gathered, the dimensions of the problem of data compatibility are evident.

STATISTICAL INFORMATION

After much discussion it was decided to allow ADT and number of trains to enter the equations as predictor variables. This allowed adjustment of the estimation of random collision probability to be made by the regression technique. The statistical problems of spurious correlation and possible correlation with other independent variables were handled by forcing these two variables to enter last in a stepwise regression technique.

Thus, the estimated equations are of the form:

$$\frac{\text{Accidents per year}}{\text{Prob. of simult. arrival}} = K_1 + \sum_{i=2}^{9} K_i V_i \qquad (29)$$

Throughout the tables, the factor "accidents per year" is scaled by 100.

An equation was considered significant if its F-ratio indicated a 95 percent or higher confidence level. Any particular variable was considered significant if its t-value indicated a 95 percent or higher level. The constants of the final forms of the regression equation were adjusted for the mean values of those variables which were not statistically significant. For passive protection types, for which many of the crossings had low volumes, it was observed that the operation of the probability relationship differed significantly for crossings with extremely low daily traffic in both urban and rural environments. It was discovered that a perceptible reduction in risk occurred as the traffic volume increased from zero to a few hundred autos per day for both STOP signs and crossbucks. Perhaps this indicated a transition in driving habits from the characteristics of a relatively deserted roadway to that of more careful behavior on a roadway with some recognizable volume of traffic. It could also be indicative of the fact that lower-volume roads are generally of a lower design standard.

The indicated approach was to estimate separate relationships for roadways used by fewer than 500 vehicles per day under both urban and rural conditions. Inasmuch as there were only a few urban crossings in the less-than-500 stratification, it was not possible to estimate separately their unique accident behavior.

Crossbucks.—Three equations were derived for this type of protection: (1) all crossings with an ADT less than 500; (2) urban crossings with an ADT greater than 500; (3) rural crossings with an ADT greater than 500.

1. For the group of low-volume highways, there were few crossings for which data on the minimum sight distance existed and practically none for which information on train speed had been gathered. From analysis of these small groups, it was determined that the influence of these factors was slight; this permitted the sample to be increased to a more meaningful size. There were 4,113 crossings in the sample. Table 27, which summarizes the results of the analysis, indicates that the equation does not predict significantly better than chance. Thus, the best predictor for accidents is:

$$V_1 = V_{10}\,(38.90) \qquad (30)$$

in which V_1 is the expected accidents per year and V_{10} is the probability of simultaneous arrivals.

2. For the urban large-volume group, considerably more data existed, although there were fewer crossings in the sample. The summary (Table 28) indicates that the accident behavior is about the same as for the low-volume group.

3. The same general pattern can be observed in the rural group (Table 29). The F-ratio again indicates that the equation as a whole is not significant. The risk coefficient for rural crossbucks is not significantly different from the coefficient for urban crossbucks.

Stop Signs.—For the analysis of STOP signs it was not

TABLE 27

CROSSBUCKS AT CROSSINGS ON HIGHWAYS WITH VOLUME OF LESS THAN 500 PER DAY

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	0.99	5.94	—	—
2	123.40	66.70	—	—
3	4.05	6.12	−2.64	1.41
5	68.45	19.43	0.47	0.42
7	2.84	3.30	—	—
8	1.14	0.55	16.84	15.90
11	38.90	422.40	—	—

Intercept = 10.532; $R = 0.05$; $F = 0.69$; $N = 4{,}113$.

TABLE 28

CROSSBUCKS AT URBAN CROSSINGS ON HIGHWAYS WITH VOLUME GREATER THAN 500 PER DAY

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	19.19	44.53	—	—
2	3460.49	4402.47	0.003	0.003
3	5.42	6.85	−1.70	2.15
4	238.50	376.72	0.011	0.033
5	71.67	20.66	0.342	0.660
6	2.77	1.26	0.236	10.70
7	2.74	3.05	−4.55	4.05
8	1.95	1.65	−2.38	9.03
9	19.14	9.05	0.557	1.463
11	30.57	204.04	—	—

Intercept = 32.36; $R = 0.1283$; $F = 0.622$; $N = 404$.

TABLE 29

CROSSBUCKS AT RURAL CROSSINGS ON HIGHWAYS WITH VOLUME GREATER THAN 500 PER DAY

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	14.04	35.56	—	—
2	2967.03	4131.93	−0.0021	0.0014
3	4.16	6.45	−1.697	0.960
5	59.70	22.59	0.163	0.220
7	2.35	7.36	−1.815	1.878
8	1.39	1.08	−1.345	5.047
11	30.35	125.21	—	—

Intercept = 29.20; $R = 0.1343$; $F = 1.323$; $N = 1{,}349$.

possible to divide the crossings into the same three groupings due to the relative smallness of the sample and the infrequent incidence of STOP signs in urban areas. STOP signs were broken into two groups: (1) low highway volumes (less than 500) (Table 30); and (2) all other (Table 31).

Crossings with automatic protection did not require stratification by large and small highway volume.

Wigwags.—Due to a small sample size, it was not possible to stratify wigwags by urban and rural. The hazard associated with protection type appears to be influenced by gradient and angle (Table 32).

Flashing Lights.—This group was stratified by urban (Table 33) and rural (Table 34). Again the protection coefficient did not appear to be influenced by the geometrics.

Gates.—For crossings with gates, the same stratification as flashing lights was made. Gates in urban areas (Table 35) appear to have the same protection coefficient as for flashing lights.

TABLE 30

STOP SIGNS AT CROSSINGS ON HIGHWAYS WITH VOLUME LESS THAN 500 PER DAY

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	1.687	6.84	—	—
2	155.00	87.89	0.335	0.540
3	4.93	4.88	−10.432	13.033
4	260.96	561.24	− 0.029	0.056
5	69.01	19.09	0.586	1.676
6	1.71	0.72	135.503	46.262
7	3.64	3.01	25.192	12.374
8	1.24	0.54	112.859	65.538
11	77.13	641.57	—	—

Intercept = 65.43; $R = 0.2263$; $F = 2.235$; $N = 425$.

TABLE 31

STOP SIGNS AT CROSSINGS ON HIGHWAYS WITH VOLUME GREATER THAN 500 PER DAY

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	20.02	39.17	—	—
2	4395.48	5386.43	—	—
3	8.36	10.88	—	—
4	288.12	281.52	0.014	0.007
5	52.73	27.31	0.141	0.078
6	2.21	0.62	—	—
7	2.12	2.64	−1.963	1.052
8	1.55	1.13	—	—
11	11.44	30.51	—	—

Intercept = 20.228; $R = 0.0512$; $F = 1.498$; $N = 303$.

TABLE 32

WIGWAGS AT CROSSINGS

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	40.76	70.34	—	—
2	9773.	8807.77	—	—
3	11.50	11.56	−0.113	0.080
4	242.57	255.80	0.004	0.006
5	63.75	21.17	0.200	0.096
6	2.98	1.36	—	—
7	2.08	1.65	4.04	1.08
8	1.41	0.94	−10.830	5.868
9	29.29	14.21	−0.142	0.082
11	7.03	15.45	—	—

Intercept = 15.90; $R = 0.4356$; $F = 5\ 659$; $N = 303$.

SUMMARY OF EQUATIONS

Crossbucks:

Highway volume below 500 per day:

$$X_1 = X_{10}\,[38.90] \tag{30}$$

Highway volume greater than 500 per day:

Urban

$$X_1 = X_{10}\,[30.57] \tag{31}$$

Rural

$$X_1 = X_{10}\,[30.35] \tag{32}$$

STOP signs:

Highway volume below 500 per day:

$$X_1 = X_{10}\,[45.13 + 2.51\,X_7 + 13.5\,X_6] \tag{33}$$

Highway volume greater than 500 per day:

$$X_1 = X_{10}\,[11.44] \tag{34}$$

Wigwags:

$$X_1 = X_{10}\,[6.06 + 0.02\,X_5 + 0.40\,X_7] \tag{35}$$

Flashing light signals:

Urban

$$X_1 = X_{10}\,[3.23] \tag{36}$$

Rural

$$X_1 = X_{10}\,[9.30] \tag{37}$$

Gates:

Urban

$$X_1 = X_{10}\,[3.23] \tag{38}$$

Rural

$$X_1 = X_{10}\,[1.93] \tag{39}$$

in which

X_1 = accidents per year, scaled by 100;
X_2 = ADT;
X_5 = angle of crossing, acute angle measured in degrees;
X_6 = total number of highway lanes;
X_7 = maximum absoluted approach gradient within 100 ft of crossing; and
X_{10} = probability of coincidental vehicle and train arrival, or

TABLE 33

FLASHING LIGHT SIGNALS AT URBAN CROSSINGS

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	25.67	47.47	—	—
2	11,126.04	10,680.19	—	—
3	13.90	14.63	—	—
6	3.38	1.30	−0.521	0.367
7	1.82	3.23	−0.093	0.144
8	2.15	1.35	−0.026	0.331
9	27.87	17.59	−0.004	0.028
11	3.23	8.50	—	—

Intercept = 5.315; $R = 0.0803$; $F = 0.578$; $N = 361$.

TABLE 34

FLASHING LIGHT SIGNALS AT RURAL CROSSINGS

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	21.49	38.43	—	—
2	4311.97	4801.10	—	—
3	15.07	16.84	0.213	0.115
6	2.36	0.88	−2.713	2.245
7	1.60	2.76	−0.180	0.613
8	1.38	1.04	−1.992	1.642
9	37.02	18.12	−0.164	0.106
11	9.30	34.84	—	—

Intercept = 31 069; $R = 0.1967$; $F = 2\ 865$; $N = 434$.

TABLE 35

GATES AT URBAN CROSSINGS

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	27.952	45.311	—	—
2	8483.80	6118.67	0.099	0.110
3	24.297	17.972	—	—
6	3.000	1.316	−0.953	1.513
7	2.271	6.541	−0.100	—
8	2.590	1.415	0.136	1.428
9	45.108	23.104	0.160	0.090
11	3.231	15.859	—	—

Intercept = 16.869; $R = 0.3025$; $F = 1.276$; $N = 83$.

TABLE 36

GATES AT RURAL CROSSINGS

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	21.93	34.78	—	—
2	2576.35	1527.04	—	—
3	35.36	15.88	—	—
6	2.400	0.809	1.320	0.717
7	2.767	2.913	−0.158	0.207
8	2.378	0.777	0.295	1.017
9	56.067	11.181	0.037	0.068
11	1.928	3.815	—	—

Intercept = − 3.580; $R = 0.3703$; $F = 1.589$; $N = 45$.

$$\frac{X_3}{86,400}\left(1 - e^{-x_2/86{,}400}\right) \qquad (40)$$

in which

X_3 = trains per day; and
X_2 = highway vehicles per day.

DISCUSSION OF VARIABLES

The simple correlations given in Table 37 illustrate the value of the approach used. There is a high correlation between accidents and probability. After accidents have been stratified by urban-rural protection type, and normalized for probability of simultaneous arrival of a vehicle and train, there is a relatively low correlation with other variables.

In summary, the data available indicate that the most important predictors of accidents are vehicle and train volumes, type of protection, and characteristics of urban and rural areas.

Protection Type.—Previous research, in the form of before-and-after studies, has developed relative hazard relationships for the various protection types. Similar relationships were computed for each protection type in this study. The method used was to calculate the mean number of accidents per year per crossing in each protection type. This value was compared with the mean probability of each protection type to form an accident rate. Setting crossbuck protection equal to one, the relative hazard is as follows:

Crossbucks	1.00
STOP signs	0.58
Wigwags	0.34
Flashing lights	0.20
Gates	0.11

These relationships are in general agreement with previous research. The reduction in risk exhibited by the use of automatic devices is evident.

The fact that no difference was found between gates and flashing lights in urban areas was surprising. Perhaps the lower train and highway speeds, street lighting, and other factors, make the use of gates in urban areas less important.

It appears that use of flashing lights and gates greatly reduces the importance of other variables.

The low risk coefficient for STOP signs on higher-volume roads is perhaps due to the fact that cues are provided by observation of other vehicles stopping.

Gradient.—Gradient appears as a factor for low-volume STOP signs, and to a lesser extent for wigwags. Through pure speculation it is believed that gradient would have the effect of causing a significant decrease in actual vehicle speeds. Furthermore, the tendency for vehicles to stall on the tracks is greater when vehicle speeds are slow. This tendency would be even greater when vehicles are required to stop on grades.

Number of Lanes.—Number of lanes appeared as a factor in low-volume STOP signs. A report by Contra Costa County (*7*) stated the opinion that hazard increases as number of lanes increases without regard to highway volume, the basic assumption being that more vehicles can get to the train and that the presence of other vehicles in adjacent lanes can obstruct the view of trains. This theory, coupled with data (*4*) which indicate a poor driver observance of STOP signs at railroad crossings, appears to be a reasonable explanation of the relationship between number of lanes and accidents.

Crossing Angle.—It was observed that for wigwag protection, hazard increases as the crossing angle approaches 90°. Smaller crossing angles bring the train more directly into the drivers view (i.e., the driver does not have to look quite as far to the right and left). Small crossing angles add to the hazard only in those rare instances when the train is traveling faster than the highway vehicle, the train approach is such that the train is behind the highway vehicle, and the placement of the vehicles is just right to allow the train to catch the vehicle on the crossing.

Nontrain-Involved Accident Model

Previous research and data previously presented in this chapter are useful only for predicting accidents involving trains. This section presents a model which will allow the prediction of accidents which occur at railroad crossings but do not involve trains. From data presented in Chapter Two, it can be determined that approximately one-half of the accidents which do not involve the train occur when the train is not present. The other one-half occur when the train is present.

This information dictates that a different basic model be used than was used for train-involved accidents.

If all of the accidents at crossings involved two vehicles, the basic model would include the probability of two vehicles arriving at the same time. However, the fact that 21 percent of the accidents are of a single-vehicle type suggests a different form of the model. The basic hazard index or accident rate generally used at spot highway locations is accidents normalized for number of vehicles. This suggests a regression model of the following form:

$$X_{11} = \frac{\text{Accidents}}{\text{ADT}/100} = K_0 + K_1 V_1 \ldots . K_m V_m \qquad (41)$$

The following variables were included in the analysis:

VARIABLE	DEFINITION
1	Average daily traffic
2	Number of daily trains
3	Highway speed
4	Crossbuck protection
5	STOP-sign protection
6	Wigwag protection
7	Flashing light signal protection
8	Automatic gate protection
9	Accidents per year
10*	Accidents per year/ADT/100

* Dependent variable.

The means, standard deviations, coefficients, and standard errors are given in Table 38. The resulting equation is:

$$X_{10} = 0.00499 + 0.00036\,X_2 + 0.00656\,X_8 \qquad (42)$$

It can be seen that the presence of gates greatly increases the number of nontrain-involved accidents. Adjusting Eq. 42 for the two situations—(1) with gates, and (2) without gates—yields the following:

With automatic gates

$$X_{10} = 0.00866 + 0.00036\,X_2 \qquad (43)$$

or

TABLE 37

SIMPLE CORRELATION OF INDEPENDENT VARIABLES WITH PROTECTION COEFFICIENT

INDEPENDENT VARIABLE	COEFFICIENT FOR PROTECTION [a] A	B	C	D	E	F	G	H	I	J
ADT	0.002	−0.074	−0.065	0.045	−0.093	−0.181	−0.163	−0.111	−0.191	−0.037
No. of trains	−0.030	−0.065	−0.062	−0.096	−0.097	−0.077	−0.026	−0.139	−0.039	−0.208
Sight distance	—	0.022	—	−0.040	+0.098	+0.037	—	—	—	—
Angle	0.019	0.057	0.057	0.045	0.046	0.120	—	—	—	—
No. of lanes	—	0.043	—	0.144	−0.070	−0.051	−0.071	−0.053	−0.122	0.296
Gradient	0.019	−0.057	−0.022	0.054	−0.120	0.069	−0.023	−0.016	−0.083	−0.200
No. of tracks	0.009	−0.031	−0.015	0.036	−0.015	0.081	−0.003	−0.053	0.108	0.144
Train speed	—	0.019	—	—	—	−0.056	0.009	−0.097	−0.085	0.199
SIMPLE CORRELATION OF PROBABILITY OF SIMULTANEOUS ARRIVAL WITH ACCIDENT RATE										
Probability	0.229	0.422	0.333	0.200	0.329	0.400	0.235	0.289	0.523	0.555

[a] A = crossbucks, highway volume < 500/day; B = crossbucks, urban; C = crossbucks, rural; D = STOP signs, highway volume < 500/day; E = STOP signs; F = wigwags; G = flashing lights, urban; H = flashing lights, rural; I = Gates, urban; J = gates, rural.

$$EA = \frac{ADT}{100} [0.00866 + 0.00036 X_2] \quad (44)$$

All other protection types

$$X_{10} = 0.00499 + 0.00036 X_2 \quad (45)$$

or

$$EA = \frac{ADT}{100} [0.00499 + 0.00036 X_2] \quad (46)$$

where EA represents expected nontrain-involved accidents per year.

The result of one of these equations, added to the result of the equations which predict expected train-involved accidents, allows prediction of the total number of accidents which can be expected to occur at a railroad crossing.

TABLE 38

NONTRAIN-INVOLVED ACCIDENTS

VARIABLE	MEAN	STD. DEV.	COEFF.	STD. ERROR
1	2805.94	3689.02	—	—
2	8.13	10.10	0.00036	0.00006
3	44.16	10.27	−0.00001	0.00007
4	0.22	0.42	−0.00003	0.00187
5	0.01	0.11	−0.00200	0.00576
6	0.01	0.07	−0.00375	0.00835
7	0.20	0.40	—	—
8	0.56	0.50	0.00656	0.00180
10 [a]	0.01	0.02	—	—

Intercept = −0.00499; $R = 0.28$; $F = 13.38$; $N = 1107$.
[a] Dependent variable.

USE OF THE MODEL

Probability of Coincidental Arrivals as a Function of Time of Day

The average daily traffic can be spread over the day by the following factors:

TIME	FACTOR	TIME	FACTOR
Midnight – 1 AM	0.012	Noon – 1 PM	0.059
1 – 2	0.009	1 – 2	0.062
2 – 3	0.006	2 – 3	0.066
3 – 4	0.007	3 – 4	0.073
4 – 5	0.011	4 – 5	0.081
5 – 6	0.015	5 – 6	0.077
6 – 7	0.036	6 – 7	0.063
7 – 8	0.049	7 – 8	0.046
8 – 9	0.059	8 – 9	0.033
9 – 10	0.056	9 – 10	0.030
10 – 11	0.055	10 – 11	0.023
11 – Noon	0.052	11 – Midnight	0.020

There is naturally some variability in these values, but they are representative of the general trend noted in both rural and urban locations. For the arrival of vehicles within an hour, assuming randomness, and returning to the hypothesis used in the model, it is possible to use

$$V_h = C_h V \quad (47)$$

in which V is the average daily traffic and C_h is the factor in the foregoing table for $h = 1, 2, 3, \ldots 24$.

The value of this added amount of sophistication over making the simple assumption that traffic is random throughout the day, and over the linear "exposure approximation," is very small. If one were only concerned with the probability of a vehicle arrival in a randomly chosen second from a 24-hr period, it would hardly be worth the effort to make this adjustment. There is, however, a very valid use for this breakdown. First, the consideration of daylight hours as differentiated from dark hours has a remarkably wide variation within a year. To be as precise as possible, it would be necessary to consider the changing hours of sunrise and sunset throughout the year, and couple this with the seasonal rise and fall in traffic volumes. Such manipulations are not possible if one were to make the assumption that traffic is random in a 24-hr period.

Second, if a railroad has an unscheduled freight passing a given intersection between 1:00 AM and 5:00 AM, it is hardly fair to include the chances of a collision with the evening peak-hour traffic. This is, of course, a question which will arise when the results of this study are to be applied and the engineer will be required to use reasonable judgment at that time. The more detailed the scheduling is, the more accurate the results will be; however, the assumption of randomness can be applied at any level without the resulting estimates being rendered useless.

Considerable improvement in the prediction of accidents could be expected if information could be obtained on hourly rail and train volume, if only because the probability of coincidental arrivals would be known more precisely. Because different risk coefficients are known to exist for day and night, it is reasonable to expect that the Poisson risk relationship for one time of day would be more highly correlated with accident experience than for another time of day. Data from the cities of Lincoln, Nebr., and Houston, Tex., enabled exploration of these relationships. For each of 124 crossings in Lincoln and 240 in Houston, it was possible to obtain day and night highway and train volumes, as well as the accident experience of the crossings. Data were not available on the day-night distribution of accidents.

Two regression equations were structured. Both equations used accidents per year as the dependent variable. One allowed the 24-hr probability, normalized for protection types to enter; the other allowed day probability and night probability normalized for protection type to enter separately. Although neither equation was statistically significant, it was possible to draw some useful inferences.

The simple correlations of accidents with the three time interval probabilities normalized for protection type are given in Table 39.

Using a 24-hr probability function as the independent variable, $r = 0.164$ was obtained. Day probability and

TABLE 39

ACCIDENTS AND RELATIVE HAZARD BY LIGHT CONDITION

	CORRELATION	RELATIVE HAZARD DUE TO LIGHT CONDITION
Accidents	1.000	—
Day	0.106	0.65
Night	0.234	1.42
24-Hour	0.164	1.00

night probability as independent variables produced $r = 0.236$.

The simple correlations and r-values add strength to the theory that more precise information on the probability of coincidental arrivals provides a better estimate of accidents.

Figure 24 presents the train-involved accident model in a simple graphic form that allows easy computation of accidents per year at any type of roailroad crossing.

The equation can be used in several ways, as follows:

1. On an ADT and daily train volume basis.
2. On a partial day basis.
3. On an hourly basis.

If available information provides only average daily vehicle volumes and average daily train volumes, one solution of the equation is all that is possible. If the available information gives the actual hours when trains operate through the crossing, the expected accidents could be calculated using the vehicle and train volumes for each hour of the day.

In some cases, the volume of scheduled trains is known, but it is also known that a certain number of unscheduled trains operate through the crossing. In those cases, expected accidents could be calculated for scheduled trains using hourly figures and for unscheduled trains using daily traffic figures.

In short, this is a technique which permits calculation of expected train-involved accidents at any level of detail, depending on the detail of the available data.

It seemed that most agencies would not want to collect information on every crossing down to the detail of hourly train and vehicle volumes. However, they might wish to calculate the expected accidents for all crossings on an ADT basis and then make detailed studies of, say, 50 or so crossings with the highest numbers of expected accidents to get a more precise estimate of the accideut potential for those crossings.

Typical calculations are as follows:

Given:

ADT = 5,000.
Daily trains = 10.
Protection = Crossbucks.
Environment = urban.
Expected train accidents/year, $EA = B\ A\ T$ (48)

B = Basic value + Correction factors
Basic value = 3.06
Correction factor = 0.00
Total = 3.06
A factor = 0.006516
EA = 3.06 × 0.006516 × 10 = 0.200 accidents per year, or one accident every 5 years.

If it is known that two of the ten trains operate sometime between 6:00 AM and 6:00 PM (daylight) and eight operate sometime in the night hours, and it is further known, or estimated, that 75 percent of the vehicular traffic operates during daylight hours and 25 percent during night hours, the expected accidents are developed by solving the equation in two steps, as follows:

$$\text{Expected accidents in daylight} = A_D T_D B\ (0.7) \quad (49)$$

$$\text{Expected accidents in dark} = A_N T_N B\ (1.4) \quad (50)$$

in which

A_D = the A-factor based on daytime vehicle volume;
T_D = number of trains in daytime;
0.7 = special factor for all daylight operation;
A_N = the A-factor based on nighttime vehicle volume;
T_N = number of trains in the night hours; and
1.4 = special factor for night operation.

The sum of the daylight and dark accidents is the total expected accidents for the crossing. That is,

$EA_{daylight} = 3.06 \times 0.009641 \times 2 \times 0.7 = 0.04.$
$EA_{dark} = 3.06 \times 0.003304 \times 8 \times 1.4 = 0.11.$
EA = 0.15, or one accident in 7 years.

If it is further known that the trains operate on schedule during the day, as follows:

1 train between 7 and 8 AM
1 train between noon and 1 PM
1 train between 1 AM and 2 AM
7 trains unscheduled, hut at night.

And it is known that the hourly vehicle volumes are 500, 300, 100, and 1,250, respectively, for those hours, the expected accidents become:

EA (7-8 AM) = 3.06 × 0.015012 × 1 × 0.7 = 0.032
EA (Noon-1 PM) = 3.06 × 0.009259 × 1 × 0.7 = 0.020
EA (1-2 AM) = 3.06 × 0.003169 × 1 × 1.4 = 0.014
EA (unsched.) = 3.06 × 0.003304 × 7 × 1.4 = 0.096

The total is 0.162, or one accident in slightly over 6 years.

This illustrates what is believed to be an important point. For three crossiugs with roughly equivalent conditions, but with different hours of train operations, it can readily be seen that the expected accidents could be greatly different. As an example, suppose one crossing had all ten trains operating in hours with volumes in the 500-vehicle range. Its expected accideuts would be nearly 0.5 per year. However, a crossing with ten trains operating at night when volumes are around the 100 level would have an EA of approximately 0.14 per year.

To obtain the partial day, or hourly, A-factors, the ratio of actual to average volumes was multiplied by the average volume. Thus, EA PER YEAR= AxBxTRAINS PER DAY

VEHICLES PER DAY	'A' FACTOR
250	.000347
500	.000694
1000	.001377
2000	.002627
3000	.003981
4000	.005208
5000	.006516
6000	.007720
7000	.009005
8000	.010278
9000	.011435
10000	.012674
12000	.015012
14000	.017315
16000	.019549
18000	.021736
20000	.023877
25000	.029051
30000	.034757

EXAMPLE:

ASSUME

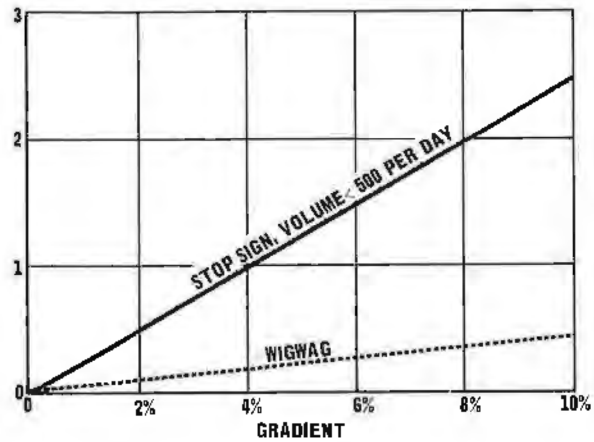
URBAN AREA
CROSSBUCK PROTECTION
5000 VEHICLES PER DAY
5 TRAINS PER DAY

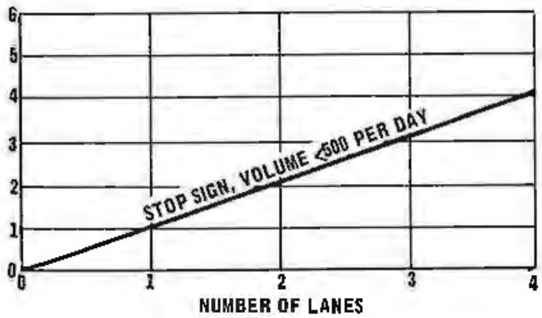
EXPECTED ACCIDENTS

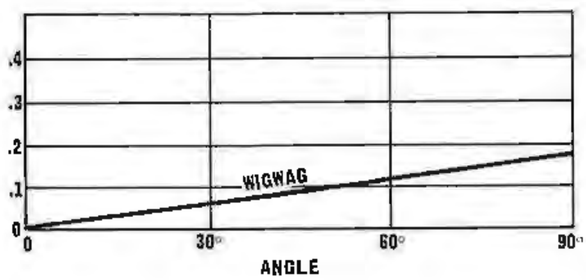
EA=.006516 x 3.06 x 5
EA=0.100
EA=1 ACCIDENT EVERY TEN YEARS

'B' FACTOR COMPONENTS
('B' FACTOR=BASIC VALUE + ADJUSTMENTS[1])

BASIC VALUES	
A-Crossbucks, highway volume less than 500 per day.	3.89
B-Crossbucks, urban	3.06
C-Crossbucks, rural	3.03
D-Stop signs, highway volume less than 500 per day.	4.51
E-Stop signs	1.15
F-Wigwags	0.61
G-Flashing lights, urban	0.32
H-Flashing lights, rural	0.93
I-Gates, urban	0.32
J-Gates, rural	0.19







[1]Adjustment equals zero if protection type is other than stop sign with volume less than 500 or wigwag.

Figure 24. Calculation of expected accidents.

Example 2:

Daylight volume $= \frac{0.75 \times 5{,}000}{2{,}500} \times 5{,}000 = 7{,}500$ = ADT to be used for *A*-factor in Figure 24, from which $A = 0.07179$.

Dark volume $= \frac{0.25 \times 5{,}000}{2{,}500} \times 5{,}000 = 2{,}500$ = ADT to be used for *A*-factor in Figure 24, from which $A = 0.02486$.

Example 3:

Volume for 7:00 to 8:00 AM $= \frac{500}{208} \times 5{,}000 = 12{,}000$, and $A = 0.11081$, where 208 = average hourly volume for a 24-hr day when ADT = 5,000.

Volume for Noon to 1:00 PM $= \frac{300}{208} \times 5{,}000 = 7{,}200$, and $A = 0.06905$.

Volume for 1:00 to 2:00 AM $= \frac{100}{208} \times 5{,}000 = 2{,}400$, and $A = 0.02388$.

The actual test of the predictive equation is not to apply it to an individual crossing and expect it to predict the exact number of accidents which have occurred there in the past three years. Accidents can not be scheduled or programmed to occur at certain times in the past or future for a precise time period.

However, based on mass data analysis of past history, the predictive equation should be a better indication of the number of accidents which will occur at a specific location than even that location's history. Too often, highway engineers are pressured into expending funds for "improvements" based on one or two spectacular accidents.

CHAPTER SEVEN

WARRANTS AND PRIORITY

Although it is possible to make some advances in automatic devices which operate the signals, it is clear that, with the great number of crossings which exist, some device less expensive than lights or gates and more effective than existing warning signs must be found for a large number of crossings. It is also clear that a better means of determining which crossings warrant special protection must be adopted. The *Manual on Uniform Traffic Control Devices for Streets and Highways* (*24*) does not offer a specific warrant for the application of automotive devices. It states:

> Automatic signals or automatic signals and gates of the type described herein shall be installed at railroad-highway grade crossings where a study of the crossing by competent engineers indicates a need for advance warning of the approach of trains. This assembly of devices shall be used for no other purposes.

The same manual distinguishes between gates and flashing lights through reference to Bulletin No. 6, *Recommended Practices, Railroad-Highway Grade Crossing Protection* (*2*), which states:

> In general, the highway crossing signal without gates is recommended for single track crossings. However, highway crossing signals with gates may be used for single track crossings when mutually agreed upon by railroad and public authority.

As a general rule, research has concentrated on ranking crossings on a system of streets or highways so that those with the greatest accident potential may be identified. From such a rank order listing, the top ten or so can be selected as a goal, or a fixed budget for crossing protection can be applied to those at the top of the list. This does not say, however, whether others on the list should be protected or at what point investment in protective devices ceases to be productive. Also, one crossing may have a higher accident potential than another, but the reduction in accident potential which could be obtained by installing higher-type protection might be greater for the second crossing than for the first.

A recent report by Newnan (*17*) presents a comprehensive economic analysis, including warrants and priority assignment. This report is recommended to individuals charged with the responsibility of determining which crossings warrant improved protection and assigning priority to crossings within a group.

Any crossing where the savings in accidents are equal to or greater than the cost of installing improved protection, warrants installation of such protection. The approach is as follows:

Determine the predicted number of accidents with existing conditions and with possible improvements for any crossing. Determine the number of accidents saved by subtracting the one from the other and apply a monetary value to the savings. This value then represents the benefit. Take the annual cost of providing and maintaining an improvement. If the benefit is greater than the cost, the improvement is warranted.

The cost factors used in this report are as follows:

One death	=	\$20,000
One nonfatal injury	=	\$ 5,000
Property damage per accident	=	\$ 1,000

Using the ratios of deaths and injuries per accident including trains for a 10-year period in Minnesota, the following costs were obtained per predicted train accident:

0.2 deaths	@ \$20,000	=	\$ 4,000
0.6 injuries	@ \$ 5,000	=	\$ 3,000
1.0 property damage	@ \$ 1,000	=	\$ 1,000
Total			\$ 8,000

Using the ratios of deaths and injuries per nontrain-involved crossing accidents for a 2½-year period in Illinois, the following costs were obtained per predicted accident:

0.1 deaths	@ \$20,000	=	\$ 2,000
0.2 injuries	@ \$ 5,000	=	\$ 1,000
1.0 property damage	@ \$ 1,000	=	\$ 1,000
			\$ 4,000

Using the following estimated costs of special devices, an annual cost was obtained:

Flashers = \$ 10,000;
amortization = \$ 1,000/year

Gates = \$ 20,000;
amortization = \$ 2,000/year

Grade separation = \$200,000;
amortization = \$10,000/year

Annual maintenance costs:*

Flashers	=	\$300
Gates	=	\$600

Annual costs:

Flashers	=	\$ 1,300
Gates	=	\$ 2,600
Grade separation	=	\$10,000

Thus, the difference in predicted accidents per year required to warrant special protection would be:

Flashers $\frac{8{,}000\ (\text{EA saved/yr})}{1{,}300} \geq 1$; EA saved/year ≥ 0.16

Gates $\frac{8{,}000\ (\text{EA saved/yr})}{2{,}600} \geq 1$; EA saved/year ≥ 0.32

Grade separation $\frac{8{,}000\ (\text{EA saved/yr})}{10{,}000} \geq 1$; EA saved/year ≥ 1.25

Figure 25, which presents this method in simple graphic form, allows preliminary analysis, based on costs and probability of simultaneous vehicle and train arrivals, to be made on a large group of crossings. A more detailed analysis using Figure 24 should be made for crossings which appear to warrant (or nearly warrant) improved protection.

Figure 25 shows that flashing lights or automatic gates are economically warranted at only a limited number of crossings which have extremely high vehicle and train traffic. Grade separations are almost never warranted on a hazard basis because a much greater rate of return can be accomplished with flashing lights or gates. On a systems basis they can sometimes be warranted because of vehicle delays.

Using a general warrant of this type, any jurisdiction could calculate its own specific warrant based on accident costs, cost of installing and maintaining signals, and other factors. In choosing the specific type of protection to be provided, due consideration could be given to delays to vehicles. For example, if gates would result in extensive delays to vehicles because of heavy switching movements near the crossing, flashers might be recommended.

It is recognized that the results of this study do not adequately take into account many factors which influence safety at a crossing. Many subjective factors other than those available in quantified form can have a bearing on the hazard. Factors which should be considered include the sight distance, depending on vehicle speeds, the visibility of the crossing, the speeds of trains, and any detracting elements in the vicinity of the crossing. Where unusual or unique situations are present, engineering judgment should be exercised concerning the possible need for lowering these warrants.

Having determined at which crossings improvements are warranted, priorities can be assigned by using the benefit/cost ratio. Crossings having the greatest potential hazard are not necessarily the ones which should be improved first. Priorities should be based on the rate of return on the investment. Thus, the crossing having the greatest benefit/cost ratio would receive the highest priority.

Example:

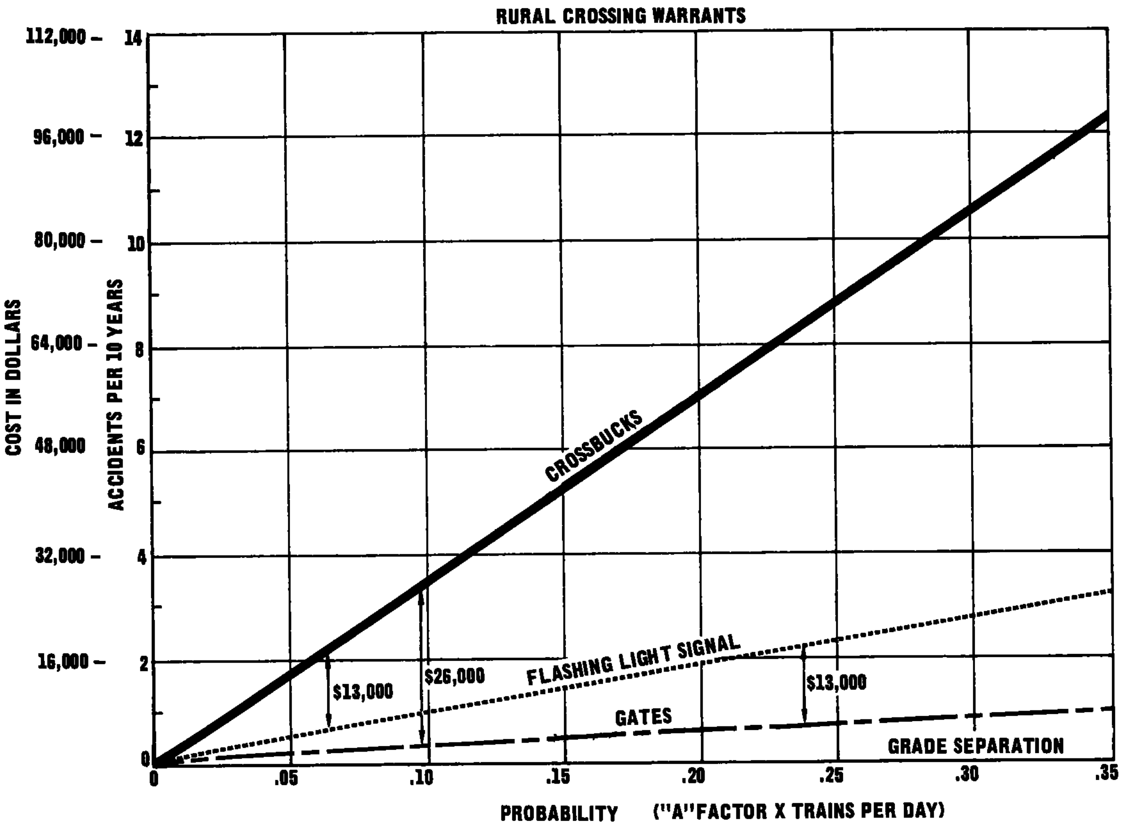
A public agency or railroad has ten crossings under its jurisdiction. The crossings have the following protection types, train volumes, and coincident highway volumes:

CROSSING NO.	URBAN OR RURAL	PROTECTION TYPE	TRAIN VOL. [b]	COINCIDENT HIGHWAY VOLUME [a]
1	Rural	Wigways [c]	20	10,000
2	Urban	Crossbucks	10	5,000
3	Rural	Crossbucks, ADT <500	12	300
4	Rural	Gates	7	4,000
5	Urban	Gates	25	25,000
6	Rural	Crossbucks	5	5,000
7	Urban	Flashing lights	2	30,000
8	Rural	Flashing lights	15	4,000
9	Urban	Crossbucks	25	25,000
10	Rural	Crossbucks	30	15,000

[a] See sample calculations of coincident volumes in Chapter Six.
[b] Adjusted for day and night train arrivals; see Chapter Six.
[c] 2% highway approach grade, 90° angle of crossing

It is desired to determine which crossings warrant improvement and to determine the priority for the improvements. First, the expected number of annual accidents with the existing protection type is determined, as follows:

* Annual maintenance costs presented here represent the lower values of the wide range over which the costs vary.



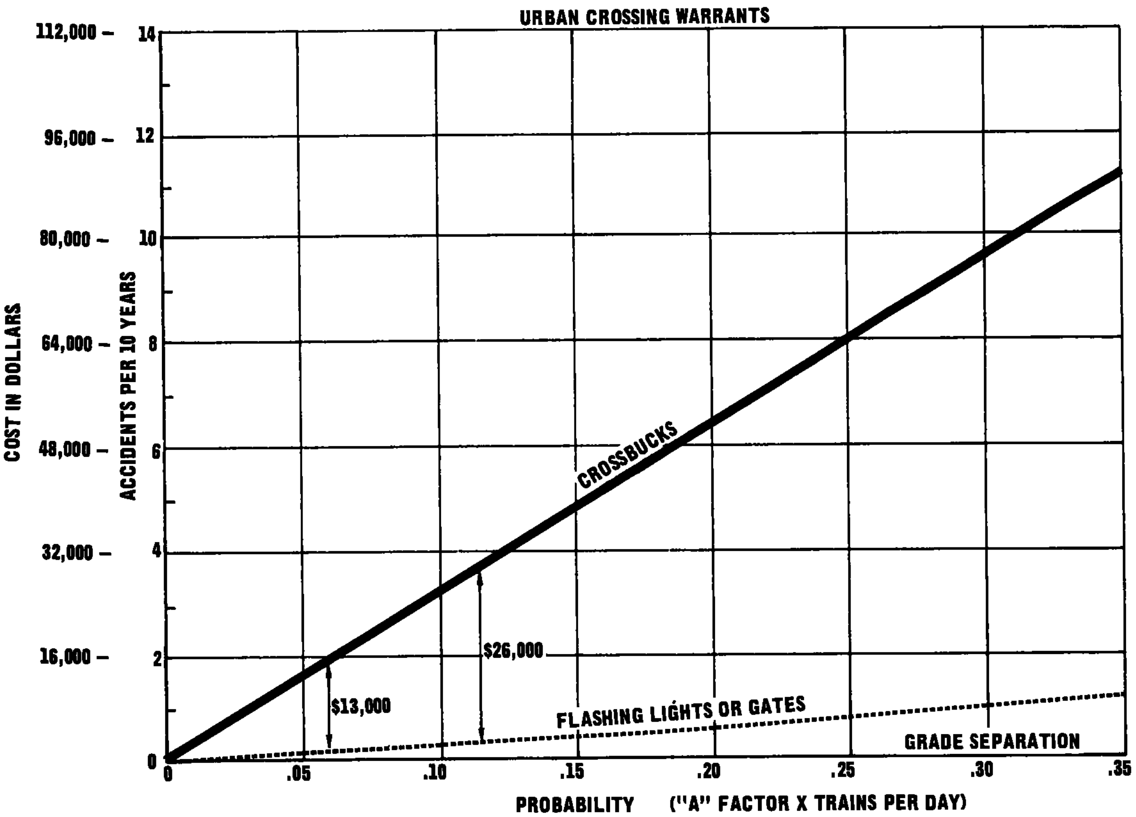


Figure 25. Warrants for improved protection.

CROSSING NO.	B FACTOR	×	A FACTOR	×	TRAIN VOL.	=	EXPECTED ACCIDENTS
1	0.61 + 0.17 + 0.15 = 0.93		0.012674		20		0.236
2	3.06		0.006516		10		0.199
3	3.89		0.000416		12		0.019
4	0.19		0.005208		7		0.007
5	0.32		0.029051		25		0.232
6	3.03		0.006516		5		0.099
7	0.32		0.034757		2		0.022
8	0.93		0.005208		15		0.073
9	3.06		0.029051		25		2.222
10	3.03		0.018432		30		1.676

Possible improvements at each crossing are then listed, along with their costs, corresponding savings in accident costs, and the ratio of benefit to cost.

CROSSING NO.	POSSIBLE IMPROVEMENTS	ADD'L. COST PER 10 YEARS ($)	ACCIDENT SAVINGS [a] ($)	BENEFIT/ COST RATIO
1	Flashing lights	5,000	0	0
	Gates	18,000	15,008	0.84
	Grade sep.	100,000	18,856	0.19
2	Flashing lights	13,000	14,280	1.10 *
	Gates	26,000	14,280	0.55
	Grade sep.	100,000	15,952	0.16
3	Flashing lights	13,000	1,184	0.09
	Gates	26,000	1,472	0.06
	Grade sep.	100,000	1,552	0.02
4	Grade sep.	100,000	552	0.01
5	Grade sep.	100,000	18,592	0.19
6	Flashing lights	13,000	5,472	0.42
	Gates	26,000	7,400	0.28
	Grade sep.	100,000	7,896	0.08
7	Gates	13,000	0	0
	Grade sep.	100,000	1,776	0.02
8	Gates	13,000	4,624	0.36
	Grade sep.	100,000	5,808	0.06
9	Flashing lights	13,000	159,112	12.23 *
	Gates	26,000	159,112	6.16 *
	Grade sep.	100,000	177,776	1.78 *
10	Flashing lights	13,000	92,888	7.14 *
	Gates	26,000	125,592	3.57 *
	Grade sep.	100,000	134,040	1.34 *

[a] Accident savings $= 10\,C\,(EA - \frac{B_f}{B_t}\,EA)$

in which accident savings is dollar benefit of improvement in 10-year period;

C = cost of an accident;
B_f = B-factor for possible improvement;
B_t = B-factor for existing protection; and
EA = expected accidents per year.

Improvements are warranted at three of the ten crossings. Improvements which are warranted are indicated with an asterisk. If $213,000 is expected to be available during the next ten years the following improvements would be made, with priorities based on the ratio of benefit to cost:

CROSSING NO.	IMPROVEMENT	PRIORITY
2	Flashing lights	3
9	Grade separation	1
10	Grade separation	2

If $139,000 will be available the following improvements would be made:

CROSSING NO.	IMPROVEMENT	PRIORITY
2	Flashing lights	3
9	Grade separation	2
10	Gates	1

If $39,000 will be available, the improvements would be:

CROSSING NO.	IMPROVEMENT	PRIORITY
9	Flashing lights	1
10	Gates	2

In each of the foregoing three cases there are alternative improvements which could be made with the available funds. However, it should be noted that in each case the improvements selected were those within the budget constraints which yield the greatest benefit in accident savings.

CHAPTER EIGHT

FUTURE RESEARCH

It is readily apparent from the review of previous research (Appendix A) that a great amount of research has been done. However, during the course of this study it was found that many types of information were not available. Other information was available only in part. In addition, in some cases, whole subjects were beyond the scope of this report. The purpose of this chapter is to outline topics for future research, and to suggest the methodology or approach.

TESTING OF PROPOSED DEVICES

First in the order of importance is the need for further testing of the devices proposed in Chapter Five. The only real test of these devices will be for a state, county, city, or railroad to adopt them, install them at many crossings and observe them for a long period of time. During that time, speed studies, interviews of drivers, and observance studies should be made periodically. Installation of these devices should be accompanied by an extensive public relations and education campaign.

TRAIN VISIBILITY

It is recommended that a controlled study of train visibility be initiated. This study would involve the application to trains of a color known to be of value under poor visibility conditions. The application of such a color, probably yellow, to the engine and subsequent two or three cars of the train would be of particular interest. In addition to color, various lighting schemes, which might improve the ability of the motorist to detect a train at night, could be used. For example, a rotating beam which shines more into the air might allow the motorist to detect the train before he could actually see it. A lighted panel along the length of the locomotive, and other lighting arrangements, could be tested.

The main purpose of an experiment of this type would be to determine the value of various color and light arrangements in reducing day and/or night accidents.

AUTOMATIC DEVICES

There is a great need for the development of a less expensive method of activating signals, gates, and bells which warn of a train's approach. Existing devices, although effective in reducing accidents, are costly to install and maintain. A benefit-cost ratio greater than one for installing flashing lights or gates can be obtained at only a small number of crossings. Future research in this area should be aimed at some method of activation other than track circuitry. Track circuitry was invented in 1872. Since that time many refinements have been made. Recent improvements, however, have simply led to increased costs, and all have been dependent on track circuitry. The current state of electronics, radio, radar, etc., should allow individuals who are knowledgable in these areas to devise a method of *activation* which would be considerably less expensive than that currently being used.

It appears that "high-speed" trains will become a nationwide reality in the near future. As this time approaches it is necessary that consideration be given to their impact upon safety at highway-rail grade crossings. It is expected that railroad lines equipped for high-speed train operation will have considerably more rail traffic than is usual today.

High-speed trains can be expected to necessitate the closing of some crossings, and the installation of automatic devices at others. Other requirements in connection with high-speed trains should be a new method of activating the devices. The state of present-day technology is not only such that it will allow such innovations, but also these innovations can be said to be overdue. Safety criteria may also require improved indications to the motorist and perhaps improved barriers which would allow the motorist to crash through one with little or no damage to his automobile, with a subsequent distance in which to either bring his vehicle to a stop or crash into a second energy-absorbing barrier. High-speed trains would occupy the crossing for shorter intervals of time, thus decreasing the need for grade separations based on vehicle delay. It is recommended that a study be initiated in the very near future with a goal of designing and testing new methods of activating devices. The methods should be applicable to crossings with high-speed train operation.

THE FAMILY OF INTERMITTENT HAZARDS

Future research should include a study of the family of devices used for such intermittent hazards as railroad crossings, school crossings, plant entrances, stadiums, fire stations. An effort has been made to adapt traffic signals to these locations. All are similar in that the hazard, congestion, etc., exists only during certain portions of the day. This creates a problem in that motorists accustomed to passing the location at only certain times of the day tend to disregard the signal. Then on the one day that they pass the location at a different time, they encounter the hazard. For situations such as trains, where scheduling can often be predetermined, complacency could be alleviated by a flashing yellow indication during certain hours. Further study should be undertaken to determine whether a standard three-color signal head or some other type of indication should be used at these locations.

Further study is also needed to determine the sequencing of the indications. At the present time there is a complete lack of uniformity in this area. Several types of devices are being used at railroad crossings, including two- and three-color traffic signals. Beacons are used at school crossings, as well as traffic signals. Where traffic signals are used, the sequence of indications given to the motorist at these locations vary, depending on the political jurisdiction in charge of installation and maintenance. Flashing greens, flashing yellows, flashing reds, and even dark signals, can each be found in certain areas of the country. Further study of the family of intermittent hazards is needed to establish uniform criteria for all of these locations.

REQUIREMENT THAT CERTAIN VEHICLES STOP AT ALL CROSSINGS

Another area in need of further study is the requirement that certain vehicles stop at all crossings. This requirement exists in many state regulations and in federal regulations as applied to interstate commerce. In one state, because of the way the law is written, it is required that certain vehicles even stop at railroad grade separations. This requirement is certainly not enforced, but it does serve to indicate the lack of attention which has been given to this legislation in recent years. There are some locations where it is exceedingly unwise to stop any group of vehicles. At other locations, stops are unnecessary and are a needless expense to the motorists.

The requirement states that certain types of vehicles must stop unless they are given an indication by a signal or flagman to proceed. The standard flashing light signal does not provide such an indication. An effort to alleviate the hazard caused by needless stopping of certain vehicles on high-volume highways has lead to the installation of two- and three-color traffic signals at many railroad crossings. In this case, it has been easier to circumvent the requirement, by installing a nonstandard device, than to change the regulation.

It is required under interstate commerce regulations that certain highway vehicles report all highway accidents in which they are involved. The same requirement applies to railroads in that they must also report all accidents. It is recommended that these two types of information be correlated to provide statistics on the numbers of train-involved accidents which also involve highway vehicles required to stop at railroad crossings. Additionally, it is recommended that statistics be tabulated on the numbers of nontrain-involved accidents which involve highway vehicles required to stop at railroad crossings. In addition to collecting the accident data, it is also recommended that the annual vehicle-miles driven by each of the various vehicle types which fall under interstate commerce regulations be collected. The accident rates for these vehicles at railroad crossings could be compared with accident rates for other commercial highway vehicles. This information would allow an economic evaluation to be made of the requirement.

The merits of the requirement, in its existing form, are obviously questionable.

PASSING LANES AND BARRIER LINES

Sufficient information was not available concerning the value of providing passing lanes at crossings, which would allow vehicles required to stop to pull off the pavement, thus allowing other vehicles to pass. There are two schools of thought on this subject. One is that vehicles which are required to stop should be removed from the traffic stream to alleviate the hazard which they create. The other, however, is that provision of a shoulder lane encourages other vehicles to pass at these locations and that the vehicles occupying the shoulder lane are so large that they obstruct the view of the passing vehicles, thus increasing the likelihood of an accident with a train. This question could be almost eliminated if there were not the requirement that certain vehicles stop at all crossings.

DATA COLLECTION

There is a strong correlation between information collected in inventories on a routine and regular basis, and research. Because certain relationships between accidents and various factors have been found to exist in a qualitative way in this report, the following is presented not simply for possible future research, but also for inclusion in future inventories.

Collection of accident data as it occurs is generally the most efficient way to obtain data for a specific study. Data collected in this manner are more reliable than data which were collected for other purposes. Consequently, more confidence can be placed in them, and better results can be obtained. Utilizing past data can be costly and in some cases is impossible.

In this particular study it was not possible to obtain many of the data which were desired. For example, accident data were generally referenced only to a crossing, and the accident data so referenced were only of one type; namely, those involving trains. This is one of the main problems with every accident model which has been developed, including the one presented in this report. At each crossing there are four quadrant sight distances, two highway sight distances, and four railroad sight distances. Also there are two highway approach speeds, two approach gradients, and sometimes even different protection types for different approaches. Many crossings have more than two approaches. For each accident, the hazard is associated with only one of each of these variables. In each of the eight or nine equations which have been developed, efforts have been made to relate the accidents to the minimum or average value of these variables, resulting in a masking of the true relationships.

The recommendations for a future study of this type can be categorized by three kinds of information which should be collected. They are:

1. Physical features at the crossing.
2. Train and highway volume data.
3. Accident data.

Physical features and volume data should be collected annually. Changes made during a year should be recorded by date to avoid the loss of a full year of data.

Physical Features at the Crossing

In coding information on physical features, each approach should be considered separately. For each approach the following data should be recorded:

1. Protection type. This information should be in sufficient detail to include precise locations and types of devices, including both signs and devices at the crossing and on the approach.
2. Number of railroad tracks, by type.
3. Number of highway lanes, pavement width, shoulder widths and type, type of surface, divided or undivided, and degree of access control.
4. Angle of crossing. It is suggested that the same angle be measured at all crossings; i.e., the near right or near left, and not simply the acute angle.
5. Sight distances. The railroad and quadrant sight distances should be recorded by quadrant. The measurement of quadrant sight distances should be consistant but the method used should incorporate highway speed and train speed.
6. Crossing length and width.
7. Approach gradient.
8. Horizontal railroad and highway alignment.
9. Type of area. Urban within ranges of population, urban fringes, rural, etc.
10. Motorist distractions. This item includes number of driveways, by type and location, within the influence of the crossing; location of intersections, advertising signs, highway signs, and control devices, and location of curb parking spaces, where applicable, etc.
11. Illumination. Both type and amount should be recorded.
12. Pavement markings.

Train and Highway Volume Data

Information on train and highway volume should be collected—by train. Scheduled trains should be recorded by arrival periods. For example, if the train is regular the arrival time could be coded to an accuracy of 1 hr (for example, 3 to 4 AM). Less regularly scheduled train arrivals might necessitate that they be coded to the nearest 2, 3, 4, or more hours.

Where trains are unscheduled, the approximate number of such trains should be recorded. Even many trains which are termed unscheduled can be assigned to a finite period of the day less than 24 hr. Where trains are scheduled but are not daily, this should be indicated, with a special code for each of the different combination of days in the week.

For each crossing, the total trains per day and average daily traffic should also be recorded.

Information of this type is readily available from most railroads. In addition to the number of trains within finite arrival times, the following information should also be collected:

1. Number of highway vehicles within the same time period. This information should be directional.
2. Approximate percentage of highway vehicles represented by trucks and buses.
3. Type of train.
4. Speed of train.
5. Average length of train.
6. Direction of train.
7. Highway speed. This item should be actual speed rather than the legal speed limit and should be measured both at the crossing and on each approach prior to the influence of the crossing. Mean and 85th percentile speeds should be recorded.

Accident Data

Accident information should be coded, with a separate card for each accident. All accidents within the influence of the crossing, not simply those in which a train was involved, should be recorded. The involvement or presence of a train should be referenced to that particular train, if it is scheduled. Considerable care should be taken to insure that the accident is referenced to the proper highway approach and quadrant. If a nonscheduled train was involved or present, that too should be indicated. If the accident involved a fixed object, the type and location of the object should be indicated. Information should be collected on skidding prior to the collision. The age and type of vehicle should be recorded. Drivers should be tested for presence and concentration of alcohol. The prior driving record (violations and accident experience) of each driver should be recorded. Data on physical defects (vision, hearing, use of limbs, etc.) should be obtained from public records or personal physicians. Other items, such as age of driver, number of passengers, whether windows were up or down, date and time of accident, weather, and other distracting elements should be recorded.

Collecting the information in this way would insure that the hazard is related to at least the proper set of variables and not to a group of data entirely unrelated to the accident.

For a study of this type, several data cards would be required for each crossing. However, statistically valid information could be obtained from a much smaller group of crossings with the data referenced to approach and quadrant.

Because of the necessity that the data be collected in mass to allow statistically valid results, and because it is difficult for any single jurisdiction to assemble the required amounts of data within a reasonable length of time, it is recommended that a single agency assume the responsibility for uniform data collection.

It is recommended that the analysis of the data include the basic model forms presented in this report. For comparison purposes, the analysis should be made on a daily volume, a day-night volume, and more precise time periods which would be as accurate as the data would allow.

REFERENCES

1. *A Policy on Geometric Design of Rural Highways.* Amer. Assn. of State Highway Officials, Washington, D. C. (1966).
2. *Railroad-Highway Crossing Protection — Recommended Practices.* Bull. No. 6, Assn. of American Railroads, Washington, D. C. (1966).
3. BAERWALD, J. E., ET AL., *Traffic Engineering Handbook.* Inst. of Traffic Engineers, Washington, D. C. (1965).
4. BEZKOROVAINY, G., and HOLSINGER, R. G., *The Use of Stop Signs at Railroad Crossings, City of Lincoln.* Lincoln, Nebr. (1966).
5. *Railroad Crossing Accidents on State Highways, Calendar Year 1963.* Colorado Dept. of Highways (Oct. 1964).
6. COMROE, J. H., ET AL., *The Lung.* P. 171. Year Book Publishers, Chicago (1955).
7. "Conflicts at Grade Crossings, a Theoretical Analysis." Contra Costa County (Calif.) Highway Dept. (Unpubl.)
8. HEDLEY, W. J., "The Achievement of Railroad Grade Crossing Protection." *Amer. Railway Eng. Assn. Proc.,* Vol. 50, pp. 849-864 (1949).
9. *A Course in Elementary Meteorology.* Pp. 47–51. H. M. Stat. Off., London (1961).
10. *Uniform Vehicle Code.* Nat. Comm. on Uniform Traffic Laws and Ordinances, Washington, D. C. (1966).
11. *Accident Facts.* Nat. Safety Council, Chicago, Ill. (1960).
12. *Accident Facts.* Nat. Safety Council, Chicago, Ill. (1961).
13. *Accident Facts.* Nat. Safety Council, Chicago, Ill. (1962).
14. *Accident Facts.* Nat. Safety Council, Chicago, Ill. (1963).
15. *Accident Facts.* Nat. Safety Council, Chicago, Ill. (1964).
16. *Accident Facts.* Nat. Safety Council, Chicago, Ill. (1965).
17. NEWNAN, D. G., *An Economic Analysis of Railway Grade Crossings on the California State Highway System.* Inst. in Eng. Economic Systems, Stanford Univ. (June 1965) 207 pp.
18. "Relative Hazards at Railroad Grade Crossings on State and Federal-Aid Highway Systems, 1957." *Tech. Rep. No. 59-5,* Oregon Highway Comm. (1959) 111 pp.
19. PEABODY, L. E., and DIMMICK, T. B., "Accident Hazards at Grade Crossings." *Pub. Roads,* Vol. 22, No. 6, pp. 123-130 (Aug. 1941).
20. PLATT, F. N., "Operations Analysis of Traffic Safety." Ford Motor Co., Dearborn, Mich. (1959).
21. SHULTZ, T. G., *Evaluation of Safety at Railroad-Highway Grade Crossings.* Purdue Univ. (June 1965) 105 pp.
22. *Accidents on Main Rural Highways.* P. 17. U. S. Bur. of Public Roads (July 1964).
23. *Highway Statistics, 1963.* U. S. Bur. of Public Roads (1965).
24. *Manual on Uniform Traffic Control Devices for Streets and Highways.* U. S. Bur. of Public Roads (June 1961).

APPENDIX A

REVIEW OF PREVIOUS RESEARCH

Safety at highway-rail grade crossings has received a great amount of attention by previous researchers. The bulk of the previous research falls into three general areas, as follows:

1. Development of hazard indexes.
2. Development of predictive equations.
3. Analysis of before-and-after accident data and other miscellaneous studies.

Research on hazard indexes and predictive equations has resulted in general agreement that vehicle and train volumes are the most important factors. These are commonly used in "average daily" terms and several researchers have pointed out the need for finer definition of these quantities. Some have used daylight and dark, others have used 6-hr periods, and at least one used hourly volumes.

The use of vehicle and train volumes as predictors of accidents and indicators of hazard simply recognizes that a vehicle and a train must be present to have a collision. Obviously, if trains do not operate through the crossing in any hour or period of the day, there is no real possibility of a collision. Additionally, it is conceded by most researchers that with a given vehicle and train volume the hours of darkness are more hazardous. For these reasons, sharp definition of the time span within which vehicles and trains operate is quite important to accident prediction.

Other factors undoubtedly modify the basic probability of an accident with given vehicle and train volumes. Sight distance, angle of crossing, number of tracks, number of lanes, gradients, etc., have all been measured and studied. There is no general agreement on their role in accident occurrence.

The index of hazard is frequently used as a priority device. There is growing mention of the need for more use of economic factors in determining whether and when a crossing should be eliminated or given improved warning and protective devices.

Before-and-after studies have provided valuable information on the relative effectiveness of different warning devices. These studies show marked similarity in their findings, with close agreement on the reductions in accidents which can be expected from the use of each device.

Several studies have pointed to the need for a broader definition of the problem. One of these, in particular, found that collisions between trains and vehicles represent only a small portion of the total accidents which occur at grade crossings. This finding casts serious question on the practice, used in many studies, of deleting from the data accidents which did not conform to arbitrary rules established by the researcher.

The following describes the techniques, results, and conclusions of past research in each of the three areas.

HAZARD INDEXES

The purpose of a hazard index is to establish priorities for improvements. The equation for hazard index may range from the very simple to the very complex.

One of the early attempts to relate the various factors in the form of a hazard index equation was in 1934 by Henry (*25*). Five primary factors were considered in this equation—(1) view, (2) attention, (3) user, (4) inherent hazard, and (5) pedestrian. The sum of these factors times the product of factors for daily train and highway traffic gave an index of hazard.

Vehicle speed, safe stopping distance, and train speed were incorporated in the view factor, which was read from a graph and given a maximum value of four (one for each quadrant) and a minimum value of zero.

Included in the attention factor were highway gradient, curvature, width, riding condition, number of tracks, track combinations, switching, angle of intersection, and other hazard factors, such as sun glare and number of pedestrians. The maximum weight given to this factor was also four (one for each quadrant) and the minimum was zero.

The user factor accounted for the effect of peak highway volumes at the time a train was expected, and the amount of local traffic. This factor ranged from a minimum of zero to a maximum of one.

It was considered that if all hazard factors were a minimum there would still be an inherent hazard. The inherent hazard was given a weight of one, which remained constant.

The final factor included a weighted value for unusually high pedestrian volumes and ranged between zero and one. The pedestrian factor was considered separate from the other four.

It is interesting to note that factors were introduced for daily train and highway traffic rather than using actual values. The effect of this was to give a heavier weight to lower volumes of highway and train traffic than if actual values had been used.

The formula developed by Henry is

$$\text{Index of Hazard} = V\,T\,(1 + F_1 + F_2 + F_3) + P\,T\,(1 + F_4) \qquad \text{(A-1)}$$

in which

V = number of vehicles factor;
T = number of trains factor;
F_1 = view factor;
F_2 = attention factor;
F_3 = user factor;
F_4 = special pedestrian factor; and
P = number of pedestrians factor.

Many variations on this formula have been developed; at least 20 were discovered in this review. Each differs from the others in the factors considered or the weight assigned to the individual factors.

A survey of 47 states, made by the American Railway Engineering Association during the 1940's, was summarized in a report by Rothrock (*59*). The survey indicated that 14 States each had its own hazard index formula. The factors considered in these formulas are as follows by the frequency with which they occurred: Vehicles per day, 14; trains per day, 14; sight distance, 10; train speed, 9; existing protection, 8; highway vehicular speed, 7; approach grade and condition, 7; angle of approach, 7; number of tracks, 7; glare or fog, 5; accident record, 3; pedestrian hazard, 3; type of train, 3; delays, 2; time crossing is blocked, 1; night trains, 1; switching, 1; coincidence of vehicles and trains, 1; probability of train and vehicle meeting, 1; attention factor, 1; inherent hazard, 1; and user factor, 1.

It is interesting to note that the only two factors on which there was complete agreement were vehicles per day and trains per day. Warrants suggested by the U. S. Bureau of Public Roads and the American Association of State Highway Officials are based entirely on the VT factor. Stephens (*65*) listed the following additional factors: Condition of crossing, condition of vehicles, driver behavior, driver mental and physical condition, economic justification, distraction elements, surprise elements.

A report prepared by the North Carolina Highway Commission (*52*) indicates that highway type is also an important factor.

Still another report, for Contra Costa County, Calif. (*14*), indicates that the number of lanes should be considered, the theory being that there is a potential for conflict between the train and the first vehicle to arrive in any lane. This potential for conflict between the train and vehicle is reduced to a negligible amount for subsequent vehicles which arrive at the crossing.

There are other factors that influence safety at grade crossings, but these probably represent the ones of greatest importance.

The various formulas encountered show little consistency in the importance assigned to the various factors.

The Ohio railroad grade crossing priority report (*40*) and the 1964 West Virginia report (*19*) indicate that 50 percent of the priority rating should be assigned to predicted accidents. In both reports, 10 percent of the priority rating is assigned to each of the following five factors: (1) Train speed of fastest train, (2) approach grade, (3) angle of crossing, (4) number of tracks, and (5) clear sight distance at points 300 ft from the tracks on the highway. The predicted accidents are derived from factors representing daily rail and highway volumes and type of protection.

A North Carolina report (*52*) briefly discusses the rationale used to arrive at the relative importance of various factors. A train traveling 50 mph or more was assumed to create three times as much hazard as a train traveling less than 30 mph. Trains traveling between 30 and 49 mph were assumed to be twice as hazardous as those traveling less than 30 mph. The hours of the day were divided into three time periods—6 AM to 4 PM, 4 PM to midnight, midnight to 6 AM.

An investigation of accident records found that the hours between 6 AM and 4 PM are four times more hazardous than the hours between midnight and 6 AM and the hours between 4 PM and midnight are five times more hazardous than the hours from midnight to 6 AM. It should be noted that hazard as mentioned here is not necessarily a measure of hazard to the individual driver, but is an indication of the number of accidents which occur during the three time periods.

The results of an accident investigation indicated that accident probability increases about 40 percent on a crossing with four blind quadrants. The following weights were applied to the various track combinations and were based on the weights used by other states: One track, main or spur, 0; two spur tracks, 2; one main track and one spur track, 3; two main tracks, 5; each additional main track, + 2; each additional spur track + 1. In an analysis of grade crossing accidents, it was found that a crossing with two main tracks is 50 percent more hazardous than a crossing with a single track.

The factors introduced for various types of protection were determined from "observations made by competent engineers" and studies made in other states. The resultant protection factors used were as follows: No protection, 1.00; crossbucks only, 0.85; crossbucks plus advance warning signs, 0.70; wigwags and signs, 0.40; automatic flashing light signals and signs, 0.25; and automatic gates with flashing light signals and signs, 0.10. Therefore, the resulting equation is

$$\text{H. I.} = \frac{VP}{100}(10L + 20Y + 30H) + (4m - 5e) + N(F_s + F_{tr}) \qquad \text{(A-2)}$$

in which

H. I. = hazard index;
P = protection factor;
V = number of vehicles per day;
L = number of trains per day with speeds less than 30 mph;
Y = number of trains per day with speeds of 30 to 49 mph;
H = number of trains per day with speeds of 50 or more mph;
m = number of trains between 6 AM and 4 PM;
e = number of trains between 4 PM and midnight;
N = total number of trains per 24 hr;
F_s = sight distance factor; and
F_{tr} = tracks combination factor.

Reports published by the Oregon Highway Commission in 1956 and 1959 were based on five years of accident data at 400 crossings in the 1956 report (*55*) and refined by five additional years in the 1959 report (*56*). As in other reports, it was found that vehicle and train volumes are strongly correlated to accident experience. Alignment, sight distance, and number of tracks were not so strongly related to accidents.

The following percentages of accident reduction were determined if the higher type protection were to be installed at a crossing without automatic protection: Wigwag, 20 percent; flashing light signals, 40 percent; automatic gates with flashing light signals, 90 percent. Given identical train and vehicle volumes, the hours of darkness were found to be 40 percent more hazardous than the daylight hours.

Sixty percent of the variability of accidents were accounted for by daily vehicle volume, daily train volume, existing protection, and light condition. A final factor which incorporated all others was the accident history divided by accidents predicted based on the previous four factors.

One of the important aspects of this hazard equation was that it allowed incorporation of the darkness factor. When train movement took place during darkness, the rating was computed separately for the two light conditions and the sum was used as the index of hazard. Daily rail and highway traffic were both reduced for each light condition to represent the true situation.

The product of the five factors then produced an index of hazard. This equation, as given in the 1959 report (*56*) is

$$\text{Index of hazard} = V\,A \qquad \text{(A-3)}$$

in which

$$V = v_1 t_1 p + 1.4 v_2 t_2 p \qquad \text{(A-4)}$$
$$A = a_1/a_2 \qquad \text{(A-5)}$$

v_1 = vehicle movements during daylight hours;
v_2 = vehicle movements during dark hours;
t_1 = train movements during daylight hours;
t_2 = train movements during dark hours;
p = protection factor (1.0 for cross-buck signs; 0.8 for wigwag signals; 0.6 for flashing lights; and 0.1 for automatic gates);
a_1 = actual number of accidents which occurred in a 5-year period; and
a_2 = predicted number of accidents which occurred in a 5-year period.

In 1948 Rothrock (*60*) assigned priorities to 163 crossings judged to be the most hazardous in West Virginia. The crossings were tabulated using six different hazard indexes as follows: (1) $V\ T$ by hourly units; (2) coincidence of traffic; (3) Peabody-Dimmick (*42*) predictive equation; (4) E. I. index; (5) 15-year accident record; (6) annual vehicle-hours of delay. Each method was discussed. Rothrock pointed out the need for breaking the exposures of vehicles and trains into smaller units than trains per day and ADT, demonstrated by the fact that vehicle traffic varies considerably throughout the day.

The point made can be illustrated by the following example:

ITEM	CROSSING A	CROSSING B	CROSSING C
Avg. daily traffic	10,000	10,000	4,800
Trains per day	3	3	3
Hours of train arrival	5:00 PM	5:00 AM	5:00 PM
	7:00 AM	11:00 PM	7:00 AM
	9:00 AM	2:00 AM	9:00 AM
% of ADT in hours of train arrival [a]	16.1	7.2	16.1
Avg. vehicles [b]	1,610	720	720
VT	30,000	30,000	14,400
VT by hour of train arrival	4,830	2,160	2,160

[a] Based on actual counts. [b] Average number of vehicles per day in train arrival hours.

Considering daily train and vehicle volumes, crossings A and B appear to have the same exposure. However, considering coincident hourly volumes, B has less than one-half the exposure of A and in fact has a true exposure equal to that for crossing C.

The second method (coincidence of traffic) assumes that vehicles are evenly spaced within an hour. Knowing the number of vehicles or the percent of ADT within the hour of arrival, and the length of time that a train will block the crossing, the number of vehicles which will be halted by the train can be calculated. The sum of these vehicles for each hour of the day gives the "coincidence of arrival."

The E. I. Index is a mathematical analysis which represents the probability of a meeting between a train and a vehicle. It contains an exposure factor (coincidence of traffic) and an impact factor. The exposure factor is

$$\frac{\text{Avg. veh. length}}{\text{Veh. speed, ft/hr}} \times \sum \left(\begin{matrix}\text{Daily traffic}\\ \text{by hour}\end{matrix} \times \begin{matrix}\text{Time crossing is}\\ \text{blocked per hour}\end{matrix} \right) \qquad \text{(A-6)}$$

The impact factor is a resultant vector quantity equal to

$$\sqrt{(V_s^2)^2 + 50(T_s^2)^2} \qquad \text{(A-7)}$$

in which V_s is vehicle speed and T_s is train speed. The mass of the train unit is assumed to be 50 times the mass of the vehicle.

Chubb (*11*) formed a composite hazard index using eight different formulas applied to 25 crossings. The formula comparing most favorably with the composite index was the simplest one—a 1932 formula developed by the California Department of Public Works and Utilities. It was simply the product of ADT, trains per day, accident history, and protection factors. The formulas used were the following:

1. Public Utilities Commission accident formula (5-year basis)

$$IH = A + I + 2K \qquad \text{(A-8)}$$

2. Illinois Commerce Commission (*25*)

$$IH = V\,R(1 + Q + A_t + U) \qquad \text{(A-9)}$$

3. City of Detroit (adapted to California conditions)

$$IH = \left[\frac{V}{1{,}000}\left(\frac{P}{10} + \frac{T}{20} + \frac{S}{30}\right) + Q + N + C\right]\left(\frac{100\% - G}{100}\right) + A \qquad \text{(A-10)}$$

4. Federal-Aid highway deficiency (also used by Public Utilities Commission as traffic factor formula)

$$IH = \frac{V\,R}{1{,}000} \qquad \text{(A-11)}$$

5. Los Angeles Grade Crossing Committee

$$IH = \frac{V}{1{,}000}\,[P + 10(T + S)] \qquad \text{(A-12)}$$

6. Public Utilities Commission composite

$$IH = \left(\frac{V}{1{,}000}\right)(2R_1 + R_2)\,M_1\,A\,G \qquad \text{(A-13)}$$

7. State of Oregon (1941)

$$IH = V\,R(U_s + R_s)(I + A) \qquad \text{(A-14)}$$

8. California Department of Public Works and Public Utilities Commission

$$IH = V\,R\,A\,G \qquad \text{(A-15)}$$

in which

IH = index of hazard;
V = number of vehicles traversing the crossing in a 24-hr period, or rating factor;
R = number of trains traversing the crossing in a 24-hr period, or rating factor;
P = number of passenger trains traversing the crossing in a 24-hr period;
T = number of through freights traversing the crossing in a 24-hr period;
S = number of switching movements traversing the crossing in a 24-hr period;
R_1 = number of trains per day exceeding 25 mph;
R_2 = number of trains per day traveling at 25 mph or less;
R_s = train speed factor;
M_1 = number of mainline tracks;
N = total number of tracks, or rating factor;
Q = quadrant visibility factor;
A = accidents, or accident factor;
G = existing crossing protection factor;
C = road condition factor;
U = user factor;
A_t = attention or distraction factor;
I = number of persons injured; and
K = number of persons killed.

One of the major criticisms leveled against the hazard index formulas has been that they do not lend themselves to an economic evaluation of loss. Rothrock (*60*) stated that economic loss should include travel time delay costs, maintenance and protection costs, and accident costs. He further stated that the accident history is not necessarily a good picture of future accident costs. This is because many changes are usually made within the time period which must be studied in order to get an accurate picture.

ACCIDENT MODELS AND PREDICTIVE EQUATIONS

Beggs (*5*) concluded that benefit/cost should be used to justify improvements and that rate of return should be used to establish priority. McLaughlin (*38*) took the same position. With respect to grade crossing improvements, he concluded that:

> Benefits are difficult to convert to monetary terms. But if highway financing is to be done prudently, these benefits must be estimated using the most logical assumptions.

And went on to say:

> Of the various numerical warrants in use in the United States only the Peabody-Dimmick and the Oregon methods lend themselves to direct economic treatment.

McLaughlin was speaking of equations developed by the Oregon Highway Department and by Peabody and Dimmick which predict the number of expected accidents.

The Peabody-Dimmick (*42*) equation (sometimes referred to as the U.S. Bureau of Public Roads formula) is believed to be the first predictive equation. It was based on a study of five years of accident data from 3,563 rural crossings in 29 states. Only crossings at which accidents had occurred were utilized. Following are some quotes regarding accidents not used in the analysis:

> Before calculating the coefficients, all data concerning accidents of the "scratch" type—those resulting from intoxication, and certain of the "car stalled on crossing" type . . . were eliminated. Accidents such as "striking gates" or "running off crossing plank" were thought to be of minor importance and were excluded from the study being made. A few other accidents of a miscellaneous nature, which were not connected with a train movement, were also eliminated from the study.

The following data were collected for each crossing used in this study:

1. Clear view down tracks (measured 300 ft from crossing).
2. Highway gradient on either side of crossing.
3. Highway alignment at crossing.
4. Highway surface type.
5. Number of tracks.
6. Angle of intersection.
7. Type of protection.
8. Average daily traffic:
   (a) Passenger vehicles;
   (b) Commercial vehicles;
9. Train traffic:
   (a) High speed;
   (b) Medium speed;
   (c) Standing or switching;
10. Number of accidents:
    (a) Persons killed;
    (b) Persons injured;
    (c) Accident causes;
11. Other special features.

Protection coefficients were developed for incorporation in the formula. The following formula was utilized for this:

$$\text{Protection coeff.} = \frac{1}{\text{No. of crossings in group}} \sum \frac{\text{Highway} \times \text{Train traffic}}{100 \times \text{No. of accidents}} \qquad \text{(A-16)}$$

The coefficients are as follows: Signs, 19; bells, 29; wigwag, 56; wigwag and bells, 63; flashing lights, 96; flashing lights and bells, 114; wigwag and flashing lights, 121; wigwag, flashing lights, and bells, 147; watchman, 8 hr, 119; watchman, 16 hr, 180; watchman, 24 hr, 228; manual gates, 24 hr, 241; automatic gates, 333.

The final prediction equation was as follows:

$$\text{Expected accidents in 5 years} = 1.28 \left(\frac{\text{Daily highway traffic}^{0.170} \times \text{Daily train traffic}^{0.151}}{\text{Protection coefficient}^{0.171}} \right) + \text{Additional parameter} \qquad \text{(A-17)}$$

Utilizing three curves, the formula can be reduced to

$$\text{Expected accidents (5 yr)} = \text{Unbalanced number} + \text{Additional parameter} \qquad \text{(A-18)}$$

The additional parameter, which amounts to a correction factor, can be determined from a fourth curve if the unbalanced number is known.

It is interesting to note that Peabody-Dimmick judged the three factors of daily highway traffic, daily train traffic, and protection as most significant for predicting accidents. It was suggested that priorities within groups having the same number of predicted accidents could be made based on geometrics. The effect of physical factors on safety was found to be insufficient to "merit their inclusion in the hazard rating formula."

Two important relationships were discussed even though they were not included in the formula: (1) the accident rate (accidents per number of vehicles) at night is much greater than the daytime rate, and (2) the same rate is higher during winter months than other months. It was suggested that this might also be due to the greater number of hours of darkness in winter. It was also suggested that the fact that some states have ten times more accidents per 10,000 registered vehicles than others could be due to differences in regulations and enforcement.

Also discussed was the fact that Oregon had indicated that road surface, sight distance, angle of intersection, number of tracks, and alignment have little or no effect on the number of accidents. It was suggested that the motorist compensates for some adverse conditions by exercising greater caution when those conditions are present. Motor vehicle and train movements at night were said to be three times as hazardous as daylight movements in urban areas and 1.8 times as hazardous in rural areas.

In conclusion, Peabody-Dimmick suggested some additional data which might enable development of an improved formula. Among these were: (1) Better estimates of highway and train movements for hour of accident, and (2) more complete descriptions of accidents.

The Oregon Highway Commission developed its first predictive equation in 1954 (*55*). In 1957 some refinements were made and a new equation was developed (*56*). Predicted accidents alone were not used as the criteria for priority assignment. Instead they were incorporated in an index of hazard equation as a ratio (see Eqs. A-3 and A-5).

The Oregon predictive equation, however, deserves further discussion. The second report (*56*) and the additional data which were utilized, allowed some refinements to be made to the 1954 equation (*55*). The refinements were represented by new coefficients, allowing the equation to remain in its original form. The resulting predictive equation was

$$\text{Predicted accidents (5 yr)} = 0.25 + 8.03 \times 10^{-5}\, v\, t\, p\, d - 1.58 \times 10^{-10}\, v\, t\, p\, d^2 \qquad \text{(A-19)}$$

in which

v = average daily traffic,
t = daily train volume;
p = protection factor; and
d = darkness factor.

A more recent predictive equation has been developed by the Armour Research Foundation for the Association of American Railroads. Although the findings are not available for publication, the data presented indicate that train and vehicle volumes are important factors in accident prediction.

A 1960 report (*41*) by the New York Public Service Commission discusses another study which produced predictive equations. Thirteen years of accident data were utilized. The crossings were selected using sampling techniques. All of the crossings with four or more accidents were included. Progressively smaller percentages of the crossings with lesser numbers of accidents were included. Crossings with no accidents were sampled on the ratio of 1 to 10 or 1 to 20, depending on the type of protection. The study was based on 170 crossings with minimum protection, 94 with flashing lights, and 80 with gates. Controls existed which accounted for changes in type of protection.

As stated in the report, the purpose of this study was to determine the relationship between "accident hazard" and "crossing characteristics" and not simply to predict the number of accidents. It was noted that although the Peabody-Dimmick equation contains a coefficient which is dependent on the type of protection, the remainder of the equation is not adaptable to the wide range of other conditions and physical characteristics found among crossings. It was the opinion of the researchers that different equations should be developed for each protection level.

The resulting equations were as follows:

For minimum protection

$$R + 1 = F(2.764G^{0.337}) \qquad \text{(A-20)}$$

$$F = 1.0937 + 0.06034Q - 0.003652A \qquad \text{(A-21)}$$

For flashing lights

$$R + 1 = F(1.690G^{0.236}) \qquad \text{(A-22)}$$

$$F = 0.81124 + 0.06986Q \qquad \text{(A-23)}$$

For gates

$$R + 1 = F(1.205G^{0.178}) \qquad \text{(A-24)}$$

$$F = 0.7788 + 0.081553K \qquad \text{(A-25)}$$

in which

Q = number of restricted quadrants, where a restricted quadrant is one for which the driver cannot see 300 ft down the tracks from a point on the highway 300 ft from the crossing;
A = acute angle between highway and railroad; and
K = number of tracks.

Schultz (*62*) evaluated the influence of environment, topography, geometry and highway-rail traffic patterns on grade crossing accidents on rural Indiana highways. The data for this study were based on 289 crossings that had experienced at least one accident during a 2-year period and 241 accident-free crossings.

The 289 crossings included most of the rural crossings in Indiana with at least one accident in 1962 and 1963. The accident-free locations were selected from the remaining crossings by a random sampling technique. The following 57 variables were studied:

1. Vehicle type.
2. Vehicle age.
3. Out-of-county.
4. Out-of-state.
5. Number of occupants.
6. Actual car speed.
7. Actual train speed.
8. Vehicle defects.
9. PCC surface.
10. Asphalt surface.
11. Gravel surface.
12. Dry pavement.
13. Ice or snow.
14. Clear weather.
15. Darkness.
16. Windows.
17. Alcohol.
18. Male driver.
19. Drive age.
20. Personal injury.
21. Fatality
22. Monday.
23. Tuesday.
24. Wednesday.
25. Thursday.
26. Friday.
27. Saturday.
28. Sunday.
29. Painted crossbucks.
30. Reflectorized crossbucks.
31. Flashers.
32. Gates.
33. No protection.
34. STOP sign.
35. White edge line.
36. Highway gradient.
37. Railway gradient.
38. Highway curvature.
39. Railway curvature.
40. Number of tracks.
41. Pavement width.
42. Advance warning sign.
43. Pavement crossing markings.
44. Number of businesses.
45. Number of advertising signs.
46. Minor obstructions.
47. Number of houses.
48. Angle of view.
49. Intersection angle.
50. Average freight train speed.
51. Number of passenger trains.
52. Number of freight trains.
53. Average train speed.

54. Trains per day.
55. ADT.
56. Average car speed.
57. Sum of 44, 45, and 47.

Factor analysis and regression analysis were performed independently. The equation resulting from factor analysis is as follows:

$$IH = 0.545 + 0.498\,(-0.242F_{AA} + 0.245F_{BB} + 0.253F_{DD} + 0.194F_{FF}) \quad \text{(A-26)}$$

in which

$$F_{AA} = -0.136Z_9 - 0.251Z_{31} - 0.224Z_{35} - 0.214Z_{41} - 0.166Z_{45} - 0.263Z_{55} \quad \text{(A-27)}$$

$$F_{BB} = +0.86Z_{10} - 0.112Z_{42} + 0.229Z_{51} + 0.302Z_{52} + 0.317Z_{54} \quad \text{(A-28)}$$

$$F_{DD} = +0.215Z_9 - 0.494Z_{10} + 0.420Z_{11} + 0.124Z_{45} - 0.140Z_{56} \quad \text{(A-29)}$$

$$F_{FF} = -0.148Z_{39} - 0.132Z_{41} - 0.449Z_{44} + 0.270Z_{45} + 0.430Z_{47} - 0.428Z_{56} \quad \text{(A-30)}$$

the subscripts represent the numbered variables, and IH is the predicted 2-year accident rate. The multiple regression analysis was performed using only the 28 variables which were common to both accident and non-accident locations.

The first analysis indicated that type of protection has no significant relationship to accident experience. The equation yielded the following coefficients for the various protective devices: Painted crossbucks, 0.376; reflectorized crossbucks, 0.300; flashers, 0.383; gates, 0.331.

The second regression analysis excluded the type of protection and yielded the following equation:

$$IH = 0.185 + 0.079X_{10} + 0.021X_{41} + 0.011X_{54} + 0.013X_{55} + 0.024X_{57} \quad \text{(A-31)}$$

in which the subscripts represent the numbered variables and IH represents the 2-year accident experience. Warrants were suggested based on the current level of protection in Indiana. The suggested warrants are as follows: $IH > 0.65$, flashers; $IH > 0.80$, gates.

Newnan (*39*) analyzed 617 crossings on state highways in California over an 18-year period (1946-1963). Predictive equations were developed. Costs were assigned to accidents and incorporated in an economic analysis to establish warrants for improvements.

The results of this study indicated that present policies should be reexamined. It was reported that "there seems to be little economic justification for installing a sizable number of the more expensive protective devices at crossings on the system. . . ." Only about one crossing in 25 currently warrants the installation of more expensive protective devices. "The costs of highway-railroad grade-separation structures exceed the economic benefits from them by several times over." In fact, it was stated that ". . . equivalent annual costs associated with grade-separation structures are so high that reduction of accidents and reduction in delays are economically insignificant factors."

It was suggested that "before authorizing grade-separation projects, public officials should weigh their worth critically." The following equations were developed for five types of protection:

Crossbucks:

$$\text{Acc./2 yr} = 0.1956 + 0.0028A + 0.0037C + 0.0329D + 0.0193E + 0.0307G \quad \text{(A-32)}$$

Standard wigwag:

$$\text{Acc./2 yr} = 0.315 + 0.0042A + 0.569B + 0.0373D - 0.0897F \quad \text{(A-33)}$$

Other wigwag, rotating and flashing lights:

$$\text{Acc./2 yr} = -0.4634 - 0.0022A + 0.0357C + 0.0139D + 0.1897G \quad \text{(A-34)}$$

Flashing lights:

$$\text{Acc./2 yr} = 0.0262 + 0.0018A + 0.0290B + 0.0217D + 0.0356F + 0.0302G \quad \text{(A-35)}$$

Automatic gates:

$$\text{Acc./2 yr} = -0.493 - 0.0037A - 0.0843B + 0.0186C + 0.0192D + 0.1625G \quad \text{(A-36)}$$

in which

A = average daily traffic, in hundreds of vehicles;
B = total number of tracks at the crossing;
C = weather visibility, or percentage of time the horizontal visibility at the crossing is limited to ¼ mile or less, stated in units of 0.1 percent (3.2% would be introduced in the equation as 32);
D = average number of trains (of all types) passing the crossing daily;
E = crossing angle, the acute horizontal angle between the axis of the tracks and the roadway, coded as follows: 0°–9°, 1; 10°–19°, 2; 20°–29°, 3; . . .; 80°–90°, 9.
F = approach grade, absolute value of the slope of the roadway adjacent to the crossing, stated in difference in elevation per 100 ft of length ("deg") and coded: < 1°, 1; 1°–2°, 2; 2°–3°, 3; . . .; ≥ 8°, 9; and
G = corner visibility, 1 + number of corners at which visibility is impaired from a point on the road 400 ft ahead of the crossing to a point 400 ft along the tracks beyond the crossing; the possible range of values is, hence, 1 to 5.

In addition to the predictive equations, this report (*39*) serves as an excellent source of information on methods of calculating economic warrants and assigning priorities. It is recommended reading for individuals concerned with the economic justification and priority assignment of improvements. Like the hazard ratings, the predictive equations and the theory on which they are based have been attacked.

Crecink (*15*) stated that no significant correlation was found between the Peabody-Dimmick predictive equation and the accident records for 1,254 Mississippi grade crossings. Combining a sight distance hazard factor with the formula produced slightly better results. No significant correlation could be found between accident records, number of train movements, volume of highway traffic, number of railroad tracks, or clear view distance.

The 1948 study by Rothrock (*59*) discusses the Peabody-Dimmick formula and notes that it only considers daily traffic. In applying this formula to West Virginia crossings, it was found to be inconsistent with the actual accident record, generally giving a much higher index.

A 1951 study of rural secondary roads in North Carolina (*52*) quoted a report by Burch and Petroff. This report indicates that there is a discrepancy between the actual accident history and that computed using the Peabody-Dimmick equation. The greatest error was found in the group of crossings which had had no accidents. It was suggested that this might be due in part to the greater error in traffic estimated for low-volume roads. This error could also be due to the fact that only crossings at which accidents had occurred were used to develop the Peabody-Dimmick equation.

BEFORE-AND-AFTER AND OTHER MISCELLANEOUS STUDIES

A report by the Contra Costa County (Calif.) Highway Department (*14, 51*) suggests that the product of vehicles and trains per day is not a good measure of hazard or exposure and that it gives too much weight to the highway traffic. The number of trains per day is, however, proportional to the hazard and exposure. The method proposed is similar to *V T* by hourly units, as presented by Rothrock, except that Contra Costa County assumed a random distribution of vehicle arrivals. Based on the assumption of random distribution, the following equation was presented as representative of the index of hazard, *C:*

$$C = TZ(1 - e^{-vt/1440Z}) \qquad \text{(A-37)}$$

in which

T = number of trains per day;
Z = number of traffic lanes;
v = number of highway vehicles per day; and
t = time, in min/day, that the crossing is blocked.

When the trains are scheduled and the hourly traffic volumes are known, Eq. A-37 becomes

$$C = \Sigma Z\,(1 - e^{-vt/60Z}) \qquad \text{(A-38)}$$

in which

v = number of highway vehicles per hour;
t = time, in min/hr, that the crossing is blocked;

and the summation is taken over all trains in a day.

A sample calculation was made for a crossing with 16 trains per day and an ADT of 875. The value found for *C* was 19.2. It was pointed out that a tenfold increase in traffic would increase *C* to 32, or less than double. Using the value of *VT* for exposure would give 14,000 at a crossing with 16 trains and 875 vpd. Increasing the highway traffic to 8,750 would give 140,000, or ten times as much exposure.

This method was tested in a grade-crossing improvement program for Contra Costa County. All crossings with conflicts greater than one per train were tabulated. A ratio of accidents per unit conflict was found to be 0.85, 0.60, and 0.26 for wigwags, flashing lights, and automatic gates, respectively. It is noteworthy that these values are consistent with the results of most before-and-after accident studies, despite the small sample size.

The inconsistencies and general lack of agreement concerning hazard indexes, predictive equations, and the weight which should be assigned to the various factors appear to be a direct result of insufficient supporting data. The low accident frequency at railroad grade crossings makes it necessary for many years of data to be collected in order to get a true picture of performance. The difficulty then becomes one of finding locations where there have been no changes made during the study period.

The changes can be used to advantage, however, by conducting before-and-after studies. One of the most comprehensive studies of this type was made by Hedley (*24*) to determine the effect changes in protection devices had on accident experience. He used the records of the Wabash Railroad over a 20-year period. His data included 321 crossings at which the protection had been changed. To account for changes in number of trains and vehicles in the 20-year period, an annual correlation was made between the product of fuel consumption (in gallons) and train miles.

Hedley found that crossings protected by automatic gates had the lowest accident experience, whereas those with nonautomatic signing had the highest. An accident quotient was obtained for ten types of protection, as given in Table A-1. Using these data, an additional calculation was made to give the relative hazard associated with changing the protection at a crossing protected by nonreflectorized crossbucks.

McEachern (*37*) conducted a similar study on three years of accident data at 190 crossings in Texas. The effectiveness of various types of protection were found to be as given in Table A-2. Again some additional computations were made and the relative hazards were determined (Table A-2).

The Illinois Commerce Commission in 1965 published (*70*) the results of a before-and-after automatic protection study, as given in Table A-3. This indicates that the relative hazards for the three types of protection are as follows:

TYPE OF PROTECTION	RELATIVE HAZARD
Crossbucks	1.00
Flashing light signals	0.23
Flashing light signals and gates	0.22

Marks (*35*), in discussing the relative merits of providing grade separations at highway-highway intersections and highway-rail intersections, presented evidence of the effectiveness of automatic protection, as given in Table A-4. Reductions found by others before and after the installation of gates were also presented, as in Table A-5.

A report by Tarbet (*69*) presented the results of a Pennsylvania study which indicated a 96 percent reduction in accidents and a 100 percent reduction in fatalities at 51 crossings after gates were installed.

The relative hazard for the three types of protection as presented by Marks and Tarbet would then be as given in Table A-6.

Accident data for all crossing protection improvements, aided financially by the state crossing protection fund and for which three years of before data and three years of after data were available, were tabulated by the California Public Utilities Commission (*1*). This included 595 crossings. A summary of the accidents at these crossings is given in Table A-7. The relative hazard for crossbucks, one wigwag, two wigwags, and flashing light signals would be as follows: Crossbucks, 1.00; one wigwag, 0.47; two wigwags, 0.33; flashing lights, 0.21.

Using several before-and-after studies, Schoppert (*61*) developed the following composite factors:

TYPE OF PROTECTION	RELATIVE HAZARD
Crossbucks	1.00
Wigwags	0.6 – 0.8
Flashing lights	0.3 – 0.6
Automatic gates	0.1 – 0.2

As can be seen when the different protection factors are put on the same base (setting crossbuck protection equal to 1.9), general agreement has been reached concerning the effectiveness of various protection devices in reducing hazard.

Reductions in accidents and injuries found in three studies made in Southern California (*75*) demonstrate the effectiveness of automatic gates in providing safer protection. These reductions are given in Table A-8 as they appeared in the report. The effectiveness of automatic gates was also shown by the types of protection in existence prior to installation of the gates. A summary of these results is given in Table A-9.

A similar study made by Collins (*13*) in Northern California found the reductions given in Table A-10.

Another study, by Tarbet (*69*), presented a before-and-after accident comparison made at three crossings in Los Angeles at which flashing amber lights were installed to supplement the advance warning sign. The type of crossing protection was also changed during the comparison period (15 crossing-years). The accident experience was adjusted to account for this change. Before the flashing amber lights were installed there were 20 accidents, whereas in the (adjusted) "after" period only 14 occurred.

Carmody (*10*) discussed three "problem" crossings in Modesto, Calif., and the treatment utilized. The problem at these crossings was that seven accidents (six at night) had occurred in a two-year period. Train volumes were low—two to six trains per day. Train speeds were under 10 mph and auto speeds were under 30 mph.

Automatic gates or flashing light signals could not be justified because of the low train volume. Because many of the train movements were at night and the bulk of the accidents were at night, the crossings were lighted. "Two 20,000-lumen, Type II, mercury vapor lamps on 30-ft poles, each 15 ft on the far side of the crossing from the motorist, make the crossing stand out from the adjacent intersections

TABLE A-1

RELATIVE HAZARD ASSOCIATED WITH VARIOUS TYPES OF GRADE CROSSING PROTECTION

TYPE OF PROTECTION	FINAL ACCIDENT QUOTIENT	RELATIVE HAZARD
Automatic gates	0.0925	0.184
Manual gates, full time	0.1513	0.301
Flashing light signals, single track	0.1773	0.352
Flashing light signals, multiple track	0.3044	0.605
Wigwag	0.2936	0.583
Manual gates, part time	0.3520	0.699
Watchman	0.3581	0.712
Automatic bell	0.3941	0.783
Reflectorized crossbucks, AREA	0.4450	0.883
Painted crossbucks	0.5038	1.000
Reflectorized crossbucks (Michigan)	0.8156	1.620

TABLE A-2

EFFECTIVENESS OF VARIOUS TYPES OF GRADE CROSSING PROTECTION (*37*)

TYPE OF PROTECTION	NO. OF CROSSINGS	ACCIDENTS PER *VT* LOWEST	ACCIDENTS PER *VT* HIGHEST	RELATIVE HAZARD
Crossbucks	65	0.0140	0.0160	1.000
Automatic signals	114	0.0040	0.0060	0.333
Automatic gates	11	0.0015	0.0024	0.133

TABLE A-3

RESULTS OF ILLINOIS 1965 GRADE CROSSING STUDY

ITEM	FLASHING LIGHT SIGNALS [a] BEFORE	AFTER	RED. (%)	FLASHING LIGHT SIGNALS AND GATES [b] BEFORE	AFTER	RED. (%)
Accidents	143	33	77	106	23	78
Fatalities	57	4	93	31	4	87
Injuries	88	11	87.5	50	6	88

[a] 177 crossings, 9,276 crossing-months. [b] 123 crossings, 9,276 crossing-months.

TABLE A-4

EFFECTIVENESS OF VARIOUS TYPES OF GRADE CROSSING PROTECTION (*35*)

		REDUCTION (%)		
TYPE OF PROTECTION	LOCATIONS	ACCIDENTS	INJURIES	FATALITIES
Flashing light signals	38	71	54	58
Flashing light signals and gates	19	—	85	91

TABLE A-5

EFFECTIVENESS OF GATES AT GRADE CROSSINGS (*35*)

		REDUCTION (%)		
STUDY	LOCATIONS	ACCIDENTS	INJURIES	FATALITIES
Ill. GTW RR	23	—	98	93
Calif. So. Pac. RR	35	80	95	94

that have only one 6,000-lumen incandescent light." Since installation (date of installation not indicated), no accidents have occurred and the treatment is believed to have been effective. The cost of installation was approximately $800 per crossing.

The results of a study by Bezkorovainy and Holsinger (*6*) of 13 railroad crossings protected with STOP signs indicate that driver compliance to STOP signs is poor. STOP-sign observance studies show that less than 16 percent of the drivers come to a voluntary full stop at railroad crossings, compared to 32 percent at a nearby street intersection. Train speeds, traffic volumes, sight distances, direction of approach, angle of crossing, number of tracks, and daytime-nighttime conditions were not found to significantly influence driver reaction to STOP signs at railroad crossings. The results of the STOP-sign observance studies at railroad crossings and a nearby street intersection are compared in Table A-11.

A Colorado Department of Highways report (*47*) summarized 57 accidents which occurred on state highways at railroad grade crossings during 1963 and part of 1964. It was prepared from police reports. Twenty-one involved trains, 25 were rear-end accidents, 2 were ran-off-road accidents, and 9 were fixed-object accidents. According to the report: "Vehicle-train collisions accounted for less than one-half of the reported accidents. Collision into the rear of a vehicle stopped or stopping at the crossing was the most common type of accident. Almost one-half of the rear-end crashes involved trucks and buses required by state law to stop at all railroad crossings."

This information indicates that accidents which occur as

TABLE A-6

RELATIVE HAZARD FOR VARIOUS GRADE CROSSING PROTECTION TYPES

TYPE OF PROTECTION	RELATIVE HAZARD
Crossbucks	1.00
Flashing light signals	0.29
Flashing light signals and gates	0.12

TABLE A-7

SUMMARY OF ACCIDENTS BEFORE AND AFTER GRADE CROSSING PROTECTION IMPROVEMENTS (*1*)

DESCRIPTION OF IMPROVEMENTS	NO. OF CROSSINGS		ACCIDENTS	PEOPLE KILLED	PEOPLE INJURED
Flashing light signals installed at crossing with crossbucks	278	Before	521	73	316
		After	112 (79%)	9 (88%)	42 (87%)
Flashing light signals installed at crossing with one wigwag	133	Before	265	28	103
		After	119 (55%)	12 (57%)	34 (67%)
Flashing light signals installed at crossing with two wigwags	69	Before	199	24	73
		After	127 (36%)	8 (67%)	26 (64%)
All automatic gate installations	96	Before	252	66	132
		After	70 (72%)	5 (92%)	11 (92%)
Miscellaneous (circuit changes, additional signals, etc.)	19	Before	25	—	19
		After	8 (68%)	2 (+100%)	4 (79%)
Total	595	Before	1262	191	643
		After	436 (65%)	36 (81%)	117 (82%)

a result of the crossing should be considered in establishing warrants for the various types of protection. Accidents reported by the railroads to the public utility commission may not provide the entire picture of crossing effectiveness to the highway user.

Johnson (*29*) presents a method for determining the maximum safe speed at railroad grade crossings dependent on the visibility at the crossing and the speed of the trains. Sight triangles, speed, and distance formulas are utilized. Three assumptions were made, as follows:

1. The safe speed of a vehicle depends on the visibility and speed of the train, along with general assumptions for reaction, acceleration, and deceleration.
2. When a vehicle is a specified distance from a grade crossing, and a train is sighted, there is a speed range that is too fast for a driver to stop and too slow for a driver to beat the train to the crossing.
3. There is a critical speed at which it is safe under all conditions assuming a perception-reaction time, vehicle deceleration rate, and a vehicle acceleration rate.

It was stated that three possible things can happen when a train and a vehicle approach a crossing. The vehicle may stop, accelerate, or collide with the train. The solution to the advisory speed included:

1. Vehicle length.
2. Distance from the driver's eye to the front bumper.
3. Perception-reaction time.
4. Deceleration (15 ft/sec^2 for a truck).
5. 20 ft of clearance allowed if stopping.
6. 50 ft of clearance allowed if accelerating.
7. Constant train speed.

One of the most interesting factors brought out in an analysis by the California Public Utilities Commission (*3*) is that 70 percent of the fatal accidents involved a highway vehicle approaching the train from the fireman's side of the locomotive. It was suggested that this might be due to the driver sitting on the left side of the vehicle and not having equal vision to the right.

The ideal protection, disregarding economy, is often said to be grade separation. A report by Kaiser (*31*) states that in Ohio twice as many deaths resulted from accidents at bridges as from accidents at railroad crossings. He further stated that 1 in 21 accidents at grade crossings were fatal, whereas 1 in 24 at structures were fatal. The incidence of fatal accidents in subways was 1 in 13. This seems to indicate that grade separation may not be the answer, especially when automatic protection provides a 90 percent reduction in accidents.

The absence of supporting data in previous research and the existence of arbitrary warrants are evidence of the need for cooperative data collection and analysis. It appears that because of arbitrary warrants and the strong public opinion, due to spectacular accidents, the return realized for money spent on protection devices may not be equivalent to the benefit received from them.

The need for conservation of the national resources and expenditure of funds where they will provide the greatest rate of return dictates that intensive research be conducted in this area.

TABLE A-8

DECREASES ACCOMPLISHED BY AUTOMATIC GATE INSTALLATIONS

		DECREASE (%)		
STUDY DATE	PERIOD	TRAIN-VEHICLE ACCIDENTS	DEATHS	INJURIES
Dec. 18, 1961	1951-60	62	85	83
Apr. 1, 1963	1951-62	60	90	84
Oct. 1, 1964	1954-63	57	89	88

TABLE A-9

SUMMARY OF EFFECTIVENESS OF AUTOMATIC GATES AT GRADE CROSSINGS, BY TYPE OF PROTECTION PRIOR TO GATE INSTALLATION (*75*)

	ACCIDENTS PER CROSSING YEAR	
PRIOR PROTECTION	BEFORE [a]	AFTER [a]
Crossbucks	0.427	0.122
Watchman	1.789	0.265
Wigwag	0.589	0.268
Flashing light signals	0.531	0.300
Manual gates	0.693	0.188

[a] Before and after installation of automatic gates.

TABLE A-10

EFFECTIVENESS OF AUTOMATIC GATES AT GRADE CROSSINGS, BY TYPE OF PROTECTION PRIOR TO GATE INSTALLATION (*13*)

	ACCIDENTS PER CROSSING YEAR	
PRIOR PROTECTION	BEFORE	AFTER
Crossbucks	0.267	0.160
Watchman	1.021	0.155
Wigwag	0.649	0.111
Flashing light signals	0.658	0.151
Manual gates	0.344	0.039

TABLE A-11

RESULTS OF STOP-SIGN OBSERVANCE AT RAILROAD CROSSINGS AND NEARBY INTERSECTION

	VEHICLES			
	AT INTERSECTION		AT RAILROADS	
	NO.	%	NO.	%
Full stop	178	31.7	257	15.4
Almost stop (0-3 mph)	312	55.6	1,021	61.2
Entered slowly (4-15 mph)	67	12.0	329	19.7
Entered fast (over 15 mph)	4	0.7	61	3.7
Total	561	100	1,668	100

REFERENCES

1. "Accident Reduction at Crossings Protected Under Crossing Protection Fund." California Public Utilities Comm., San Francisco (Aug. 26, 1965).
2. ALBRIGHT, C. C., "Design and Construction Features That Make for Highway Safety Conditions Encountered by the Pennsylvania Highway Department." *Roads and Streets*, Vol. 69, No. 3, p. 105 (Mar. 1929).
3. "Analysis of Fatal Accidents at Grade Crossings, Year 1962." California Public Utilities Comm., San Francisco (Dec. 1954) 5 pp.
4. "Annual Report of Railroad and Highway Accidents for Year 1960." Eng. Oper. Branch, Transp. Div., California Public Utilities Comm.
5. BEGGS, A. K., "Railroad-Highway Grade Crossing Problems: Economic Principles." Stanford Res. Inst. (1952) 55 pp.
6. BEZKOROVAINY, G., and HOLSINGER, R., "The Use of Stop Signs at Railroad Crossings." Traffic Eng. Dept., City of Lincoln, Nebr. (1966) 54 pp.
7. BLYTHE, J. D., "Highway Lighting and Accidents in Indiana." *HRB Bull. 146* (1956) pp. 1-7.
8. BOURLAND, H. M., "Light Rural Highways, Decrease Accident Problems." *Amer. City*, Vol. 59, No. 6, p. 135 (June 1944).
9. BOWMER, C., "State of Arizona Railroad-Highway Crossing Inventory on the State Highway System." Arizona Highway Dept., Phoenix (1964) 130 pp.
10. CARMODY, D. J., "Lighted Crossings Are Safe." *Rural and Urban Roads*, Vol. 4, No. 9, (Sept. 1966).
11. CHUBB, T. M., "Railroad Crossing Protection." *Traffic Safety Res. Rev.*, Vol. 4, No. 3, p. 12 (Sept. 1960).
12. CHUBB, T. M., "Safety at Railroad Grade Crossings." Los Angeles Dept. of Public Utilities and Transportation (1959) 19 pp.
13. COLLINS, R. O., "Effectiveness of Automatic Crossing Gates in Northern California, 1954 through 1964." California Public Utilities Comm., San Francisco (Mar. 1965).
14. "Conflicts at Grade Crossings, A Theoretical Analysis." Contra Costa County (Calif.) Highway Dept. (unpubl.).
15. CRECINK, W. J., "Evaluating Hazards at Railroad Grade Crossings." *Proc. HRB*, pp. 154-159 (1948).
16. "Deficiency Ratings of Iowa Primary Highway Railroad Grade Crossings." Iowa State Highway Comm., Ames (May 1, 1963) 25 pp.
17. "Driver Obedience to Traffic Signals Coordinated with Train Movements." Los Angeles Dept. of Public Utilities and Transportation, 6 pp.
18. "Elimination of Hazards of Railway-Highway Crossings." *Policy and Proc. Memor. 21-10*, U. S. Bureau of Public Roads (Oct. 3, 1958).
19. "Evaluation Criteria to Establish Sufficiency Ratings for Railroad Grade Crossings." West Virginia State Road Comm. (1964).
20. "Forum—What Criteria Are Used to Determine Where Automatic Protection Devices Are Needed at Grade, Particularly on Non-Federal-Aid Roads." *Better Roads*, Vol. 34, No. 3, p. 15 (Mar. 1964); No. 4, p. 36 (Apr. 1964).
21. GAVEY, J. W., "Traffic Signals Near Railroad Crossings: Railroad Company Practices." *Proc. 15th California Street and Highway Conf.*, pp. 92-95. Univ. of California (Jan. 1963).
22. "Grade Crossing Accidents in Minnesota." *Publ. No. 9*, Minnesota Legislature Res. Comm. (1948).
23. HALE, H. H., "Railroads + Highways — Engineering Cooperation = Trouble." *Proc. Western Assn. of State Highway Officials* (1960) pp. 19-25.
24. HEDLEY, W. J., "The Achievement of Railroad Grade Crossing Protection." *AREA Proc.*, Vol. 50, pp. 849-864 (1949).
25. HENRY, W., "Method for Determination of an Index, or Measure of the Hazard to the Public at Railroad-Highway Grade Crossings." Illinois Commerce Comm., Springfield (reprint of 1942).
26. HIBBARD, W. F., "Traffic Signals Near Railroad Crossings: Viewpoint of the PUC." *Proc. 15th California Street and Highway Conf.*, Univ. of California, p. 89 (Jan. 1963).
27. "Highway-Railroad Grade Crossing Data." Wisconsin Public Service Comm. (May 1965).
28. HUTCHINSON, A. L., Traffic Signals Near Railroad Crossings: Some Problems in Los Angeles. *Proc. 15th California Street and Highway Conf.*, Univ. of California, pp. 96-97 (Jan. 1963).
29. JOHNSON, A. A., "Maximum Safe Speeds at Railroad Grade Crossings." *Traffic Eng.* (June 1958).
30. JORGENSON, R. E., and MITCHELL, R. G., "Accident Analyses for Program Planning." *Proc. HRB* (1949) pp. 336-348.
31. KAISER, H. K., "Traffic Accidents on Highway Bridges on Rural State Highways in Ohio." *Highway Eng. Conf. Proc.*, pp. 119-124. Ohio State Univ. (1956).
32. KARBER, J. W., "The Railroad-Highway Grade Crossing Problem." Presented before 48th Spring Conf. of Southeastern Association of Railroad and Utilities Commissioners, Biloxi, Miss. (Apr. 17, 1964) 16 pp.
33. LARSEN, M. B., "Requirements for Protective Devices at Railroad Grade Crossings." *AASHO Conv. Group Meetings and Papers*, pp. 326-333 (1960).
34. MARKS, H. L., "Grade Crossing or Grade Separation." Presented at Twelfth Calif. Street and Highway Conf., Univ. of Calif., Los Angeles (Jan. 28, 1960) (unpubl.)
35. MARKS, H. L., "Accident Reduction at Railroad Grade Crossings: Crossing Gates and No. 8 Flashing Signals." (1956) (unpubl.)
36. MATTHEWS, R. W., "Traffic Signals Near Railroad Crossings: Practice on State Highways." *Proc. 15th California Street and Highway Conf.*, Univ. of California, pp. 90-91 (Jan. 1960).
37. MCEACHERN, C., "A Study of Railroad Grade Crossing Protection in Houston." *Proc. Inst. Traffic Eng.*, pp. 168-172 (1960).
38. MCLAUGHLIN, W. A., "Highway-Railway Grade Crossing Treatments." *Tech. Pub. No. 13*, Canadian Good Roads Assn. (Oct. 1960) 84 pp.

39. NEWNAN, D. G., "An Economic Analysis of Railway Grade Crossings on the California State Highway System." Inst. in Engineering—Economic Systems, Stanford Univ. (June 1965) 207 pp.
40. "Ohio Railroad Crossing Priority Report." Ohio Dept. of Highways (May 1959) 165 pp.
41. "On a Statistical Relation of Accident Hazard to Grade Crossing Characteristics." *Res. Memo No. 7*, New York Public Service Comm., Albany (1960) 28 pp.
42. PEABODY, L. E., and DIMMICK, T. B., "Accident Hazards at Grade Crossings." *Pub. Roads*, Vol. 22, No. 6, pp. 123-130 (Aug. 1941).
43. "Prevention of Rail-Highway Grade Crossing Accidents Involving Railway Trains and Motor Vehicles." Interstate Commerce Comm., Dockett No. 33440, Washington, D. C. (Jan. 22, 1964).
44. "Program Planned to Cut Accidents at Rail Crossings." *Automotive News*, Vol. 37, No. 3841, p. 80 (Dec. 11, 1961).
45. "Rail-Highway Grade Crossing Accidents, 1935-1954." Bur. of Transport Econ. and Statistics, Interstate Commerce Comm., Washington, D. C., 123 pp.
46. "Rail-Highway Grade Crossing Accidents, 1955-1963." Bur. of Transport Econ. and Statistics, Interstate Commerce Comm., Washington, D. C.
47. "Railroad Crossing Accidents on State Highways, Calendar Year 1963." Colorado Dept. of Highways, Denver (Oct. 1964).
48. "Railroad Crossing Protection Study." Traffic Eng. Dept., City of Amarillo, Tex. (Feb. 1964).
49. "Railroad Crossing Study." Traffic Eng. Dept., City of Amarillo, Tex. (Aug. 18, 1960).
50. "Railroad Crossings on the State and Federal Aid Highway Systems of New Hampshire." New Hampshire Dept. of Public Works and Highways (Nov. 1964) 26 pp.
51. "Railroad Grade Crossing Survey." Contra Costa County (Calif.) Highway Dept. (1953) (unpubl.)
52. "Railroad Grade Crossing Hazard Rating Study on North Carolina Secondary Rural Roads, Parts I and II." North Carolina State Highway and Public Works Comm. (Sept. 1951).
53. "Railway Crossings in Japan." Japanese Ministry of Transportation, Tokyo (1957).
54. "Recommended Standards and Practices for Railroad-Highway Grade Crossing Protection." *Bull. No. 5*, Assn. of American Railroads, Washington, D. C. (1955) 30 pp.
55. "Relative Hazards at Railroad Grade Crossings on State and Federal-Aid Highway Systems, 1954." *Tech. Rep. No. 56-3*, Oregon Highway Comm. (1956) 113 pp.
56. "Relative Hazards at Railroad Grade Crossings on State and Federal-Aid Highway Systems, 1957." *Tech. Rep. No. 59-5*. Oregon Highway Comm. (1959) 111 pp.
57. "Report on Railway-Highway Grade Crossings." South Carolina State Highway Dept. (1963) 44 pp.
58. RIVERS, J., and GURNETT, G., "Effect of Gates on Vehicle-Train Accidents at RR Crossings." (1955) (unpubl.)
59. ROTHROCK, C. A., "Hazard Evaluation Formulae for Railroad Grade Crossings." *Proc. Southeastern Assn. of State Highway Officials* (1947).
60. ROTHROCK, C. A., "Railway Grade Crossing Priorities in West Virginia." West Virginia State Road Comm., Charleston (1948).
61. SCHOPPERT, D. W., "Traffic Control and Roadway Elements: Their Relationship to Highway Safety." Automotive Safety Found., pp. 61-64 (1963).
62. SHULTZ, T. G. "Evaluation of Safety at Railroad-Highway Grade Crossings." Purdue Univ. (June 1965) 105 pp.
63. "Sodium Lights Show Railroad Crossing." *Amer. City*, Vol. 57, No. 1, p. 93 (Jan. 1942).
64. "Speed with Safety at Railroad Crossings." *Research for Industry*, Vol. 15, No. 1, p. 14. Stanford Res. Inst., Menlo Park, Calif. (Jan.-Feb. 1963).
65. STEPHENS, B. M., "Factors to Be Considered in Classifying Highway-Railway Crossings with Respect to Public Safety." *AREA Proc.*, Vol. 54, No. 504, pp. 489-491 (Nov. 1952).
66. "Summary, Highway Railroad Grade Crossing Accidents in the State of Iowa." Iowa State Commerce Comm., Des Moines (1958).
67. SWANSON, C. O., "Railway-Highway Grade Crossing Motor Vehicle Traffic Accidents in Illinois—1961." Illinois Div. of Highways (Feb. 1, 1963) 35 pp.
68. SWANSON, C. O., "Railway-Highway Grade Crossing Motor Vehicle Traffic Accidents in Illinois—1962." Illinois Div. of Highways (July 22, 1963) 10 pp.
69. TARBET, T. V., "Improved Railroad Crossing Protection and Coordination of Traffic Signals with Train Movements." Los Angeles Dept. of Public Utilities and Transportation.
70. THOMAS, R. B., "Results Accomplished by the Use of the Grade Crossing Protection Fund Established by the Illinois Legislature Beginning September 1, 1955, and Administered by the Illinois Commerce Commission." Illinois Commerce Comm. (1965) 13 pp.
71. *Traffic Safety Memo No. 113*. National Safety Council. (July 1963).
72. VANDERSTEMPEL, T. M., "Protection Problems at Railroad Grade Crossings." *Traffic Quart.*, Vol. 14, No. 4, pp. 541–550 (Oct. 1960).
73. WEBSTER, L., "Analysis of Railroad Crossing and Accident Data for the State of Ohio During the Ten-Year Period, 1949 Through 1958." Armour Res. Found., Illinois Inst. of Tech. (Sept. 1, 1961).
74. WISE, H. F., ASSOC., "Railroads and Planning in Metropolitan Stockton." A report to City Planning Dept., Stockton, Calif. (Mar. 1955) 100 pp.
75. YOUNG, L. C., "Effectiveness of Automatic Crossing Gates in Southern California, 1954 Through 1963." California Public Utilities Comm., Los Angeles (Oct. 1, 1964) 3 pp.

APPENDIX B

APPLICATION OF HUMAN FACTORS RESEARCH IN DESIGN OF WARNING DEVICES FOR HIGHWAY-RAIL GRADE CROSSINGS*

Officials responsible for the design, constrnction, maintenance, and traffic control of the nation's highways are continually faced with the problem of devising effective techniques for alerting drivers to the dangers that lie ahead. These dangers may take many forms and, correspondingly, a considerable variety of warning techniques may be appropriate.

This report is concerned with only one of these dangers, the highway-rail grade crossing, and with certain human factor considerations in developing appropriate (i.e., effective) measures for warning the driver who is in proximity to such a crossing.

The problem is two-fold, in that:

1. The driver must first be alerted to the fact that he is approaching a crossing, an event that should (automatically and/or consciously) call for the immediate initiation of certain perceptual and driving patterns.

2. The driver must be alerted, by a secondary set of stimuli when a train is actually in or approaching the crossing, an event calling for additional perceptual and operational responses.

These are interrelated, but distinctively different, circumstances, and the development of effective warning techniques must proceed apace for each.

The problem is complicated by the fact that drivers encounter highway-rail grade crossings in a multiplicity of varied circumstances; e.g., in urban, suburban or rural settings, at irregular intervals in both space and time, in an assortment of geometric and geographic configurations, carrying a wide range of traffic and rail volumes, and so on. Still another difficulty is imposed by the transitory nature of the physical environment; e.g., day vs night, and inclement vs clear weather.

As a consequence, there is a lack of uniformity in the circumstances under which the driver is expected to perceive and respond to highway-rail grade crossings. At the same time, however, current traffic engineering emphasis is on uniformity of signs, signals, and markings. This conflict is discussed by Schoppert, et al. (*125*), who state:

> A great number of situations can be covered by standard sets of signs. However, situations that confront motorists are of such complexity and variety that it is impractical to attempt to develop a standard set of signs that specify the exact message content, size, syle, and location to be used in all situations. The motorist can be served better by signing designed to *fit individual conditions at each location*, and such signing should be governed by *uniform application of a few basic principles* rather than non-uniform use of a few standard signs.
>
> The development and use of basic principles which allow sufficient latitude for the application of sound engineering judgment is preferable to rigid adherence to handbook rules. This concept may appear to some as inconsistent with the concept of uniformity. Actually, the reverse is trne. By definition, uniformity means treating similar situations similarly. Hence, different, novel and nnique situations must be treated individually. The application of standard treatments to non-standard situations violates this definition of uniformity and the result is usually a less-than-adequate product. Thus, signing uniformity should be a nniformity of *basic principles* designed to provide motorists with information necessary to achieve two goals: to follow a pre-selected route with an absolute minimum of uncertainty; and to maintain orientation with respect to prominent points along the route. (pp. 22–33)*

Although these comments were made in reference to freeway signing needs, they may be equally as applicable to highway-rail grade crossings.

The Human Factors Approach

The scientific study of human behavior is a relatively recent development, when compared with the more traditional fields of scientific endeavor. Within this young branch of science, the past decade has seen the term "human factors" come into being to describe the application of research findings to problem-solving and man-machine system design (a field of interest which itself has experienced most of its activity in the past 25 years).

Interest in research into the problem of traffic safety also is a relatively recent development. The young subscience of "human factors" has been found to be of considerable value in the equally young field of traffic safety. With regard to the specific problem of accidents at highway-rail grade crossings, the human factors approach can make certain specific contributions. It can define the range of human performance, and thereby can specify the limits of task requirements beyond which man cannot reasonably be expected to perform adequately. For example, human factors research can tell that, even under the most favorable of circumstances, simple human reaction to a simple stimulus cannot be expected to consume less than 0.15 sec. It has also been learned that human performance in general has some characteristics that are significant for the problem at hand. For example, humans have relatively short attention spans; they tend to become bored (less interested) with repetitive tasks; they function largely on the basis of differences in level of stimulation, rather than absolute levels

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(thresholds); and their perception of the world around them is greatly influenced by their past experience, which leads them to expect or anticipate certain types of stimulation in certain specific contexts.

All of this information can be used to attack the problem of grade crossing accidents in the following ways:

1. Human performance limitations can be used in the design and placement of specific signs, signals, and markings for use in specific situations.
2. Knowledge of the general characteristics of human performance can provide a base for formulating general basic principles for application at all grade crossings.
3. Strategies can be formulated to guide the engineer's actions at problem locations and help him to recognize potentially hazardous crossings.

A caution is necessary at this point. The science of human behavior is not as yet capable of providing guidelines so definitive as to permit the development of foolproof warning systems. Thus, short of creating grade separation structures at every crossing (and even these structures present a hazardous object with which drivers will occasionally collide), one is faced at the outset with compromise solutions that can reduce, but not erase, the danger of grade crossing accidents. Recognizing this limitation, the human factors approach can suggest explanations for system failures that may lead to successful remedial actions. These explanations might otherwise never be forthcoming.

Finally, the human factors approach can make its greatest contribution by providing techniques for evaluating the various proposed remedial systems and components for warning drivers. Many of the facts included herein will be of value only insofar as they can assist in the formulation of plans for the efficient testing of the many feasible improvements that will suggest themselves during the course of the over-all study.

The following report provides a summary of human factor considerations that are relevant to the problem at hand, and that may be helpful in formulating not only specific solutions to specific problems, but also general principles of design and application for new systems to reduce accidents at highway-rail grade crossings. Prominent among these considerations are the limits of human performance. Some of these known limits are described next, grouped according to the sensory channels through which information arrives to the driver.

AVAILABLE SENSORY CHANNELS

In driving, as with most of life's activities, behavioral responses are a consequence of perceptions, real or imagined. The driver's ability to respond in an appropriate manner depends, to a great extent, upon how accurately his perceptions reflect the real-world situation. The accuracy of an individual's awareness of his driving environment is a function not only of his sensory capabilities, but also of the degree to which he is presented with perceptual aids, in the form of devices such as signs, signals and markings, that extend his perceptual radius.

There are a limited number of ways in which information can come into the driver's awareness. These will now be discussed in order of their importance to the driver.

Vision

Of all the sensory channels available to him, the driver to an overwhelming degree depends on vision to provide him with information about the environment. The driver's reactions to his visual environment are dependent not only on his basic visual capabilities but also on the degree to which they are utilized at any given time. Thus, the efficiency of a driver's visual sense cannot be defined solely in terms of his physiological capabilities. It is this fact that may at least partially explain why to date all efforts at relating visual ability to driving performance have failed to reveal any significant relationships. As Goldstein (*62*), Burg (*26*) and others point out, most of the studies conducted in this area have methodological shortcomings; e.g., small sample size, unrepresentative sample, and so on. However, the two most important weaknesses of research of this nature are (a) the questionable validity of generalizing from performance on selected vision tests to visual efficiency on the road, and (b) the equally questionable validity of using "driving record" (i.e., accidents and violations) or "Driveometer" scores as a measure of driving performance or so-called "driving ability."

Despite these difficulties, however, it remains possible to define some of the aspects of the visual task in driving, and the effects that different commonly encountered individual and environmental factors have on the performance of this task.

INFORMATION-HANDLING CHARACTERISTICS

"By means of his visual sense a human observer is able to perceive positions, sizes, shapes, motions, textures, and colors of objects in his environment. . . . Many aspects of these perceptions can be predicted from the characteristics of the environment." (*133*, p. 836)

As indicated earlier, visual efficiency is a function of several factors; however, this section is concerned with a listing of those physiological capabilities (response characteristics) of the normal eye most pertinent to the driving task, together with the implications of each of these capabilities for the problem at hand.

1. *Visual acuity*.—The term "normal" visual acuity (a misnomer, at best) signifies that an individual is capable of discriminating an object that subtends only 1 minute of arc of his visual field (20/20 vision). This is equivalent to 0.35 in. at a distance of 100 ft (*55*).

Implications: The minimum discriminable letter (or symbol) size at a given distance is thereby established, assuming optimal conditions (20/20 vision, adequate light, sufficient time for steady, straight-ahead fixation, etc.) Under the normal range of driving circumstances this minimum figure must be greatly increased to compensate for drivers with less than 20/20 acuity, low illumination levels, limited fixation time, restricted visibility, and so on.

2. *Color vision*.—For a given level of illumination, an

individual with "normal" color vision is differentially sensitive to the different spectral colors. For example, colors whose wavelengths fall near the center of the visible spectrum are more effective in eliciting a response (at a given level of illumination) than those that lie at either end of the spectrum (*133*, p. 934). This means that yellows and greens are more effective than reds and blues. Sensitivity to different colors changes as level of illumination changes, varies somewhat from individual to individual, and is interrelated with the brightness variable (*104*). As level of illumination decreases, color differentiation ability lessens, until at very low light levels all colors take on the appearance of varying shades of grey. Thus, in dim light brightness rather than hue plays the major role in differentiation among colors (*77*).

Implications: In order properly to utilize color in signs, signals, and markings, it is necessary to know the range of lighting conditions under which these devices will be seen, and the choice of colors to use must, at least partially, be dictated by human color sensitivity at these different levels of illumination. For example, because at lower luminance levels light yellow-green is most easily distinguished, whereas colors toward the red and blue end of the spectrum become relatively less visible (*55*), it may be advisable to utilize light yellow-green colors more frequently in signs or markings to be used where low illumination levels prevail. Also, because brightness plays an ever-increasing role as illumination decreases, it may become necessary to rely on brightness differences as a complement to hue differences. This would be in agreement with the principle of redundancy in system design to increase reliability of system performance.

Also to be considered is the ability to distinguish among colors. Chapanis (*29*) states that although there theoretically are millions of possible discriminable colors (combinations of hue, saturation, and brightness), there are at most only 150 discriminable wavelengths in the visible spectrum. Furthermore, of these, only 12 or 13 colors can be repeatedly identified without appreciable error. Are the colors chosen for signs, signals, and markings distinctly different from one another in the driver's perception? Also, what is the psychological impact of different colors (to be discussed later)?

3. *Contrast and low illumination levels.*—Not only the size of the test object (i.e., visual angle subtended), but also the degree of contrast between the test object and its surroundings, is important to the discrimination of that object. Generally speaking, the greater the contrast with its background, the more legible the object is; however, an extreme contrast ratio (e.g., 50 to 1) can be adjudged "unpleasant" (*117*). Low illumination levels (as at night) decrease the visual powers of acuity, contrast, form perception, stereoscopic depth perception, and the ability to judge size, motion, and position (*117*). However, in low illumination, contrast plays a more important role in legibility than does acuity (*117, 121*), because acuity will be halved (*116*).

Implications: For maximizing the target value of signs or markings, especially when low illumination levels prevail, the principle of contrast must be utilized, considering the message and its background in terms of brightness (as well as hue) differences. Back lighting must be compared with front lighting, and back shields used if necessitated by the natural background. For example, at dusk the sky is still bright; however, road-level objects merge with the dark, shadowy background, and sky brightness provides enough glare to prevent the retina from adapting enough to use the small amount of light at the road levels. In lower light levels, signs must have letters five times as large and contrast 6 to 20 times greater in order to be as legible as the same sign seen in higher light levels (*116*).

4. *Glare.*—Glare (excessive light falling upon the retina) decreases the contrast between the target and its surrounds, thus lessening legibility (*18*).

Implications: Under conditions where glare (e.g., from oncoming or following headlights, instrument panel lighting, or direct or reflected sunlight) is likely to be a problem, repositioning of a sign and/or increasing the contrast (message to background) may be required. Although opposing headlights are occasionally of value by providing silhouette effects, these are useful for showing up obstacles, and would hinder, not aid, legibility of signs (*83*).

5. *Illumination level.*—Generally speaking, as illumination level increases, visual functioning (e.g., acuity, color discrimination) improves (*131*); however, when illumination becomes too high, visual efficiency will be impaired (*133*, pp. 958-9), inasmuch as too-high illumination creates glare, which in turn lessens contrast and, thereby, legibility.

Implications: Some trade-off must be made between illumination that is feasible (economically) and illumination that would bring the crossing up to daylight levels, while avoiding glare or unduly high contrasts with the surround (i.e., islands of light).

6. *Visual fatigue eyestrain.*—Visual fatigue can occur under conditions of decreased, flickering, unsteady, or varying light, and glare (*117, 18*).

Implications: Adequate, steady, non-glare illumination is desirable to prevent eyestrain. This applies to highway illumination, sign and signal illumination, and vehicle lighting systems.

7. *Perception and recognition time.*—Response time to visual stimuli increases with an increasing complexity or number of the stimuli. The more complex the visual field, the more things one has to attend to, the longer it takes for any one thing to be reacted to (*64*). Response time also increases as the stimuli become less distinct and/or more ambiguous. Essen (*47*) has shown that reaction times to lights increase as the lights are placed farther from the observer. The results suggest that reaction times obtained at near point must be increased if they are to be applied to the driver in motion, whose attention is directed farther and farther down the road as his speed increases. Finally, response time increases with increasing angular displacement of the stimulus from the direct line of sight (*11*).

A minimum glance to read a target outside of the 5° arc of clear vision requires from 0.6 to 1.0 sec (*53*). This "glance" reading time will permit recognition (comprehension) of three to four short, familiar words (*53, 78*).

Perception of unfamiliar patterns, words, etc., will be less rapid.

Implications: It is obvious that the foregoing facts on response time must be related to distance and speed when designing signs and markings. As Forbes (*53*) points out, a warning time of 8 to 10 sec at a speed of 50 mph is necessary for a "comfortable" deceleration of 4-6 mph. Glance time must be added to this. Forbes derives the 10-sec warning time from a combination of reading time, perception-reaction time, and time to slow the vehicle (*54*).

Other implications are that the warning should be as simple, direct and familiar as possible, and that sign placement should fall as close to the central 5° arc of clear seeing as possible. In any event, a sign should not be placed outside of the central 50° or 60° of the visual field, to be reasonably assured that it lies within what Danielson (*34*) calls the "safe" region.

8. *Age effects.*—Performance of most visual functions deteriorates markedly in older age. Of particular importance in driving are acuity, sensitivity to glare, and vision under low levels of illumination, all of which deteriorate (*117, 16, 4*).

Implications: Richards (*116*) feels that essential signs and signals should be designed to accommodate older drivers, by being made larger and brighter. Peckham and Hart (*111*) feel that elderly drivers should be persuaded not to drive at night, if at all possible. A more general concept to be considered is that of designing for, say, the lowest 10th percentile of visual performance among drivers given a general license. (Special limited licenses are issued to drivers with particular vision problems.)

PERFORMANCE DECREMENT

Discussed in this section are the adverse effects upon visual performance occasioned by various physical, physiological, psychological, and environmental conditions. Where possible, suggestions are made for reducing this decrement through proper traffic engineering.

1. *Decrement due to physical deficiencies:*

(a) Color blindness or weakness. Approximately 8 percent of male drivers and 0.5 percent of female drivers have defective color vision of varying types and severities (*106*). However, research conducted with red, amber, and green traffic signal lights (e.g., *105*) has indicated that it is possible to specify colors whose compositions are such that (in conjunction with manipulation of the brightness variable) they are recognized nearly as readily by color defectives as by color normals. Except to a very few drivers, a "green" signal is quite readily recognized if it has a blue component. Another study (*88*) has shown golden yellow to be more visible under all conditions for both color normal and color deficient subjects.

Implications: Poor color vision could be included as an item of interest in special studies of grade crossing accidents. Evaluation of proposed changes in signs and markings could be tested by including drivers known to have high degrees of color weakness in the subject sample.

(b) Restricted field of vision. Few facts are available concerning the effects of restricted visual field upon driving performance (*26*). Danielson (*34*) feels that a field (monocular or total binocular) as low as 50° is "reasonably safe" if the driver is cautious, obeys laws, is physically and mentally sound, and has a static acuity of 20/40 or better in his better eye. No conclusions based on valid research will confirm or reject this viewpoint, although it is well known that drivers will often "compensate" for their visual deficiencies, thus masking the true effect of their disability (*52*). It appears safe to say, however, that as a general rule, sign placement should be as close as possible to the center of the visual field (where acuity and color discrimination are best).

Implications: A field of 50° to 60° is as large as should be used in planning the design of railroad crossings and in diagramming collision courses.

The widely held opinion that effective field of view decreases with speed is often misinterpreted to indicate that the actual field narrows, which, of course, it does not. Angular velocity of roadside objects does, of course, increase with speed, and the driver's attention can be expected to be directed farther down the road as his speed increases. Both of these factors tend to define an effective field that narrows with speed. Hulbert, in an internal report to the California Division of Highways, has suggested a 60° cone of vision as being useful for optimizing the placement of highway signs at freeway ramps.

(c) One-eyedness. Many of the same comments apply here as are made in the foregoing with reference to restricted field of vision. Because the one-eyed driver is much more likely to be conscious of his limitation than the individual with a moderately restricted field, he is more likely to compensate (e.g., by moving his head back and forth more often than the normal driver). The one-eyed driver also will lose one of the cues of depth perception (i.e., binocular disparity). However, there is no evidence that this loss impairs driving performance. Shipley (*127*) states (from personal experience) that, with practice, monocular driving does not seem to be particularly hazardous.

(d) Reduced visual acuity. The driving population, of course, does not have the range of visual acuities to be found in the general population, due to vision screening at the time of licensing. Although in the general population 2 percent have less than 20/200 binocular distance acuity (*16*), nominally, at least, drivers will have acuity no worse than 20/75 in the worst eye, inasmuch as this is the most permissive screening requirement in the United States (*1*). In practice, however, it is not unusual to find drivers whose acuity is 20/100 or worse. Although restricted licenses are often granted in such cases, frequently such a driver has managed to pass the screening test, and has obtained an unrestricted license.

Implications: It must be assumed, therefore, that at least a small percentage of drivers have acuity levels far below what is normally expected, and corresponding steps must be taken to provide signs and markings that will be legible to these drivers. For example, at threshold, a driver with 20/100 vision requires letters five times as large as those which a 20/20 individual can just see. This corresponds to a stroke-width of 1.75 in. at a distance of 100 ft.

(e) Other. Little factual information is available regarding the effects on driving performance of other visual deficiencies, such as abnormal muscle balance and hypersensitivity to light. Research currently under way should throw light on these areas, but at present no conclusions can be drawn.

2. *Decrement due to temporary physiological states:*

(a) Fatigue. It is generally acknowledged that anything over moderate fatigue is detrimental to performance of any sort (*68*). The California Highway Patrol estimates drowsiness as the cause of 10 percent of all single-car accidents (*28*). It is extremely likely that fatigue, as reflected in inattention, faulty driving, or poor judgment, is responsible for an even larger proportion of all types of motor vehicle accidents. Suhr (*134*) has shown performance decrement in a simulated driving task to occur within two hours. Furthermore, Suhr found that the drivers could not (or would not) accurately evaluate their own level of driving efficiency. It is often quite difficult to show fatigue effects in experimental situations (*40*) because the subject will usually "pull himself together" for his performance test, unless he is kept unaware of the fact that he is being tested. Nevertheless, fatigue effects have been shown (*92, 48*), and rest pauses and increased blood-sugar levels have been shown to at least partially reduce fatigue effects.

Implications: It is uncertain whether any actions on the part of traffic engineers can alleviate the danger to himself and others posed by the fatigued driver, other than those that lead to over-emphasis in warning, which can do more harm than good by causing an over-reaction among normally alert drivers. At this time there do not seem to be any remedial steps peculiar to the grade-crossing problem.

(b) Alcohol. According to West (*146*) there are estimated to be more than 700,000 problem drinkers among Californians of driving age (over 15). Of these, 100,000 are advanced alcoholics. A report prepared by the California Highway Patrol (*28*) states that 15 percent of all single-car accidents are caused by drinking or drugs. In a subsequent study of fatal single-car accidents, 76 percent of the male victims had been drinking, while 70 percent had blood alcohol concentrations of 0.10 or higher. The comparable figures for female drivers were 51 percent and 40 percent, respectively (*118*). Estimates of the proportion of all fatal accidents in which alcohol is a factor have run as high as 50 percent (*67, 59*).

Needless to say, the drinking driver is a problem, on many counts. Insofar as visual functioning is concerned, some impairment of visual acuity, binocular vision, sensitivity under low illumination levels and glare recovery all have been demonstrated to occur under relatively low blood alcohol concentrations (*66*).

From the traffic engineer's standpoint, there is little to do to remedy the situation besides overemphasis on legibility, redundancy in warning, and so on, all of which are discussed later herein.

(c) Drugs. As Rehling (*114*) points out, different types of drugs have differing effects, and it is not possible to categorize drug effects on driving performance in any simple fashion. Some drugs (e.g., narcotics) impair sensory functions of all sorts, whereas others (e.g., amphetamines) tend to increase alertness, but at the expense of concentration.

Thus, it is impractical at the present time to suggest ways to compensate for drug effects in the development of warning devices. It can be expected that the remedial efforts that are effective to any degree will also act to reduce accidents at grade crossings.

3. *Decrement due to psychological states.*—Among those transitory or permanent psychological states that influence driving performance (e.g., poor driving attitude, emotional stress, carelessness, inattention), only one is a legitimate concern of the traffic engineer; i.e., inattention. (In a study by Fisher (*50*), an attitude of hostility was seen to lead to misperception; however, there is little the traffic engineer can do to remedy this problem, other than to make the messages as clear and unmistakable as possible.) An inattentive attitude may, of course, be an accompaniment to a more deep-seated problem, such as emotional stress. Nevertheless, the effect in driving remains the same, and the task of the traffic engineer is the same; i.e., to devise means for gaining the attention of the driver and calling upon him to perceive (and thereby respond to) a warning device. Principles for accomplishing this are discussed in a later section.

4. *Decrement due to vehicle characteristics.*—Vehicle characteristics that influence visibility include windshield area and design, windshield glass composition, size and placement of roof pillars, dash panel design, seat design (as it influences driver eye position), and headlighting systems.

(a) Windshield glass composition. Studies on this topic (e.g., *65, 71, 120, 147*) have shown that whereas clear safety plate reduces luminous transmittance by 12 to 14 percent, tinted windshield glass may reduce transmittance by as much as 35 percent. The consensus is that the daytime advantages of tinted glass (glare reduction and absorption of radiant heat) do not justify the concurrent nighttime loss of visibility distance, which may be particularly hazardous under conditions of low luminances with poorly reflecting targets and backgrounds. The American Standards Association Safety Glazing Code specifies that windshield glass must permit regular (parallel) luminous transmittance of not less than 70 percent of the light. There are those (*65, 71*) who feel this standard is too permissive and that visibility loss should be kept to an absolute minimum because most visible information is seen through windshield glass, and the resultant losses can play an important role in perception.

(b) Windshield, roof pillar, and dash panel design. Results of several studies (e.g., *70, 58, 2, 3, 136*) have clearly shown that the numerous configurations in use today make it difficult to generalize regarding the effects of design on visibility. The size and placement of windshield pillars, which can create dynamic blind spots or obscurations (*115*, p. 183) into which signs (and even the train itself) may disappear, is a critical factor. The extensive curvature often found in windshields of present-day cars can introduce distortion (or even obscuration) in critical areas of the visual field (*136*). Dash panels may hinder visibility by intruding into the windshield area, or by imparting glare (direct or reflected) into the driver's eyes, or by being so difficult to read that they divert the driver's attention from the road for too long a period.

Although there are no standards for windshield design, an SAE subcommittee has developed a method for determining those windshield areas which are believed to be essential for forward visibility (*7*). It is based on the driver's being able to see traffic signals in time to stop behind a crosswalk when operating at a residential speed limit.

Implications: Visibility areas from the driver's position in the vehicle definitely restrict the amount of information that can be presented to the driver by signs and markings. The implication here is that signs or signals should be installed on a redundancy principle, so that if some of them happen to fall in "blind" areas of the driver's field, there will be other signs or signals that are visible. Another problem is that as vehicles are designed to be lower (or if driver eye position is low), there is a consequent reduction in the viewing angle of pavement markings. This may necessitate redesign of pavement markings, and it also bears upon placement of pavement markings relative to vertical curvature.

(c) Driver eye position. There is great variation in eye position (*101*) as a function of driver height and weight, seat compressibility, the amount of vertical seat adjustment provided, and the driver's posture and driving attitude. The eye height from the pavement determines the angle of view of the road ahead and the limitations of visibility imposed by vertical curvature. Eye height relative to the windshield-dash-roof-steering wheel configuration also influence the area of the road ahead which is visible to the driver.

The greatest source of variation lies in the vehicles themselves, which range from low sports models to large trucks and buses. Generally speaking, the lower eye levels pose more and greater problems for the traffic engineer.

(d) Headlight system design. A major vehicle characteristic affecting visibility at low illumination levels is the quality and distribution of light emitted by modern headlight systems. Present-day vehicle codes do not strictly regulate the design of vehicle headlights. Normally, a vehicle code will specify the maximum and minimum allowable number of headlamps, the range of permissible heights above the ground at which they may be mounted, their maximum (not minimum) permissible candlepower, and, finally, statements to the effect that the "upper beams must reveal persons and vehicles at at least 350 ft" and the "lower beam must reveal persons and vehicles at at least 100 ft" (*143*).

Unquestionably, modern, properly aimed headlights in good condition will permit a person with normal vision to see anticipated objects at distances considerably in excess of those set forth in the usual vehicle code. For example, Solomon (*132*) using drivers who were anticipating familiar signs, driving at 30 mph with properly aimed low-beam headlamps (modern single units) found mean legibility distances ranging from 478 to 614 ft, depending on the type of (reflectorized) signs used.

However, it is not known how far ahead the fatigued driver with less than 20/20 acuity will be able to see an unexpected, low-reflectance object, when his windshield is finely pitted from age, when his lights are not aimed properly, when a light rain is falling, and when the lights from opposing cars are creating glare (which will further reduce his visibility distance (*82, 142*)). No research has been conducted that can answer a question of this complexity. Some idea of the potential loss in visibility distance is provided by Roper (*119*), who showed that alert drivers, not anticipating any objects, traveling at 50 mph with properly aimed dual-unit headlamps on low beam (with no opposing glare), can see a medium-grey target of 7 percent reflectance * at a distance of approximately 450 ft. However, when the headlamps are mis-aimed by only ½° (which Roper says is about average), this distance drops to about 325 ft; with a mis-aim of 1°, visibility distance drops to only 175 ft. This represents approximately 2⅓ sec of travel at 50 mph. Furthermore, as Lauer and Stone (*91*) point out, legibility distance is only about 85 percent of visibility distance.

Implications: It is readily apparent, then, that by a combination of not uncommon conditions, a situation quickly arises where legibility distance can drop to an alarmingly low figure, one in which the unexpected, low-reflectance object can create an extremely dangerous hazard. The implications of these findings for the traffic engineer are obvious—greater legibility of signs and markings and more advance warning.

5. *Decrement due to nonoptimum environment.*—The

* Reflectance of clothing ranges from 2 to 15 percent, the average for men's clothing being about 5 percent (*94*).

detrimental effect on visual performance of nonoptimum environmental conditions, such as physical obstructions (e.g., a truck obscuring the sign), adverse weather, heavy traffic, poor vertical or horizontal alignment, poor ventilation in the vehicle, are relatively obvious and need little discussion here. All of these factors will bear upon factors already discussed. For example, physical obstructions, adverse weather, poor alignment, etc., all bring about a reduction in visibility distance. Heavy traffic, aside from being a hazard in itself from an exposure viewpoint, helps divert the driver's attention from the business of driving (and also may lead to frustration and subsequent poor judgment). Poor ventilation and high noise levels can create fatigue, with its consequent effects.

Implications: Fog conditions can be such that pavement markings are the only warning devices visible to the driver. In this case, and perhaps in general, there is a need for these markings by themselves to convey the intelligence that (1) a grade crossing is near, (2) here is the crossing, and (3) now you are past the crossing. Under these circumstances, audible warnings may be the only feasible means of informing the driver that a train is approaching.

6. *Decrement due to interaction with other sensory channels.*—Little research has been conducted in this area, with the exception of the effects of high sound levels in the vehicle. Broussard, et al. (*23*) found that visual contrast thresholds for low brightness differences were not significantly affected by 2 hr of 90-decibel noise (a common vehicle noise level). Loeb and Jeantheau (*96*) found that noise and vibration increased response times to a visual monitoring task, whereas heat (120 F) had little effect. Benko (*14*) found that undue amounts of noise affect the visual field, and the color fields are first affected.

Implications: There are no definite conclusions to be drawn here; the consensus of many researchers is that the quality of the sound may be more disruptive than the actual level of the sound. However, nothing can be said regarding implications of this for traffic engineers except that most interactions can be expected to render the driver less sensitive to stimulation (increase his threshold levels) as compared with threshold levels determined in the usual laboratory-conducted research.

PRINCIPLES FOR OPTIMIZING CHANNEL UTILIZATION

Out of the foregoing discussions have emerged some facts concerning visual performance that may be translated into workable principles to guide the traffic engineer. These will be considered from the standpoint of target value (primarily) and legibility. Target value * refers to the degree to which the sign (signal, marking) gets the attention of the driver. Legibility is concerned with how readily the driver perceives (and understands) the information being conveyed by the sign, signal, or marking once it is noticed.

* Target value may be considered a function of many factors, such as background (color, luminance, distracting elements), foreground (weather, light, distracting elements), contrast, illumination, size, and (sometimes) shape.

1. *Size.*—It is evident that the size of the message is crucial to legibility. A large number of studies (e.g., *15*) have shown that increases in letter height, width, and spacing all increase legibility distance. It is also obvious that the over-all size of the sign is crucial to target value, and it interacts with other attention-getting aspects, such as color, shape, illumination. In view of the fact that performance decrement can be brought about by so many factors, signs and markings must be designed to be legible under all but the most extremely adverse conditions.

Principle: Insofar as is practical within the limits of space and cost, and all other considerations being equal, warning messages (and therefore signs) should be made as large as possible.

Letter size should be a function of prevailing speeds (and placement of the sign should also be determined by prevailing speeds). Several rules-of-thumb have been proposed as follows:

(1) For speeds up to 30 mph, 4- to 8-in. letters should be used; for speeds from 30 to 70 mph, 8- to 12-in. letters (*107*). The same author provides formulas for determining letter size:

$$X = \frac{S}{10} + \frac{V}{100}(N+6) \qquad \text{(B-1)}$$

$$H = \frac{4}{3}\left[\frac{S}{10} + \frac{V}{100}(N+6)\right] \qquad \text{(B-2)}$$

in which

X = height of lower case letters, in inches;
H = height of upper case letters, in inches;
S = sideways displacement of sign from driver's path, in feet; and
V = driver's speed, in mph.

(2) Allen (*5*) found that 1-in. of letter height is necessary for every 88 ft of legibility distance during the day, and this legibility distance decreases 15 percent at night. However, these would be considered threshold values for alert, anticipating subjects moving at 20 mph. For speeds in excess of 60 mph, and for a driver with less than 20/20 vision (say 20/50) who is not anticipating the sign, these values should be multiplied by a factor of at least 8 to 10.

(3) Mitchell and Forbes (*103*) developed the following formulas based on the assumptions that a comfortable deceleration takes 8 to 10 sec; perception-reaction time takes 1.5 sec; glance reading time for a 3- to 4-word sign is 0.6 to 1.0 sec (3 to 11 sec if more than 4 words on the sign); warning time must include reading time, perception-reaction time, braking time, and safety factor; and, finally, that the 90th percentile of design speed is conservative:

Total warning time for slowing:

$$X = 1.47 \times 11.5V_i \qquad \text{(B-3)}$$

Total warning time for stopping:

$$X = 1.47V_i \times 3.5 + 1.08V_i/4 \qquad \text{(B-4)}$$

Legibility distance:

$$L = X - A \qquad \text{(B-5)}$$

Letter height:

$$H = L/l \qquad \text{(B-6)}$$

in which

X = total warning time, in sec;
V_t = design speed, in mph;
L = legibility distance, in ft;
H = letter height, in in.;
l = legibility distance of letter, in ft; and
A = distance in advance that sign is to be placed, ft.

With regard to letter style, case, spacing, stroke width, etc., much research has been conducted, all of which supports current lettering standards (e.g., BPR Standard Series E alphabet).

2. *Message area.*—The ratio of message size to sign size is a factor influencing legibility (and, to a limited extent, target value) that has not received too much attention. It has been recommended that the message be limited to 25 percent of the total sign size (*90*). Only the hazard warning signs tend to conform to this ratio; most information signs devote 50 to 80 percent of the sign area to the message. Another study (*22*) found that legibility increases with an increase in border width.

Principle: Message size on hazard warning signs should not exceed 25 percent of the total sign area.

3. *Message content.*—Closely related to message area is message content. Enough research has been done (*76, 125, 132, 97*) to demonstrate conclusively that:

Principle: For maximum understandability and legibility, sign (or pavement) messages should be as short as possible.

Given a certain size panel, shorter messages permit larger letters, a factor consistent with increased legibility. However, caution must be exercised lest understandability be reduced by over-abbreviation of the message. Symbols can, if universally understood, replace a written message. However, very few symbols, if any, can make this claim, and therefore will need to be accompanied by a written message.

4. *Placement:*

Principle I: For maximum efficiency and performance, and least accumulation of dirt, signs should be placed approximately 6 ft above the road crown and 10 ft from the road's edge (*141, 35*). However, departure from this rule, so as to place signs lower and closer to the roadway, is encouraged by this writer whenever the situation calls for such departure. If this is done, special attention to sign maintenance is required.

Principle II: The warning signs should be placed far enough in advance of the crossing to permit ample time for comfortable deceleration if a stop is necessary.

According to Forbes' (*54*) calculations, a 10-sec warning time is necessary at 50 mph; if 10-in. (high) narrow letters, or 8-in. (high) wide letters are used, the sign should be placed 400 ft before the crossing. If the sign is placed at the crossing, the letters should be 18 in. high and proportionately wide. Proportional letter heights should be used if sign placement falls between these extremes of placement, as indicated by Eqs. B-1 through B-6.

Placement is also affected by contrast with background.

5. *Color.*—Along with reflectorization, the color of traffic signs is most often the subject of comprehensive studies. However convincing the results of these studies, the fact is that color for coding purposes has not been utilized to the fullest extent (*13, 10, 53, 17*). Color coding can be extremely useful as an adjunct to shape and message in conveying information to the driver. (As a matter of fact, Birren (*17*) found that size, shape, and color were more important than message in gaining attention.) Colors used for coding purposes should be chosen that are easily distinguished from one another, and that will increase the target (i.e., attention) value of the sign under low illumination and/or adverse weather conditions.

From the research conducted to date, the following conclusions appear justified:

Principle I: To provide maximum target value and visibility distance for an object under low illumination levels a yellow or yellow-green hue is best to use (*88, 133, 55, 89, 51*). (Oranges and reds are *not* good because they lose visibility at low illumination levels.)

Principle II: Black markings on a yellow background appear to present the best combination of target value and legibility for all-around (i.e., day and night) use. Most reports indicate that black markings on white sign backgrounds do not have sufficient target value (*13, 17, 79, 38*).

Principle III: The use of combinations of colors may provide (1) optimum target value for both day and night illumination, (2) maximum contrast against all types of backgrounds, and (3) optimum possibility for color-weak drivers to notice them.

6. *Shape.*—Very few studies have been conducted to determine the actual value of shape-coding traffic regulatory signs, so it is not possible to draw firm conclusions. However, there is strong feeling (e.g., *95*) that greater use should be made of shape differences, especially when combined with color differences. The use of a nonstandard triangular shape has proven highly effective as a warning sign in Canada (*129*).

Shape coding must be applied with the same caution as with colors; i.e., the shapes used must be easily distinguished from one another, or shape coding loses its value. As Bell (*13*) points out, black-on-yellow STOP and RR signs can readily be confused at a distance due to their insufficiently dissimilar shapes.

7. *Contrast.*—Legibility increases with contrast differences between the message and its background.

Principle I: The sign message should provide strong contrast with the rest of the sign, and the sign itself should contrast with its background.

For example, whereas white letters on a green sign may provide good contrast, placing the green sign against green foliage will lower the overall target value of the sign. In such situations, sign placement should be altered to provide better contrast with its background; if this is not possible, it may be desirable to place the green sign, for example, on a larger backboard of contrasting color (e.g., yellow).

Another aspect of contrast becomes important in signal-light devices; i.e., steady versus intermittent stimulation.

Principle II: Flashing lights are more conspicuous than continuous lights.

Although a moving light (e.g., wigwag) is more noticeable than a stationary light, a flashing light (of equal intensity) appears brighter, and therefore more attention-getting than either (*133*, p. 976). Available data on highway-rail grade crossing accidents seem to support this statement (*140*). Peckham and Hart (*110*) suggest the use of a visual warning device that presents groups of short light flashes above the background luminance at rates of several per second. This type of display would more readily elicit a visual response than a steady stimulus of equal contrast. (Work is currently under way at the University of South Dakota on the optimum flash rate and duration of flash for warning lights; however, no results of this research are available as of this writing.)

8. *Illumination and brightness.*—Illumination is important to legibility (*131, 44, 85*) provided it is not so high as to create glare * (*17*). The object of illumination is to provide brightness contrast between the potential obstruction (or warning sign) and its background (*142*). Shapiro (*126*), in comparing the effects of letter style, height-to-strokewidth, and illumination upon legibility found that illumination was the only significant variable.

Principle I: Within the limits of economic feasibility, all hazardous obstructions (e.g., highway-rail grade crossings), and all signs, signals, or markings warning thereof, should be illuminated as much as possible short of creating a glare situation.

Illumination may be provided by external sources (e.g., luminaires or floodlights), by internal sources (e.g., warning lights or self-illuminated signs), or by the light provided by the vehicle headlamps. The lower the contrast, the higher the background luminance must be to maintain performance level (*19*).

With regard to external light sources, Elstead, et al. (*46*) conclude that traffic signs should have 10 to 20 ftL (foot-lamberts) in rural and suburban areas where ambient luminance on signs is from 0.4 ftL to negligible.

In the case of vehicle headlighting, reflectorization is highly recommended as a means of increasing target value and visibility distance for the obstruction, signs, and markings (*44, 37, 149*). It is intended primarily for rural and suburban areas, and is not intended to replace auxiliary illumination in the form of floodlighting or backlighting, particularly in urban areas where traffic control signs must compete with illuminated advertising or other urban illumination.

Extensive research has been conducted on the effects of reflectorization, and the results of this research seem to demonstrate conclusively the value of reflectorization of signs and markings in improving nighttime target value and legibility distance. Among the major findings to date are the following:

(1) for reflectorized messages, there is an interaction between contrast direction and strokewidth. That is, narrower strokewidth for light letters on dark background gives the same legibility as wider strokewidth for dark letters on a light background (*72*).

(2) Illuminated signs provide best legibility on either high or low beams (10 ftL is optimal illumination); however, in the absence of illumination, reflective sheeting provides almost as much legibility on high beams, and 15 to 30 percent less legibility on low beams (*5*). (Initial cost of illuminated painted signs (including one year's electricity) exceeds that of a reflectorized sign (*128*).)

(3) The relative effectiveness of reflective sheeting and reflector buttons continues to be debated; however, one study (*144*) reports that reflective sheeting provides a more aesthetic appearance, somewhat easier maintenance, and maintains a greater proportion of its effectiveness in rain and other types of adverse weather.

(4) Increasing the reflectorized area increases target value (*38*). In a study of reflectorization of boxcars (*93*), it was shown that the larger the reflectorized area, the lower the illumination necessary to detect movement. The study also showed that concentration of reflectorized material (into larger areas) is better than scattering.

From all of these results it is evident that:

Principle II: Particularly in rural or suburban areas, where little or no external fixed lighting is present, reflectorization should be used to improve target value and legibility distance of obstructions, signs, and markings.

9. *Symbology.*—Traffic symbology is a graphic means of replacing legends, primarily to decrease the driver's perception-reaction time and secondarily to provide adequate recognition by illiterate drivers (*45*). "Pictorial" signs portray the real object (e.g., a picture of a locomotive for use as a RR warning sign), whereas "abstract symbol" signs depend on the viewer knowing their meaning (e.g., the European STOP sign). Universal symbol meanings are difficult to achieve because of cultural differences and engineering advancements in different countries. Also, some conditions, such as fog and radiation, are extremely difficult to represent.

Brainerd, et al. (*21*) studied the interpretability of 30 European signs by United States drivers and found that interpretability approached 100 percent after one exposure to correct meanings. They also found that the most easily interpreted signs were either "pictorial" or were counterparts of U.S. road signs. "Abstract symbol" signs were generally more difficult to interpret. The authors conclude that stereotypes for some road signs do exist, and the use of such stereotypes can increase interpretability.

Too little research has been done in this area to permit the formulation of generalized principles. However, the concept, which is one of providing concise, quickly (and universally) understood messages is an important one, and merits further investigation. Perhaps a combination of symbols and legends is required to maximize the probability of conveying the information to both literate and illiterate (or non-English-reading) drivers. This would be in agreement with the general principle of redundancy in signs and markings.

* Glare increases the effective luminance level and also decreases target contrast (*18*), and this must be controlled.

Audition

It is not documented, but it is generally assumed, that next to the visual channel the driver depends most often on his auditory sense to provide him with information about his environment. Specifically, the driver utilizes his auditory sense primarily as a supplement to vision in providing information about the road surface, the presence of other vehicles, the mechanical functioning of his own vehicle, and as a clue to his vehicle speed and the nature of the terrain.

It is extremely difficult to estimate the importance of hearing in the operation of a vehicle, because no significant research has been reported in this area (*62*). With regard to demonstrating a relationship between defective hearing and accident experience, some of the same problems exist as were described previously in connection with vision. That is, to a large extent the individual has demonstrated the ability to compensate for hearing defects by more efficient utilization of his remaining senses or by the exercise of greater-than-average caution. However, popular opinion to the contrary, a recent study of the driving records of deaf drivers in California (*139*) has revealed them to have a slightly worse-than-average record. Although not conclusive, the study indicates the need for further research in this area, especially when one considers the potential magnitude of the problem (an estimated 420,000 Californians of driving age have impaired hearing (*146*)).

INFORMATION-HANDLING CHARACTERISTICS

As with vision, auditory efficiency is not a function solely of physiological capability, but also of the degree of utilization of this capability. In turn, this utilization is a function of several factors, both internal and external.

Auditory sensitivity may be defined in terms of response to different frequencies and intensities of the sound stimulus, as well as to such lesser known sound attributes as volume, brightness, density, purity or complexity, and many others (*133*, pp. 985ff). With regard to the driving situation, the following characteristics of auditory sensitivity seem the most relevant:

1. *Frequency.*—Generally speaking, the human ear is sensitive to frequencies ranging from below 20 cycles per second (cps) to over 20,000 cps. To a large extent, this sensitivity is a function of many other characteristics of the sound (i.e., intensity, duration, purity, etc.) The ear is maximally sensitive in the 1,000- to 2,000-cps range for normal young adults; as a result, all other sound attributes being equal, a frequency of approximately 1,000 to 2,000 cps will provide the most communication for the least expenditure of sound energy. (It is important to remember, however, that other sound attributes may have a more significant effect on communication than energy.)

2. *Intensity.*—With threshold to sound defined as 0 decibels (re 0.0002 dyne/cm^2), discomfort is experienced at approximately 110 to 120 db, and pain is usually reported at 140 db. For reference purposes, the sound level inside a single vehicle reaches peaks of close to 90 db (*61*). Noise levels inside vehicles driving in traffic have been known to reach even higher levels.

Implications: Warning system components relying on sound stimuli to alert the motorist will have to deliver sufficient energy to compete with 90- to 100-db noise levels inside the vehicle. This may demand such high-intensity sound sources as to approach the threshold of pain for nearby pedestrians.

3. *Masking.*—Masking represents the inability of the auditory mechanisms to separate one tone from another, or to discriminate a tone because of the presence of noise. Masking commonly occurs when the two tones in question are close in frequency. Low-frequency tones more effectively mask high-frequency tones than in the converse situation. Masking increases as the intensity of the masking tone (or noise) increases, although this is at least partially dependent on the relative frequencies (*133*, pp. 1,005ff).

Implications: In the use of sound for communication, it is important to consider the intensity and frequency of other sounds that are present, so as to minimize the masking effects of this background noise. This may enable avoidance of the danger of extremely high (150-db) sound levels from warning devices.

4. *Auditory fatigue.*—Immediately prior stimulation of the auditory mechanisms leads to adaptation (a temporary loss of sensitivity), which in turn raises the threshold for a subsequent sound (*133*, p. 1,011). (It is well known that cessation of a prolonged sound or noise also acts as a stimulus.)

Implications: For maximum probability of perceiving a sound stimulus to be used for communication, it is important that this stimulus be temporally isolated from other sound stimuli. Although this state cannot be completely attained, it nevertheless is a worthy goal. For example, care could be exercised to create and maintain smooth, even pavement at the approach to grade crossings. This design would produce a dramatic and sudden reduction in tire noise. This sudden quieting, in itself, would serve to alert the driver.

5. *Sound localization.*—The localization of a sound falling in the vertical plane bisecting the body is extremely difficult, with the head held stationary.

Implications: Sources of sound used for communication of a message to the driver should not be in the median plane if knowledge of the origin of the source is important to the driver.

6. *Perception and recognition time.*—As with the other senses, response time to auditory stimuli increases as the stimuli increase in number or complexity or ambiguity. A particularly important role is played by the phenomenon of masking, previously described. The more favorable the signal-to-noise ratio is, the more readily the signal is perceived and, hence, responded to.

Considerably less research has been conducted on response to auditory stimuli than on response to visual stimuli. Nevertheless, the most consistent finding (e.g., *86*, *130*) is that auditory stimuli produce the fastest reaction times, followed by visual stimuli and, lastly, tactual stimuli. It is also shown that reaction time to more than one sensory stimulus (e.g., visual plus auditory) is shorter than to only one.

Implications: As with vision, auditory response time must be related to distance and speed, in designing aural warning devices. The slightly shorter reaction time to sound stimuli should not affect the design of these devices; however, it may turn out that when visual and auditory stimnli are presented simultaneously, due to its reaction time advantage the anditory stimulus might be the first warning signal to reach the motorist's awareness.

7. *Age effects.*—As is the case with most of man's capabilities, auditory sensitivity deteriorates with increasing age. The most important loss is sensitivity for the higher frequencies, which begins in the early twenties and continues progressively thereafter (*133*, p. 997).

Implications: In order to prevent older drivers from being unduly penalized, sonnd stimuli used for warning devices should not utilize high frequencies (higher than 1,000 cps, e.g.)

PERFORMANCE DECREMENT

1. *Decrement due to physical deficiencies.*—The primary physical deficiency of concern here is partial or total deafness, which, as Boies (*20*) points out, can impair normal driving performance, if it is bilateral. As indicated earlier (*146*) approximately 5 percent of the driving-age population have impaired hearing (40 percent of these are over 65 years of age), and an additional 0.1 percent are totally deaf. Unlike the blind or nearly blind individual, the deaf or nearly deaf person is often able to obtain a driver's license. In view of this fact, it is obvious that the use of aural warning devices is practical only if accompanied by the installation of visual warning devices, thus providing a cross-modality redundancy.

Also, it is necessary to use aural stimnli with intensities well above threshold values for normal yonng adults, in order that they may he perceived by as large a segment of the impaired-hearing driving population as possible. Also, additional intensity will be needed to overcome noise levels in the moving vehicle.

2. *Decrement due to temporary physiological states:*

(a) *Fatigue.* As indicated earlier, fatigue is detrimental to performance of any sort, although Sipowicz and Baker (*130*) have shown fatigue to bring about less decrement in an auditory task than in a visual one. The specific effects of fatigue on auditory sensitivity are not well known; however, the inattention that generally accompanies fatigue will be detrimental to auditory reaction time, as it is to reaction time in other sensory modalities. Again, the traffic engineer's only approach to this problem lies in the direction of over-emphasis of the auditory warning signal by means of repetition, variety, and/or increased intensity.

(b) *Alcohol.* Fox and Fox (*59*) indicate clearly that alcohol consistently increases the reaction time to an auditory stimulus. The counteraction to this effect seems to be an increase in warning time; i.e., the aural warning signal should be given further in advance (temporally) of the hazard.

(c) *Drugs.* As indicated for vision, different drugs have different effects on sensory capabilities, and no general statement can be made covering drng effects on hearing.

3. *Decrement due to psychological states.*—The primary psychological state of concern here is inattention, regardless of its cause. Inattention has the net effect of increasing auditory reaction times due to the delay in perception it causes.

4. *Decrement due to vehicle characteristics.*—The only vehicle characteristic of importance here is the noise level in effect while the vehicle is operating, and the degree to which this noise will mask out any warning sound. Chiesa (*30*) reviews other research and contributes data of his own to conclude that (1) sound patterns within the moving vehicle are qnite regular for each rough road for each vehicle; (2) smooth road noise is not only regular but also traceable to various portions of the vehicle; and (3) methods of analysis are available to identify noise patterns in vehicles. These findings indicate that techniques are available to specify sound signals that would suffer least interference from vehicle-road noise sources. These techniques could be used to evaluate the effectiveness of auditory warnings, such as bells, whistles, rumble strips, and radio broadcasts.

As mentioned earlier, noise levels inside vehicles driving in traffic have been known to reach levels in excess of 90 db. However, these high sound levels occur within certain frequency bands, and are generally not so loud that they prevent conversation among vehicle occupants. The effects of prolonged exposure to these noise levels are not clear, although Davis (*36*) did not find any significant effects, either auditory or nonauditory, of prolonged exposure to high-intensity noise levels by aircraft carrier personnel. However, Davis feels that these noise levels have two undesirable side effects; i.e., they provide interference with communication, and there is a decrement in performance during actual exposure. Both of these side effects, of course, are of concern in the driving situation.

The implication is clear, here, that if auditory warning signals are to be heard within the vehicle they must be either loud enough to override the fairly high noise levels (which would put them at or near discomfort level), or they must have such a distinctive pattern that even at lower intensity levels they still can be discriminated from the background noise.

5. *Decrement due to nonoptimum environment.*—Insofar as auditory sensitivity is concerned, there are two factors of concern, both of which have been previously discussed. These are (1) high-intensity masking noise (e.g., from traffic, rain beating on the roof), providing an unfavorable signal-to-noise ratio; and (2) the factor of inattention, caused by excessive demands upon the driver as a result of heavy traffic, adverse weather, etc. Perhaps it will be possible to design warning systems that provide higher-intensity stimulation during certain nonoptimum environmental conditions. The so-called "fog speed" signs currently nnder development in California are an example of this type of system.

6. *Decrement due to interaction with other sensory channels.*—As indicated for vision, research in this area has been lacking. Only one general comment can he made; i.e., in any complex situation where several of the driver's sensory channels are actively transmitting information at the same time, the attention that the individual can afford to pay to any one channel must be reduced, and correspond-

ingly, his response to information being transmitted via that channel will not be initiated as rapidly as would otherwise be the case (*64*).

PRINCIPLES FOR OPTIMIZING CHANNEL UTILIZATION

Unlike the previous section on vision, the relative lack of research on the driver's utilization of the auditory channel makes it difficult to set forth specific principles to guide the traffic engineer who wishes to utilize sound in a warning system. Nevertheless, from the preceding section a few basic facts emerge, which may be regarded as guidelines, as follows:

1. Auditory warning signals must be of sufficiently high intensity and/or of sufficiently distinctive character to stand out from the background noise level ever-present in moving vehicles.
2. These signals should be of sufficient intensity, if possible, that all but the more seriously aurally-impaired drivers will be able to hear them.
3. Signal frequency should not exceed 1,000 cps for maximum communication value over the broadest age range.
4. Temporal placement of the signal should be governed by the same principles of advance warning as given earlier for vision. For example, following the recommendation of Forbes (*54*), a 10-sec warning should be given for a speed of 50 mph.
5. As with vision, intermittent stimulation is more effective than steady stimulation. Hence, an intermittent auditory warning signal is preferable to a steady one.
6. Where possible, an auditory warning signal should be accompanied by a visual (or other sensory) stimulus to increase the probability of signal detection (cross-modality redundancy) and to provide an alternate warning channel for deaf or nearly deaf drivers. These combinations of signals should be complementary, rather than competitive.

Touch and Vibration

Placing a distant third to vision and audition in relative importance to the driver is cutaneous sensitivity. Compared with the phenomenal range and richness of the auditory and visual stimuli to which the human can respond, the skin sense is relatively crude and insensitive. Although the skin is sensitive to a variety of stimuli (e.g., pressure, pain, cold, warmth, electricity, chemicals) the primary concern here is with its sensitivity to pressure (touch) and displacement (vibration). The driver uses these sensitivities to provide information about the road surface (texture and evenness), its vertical and horizontal alignment, vehicle acceleration and deceleration, and, to a certain extent, the mechanical functioning of the vehicle.

Almost no research has been conducted which investigates the role of cutaneous sensitivity in driving performance. Vibration has often been investigated, but usually in relation to riding comfort (e.g., *32*), and recent research has usually been limited to heavy equipment such as trucks and other military and industrial vehicles, because it is generally conceded that in modern automobiles vibration is well controlled and does not constitute a ride problem.

Despite this relative lack of factual information, there is increasing interest in the role of the skin sense as a communication channel, and it is an area that merits much further research. As Hawkes points out (*69*, p. 160), "nearly every conceivable problem in the area of cutaneous research needs additional work."

INFORMATION-HANDLING CHARACTERISTICS

Because of the aforementioned lack of research, relatively little is known about the information-handling characteristics of the skin, especially as related to the task of driving. The brief summary that follows presents the few facts that are relevant.

1. *Touch sensitivity.*—The sensation of touch may be aroused without direct contact on the skin, simply by moving a hair. The touch sensation is otherwise aroused by deformation of the skin, not contact *per se*. The rate at which the skin is deformed is an important variable (*133*, p. 177). Extreme deformation will result in a sensation of pain.
2. *Vibratory stimulation.*—Separate touches can be sensed as discrete up to a frequency of about 20 per sec, depending on the individual. Above this frequency, the individual experiences a smooth vibratory sensation, with maximum sensitivity occurring in the region of 250 cps (*133*, p. 1,177).
3. *Adaptation.*—As with most sensory modalities, the skin sense displays adaptation; i.e., the diminution or complete disappearance of sensation under continued stimulation. For example, a light weight resting on the skin is soon not felt at all, and a slow increase in threshold values occurs when vibratory stimulation is continued for a long time. The term "adaptation" is also used to describe the blunting of response as a result of previous stimulation; e.g., the numbness in the skin covering the buttocks and back of the thighs after one remains seated for a long time (*133*, p. 1,180). This may be referred to as a form of cutaneous fatigue, and is analogous to the auditory fatigue mentioned earlier.
4. *Reaction time.*—As mentioned earlier, tactual reaction time is slower than either visual or auditory reaction time (*86*). However, when a tactual stimulus is added to the stimulation of another sense modality, the resulting reaction time is shorter than to either stimulus by itself. Tactual reaction time will also vary as a function of the nature of the stimulus applied to the skin.

As previously emphasized, although little is known about the skin as a sense channel, the consensus among researchers in this field is that there are many possibilities for cutaneous communication (*69*). It has already been demonstrated that vibro-tactile communication under laboratory conditions is feasible. There is further interest in the study of a communication system based on electrical impulse signals; if it is possible to stimulate the skin electrically with very low-frequency pulses (1 to 8 pulses per sec) where there is no tissue damage or pain, electro-pulse stimulation is more advantageous than vibro-tactile stimulation in that qualitative stimulus differences are more easily sensed, and the stimulated area can be confined much more readily within narrow limits. The latter is true because a vibratory stimulus applied to one portion of the skin soon leads to a spreading of the sensation to adjacent portions of the skin.

According to Gilmer (*69*, pp. 76-84), a cutaneous communication system can provide information of great diversity, and would be especially useful in providing safety through redundancy (cross-modality stimulation). He continues that there are at least seven classes of information that can be conveyed through the skin. Stimulus intensity, frequency, and/or duration can convey amounts; relationships between the loci of two (or more) stimuli can provide relational information by means of "coordinates"; directions and rates also can be transmitted to the skin; the potential of a practical "language" system (superior to Morse code) has already been experimentally demonstrated; the attention-demanding qualities of vibratory stimulation are unique for warning; and, finally, this type of stimulation shows promise for maintaining vigilance, or alertness.

As Gilmer summarizes current thought, vibratory stimulation may be used to advantage: (a) as an aid to spatial orientation, (b) in making relational comparisons, (c) to alert or warn quickly, (d) where there is a demand for rapid referability, (e) where unusual stimulation is desirable, (f) as an aid to vigilance through both warning and redundancy, (g) where the uniqueness of the situation can make vibration a part of the habit structure, (h) where environmental conditions handicap both auditory and visual presentation, (i) to supplement communication in multiple-task performance (e.g., driving), (j) where previous habits are not auditory or visual, (k) where response quickly follows presentation, (l) where simple reference information is needed continuously over long periods of time, (m) for simple signals anticipated by the operator, and (n) where conditions handicap the eye and the ear.

Before concluding this discussion on the information capacity of the skin sense, it should be noted that, in addition to the necessity for basic research into the parameters of tactual stimulation, there are a number of major questions that have to be answered. For example, should attempts be made to develop a general skin language, or should coding be made specific to each problem situation? How many bits of information can be transmitted by the skin under some given condition? To what extent does "skin deafness" occur? What about channel loads, the effects of distraction, and error ranges? Should the stimuli be presented as discrete elements, regular or irregular, in or out of sequence, for a fast response or for a slow response, all of which are related to the demands of the output?

PERFORMANCE DECREMENT

As expected, few research studies have been concerned with decrement in cutaneous performance. Most of the studies in this area have related to vehicle riding qualities, and the consensus of this research (e.g., *124*) is that only low-frequency vibrations (under 10 cps) constitute a ride problem. Prolonged exposure to low-frequency virbrations of this magnitude have been demonstrated to have deleterious medical and performance effects. It is hypothesized that man is less tolerant of vibration frequencies from 4 to 10 cps because this is the range of natural resonance of major internal organs (*12*).

With reference to alcohol effects, Wolff, Hardy and Goodell (*148*) found that the ingestion of alcohol raised the threshold of pain (and therefore, presumably, of touch). It is interesting that this elevation of threshold lasted for as long as 2½ hr after taking the dose of 28.4 ml of alcohol.

Finally, Brown, et al. (*24*) found that intense auditory noise had little effect on the reception and processing of cutaneously-presented information. In another study, Brown, et al. (*25*) found that the simultaneous presentation of a visual discrimination task significantly impaired the processing of cutaneous information, demonstrating the deleterious effects of attention-sharing.

PRINCIPLES FOR OPTIMIZING CHANNEL UTILIZATION

From the foregoing brief review of the meager information available, it is obviously difficult to specify anything approaching a set of principles that would be of practical value to the traffic engineer. It is equally clear, however, that the skin sense is potentially of significant value as a means of providing at least supplemental information to the driver, and as interest and research in this area continue to grow it is entirely probable that the next decade will witness the emergence of cutaneous sensitivity as an important medium for communication, at least in specific problem areas, such as vehicle manipulation of all types.

From what is known at the present time, however, it is possible to make a few general statements regarding the use of cutaneous stimulation as a warning signal, as follows:

1. The skin as a sensory channel seems to be unique in that it is rarely, if ever, "busy." It thus has the opportunity to learn and become habituated to a code that cannot be interfered with under certain conditions.

2. There are two kinds of warning situations favorable to vibro-tactile stimulation. One involves the break-in to an on-going activity, where attention is demanded above and beyond the activity in which the receiver is engaged. The second involves prewarning, where the cutaneous stimulus is used to alert the individual to an impending communication from some other sensory channel. It is in connection with the latter approach that consideration should be given to the use of such devices as rumble strips (or the converse situation of smooth strips, as was mentioned earlier). A fair amount of field research (e.g., *122*) seems to indicate that the installation of rumble strips at hazardous locations reduces accident and/or violation experience at these locations. In cases such as these, the rumble strip (imparting both vibratory and auditory stimulation to the driver) serves not only to warn the driver of an impending hazard but also calls his attention to the primary warning devices (visual and/or auditory). The effectiveness of such an approach, of course, depends largely on the uniformity or consistency of its application, as well as on the effectiveness of appropriate public educational campaigns.

3. At its lowest level, vibro-tactile stimulation can be used as an on-off stimulus to signal any one of a variety of conditions. Furthermore, unlike visual stimulation, the tactile stimulus cannot be shut out. (It can, however, be masked by other tactile stimulation, and basic data are yet to be obtained in this vital area of signal-to-noise ratio.) From this it is easy to envision a vibratory device, embedded

in the vehicle seat, that could be activated either electrically (to provide warning about excessive vehicle speed, for example), or by means similar to those used in the induction radio principle. The latter situation is perhaps the one most applicable to the problem at hand.

4. Finally, the general principles specified for both vision and audition are also applicable here. That is, the intensity, frequency, duration, and locus of the stimulation should be so selected as to permit the stimulus to be discriminated readily (by the majority of drivers) from any other stimulation being experienced by the driver, taking care, of course, to avoid reaching the threshold for pain. Lack of research prevents indicating the precise specifications for such an optimum stimulus at the present time.

Other Sensory Channels

The remaining sensory modalities (e.g., kinesthesis, vestibular sensitivity, taste, smell) are not relevant to the present problem. Although some of these senses are extremely valuable in providing information to the driver about his environment, there is at present no practical approach to their utilization as channels for warning information.

FACTORS INFLUENCING THE PROBABILITY OF SIGNAL DETECTION

There is evidence that man operates as a "one-track-at-a-time" device that can shift rapidly from one information channel to another, but cannot simultaneously accept inputs from more than one channel. As Cumming (*33*) points out, man samples information from many sources, integrating it continuously to maintain a current over-all appreciation of the changing scene. Deese (*39*) regards a man involved in a task as a detecting instrument that is continuously performing a kind of averaging of previous input in order to extrapolate the results to future behavior of the environment that he is observing.

Man is also known to have a large memory system with direct access, and his most notable asset is his ability to reason, and to reconstruct memories into new configurations. However, man's weakest performance is associated with tasks that demand long-term attention; i.e., the so-called "vigilance" tasks that involve continuous monitoring of the input of (usually) one primary information channel, such as vision. The common examples of one-channel monitoring tasks are those of radar and sonar operators.

Driving is a multi-channel vigilance task with an input of information that is far richer and varied than that experienced by the radar operator. However, the basic problem remains the same; namely, how to increase the detection rate for signals or, conversely, how to minimize the number of missed signals. In this section we will discuss some of the factors influencing the probability of detecting a signal and, where possible, suggestions will be made for improving this probability in relation to the driving task.

Vigilance Behavior

Interest and research in the area of "vigilance" have assumed significant proportions only in the past 25 years. Many military tasks involve long hours of visual search for targets, and it was recognized during World War II that humans do not perform very well at these tasks, especially under conditions where the probability of target detection is low (*98, 60*). An often-cited report by Deese (*39*) credits N. H. Mackworth with defining the term "vigilance" to mean "a high state of readiness to perform adaptive and purposive acts." Operationally, vigilance is defined by derived performance measures, such as the probability of responding to a stimulus interpolated in a period of monitoring an information channel.

FACTORS FACILITATING DETECTION PERFORMANCE

Among the factors instrumental in maintaining a high level of detection performance during vigilance tasks are the following:

1. Knowledge of results (*8*). That is, when the monitor is kept informed of when he has detected or failed to detect a signal, his error rates decreases.
2. High signal frequency (*8, 31*). If the signals are presented relatively frequently during the monitoring period, error rate appears to decrease.
3. Intersignal regularity (*8*). When the signals are presented at more or less regular intervals, the error rate decreases.
4. Known presence of the experimenter (*8*). The presence of the experimenter appears to have the effect of keeping the monitor more vigilant.
5. Cross-modality redundancy (*109*). Simultaneous visual and auditory stimulation leads to a higher detection rate than if either channel is used alone. The results of this study imply that the use of dual-channel displays in applied vigilance situations is justified. In this connection, auditory signals were found to have a higher detection rate than visual signals (*130*).
6. Intensity of stimulation (*9*). In a sonar operation, increasing the gain of the (auditory) signal resulted in improved detection performance.

FACTORS ADVERSELY AFFECTING DETECTION PERFORMANCE

Research has shown that among those factors detrimental to detection performance are the following:

1. Age (*135*). Older subjects are as vigilant as younger subjects in initial stages of a monitoring task, but their vigilance soon declines to a significantly lower level.
2. Competing tasks (*108*). The performance on a primary vigilance (monitoring) task is significantly impaired by the presence of an adjacent display on which occasional secondary signals are presented.
3. Noise, vibration, heat (*96, 80*). Noise, vibration, and heat, singly or in combination, have been found to impair detection performance. The noise must be continuous and of relatively high levels; e.g., 110db (*80*).
4. Drugs and alcohol (*114, 59*). Both drugs and alcohol have been shown to impair performance in continuous monitoring tasks.
5. Fatigue. Although fatigue (sleep loss) has been shown to impair detection performance (*31*), it has also been demonstrated that the principle of high signal frequency can partially offset the adverse effects. Corcoran (*31*) showed that doubling the workload (i.e., a high rate

of signal presentation) required of subjects suffering from loss of sleep resulted in less performance decrement than a normal rate of signal presentation. On the other hand, McGrath (*100*) found that subjects paced themselves during a vigilance task.

With regard to driving, the effects of sleep loss are not clear, but some studies (e.g., *42*) indicate that the complexity of the task may prevent measurable losses of performance. Other studies of sleep loss (e.g., *41, 56, 48, 74*) suggest that attention span narrows, and the ability to perform several tasks simultaneously falls off. This may be due to a decrease in the ability to shift attention rapidly among the subtasks. Extreme conditions of sleep loss result in the driver devoting all of his attention to a single subtask (e.g., steering), while completely failing to attend to others (e.g., speed control) (*112*).

Deese (*39*) points out that in extended vigilance situations, such as driving on a modern superhighway, or long-distance truck driving, especially at night (*98*), the driver can lose vigilance beyond the point of voluntary recovery, and try as he might he cannot increase his attentiveness to the signals being searched for unless an extraneous even of sufficient impact (e.g., a loud horn (*113*)) comes along to restore his ability to observe and detect signals. A break in the driving task (i.e., rest pause) can serve the same purpose (*134*).

Actual Likelihood of Encountering a Train

Two factors enter into the probability of a driver actually encountering a train on a given trip, as follows:

1. The density of highway-rail grade crossings along the trip route.
2. The schedule of rail traffic at these crossings.

This probability can vary over a wide range, because many trips will not include any grade crossings at all (per unit time), whereas other trips of equal time length may include a relatively large number (10 or more) of crossings. Considering, also, the wide range in train schedules, the probability of encountering a train is seen to be quite low for most trips, although it may be high (approaching unity) for a very few regularly-made trips that happen to coincide with scheduled trains.

It is suggested that the frequency of encountering highway-rail grade crossings is quite low relative to the frequency with which other traffic control and warning systems are encountered (e.g., stop signals at intersections). This relative rarity acts to reduce the probability that any one crossing will be perceived.

Rarer still is the instance of encountering a train as it is approaching a crossing, and if it were not for the fact that additional cues (e.g., train horn) are available when the train is approaching, there would likely be a larger number of crossing accidents than there are. If the train is actually in the crossing, there are even more cues available to the driver. This may account for the fact that, according to Interstate Commerce Commission figures, more than 90 percent of train-car accidents involve either the train striking the car or the car striking the front of the train.

The implications of this discussion are as follows:

1. Crossing density should be taken into account in creating warrants for warning systems. An isolated crossing merits more warning simply because it is isolated. Whereas the frequency of trains is already used in developing crossing signal warrants, perhaps the combination of train frequency and crossing density should be used instead.
2. Other factors (such as trip habits, trip purposes) also enter into the probability of individual drivers encountering crossings and trains. Unfortunately, it is not possible at this time to find a way to include these factors in establishing warrants. Also, it is likely that remedial efforts in these areas would involve law enforcement, driver education, and trip-planning agencies rather than the field of traffic engineering.

Perceived Likelihood of Encountering a Train

Man seems to perceive and to choose his reactions as a function of a personal probability model that he establishes based on his experience. (McGrath (*100*) found that subjects assigned probabilities to signal occurrence in a vigilance situation; they performed extraneous behavior, and took a chance that this behavior would not interfere with their signal detection.) This probability model is based not only on the driver's estimate of the probability of occurrence of an event (e.g., a crossing or a train), but also on the probability and severity of the various consequences. The driver assigns weights to the various response behaviors he may choose, and these weights are chosen on the basis of the desirability or, conversely, the punishment, he has learned to be associated with the behavior. It is possible to formulate a general equation to express the concept; i.e.,

$$R = f(P\,W) \qquad \text{(B-7)}$$

in which

R = response behavior;
P = probability of an adverse consequence; and
W = severity of this adverse consequence.

In the highway-rail grade crossing situation, W (being hit by the train) is high, but P (likelihood of this happening) is low. On the other hand, the speeding driver is faced with a much lower W (receiving a traffic citation), but the likelihood of this occurring (P) is much higher. Unfortunately, even in cases where both P and W are high (e.g., dead-end streets), it has not been possible to prevent all accidents. Steps to increase awareness of the penalty for misperception are a function of education and law enforcement, and one can state only that to the extent such activities are effective, they should help to reduce accidents.

In the previous section it was suggested that the probability of perceiving trains and crossings is directly related to the frequency with which they are encountered. It would follow, therefore, that this probability must also be directly related to the density of crossings and the frequency of train traffic. However, one important factor may disrupt this relationship; namely, the driver's awareness of these encounters with crossings or trains. That is, it is possible that due to a combination of factors (e.g., inattention, ineffective warning devices, rails smoothly embedded in the roadway) a driver may pass through a crossing without ever being aware of it. If this occurs, there is usually no way in which the driver can subsequently become aware of this missed crossing and, therefore, this crossing will not contribute to formulation of the driver's probability model for perceiving subsequent crossings.

It is important to note that the present system of traffic control provides a penalty for not seeing a crossing only when the crossing is protected by a barrier, or when an accident or near-accident occurs with a train. This lack of "feedback" when a misperception has occurred must lead to poorer vigilance behavior than when a penalty is given for misperception (e.g., a missed STOP sign leading to a traffic citation). Furthermore, one's acceptance of there being a direct relationship between frequency of stimulation and probability of occurrence is improperly altered.

The previous discussion has been concerned with two of the factors that influence the perceived likelihood of encountering a train; i.e.,

1. Knowledge (awareness) of crossing density (for a given trip).
2. Knowledge (awareness) of the frequency of train traffic.

Other factors also enter into this likelihood; e.g.,

3. Nature of the trip. For example, a business trip through an urban industrial area is in many ways different from a rural pleasure trip. The driver's frame of reference and expectations (probability model) can be quite different in the two cases.
4. Familiarity with the area, as well as knowledge of the type of traffic (and its general relationship to time of day.) These are of obvious importance.
5. Context provided by the terrain. The terrain, and other aspects of the environment in which the trip occurs, can provide many cues that will cause the driver to be aware of the possibility of crossings and train traffic. The most obvious example is the case of a road paralleling a railroad track; the driver will be on the lookout for a crossing.
6. Cues provided by signs and markings. These are of prime importance, and have been discussed in previous sections.

Implications: Any given driver's expectation of encountering crossings and trains is a complex interaction of his past and immediate experience. Some of this experience can be modified by the traffic engineer. For example, signs could provide information about the density of crossings (for a given area or distance) for the benefit of the unfamiliar motorist. It might also be possible to utilize signs, markings, or devices that indicate the average speed and relative frequency of train traffic at each crossing. (Perhaps color coding could be used to advantage here.) Finally, the terrain and other environmental cues may be taken advantage of (and even manipulated), to increase the driver's awareness of crossing hazards.

Level of Functioning of Available Sensory Channels

Preceding sections have dealt in detail with descriptions of the information channels available for alerting the driver. Some discussion was given of the range of stimulation for each channel, and it was stated that it is not possible to specify stimulus values that will guarantee perception.

Furthermore, in the section on vigilance it was pointed out that detection performance was affected by the level of functioning of available sensory channels. That is, such transient factors as fatigue, drugs, and alcohol operate to the decrement of detection performance, as do permanent factors such as age.

It is obvious that the level of functioning of sensory channels at any given time is a major factor influencing the probability of detection of a warning signal. In view of the detailed discussions presented elsewhere in this report, no further comments will be made at this time.

Principles for Optimizing Signal Detection

From the foregoing discussion of vigilance and detection, it is possible to specify some principles relating to rail-highway grade-crossing protection, as follows:

1. Crossing density. The more crossings a driver encounters on any given trip, the more likely he is to be aware of them. Thus, where crossing density is low (i.e., low stimulus frequency) it becomes even more important to inform the driver of this density, and of the existence of each crossing.
2. Train traffic volume. Because of the relatively low volume of train traffic at most crossings (i.e., low stimulus frequency) it is important that the lower the train traffic volume, the more impact the train-approaching warning must have for that crossing.
3. Regularity of train scheduling. When trains run at irregular intervals (i.e., irregular stimulus frequency), or when they run at unusual or unscheduled times, they should approach the crossing at slower speeds, due to the probability model set up in the head of the habitual user.
4. Knowledge of results (feedback). If possible, some system should be designed to insure that the driver is made aware (immediately) as he passes through a crossing.
5. Cross-modality stimulation. As mentioned in earlier sections, cross-modal stimulation is more effective than stimulation of only one information channel. Warning systems should be devised to provide this multi-channel stimulation.
6. Distraction (competing tasks). As discussed earlier, care should be taken to avoid distractions that interfere with the driver's perception of the warning. In relation to this, it should be pointed out that a low "noise" level on one information channel enhances perception on other channels, whereas a high "noise" level on one channel will interfere with perception on the other channels.

FACTORS INFLUENCING DRIVER RESPONSE TO DETECTED SIGNALS

In previous sections an attempt has been made to present a relatively comprehensive discussion of the factors that determine whether or not a driver will detect a (warning) signal in time either to respond appropriately or to respond at all. This section discusses the nature of a driver's response to a signal once he has detected it. As a consequence, the discussion is devoted primarily to those aspects of the stimulus-response behavior pattern that occur after the initial step of perception. The term "perception," as used here, connotes not only an awareness of the existence of the signal, but also a comprehension of the meaning of the message that the signal is intended to convey.

Driver response to a detected signal may be thought of as a sequence involving three stages. The first stage, which directly follows the perception phase previously referred to, finds the driver making a decision as to how he will respond to the signal. (The response he decides upon may or may not be appropriate to the situation.) Once this decision is reached, the next step is for the driver to implement the decision by making what he feels are the appropriate motor responses. The final step in the sequence occurs as the vehicle responds to the driver's physical actions, an event whose nature is determined by the vehicle response characteristics. These vehicle response characteristics are, in turn, a function not only of the design and structure inherent in the vehicle, but also of the vehicle's mechanical condition at the time and such environmental factors as the coefficient of friction of the road surface, and the vertical and horizontal alignment of the road.

In the following sections each of these three major phases of the response sequence is discussed in terms of available knowledge.

The Decision Process

Although most experimental measurements of driver reaction time represent the sum of the separate reaction times for perception, decision, motor reaction, and vehicle response, it has been shown that perceptual and decision reaction times are more variable, and can consume a far greater span of time (for a given individual in a given vehicle in a given environment), than motor response and vehicle response times. It follows, therefore, that in order to reduce over-all response time to a minimum, the most productive approach would be to reduce perception and decision times. Suggestions for reducing perception time have been given in previous sections; reduction of decision times is taken up in the following.

As Forbes (*53*) and Forbes and Katz (*55*) point out, driver response time increases with both the number of choices and the complexity of judgment required. Conversely, the probability of error is reduced with a reduction of this complexity (*53, 63*). The number and complexity of choices affect not only decision time, but also the clarity with which these choices stand out. That is, if the choices may be regarded as the signal, and irrelevant information is considered as background noise, the lower the signal-to-noise ratio, the longer the decision time. This has been demonstrated by Hick (*73*), who found that the presence of irrelevant information was detrimental to performance. Festinger and Wapner (*49*) showed that the longer the decision time required, the greater the number of errors committed.

Another factor related to decision time is age. Griew (*63*) found that older subjects took longer to decide to react than younger subjects. This result may be due to a slowing down, with increasing age, of the rate at which alternatives can be sorted out.

A final factor relevant to the present problem concerns the variable of experience. By this is meant the familiarity of the driver with the type of stimulus (warning signal, e.g.) and, consequently, his experience in responding to this stimulus. Johansson and Rumar (*81*) have shown that braking-reaction times increase with increasing degrees of unexpectedness of the stimulus, and Klemmer (*87*) has also found that uncertainty about when the stimulus is to occur will increase reaction time. The implication here is that the more experienced driver will have encountered a greater variety of situations, will practice defensive driving to a greater extent, and thus is less likely to "block" when encountering an unexpected or unfamiliar stimulus. As a consequence, his average decision time may be expected to be shorter.

From the foregoing it becomes apparent that in order to reduce decision time (hence, total reaction time) to a minimum, the following principles may prove useful:

1. The number of alternative responses to a warning signal should be kept as low as possible. That is, the warning device should clearly indicate (by specific message and/or by well-established convention) the single appropriate response.
2. If a choice of two or more alternative responses is available to the driver, this choice should be as obvious and simple as possible. For example, the common situation of a sudden obstacle appearing in the driver's path usually presents two simple avoidance alternatives (i.e., braking or swerving, or both), and studies (e.g., *102*) have shown that the total response time may vary from perhaps 1.25 sec to 2 sec. On the other hand, a railroad wig-wag signal in operation, with no train in sight, presents the driver with a choice of braking, swerving, slowing, continuing at the same rate of speed, speeding up, etc., all further complicated by the fact that the driver is usually trying to look in both directions for the train. A situation such as this can add 1 or 2 sec to the total response time, a delay which often is critical (*54*). An automatic gate does not present this variety of alternatives; a crossbuck presents even more.
3. Irrelevant information should be kept to a minimum. The warning device should present its message clearly and unambiguously, and no other warning devices (or other signs, signals, or markings) employed at the same location should present any information to the driver that will in any way confuse, contradict, or modify the basic warning message. For example, a railroad crossing is no place for directional signing. All distractions have the effect of increasing response times (*99*); they provide competition.

Motor Reaction Time

Reaction time has been an area of research interest for hundreds of years. As a result, a vast amount of information is available. Only a brief summary of some of the more relevant facts is attempted here. Among the factors influencing motor reaction time are the following:

1. Age and sex. It has been well established that after about the age of 30, motor reaction time gradually

increases with increasing age. It has also been generally found that the reaction time of males is faster than that of females (*138*).

2. Multiple stimuli. As indicated in earlier sections, reaction time to any one stimulus increases as the number of possible stimuli increases (*123, 11, 64*). That is, complex reaction time (when the driver has to be prepared for any one of a number of simple stimuli, such as a traffic signal, pedestrian, leading car stopping) is longer, and results in more errors (*64*), than when he need concern himself with only one stimulus (e.g., a STOP sign in the middle of a rural area with no other vehicles or people in sight). This is a function of the previously-mentioned phenomenon of "attention-sharing." We are here referring to a situation where each of the potential stimuli calls for a specific, simple, well-established response (e.g., braking), and thus are not concerned with decision time.

3. Cross-modality stimulation. As already mentioned, reaction time to simultaneous stimuli in two or more modalities is shorter than to any one of the stimuli presented by itself. Reaction times to auditory stimuli are fastest, followed by visual and then tactual reaction times (*138, 86*).

4. Fatigue. As is the case with most other aspects of performance, fatigue has a detrimental effect on motor reaction time (as it does on both perception and decision time). Lauer and Suhr (*92*) found that a rest pause interpolated in a continuous driving task significantly reduced response time to a red attention light.

5. Temperature. Studies by Teichner (*137*) and Forlano (*57*) have shown that reaction time is adversely affected by temperature only at relatively extreme levels (e.g., 117 F and up, and − 30 F or − 40 F and down). In the case of extreme cold, protecting the extremities eliminates the detrimental effects of temperature on reaction time. On the other hand, increasing wind speeds of 10 mph and up, at low ambient temperatures, increases reaction times.

6. Alcohol and drugs. As summarized by Fox and Fox (*59*), the evidence is unmistakable that alcohol increases response time by significant amounts. It is difficult, however, to determine just how much of this decrement takes place in the perception, decision, or motor reaction phases of the response; nevertheless, there is no question that all three phases are adversely affected.

With regard to drug effects, again it is not possible to generalize for all types of drugs. Some categories depress sensitivity to stimuli; others increase this sensitivity, but at the expense of alertness (*114*).

7. Vigilance and anxiety. The data on anxiety in relation to response times are not conclusive, although there is some evidence (e.g., *145*) that increased anxiety leads to reduced reaction times. It is obvious that this would not hold true if anxiety reached such a high level as to disrupt the individual's behavior altogether.

Insofar as vigilance is concerned, Teichner (*138*) concludes that the longer the period of time during which the individual must maintain a vigilant attitude, the longer the reaction time, once the stimulus does present itself.

From this brief review of some of the known facts, it is obvious that it is possible to reduce reaction time in a number of ways. The following guidelines may be of practical value to the traffic engineer:

1. Multiple stimuli should be avoided, unless they all convey the same message. That is, the driver approaching the railroad crossing should not be presented with any information except that pertaining to the existence of the crossing (and of the train, if present or approaching).
2. Where possible, warning devices that stimulate more than one sense modality at the same time should be utilized.
3. Warning should be given sufficiently in advance of the hazard to insure that the vast majority of drivers (including, for example, those who are elderly, or fatigued, or drunk) will have enough time and distance to react.

Although research has yet to show a substantial relationship between reaction time and driving performance (*62*), there is no question that the inability to react quickly enough plays a small but significant role in certain types of accidents.

Vehicle Response Characteristics

In terms of the manner in which the vehicle responds to the driver's "commands," there is little the traffic engineer can do in the direction of improvement, with the exception of those aspects of the environment over which he has control; i.e., the road surface (texture, composition, and evenness) and road alignment. It is obvious that a straight, level, even road surface with as high a coefficient of friction as possible will optimize vehicle response time. However, as this does not fall within the area of warning devices, no further discussion is presented.

Other Considerations

The previous comments on decision time and motor reaction time have all been made with the assumption of normal (if not always appropriate) response patterns. However, before closing this section a brief discussion of inappropriate response patterns seems in order. Specifically, we are concerned with the perseveration of an inappropriate response under stress.

"Perseveration" is a term that has been used in several ways to describe recurrent and sometimes persistent behavior of man and animals, and is sometimes manifested, for example, by the tendency to stick at a piece of work (*43*).

In particular, this term usually refers to a type of behavior often exhibited in problem-solving situations, where the individual displays a persistence in using a given approach to solving the problem, even when that approach is not proving to be fruitful. This type of individual may be contrasted with the one who is flexible and can adapt and adjust to a variety of approaches to solving the problem. Although there is by no means unanimity of opinion, it is commonly believed that perseveration may be a distinct personality trait, although one not easily measured (*6*).

More recently, attention as been drawn to man's behavior under various kinds of stress-producing situations.

One tendency that has been noted repeatedly is that of perseveration of a response. It appears that under stress, man often will attempt only one solution to a problem, and continue to try this solution even though it does not (and often cannot) solve the problem at hand. Similar tendencies appear in children and lower animals, leading some investigators to suggest that when under stress, man's behavior regresses to simpler levels.

Railroad crossings at grade present several opportunities for demonstration of this phenomenon. Although the evidence presented is anecdotal in nature, it is nevertheless useful. Many accounts exist of the driver whose car is stalled on the tracks, who apparently persists (perseverates) in attempting to start the car until he is struck (and usually killed) by the approaching train. The driver persists in this inappropriate behavior even though there are other means of successfully solving the problem. It is as though man has the capacity for engaging in only one approach to solving a problem when there is great urgency involved (and dire consequences for failure).

The implications of this discussion, as far as railroad grade crossing warning protection is concerned, are as follows:

1. Provide a proper solution for anticipated problems by:
   (a) Training drivers to associate a single, appropriate solution with each type of problem likely to be encountered.
   (b) Recognizing that this type of problem can never be completely eliminated, and that other means of averting such a collision must be found; e.g., alerting the train engineer, far enough in advance, to the fact that a vehicle is stalled on the tracks.
2. Avoid design of "dilemma zones", where it is not clear that only one safe solution to the problem exists.
3. Assume that many factors are operating to increase the likelihood of this inappropriate behavior; e.g., age, alcohol, fatigue, reduced visibility.
4. Design warning systems that present a clear-cut "go-no go" decision to the driver, because under the stress of an approaching train it is unlikely that drivers can alter their initial decision even though it soon becomes obvious that this decision is incorrect. This point relates to the comments made earlier in reference to decision time.

Related to this discussion of perseveration is the fact that man is often observed to revert to old habit patterns under stress, with a consequent "negative transfer of training." That is, under the pressure of a stressful situation the driver may automatically call upon a previously well-learned response pattern, rather than a more appropriate response pattern that has not been learned well (or at all). A common example of this is the driver who, when first placed in an unfamiliar car which has an automatic shift lever quadrant different from that in his regular car, under stress, will put the car in reverse, for example, when he intended to put it in drive.

Any design of new or novel systems must take into account the strong likelihood of unwanted and unfortunate carry-over of habits and response patterns from present systems to the new system. This normal tendency becomes accentuated under stress, when it is most likely to have disastrous results. The implications of this for railroad crossing warning systems are as follows:

1. Incorporate some features of the existing systems into the new system.
2. Anticipate as many as possible of the confusions or misinterpretations that could result from carry-over of old responses to the new system, and design accordingly.
3. Assume that some driver errors will be associated with any change-over to new-model vehicles; e.g., some accidents have been traced to drivers who were not quite used to driving a vehicle with an automatic transmission, or power steering, or power brakes. There is little the traffic engineer can do about this except to design an extra margin of safety into his warning system.

SUMMARY AND RECOMMENDATIONS

The material in this report provides evidence that although there are many areas where human factors research is sadly lacking, there nevertheless is sufficient valid information available to permit the specification of a number of general principles that may be used by the traffic engineer as guidelines in the development of more effective railroad crossing warning systems. These general principles may be given as follows:

1. Take into account the full range of human characteristics; i.e., do not use only the "normal" or "average" driver in specifying design requirements.
2. Minimize uncertainty in decision-making by making alternative courses of action as few and as simple as possible.
3. Provide the driver with prior warning of the responses he will be asked to make. This warning should be far enough in advance to allow ample time to detect the warning signal and to make the appropriate responses, but not so far in advance as to fall victim to man's relatively short-term memory.
4. Avoid the presentation of any extraneous or irrelevant information that could interfere with attention to the important cues.
5. Maximize the detectability (target value), legibility, and clarity of meaning of the warning devices (signs, signals, or markings), following the principles set forth in previous sections. Use simple, direct, specific warnings.
6. Design the warning systems to include redundancy. This redundancy may take two forms; i.e., repetition of the message by means of several signs, signals, or markings, and the use of multi-channel stimulation (e.g., rumble strips in addition to signs).
7. Use uniformity as a basic principle of signing; however, develop unique warning systems for unique situations. The principle of uniformity is upheld if these unique systems are reserved for use only in unique situations, such as the isolated or unprotected crossing. With regard to unprotected crossings, it should be pointed out that present warning systems offer very few cues for

the motorist to distinguish between a crossing that has some signal protection and one that does not.

8. Where the hazard (highway-rail grade crossing) occurs infrequently (that is, where the hazard is an isolated one), provide warning devices with maximum detectability, and utilize the principles of redundancy and uniqueness (items 6 and 7).

9. Avoid false, or unnecessary, warnings, because a warning followed by a zero change in conditions distracts the driver's attention to no useful purpose, and it is possible that other perceptually similar signs that are of value in aiding the driver may subsequently be ignored due to a generalization process (*84*).

Based on these general principles, as well as the many specific principles given throughout previous sections of this report, the following recommendations are made for consideration in the design of more adequate grade crossing warning systems:

1. Make greater use of color and shape coding than has previously been the case.
2. Where possible, provide adequate illumination for each crossing.
3. Provide adequate advance warning for every crossing.
4. Make use of cross-modality stimulation; specifically, investigate the feasibility of rumble strips (tactual and auditory stimulation), horns * (auditory stimulation), etc.
5. Provide redundant information, both by repetition of the message and by cross-modality stimulation.
6. Utilize the intermittent stimulation principle for all automatic signals.
7. Utilize automatic signals whenever possible; when not possible, provide unique nonautomatic warnings with greater impact than the standard nonautomatic warnings. That is, crossings without activated signals should be marked quite differently from those with activated signals so that the driver, upon approaching them, is made aware of the fact that it is his responsibility to determine whether or not a train is approaching.
8. Insure a minimum amount of distracting or irrelevant information by removing all extraneous messages from the immediate vicinity of the crossing.
9. Use warning devices of greater impact for isolated crossings.
10. Investigate the feasibility of providing the driver with prior information about crossing density and train traffic volume.
11. Incorporate some features of existing warning systems into any new and novel systems developed, to prevent adverse effects from negative transfer of old habits.
12. Provide the traffic engineer with warrants for crossing protection devices that are sufficiently flexible to permit him to utilize unique warning "packages" for unique crossing situations. A set of such warning packages, graded according to impact or attention value, could be part of the traffic engineer's arsenal.

* Currently under way is an exploratory study, being conducted by the California Division of Highways, to alert drivers entering freeways via off-ramps. Utilizing the cross-modality stimulation principle, a truck-type air horn, large red light, and large white-on-red sign are all mounted at the entrance to the off-ramp. All three signals are triggered by a "wrong-way" vehicle detector buried in the ramp pavement.

SUGGESTIONS FOR DEVELOPMENT AND EVALUATION OF NEW WARNING SYSTEMS

In designing new crossing warning systems, the following four interacting phenomena may prove useful:

1. Size constancy. Humans tend to assume, based on experience, that familiar or uniformly-shaped objects are of an expected or uniform size, and that apparent differences in size are due to distance. Based on this, it may be possible to design a system of signs or markings to intentionally mislead the driver into thinking the crossing is nearer than it is in reality, thus hastening the initiation of deceleration responses.
2. Spacing constancy. Within limits, humans tend to assume, and therefore to perceive, an equal spacing between similar objects placed in a row (e.g., telephone poles). The rate at which these objects are passed is a major cue to vehicle speed. This phenomenon may be made use of to design a system of signs or markings that causes the driver to perceive his speed as being faster than it really is, thus reducing the apparent time to reach the hazard, and causing an earlier initiation of deceleration.
3. Barrier effect. Research (*27*) has shown that drivers will react to objects at the side of the road (i.e., on the shoulder), as though they restricted vehicle passage. This finding could be used to develop a configuration of roadside objects (signs) that would cause the driver to reduce his speed and, perhaps, raise his general level of alertness.
4. Convergence effect. The angle of convergence of parallel lines is a major factor in distance perception, and narrowing of the lane width is known to reduce speed. This fact might be utilized in designing pavement markings (lane lines) that converge with the approach of the crossing, thus causing the driver to reduce speed.

Utilization of any or all of these phenomena in designing warning systems might prove effective in reducing vehicle speed as the driver approaches a crossing, an effect that would allow the driver more time to respond appropriately. However, when combined in any given configuration of signs and markings, these phenomena can interact with one another to produce total effects that are quite different than might at first be expected. Any use of these human factors must be carefully evaluated with an eye toward the total effect.

There are several strategies that may be employed by the traffic engineer in evaluating proposed warning systems. One technique is to progressively degrade the visual information display, thereby to determine those elements of the display that are most resistant to decay. Gradual reduction of the illumination level is one means of degrading the image. This technique is most suitable for laboratory settings, although it can be used in field tests as well.

A "funnel" approach to the testing of signs and markings has been described as having merit (*75*). This approach consists of subjecting a large number of warning systems to a series of progressively more stringent tests, beginning with "quick and easy" evaluation and progressing to more complex and costly evaluational techniques. At each successive level, only the better systems will survive for further testing.

3. It may be desirable to employ drivers with known handicaps to serve as test subjects. For example, deaf drivers may be able to perceive vibrations generated by some types of rumble strips even though they cannot hear the accompanying noise.

4. Whatever techniques are used, great care should be exercised to conceal the true purpose of the testing from the driver subjects. This is best accomplished by creating a false purpose for the testing, and following through with it sufficiently to effectively mislead the subject. This approach is the only way to be reasonably sure of obtaining a natural response from the driver. However, this technique makes it impossible to use the driver as his own control, and thereby necessitates the utilization of a larger number of subjects.

REFERENCES

1. ALGEA, C. W., "Licensing of Motor Vehicle Operators." *Rep. No. 177-1,* Eng. Exper. Sta., Ohio State University (1961) 54 pp.
2. ALLEN, M. J., "Certain Visual Aspects of the Average Modern American Automobile." *Jour. Am. Optom. Assn.*, 34(5) 380-383 (1962).
3. ALLEN, M. J., "Daytime Automobile Windshield and Dash Panel Characteristics." *Am. Jour. Optom. and Arch. Am. Acad. Optom.* (Feb. 1963) 13 pp.
4. ALLEN, M. J., and LYLE, W. M., *The Relationship Between Night Driving Ability and the Amount of Light Needed for a Specific Performance on a Low Contrast Target.* Div. of Optometry, Indiana Univ. (1963) 13 pp.
5. ALLEN, T. M., "Night Legibility Distance of Highway Signs." *HRB Bull. 191* (1958) 33-40.
6. ALLPORT, G. W., *Personality: A Psychological Interpretation.* Holt (1937) 588 pp.
7. *Automotive Safety Glazing Manual.* Soc. of Automotive Engineers, *Rep. No. SAE J906* (Mar. 1965).
8. BAKER, C. H., "Maintaining the Level of Vigilance by Means of Artificial Signals." *Jour. Appl. Psychol.*, 44(5), 336-338 (1960).
9. BAKER, C. H., PARKER, E. L., *and* RITTGER, J. C., *Sonar Operator Detection Performance at Sea.* Human Factors Research, Inc., Los Angeles (1964) 14 pp.
10. BALLARD, S., and KNOLL, H. A., (Eds.) *The Visual Factors in Automobile Driving.* AF-NRC Committee on Vision, NAS-NRC Pub. 574 (1958) 25 pp.
11. BARTLETT, N. R., BARTZ, A. E., and WAIT, J. V., "Recognition Time for Symbols in Peripheral Vision." *HRB Bull. 330* (1962) 87-91.
12. BEAUPERT, J. E., "Subjective Reaction to Whole-Body Vibration." Paper presented at 8th Ann. Meeting, Human Factors Society, Washington, D.C., (Oct. 19, 1964).
13. BELL, F. L., "Human Engineering for Traffic Safety." *Traffic Eng.*, 24, 10-12 (1953).
14. BENKÖ, E., "Weitere Angaben über die durch lärmschäden bedingte Gesichtfeldeinengung." *Opthalmologia*, 143, 76-80 (1962); *Biol. Abst.*, 39, 6280 (1962).
15. BERGER, C., "Experiments on the Legibility of Symbols of Different Width and Height." *Acta Opthal.*, 28, Suppl., 423-434 (1950).
16. *Binocular Visual Acuity of Adults (United States—1960-1962).* U.S. Dept. of Health, Education and Welfare, Series 11, No. 3, National Center for Health Statistics, Public Health Service (June 1964) 27 pp.
17. BIRREN, F., "Safety of the Highway: A Problem of Vision, Visibility and Color." *Am. Jour. Ophthal.*, 43, 265-270 (1957).
18. BLACKWELL, H. R., "Quantitative Relationships of Illumination and Vision." *Arch. Indus. Health*, 16, 108-121 (1957).
19. BLACKWELL, H. R., PRICHARD, B. S., and SCHWAB, R. N., "Illumination Requirements for Roadway Visual Tasks." *HRB Bull. 255* (1960) 117-127.
20. BOIES, L. R., "Otological Aspects of Crash Injuries." *Jour. Am. Med. Assn.*, 163, 229-230 (1957).
21. BRAINERD, R. W., CAMBELL, R. J., and ELKIN, E. H., "Design and Interpretability of Road Signs." *Jour. Appl. Psychol.*, 45 (2) 130-136 (1961).
22. BRIDGEMAN, C. A., and WADE, E. A., "Optimum Letter Size for a Given Display Area." *Jour. Appl. Psychol.*, 40, 378-380 (1956).
23. BROUSSARD, I. G., WALKER, R. Y., and ROBERTS, E. E., JR., "The Influence of Noise on the Visual Contrast Threshold." *U.S. Army Med. Res. Lab. Rep. No. 101* (1952) 17 pp.
24. BROWN, R. L., GALLOWAY, W. D., and GILDERSLEEVE, K. R., "Effects of Intense Noise on Processing of Cutaneous Information of Varying Complexity." *Perceptual and Motor Skills,* 20, 749-754 (1965).
25. BROWN, R. L., GALLOWAY, W. D., and SAN GUILIANO, R. A., "Effects of Time-Sharing and Body Positional Demands on Cutaneous Information Processing." *Perceptual and Motor Skills*, 20, 1021-1026 (1965).
26. BURG, A., "An Investigation of Some Relationships Between Dynamic Visual Acuity, Static Visual Acuity and Driving Record." *Report No. 64-18,* Dept. of Engineering, Univ. of California (Apr. 1964) 131 pp.; also available as Univ. Microfilms No. 64-9631.
27. CASE, H. W., HULBERT, S. F., MOUNT, G. E., and BRENNER, R., "Effects of a Roadside Structure on Lateral Placement." *Proc. HRB*, 33, 364-370 (1953).
28. *Causes and Characteristics of Single Car Accidents, Part I.* California Highway Patrol, Sacramento (Feb. 1963) 20 pp.
29. CHAPANIS, A., "Color Names for Color Space." *Am. Sci.*, 53, 327-346 (1965).
30. CHIESA, A., "Experimental Studies on Noise Inside Cars." *Jour. Sound Vibration*, 1(2), 211-225 (1964).
31. CORCORAN, D. W. J., "Doubling the Rate of Signal Presentation in a Vigilance Task During Sleep Deprivation." *Jour. Appl. Psychol.*, 47(6), 412-415 (1963).

32. COX, H. L., "The Riding Qualities of Wheeled Vehicles." *Proc. Inst. Mech. Eng., Automobile Div.* (1955-56) pp. 265-278.
33. CUMMING, R. W., "The Analysis of Skills in Driving." *Australian Road Res.*, 1(9), 4-14 (1964).
34. DANIELSON, R. W., "Relationship of Fields of Vision to Safety in Driving." *Traffic Safety Res. Rev.*, 2(3), 8-25 (1958).
35. DAVIS, E. P., and FITZPATRICK, —, "Sign Placement to Reduce Dirt Accumulation." *HRB Bull.* 89 (1954) 7-13.
36. DAVIS, H., "Project ANEHIN: Auditory and Non-Auditory Effects of High Intensity Noise. Final Report." *USN Sch. Aviat. Med. Project Rep.* (1958) No. NM 13 01 99, Sub 1, No. 7, 226 pp.
37. DEBONS, A., and CRANNELL, C. W., "The Legibility of 'Scotchlite' versus Other Materials." *Jour. Appl. Psychol.*, 42(6), 389-395 (1958).
38. DECKER, J. D., "Highway Sign Studies, Virginia, 1960." *Proc. HRB*, 40, 593-609 (1961).
39. DEESE, J., "Some Problems in the Theory of Vigilance." *Psychol. Rev.* 62, 359-368 (1955).
40. DEGRAEVE, J. H., *Investigation into the Effect of Fatigue on the Speed of Perception.* Flying Personnel Research Comm. (Gt. Britain), FRPC Report No. AD40376, Memo 42 (Apr. 1953).
41. DOBBINS, D. A., TIEDEMANN, J. G., and SKORDAHL, D. M., *Field Study of Vigilance Under Highway Driving Conditions.* U.S. Army PRO OCRD Tech. Res. Note (1961) No. 118.
42. DOBBINS, D. A., TIEDEMANN, J. G., and SKORDAHL, D. M., "Vigilance Under Highway Driving Conditions." *Percept. Mot. Skills,* 16, 3-9 (1963).
43. DORCUS, R. M., and SHAFFER, G. W., *Textbook of Abnormal Psychology* (3rd Ed.). Williams and Wilkins (1945) 547 pp.
44. DUNNETTE, M. D., "Driver Opinions and Reported Performances Under Various Interchange Marking and Nighttime Visibility Conditions." *Jour. Appl. Psychol.,* 45(3) 170-174 (1961).
45. ELLIOTT, W. G., "Symbology on the Highways of the World." *Traffic Eng.*, 31, 18-26 (1960).
46. ELSTAD, J. O., FITZPATRICK, J. L., and WOLTMAN, H. L., "Requisite Luminance Characteristics for Reflective Signs." *HRB Bull. 336* (1962) 51-60.
47. ESSEN, J. V., "The Reactions to a Light Signal at a Distance and Nearby." *Ned. Tijdschr. Psychol.*, 4, 7-16 (1936).
48. FELLENIUS, V., AHNME, B., KOLSRUD, B., REHNBERG, A., and SVARD, S., "The Fatigue Factor in Traffic." (in Swedish) English summary in *Internat. Road Safety Traffic Rev.*, 4(3) 30-32 (1956).
49. FESTINGER, L., and WAPNER, S., "A Test of Decision Time: Reliability and Generality." *CAA Div. Res. Rep.* (1945) No. 48.
50. FISHER, S., "Hostility and Perception of the Horizontal." *Perceptual and Motor Skills,* 11(1), 28 (1960).
51. FITZPATRICK, J. T., and WILCOX, R. S., "Properties of Daylight Fluorescent Color Systems Pertinent to the Consideration of Their Use on Navigation Aids. *Proc. 6th Internat. Conf. on Lighthouses and Other Aids to Navigation* (Sept.-Oct. 1960).
52. FLETCHER, E. D., "Visual Acuity and Safe Driving." *Jour. Am. Optom. Assn.*, 20(7), 439-442 (1949).
53. FORBES, T. W., "Driver Characteristics and Highway Operation." *Traffic Eng.*, 24, 49-51 (1953).
54. FORBES, T. W., "Psychological Applications to the New Field of Traffic Engineering." *Jour. Appl. Psychol.*, 25(1), 52-58 (1941).
55. FORBES, T. W., and KATZ, M. S., *Summary of Human Engineering Research Data and Principles Related to Highway Design and Traffic Engineering.* American Institute for Research, Pittsburgh (1957) 53 pp.
56. FORBES, T. W., KATZ, M. S., CULLEN, J. W., and DETERLINE, W., "Sleep Deprivation Effects of Components of Driving Behavior." Paper presented at Ann. Meeting, Am. Psychological Assn. (Sept. 1957).
57. FORLANO, G., "The Effect of Ambient and Body Temperatures upon Reaction Time." *CADO Tech. Data Dig.*, 15, 18-26 (1950).
58. FOSBERRY, R. A. C., and MILLS, B. C., "Measurement of Driver Visibility and Its Application to a Visibility Standard." *Proc. Inst. Mech. Eng.*, Automobile Div., No. 2, 50-63 (1959-60).
59. FOX, B. H., and FOX, J. H., (Eds.) "Alcohol and Traffic Safety." Pub. Health Serv. Publ. No. 1043, U.S. Dept. of Health, Education, and Welfare (1963) 258 pp.
60. GARVEY, —, HENSON, —, and GULLEDGE,—, Effect *of Length of Observing Time on Earth Satellite Visibility.* Nav. Res. Lab. Rep. No. 5094. (1958).
61. GLADWELL, G. L. M., "A Review of Noise and Vibration in Motor Cars." *Jour. Sound Vibration,* 1(2) 202-210 (1964).
62. GOLDSTEIN, L. G., "Human Variables in Traffic Accidents: A Digest of Research and Selected Bibliography. *HRB Bibl. 31* (1962) 8 pp.
63. GRIEW, S., "Complexity of Response and Time of Initiating Responses in Relation to Age." *Am. Jour. Psychol.*, 72(1), 83-89 (1959).
64. HABER, H., "Observation-Attention-Reaction in an Enlarged Visual Field." *Industrielle Psychotechnik,* 9, 229-245 (1932).
65. HABER, H., "Safety Hazard of Tinted Automobile Windshields at Night." *Jour. Opt. Soc. Am.*, 45(6), 413-419 (1955).
66. HADDON, W., JR., "Alcohol and Highway Accidents." *Proc. Third Internat. Conf. on Alcohol and Road Traffic,* London (Sept. 1962) 1-11.
67. HADDON, W., JR., and BRADESS, V. A.,"Alcohol in the Single-Vehicle Fatal Accident." *Jour. Am. Med. Assn.*, 169(14), 127 (1959).
68. HARRIS, S. J., "The Effects of Sleep Loss on Component Movements of Human Motion." *Jour. Appl. Psychol.*, 44, 50-55 (1960).
69. HAWKES, G. R. (Ed.), "Symposium on Cutaneous Sensitivity." *U.S. Army Med. Res. Lab. Rep. No. 424* (Feb. 1960) 165 pp.

70. HEATH, W., and FINCH, D. M., "Determination of Windshield Levels Requisite for Driving Visibility." *HRB Bull. 56* (1952).
71. HEATH, W., and FINCH, D. M., "Effect of Tinted Windshields on Nighttime Visibility." *HRB Bull. 68* (1953) 1-15.
72. HERRINGTON, C. G., "Design of Reflectorized Motor Vehicle License Plates." *Proc. HRB*, 39, 441-466 (1960).
73. HICK, W. E., "Reaction Time for the Amendment of a Response." *Quart. Jour. Exp. Psychol.*, 1(3), 175-179.
74. HULBERT, S. F., "Blood Sugar Level, and Fatigue Effects on a Simulated Driving Task." *Rep. No. 63-53*, Dept. of Engineering, Univ. of California, Los Angeles (1963) 23 pp.
75. HULBERT, S. F., "Human Factors in Traffic Safety: The Levels of Research." *Proc. 17th California Street and Highway Conf.* (1965) 44-46.
76. HULBERT, S. F., and BURG, A., "The Effects of Underlining on the Readability of Highway Destination Signs." *HRB Bull. 36* (1957) 561-574.
77. HUNT, W. G., "Light and Dark Adaptation and the Perception of Color." *Jour. Opt. Soc. Am.*, 42, 190-199 (1952).
78. HURD, F., "Glance Legibility." *Traffic Eng.*, 17, 161-162 (1946).
79. JACKMAN, W. T., "Driver Obedience to Stop and Slow Signs." *HRB Bull. 161* (1957) 9-17.
80. JERISON, H. J., "Effects of Noise on Human Performance." *Jour. Appl. Psychol.*, 43(2), 96-102 (1959).
81. JOHANSSON, G., and RUMAR, K., "Drivers' Brake-Reaction Times." *Rep. No. 26*, Dept. of Psychology, Univ. of Uppsala, Sweden (1965) 16 pp.
82. JOHANSSON, G., and RUMAR, K., "Light Adaptation and Glare." *Rep. No. 12*, Dept. of Psychology, Univ. of Uppsala, Sweden (Nov. 1963) 17 pp.
83. JOHANSSON, G., and RUMAR, K., "Silhouette Effects in Night Driving." *Rep. No. 19*, Dept. of Psychology, Univ. of Uppsala, Sweden (June 1964) 37 pp.
84. JOHANSSON, G., ET AL., "Drivers and Road Signs. I." *Rep. No. 11*, Dept. of Psychology, Univ. of Uppsala, Sweden (1963) 8 pp.
85. JOHANSSON, G., ET AL., "Visible Distances During Night Driving." *Rep. No. 9*, Dept. of Psychology, Univ. of Uppsala, Sweden (Aug. 1961) 26 pp.
86. KATCHMAR, L. T., "A Review of the Literature on Reaction Time." *Tech. Rep. No. 5*, Univ. of Maryland (Mar. 1952).
87. KLEMMER, E. T., "Time Uncertainty in Simple Reaction Time." *Jour. Exp. Psychol.*, 51(3), 179-184 (1956).
88. LAHR, L. E., HEINSEN, A. C., JR., ANDERSON, H. G., and SLOAN, E. F., "A Field Study of the Relative Visibility of Various Colors." *California Fish and Game* (undated reprint).
89. LAUER, A. R., "Improvements in Highway Safety." *Proc. HRB*, 12, 389-401 (1932).
90. LAUER, A. R., and HELWIG, —, "Improvement in Highway Signs." *Am. Highways*, 11, 14, 15, 19 (1932).
91. LAUER, A. R., and STONE, J. A., "Legibility Distance and Visibility Distance." *Optom. Weekly*, 46, 727-728 (1955).
92. LAUER, A. R., and SUHR, V. W., "The Effect of a Rest Pause on Driving Efficiency." *Perceptual and Motor Skills*, 9, 363-371 (1959).
93. LAUER, A. R., and SUHR, V. W., "An Experimental Study of Four Methods of Reflectorizing Railway Boxcars." *HRB Bull. 146* (1957) 45-50.
94. LEBENSOHN, J. E., "Lighting for Traffic Safety." *Am. Jour. Ophthal.*, 32(10), 1415-1418 (1949).
95. LEGRAND, Y., ET AL., "Problemes Visuels Relatifs a la Conduite des Vehicules." *Ann. Ocul.*, 195, 160-165 (1962).
96. LOEB, M., and JEANTHEAU, B., "The Influence of Noxious Environmental Stimuli on Vigilance." *Jour. Appl. Psychol.*, 42(1), 47-50 (1958).
97. LUCAS, D. B., and BRITT, S. H., *Advertising Psychology and Research.* Chapters 2 and 3. McGraw-Hill (1950).
98. MACKWORTH, N. H., "Vigilance: Report of a Symposium on the Problem of Vigilance." *Advanc. of Sci.*, 13, 389-410 (1957).
99. MATT, H., "The Influence of the Load of Attention on the Speed of Reactions." *Indus. Psychotech.*, 9, 104-112 (1932).
100. MCGRATH, J. J., *Subjective Reactions of Vigilance Performers.* Human Factors Research, Inc., Los Angeles (1960) 7 pp.
101. MELDRUM, J. F., "Automobile Driver Eye Position." *SAE Rep. No. 650464* (1965) 17 pp.
102. MISSBACH, G., "To Stop or to Pass? Experimental Studies on Motor Vehicles." *Indus. Psychotech.*, 12, 137-148 (1935).
103. MITCHELL, A., and FORBES, T. W., "Design of Sign Letter Sizes." *Proc. Am. Soc. Civil Eng.*, 68, 95-104 (1942).
104. MOUNT, G. E., CASE, H. W., SANDERSON, J. W., and BRENNER, R., "Distance Judgment of Colored Objects." *Jour. Gen. Psychol.*, 55, 207-214 (1956).
105. NATHAN, J., HENRY, G. H., and COLE, B. L., "Recognition of Coloured Road-Traffic Signals." *Austral. Road Res.*, 2(3), 40-42 (1965).
106. NATHAN, J., HENRY, G. H., and COLE, B. L., "Recognition of Road Traffic Signals by Persons with Normal and Defective Colour Vision." *Austral. Road Res.*, 1(7), 30-38 (1963).
107. ODESCALCHI, P., RUTLEY, K. S., and CHRISTIE, A. E., *The Time Taken to Read a Traffiic Sign and Its Effect on the Size of Lettering Necessary.* Rd. Res. Lab. Note No. LN/98/90 KSR. AWC (British) (1962).
108. O'HANLON, J., JR., and SCHMIDT, E. A., *The Effect on the Level of Vigilance of an Adjacent Secondary Vigilance Task.* Human Factors Research, Inc., Los Angeles (1964) 19 pp.
109. OSBORN, W. C., SHELDON, R. W., and BAKER, R. A., "Vigilance Performance Under Conditions of Redun-

dant and Non-Redundant Signal Presentation." *Jour. Appl. Psychol.*, 47(2), 130-134 (1963).

110. PECKHAM, R. H., and HART, W. M., "A Hypereffective Visual Signal for Night Driving Warning Device." *HRB Record No. 25* (1963) 84-85.

111. PECKHAM, R. H., and HART, W. M., "Retinal Sensitivity and Night Visibility." *HRB Bull. 226* (1959) 1-6.

112. Personal communication from Thomas Rockwell, Ohio State Univ.

113. POLLACK, I., and KNAFF, P. R., "Maintenance of Alertness by a Loud Auditory Signal." *Jour. Acoust. Soc. Am.*, 30(11), 1013-1016 (1958).

114. REHLING, C. J., "Drugs and the Driver." *Traffic Safety* (Oct. 1960) 14-15.

115. *Research on Road Safety.* H. M. Stat. Off., London (1963) 602 pp.

116. RICHARDS, O. W., "Night Driving Seeing Problems." *Am. Jour. Optom.*, 35, 565-579 (1958).

117. RICHARDS, O. W., "Vision at Levels of Night Road Illumination." *HRB Bull. 56* (1952) 36-65.

118. "The Roles of Carbon Monoxide, Alcohol and Drugs in Fatal Single-Car Accidents." *Proc. California Transp. Agency Traffic Safety Res. Seminar* (Oct. 1965) 50-51.

119. ROPER, V. J., "Aiming for Better Headlighting." *HRB Bull. 191* (1958) 49-52.

120. ROPER, V. J., "Nighttime Seeing Through Heat-Absorbing Windshields." *HRB Bull. 68* (1953) 16-30.

121. ROPER, V. J., "Relation of Visual Acuity and Contrast Sensitivity Under Nighttime Driving Conditions." *HRB Bull. 336* (1962) 114.

122. *Rumble Strips Used as a Traffic Control Device: An Engineering Analysis.* Div. of Highways, Dept. of Public Works, State of Illinois (Apr. 1964) 34 pp.

123. SALTZMAN, J. J., and GARNER, W. R., "Reaction Time as a Measure of Span of Attention." *Jour. Psychol.*, 25, 227-241 (1941).

124. SCHMITZ, M. A., and SIMONS, A. K., "Man's Response to Low-Frequency Vibration." *Report No. 59-A-200*, Am. Soc. Mech. Eng. (1959).

125. SCHOPPERT, D. W., MOSKOWITZ, K., HULBERT, S. F., and BURG, A., "Some Principles of Freeway Directional Signing Based on Motorists' Experiences." *HRB Bull. 244* (1960) 30-87.

126. SHAPIRO, H. B., "Factors Affecting the Legibility of Digits." *Am. Psychol.*, 6, abst. 364 (1961).

127. SHIPLEY, T., "Visual Efficiency in Monocular Driving." *HRB Bull. 127* (1956) pp. 53-62.

128. "Sign Legibility Study." *Tech. Bull. No. 22,* Oregon State Highway Dept. (July 1954).

129. "Simple Highway Safety Device Developed by Canadians." *Constr. World,* 20(6), 12 (1965).

130. SIPOWICZ, R., and BAKER, R. A., "Effects of Intelligence on Vigilance: A Replication." *Perceptual and Motor Skills,* 13(3), 398 (1961).

131. SOAR, R. S., "Stroke Width, Illumination Level, and Figure-Ground Contrast in Numeral Visibility. *Jour. Appl. Psychol.*, 39(6), 429-432 (1955).

132. SOLOMON, D., "The Effect of Letter Width and Spacing on Night Legibility of Highway Signs." *Proc. HRB,* 35, 600-617 (1956).

133. STEVENS, S. S., (Ed.), *Handbook of Experimental Psychology.* Wiley (1951) 1436 pp.

134. SUHR, V. W., "Final Report of Study on the Effect of a Periodic Refreshment Pause on Simulated Automobile Driving Performance Efficiency. *HRB Bull. 212* (1959) 27-37.

135. SURWILLO, W. W., and QUILTER, R. E., "Vigilance, Age, and Response Time." *Am. Jour. Psychol.*, 77, 614-620 (1964).

136. SUTRO, P. J., "Windshield Visibility Clearance." *Traffic Safety Res. Rev.*, 1(1) 15-28 (1957).

137. TEICHNER, W. H., "Reaction Time in the Cold." *Jour. Appl. Psychol.*, 42(1), 54-59 (1958).

138. TEICHNER, W. H., "Recent Studies of Simple Reaction Time." *Psychol. Bull.*, 51(2), 128-149 (1954).

139. *The Totally Deaf Driver In California. Part II. Rep. No. 16,* California Dept. of Motor Vehicles (Dec. 1964) 30 pp.

140. *Traffic Control and Roadway Elements: Their Relationship to Highway Safety.* Automotive Safety Found. (1963) 124 pp.

141. "Traffic Signs Find New Answers." *Traffic Eng.*, 24, 263 (1954).

142. TURNER, H. J., "The Interaction Between Fixed Lighting and Vehicle Headlights." *Austral. Road Res.*, 2(3) 3-22 (1965).

143. *Uniform Vehicle Code.* National Comm. on Uniform Traffic Laws and Ordinances, Washington, D. C. (1962) 210 pp.

144. VANDERSTEMPEL, T. M., "Protection Problems at RR Grade Crossings." *Traffic Quart.*, 14(4), 541-549 (1960).

145. WENAR, C., "Reaction Time as a Function of Manifest Anxiety and Stimulus Intensity." *Jour. Abn. Soc. Psychol.*, 49(3), 335-340 (1954).

146. WEST, I., "The Impaired Driver—A Critical Review of the Facts." *Calif. Health,* 20(23), 177-180 (1963).

147. WOLF, E., MCFARLAND, R. A., and ZIGLER, M., "Influence of Tinted Windshield Glass on Five Visual Functions." *HRB Bull. 255* (1960) 30-45.

148. WOLFF, H. G., HARDY, J. D., and GOODELL, H., "Studies on Pain: Measurement of the Effect of Ethyl Alcohol on the Pain Threshold and the 'Alarm' Reaction." *Jour. Pharmacol.*, 75, 38-49 (1942).

149. WRIGHT, K. A., and BLEVIN, W. R., "The Nighttime Luminance of White Roadlines." *Austral. Road Res.*, 2(4), 3-11 (1965).

APPENDIX C

RESULTS OF OPINION SURVEY ON RAILROAD GRADE CROSSING PROTECTION

The opinion survey on railroad grade crossing protection was conducted by soliciting responses from employees of the research agency who had not participated in the field testing program. Part I consisted of ascertaining the reactions of those surveyed to a number of movie and slide scenes showing various signs observed. The subject was asked to check "like" for a sign meaningful to him, "dislike" for a sign having no meaning to him, and "no opinion" for a neutral reaction.

In Part II the subject was asked to rank each of several proposals in order on the basis of how each best meets the needs described. Each sign grouping was shown on the screen in sequence.

Of the 23 subjects, 1 was an associate of the research agency firm, 13 were engineers, and 9 had other job classifications. The results are given in Tables C-1 through C-5.

TABLE C-1

RESPONSES TO GRADE CROSSING PROTECTION SCENES (PART I)

SCENE			RESPONSES (NO.)		
NO.	DESCRIPTION	FIG. NO.	LIKE	DISLIKE	NO OPINION
	(*a*) CROSSING WITH ACTIVE PROTECTION				
1	Existing condition	—	—	—	—
2	One proposal under night conditions	—	—	—	—
3	R-X-R Signal Ahead	17	2	16	5
4	Railroad Signal Ahead	17	7	12	4
5	Railroad (Symbol) Ahead	17	13	8	2
6[a]	(Symbol)	17	4	10	9
	(*b*) CROSSING WITH PASSIVE PROTECTION				
7	Existing condition	—	—	—	—
8	One series of proposals under night conditions	—	—	—	—
9	Train Crossing	20	4	10	9
	Reduce Speed	20	9	7	7
	View of Trains Limited	20	9	9	5
	← Look for Trains →	20	10	8	5
	Small target, large crossbuck	19	12	8	3
10	Track angle, white road	16	13	7	3
	← Look for Trains →	16	13	6	4
	Small target (BYG),[b] large crossbuck	19	7	10	6
11	Train Crossing	21	6	10	7
	Reduce Speed	21	8	9	6
	View of Trains Limited	21	9	10	4
	← Look for Trains →	21	13	8	2
	Small target, large crossbuck	19	10	9	4
12	Track angle, white road	18	13	7	3
	"Look" symbol	18	3	15	5
	Triangular target, small crossbuck	15	10	9	4
13	Track angle, white road	18	13	7	3
	"Look" symbol	18	3	14	6
	Triangular target, large crossbuck	15	17	1	5
14	Track angle, white road	18	12	6	5
	"Look" symbol	18	2	15	6
	Small target (BYG),[b] large crossbuck	19	5	12	6
15	Track angle, white road	18	12	7	4
	"Look" symbol	18	2	15	6
	Large target, large crossbuck	19	11	8	4
16	Train Crossing	20	4	12	7
	Reduce Speed	20	7	8	8
	View of Trains Limited	20	7	8	8
	← Look for Trains →	20	7	12	4
	Trains Cross Here ↓ — End of Xing (BYG)[b]	22	5	15	3
17	Track angle, black road	18	5	14	4
	"Look" symbol	18	3	17	3
	Small target (BYG),[b] small crossbuck	19	5	15	3
18	Delineators only	21	7	8	8

[a] Still pictures only. [b] Brilliant yellow-green.

TABLE C-3

RESPONSES TO PROPOSALS FOR OTHER SIGNS AT GRADE CROSSINGS WITH PASSIVE PROTECTION (PART II)

SIGN		RESPONSES (NO.)		
DESCRIPTION	FIG. NO.	USEFUL	NOT USEFUL	MAYBE
Reduce Speed	20	17	5	1
View of Trains Limited	20	13	10	—

TABLE C-5

COLOR PREFERENCE OF SURVEY SUBJECTS FOR USE ON GRADE CROSSING PROTECTION SIGNS (PART II)

COLOR	PREFERENCES (NO.)
Yellow	10
Brilliant yellow-green	11
Other	2

TABLE C-2

ORDER RANKING OF PROPOSALS FOR ADVANCE GUIDE SERIES (PART II)

SIGN		RESPONSES (NO.) BY RANK						
DESCRIPTION	FIG. NO.	NO. OF CHOICES	1	2	3	4	5	NO VOTE
(*a*) CROSSING WITH ACTIVE PROTECTION								
R-X-R Signal Ahead	17	5	3	4	5	4	7	0
Railroad Signal Ahead	17	5	2	4	4	8	4	1
Railroad (Symbol) Ahead	17	5	12	2	4	3	2	0
Symbol only	17	5	2	7	3	4	5	2
Existing round R-X-R	—	5	3	5	6	1	7	1
(*b*) CROSSING WITH PASSIVE PROTECTION, FIRST SIGN								
Track angle, white road	18	4	15	1	6	0	—	1
Track angle, black road	18	4	2	8	4	8	—	1
Train Crossing	20	4	2	2	6	12	—	1
Existing round R-X-R	—	4	3	10	4	3	—	3
(*c*) CROSSING WITH PASSIVE PROTECTION, SECOND SIGN								
← Look for Trains →	16	2	17	5	—	—	—	1[a]
Symbol only	18	2	5	17	—	—	—	1[a]

[a] Other sign preferred.

TABLE C-4

ORDER RANKING OF PROPOSALS FOR AT-CROSSING SERIES ON GRADE CROSSINGS WITH PASSIVE PROTECTION (PART II)

SIGN		RESPONSES (NO.) BY RANK						
DESCRIPTION	FIG. NO.	1	2	3	4	5	6	OTHER
Triang. target, large crossbuck	15	13	4	1	0	3	2	0
Triang. target, small crossbuck	15	0	4	3	4	3	8	1
Lg. square target with crossbuck	19	2	3	2	4	10	2	0
Sm. square target with crossbuck	19	2	5	2	4	5	4	1
Trains Cross Here ↓ — End of Xing	22	4	3	7	4	0	4	1
Existing crossbuck, no background	—	1	3	7	5	1	6	0

APPENDIX D

INSTRUCTION TO FIELD CREW FOR MEASURING SIGHT DISTANCE

Each approach will require a separate form. In other words, each crossing will require at least two forms.

Information concerning *district, county, route, crossing no., railroad,* and *location* will be provided before leaving the office.

Approach will be referenced to compass direction (N, NE, E, SE, S, SW, W, NW) according to the direction from the crossing.

Train speed will be recorded in the office. This is the maximum speed of trains using a particular crossing.

Highway speed limit is to be recorded as the posted speed on the approach. If the speed limit is not posted, speed limit as fixed by state law will be used.

The *realistic highway speed* is the maximum speed at which some drivers could be expected to approach the crossing. The speed recorded here may be either higher or lower than the speed limit, depending on conditions at the crossing and the arbitrary decision made by the field crew. It may also be different for different approaches to the same crossing.

Corresponding distance No. 1 and *corresponding distance No. 2* are found by entering Table D-1 with highway speed limit and realistic highway speed, respectively. These two distances represent the safe stopping distances for vehicles traveling at various speeds.

Sight distance No. 1 is defined as the distance the driver is from the crossing when either the crossing or the crossbucks become clearly visible to him.

The following pertain to additional sight distances; in all cases R will pertain to the distance that the driver can see down the tracks to his right, L will pertain to the distance the driver can see down the tracks on his left side:

Sight distances 1R and *1L* are the distances the driver can see to his right and left, respectively, from a point on the highway equal to sight distance No. 1.

Sight distances 2R and *2L* are the distances the driver can see down the tracks to his right and left, respectively, from a point on the highway equal to corresponding distance No. 1.

Sight distances 3R and *3L* are the distances the driver can see down the tracks to his right and left, respectively, from a point on the highway equal to corresponding distance No. 2.

Sight distances 4R and *4L* are the distances the driver can see down the tracks to his right and left, respectively, from a point on the highway 20 ft from the tracks.

Each of the sight distances discussed is shown in Figure D-1.

TABLE D-1

SAFE STOPPING DISTANCE PLUS CLEARANCE FOR VARIOUS HIGHWAY SPEEDS, DESIGN VALUES

HIGHWAY SPEED (MPH)	CORRESPONDING DISTANCE (FT)
0	20
10	65
15	95
20	125
25	165
30	215
35	270
40	330
45	395
50	470
55	560
60	640
65	745
70	840
75	965

Number of lanes refers to the number of moving traffic lanes generally available on the approach to the crossing. This will be readily apparent if lane lines have been painted. Otherwise, it will have to be estimated. In estimating, it will be assumed that one lane is 9 to 12 ft wide. Dividing this number range into the total width of the traveled way (both directions) and rounding down to the nearest number of whole lanes, then dividing by two will give the number desired for this blank. Sometimes this method will not work. For example a 36-foot traveled way could be four 9-ft lanes or three 12-ft lanes. The recorders decision will be based on how the roadway is used by traffic. A roadway which does not allow two cars to meet will be coded as one-half lane.

Lane width will be a direct measurement if lane lines have been painted. Otherwise, it will be total approach width (always a direct measurement) divided by the num-

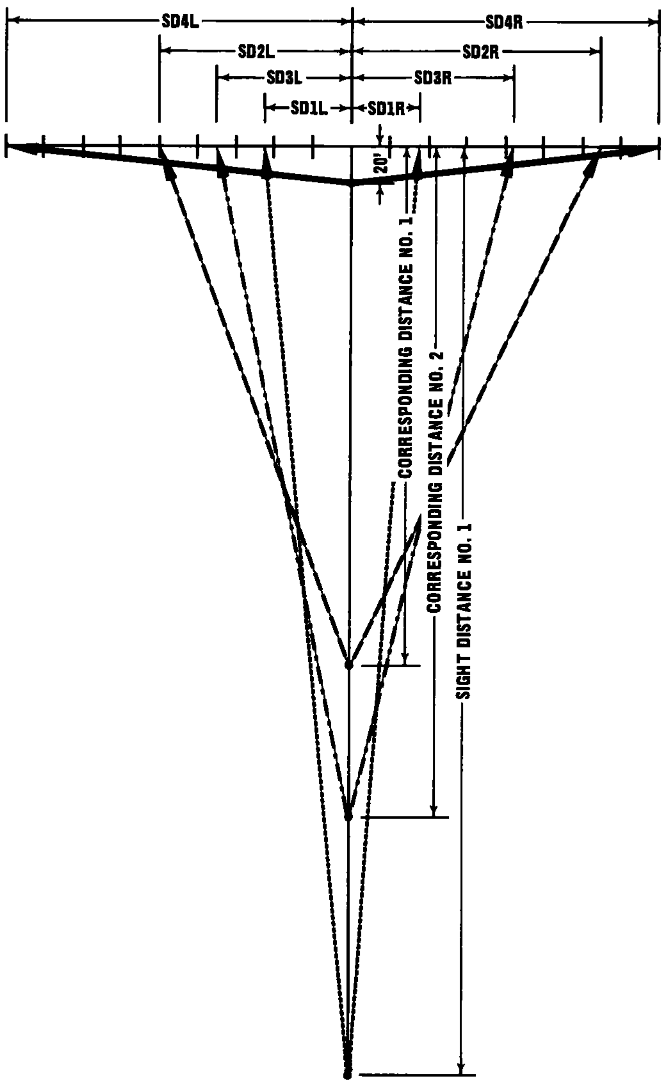

Figure D-1. Illustration of design sight distance.

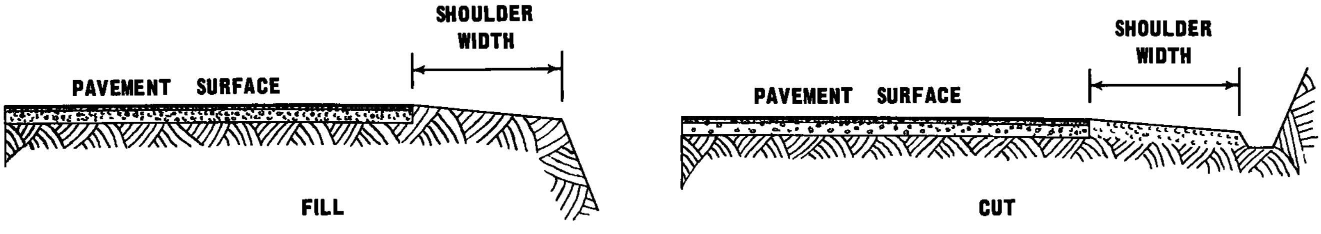

Figure D-2. Definition of shoulder width.

ber of lanes. Total approach width equals the total width of the road divided by two.

Shoulder width is illustrated in Figure D-2. This value will always pertain to the right shoulder.

Median width will be measured for divided highways only and will be recorded as the pavement-edge-to-pavement-edge distance.

Grade is to be recorded to the nearest percent. The distance in advance of the crossing over which this grade prevails shall also be recorded.

Pavement type will be recorded as dirt, gravel, low-type bituminous, high-type bituminous, or concrete.

Signs and warning devices are to be recorded in sequence, beginning at the crossing and working away from it. The abbreviation for the device, the distance from the crossing, the distance from the pavement edge, and an R for drivers right or an L for drivers left will be indicated for each (AW 500′-6′R). Acceptable abbrevations are as follows: crossbuck, XB; wigwag, WW; Flashing light signals, FLS; traffic signals, TS; flashing lights and gates, FLG; round advance warning sign, AW; stop sign, SS.
Other abbreviations shall be marked with an asterisk and spelled out on the back of the form.

Driveways and intersections are to be recorded as follows: Drv. 98 (12), Int. 30 (24). The first number after the abbreviation indicates the distance of its centerline from the crossing. The second number (in parenthesis) indicates the width of the driveway or intersection. Where a median is present only those driveways and intersections on the approach side will be recorded unless a median opening is provided.

Angle of crossing will be estimated to the nearest 15°.

Number of tracks will be recorded directly; each track is composed of two rails.

Length of crossing and *width of crossing* are measured with respect to the highway, not the railroad (i.e., length is from end of pavement to beginning of pavement).

Width of crossing will be measured perpendicular to the pavement edge.

Width of pavement adjacent to crossing will be measured perpendicular to the pavement edge at the point where the pavement ends.

Condition of crossing will be recorded according to the field crew's best judgment.

Comments will be recorded for any information which does not adapt itself to the form. Where there is not sufficient room on the form to record pertinent information, the back of the form may be used.

A plan view of each crossing approach will be prepared. The plan view will show all obstructions in the sight triangle. Distances along the highway and railroad to points perpendicular to the obstructions will be shown. A description of the obstruction will be recorded (i.e., brush, embankment, warehouse, barn, etc.)

In both the plan view and on the form, the study area at each crossing will include a distance of 1,600 ft down the railroad on each side of the crossing, and 1,000 ft down the highway. Sight distances in excess of these values will be recorded as 1,600 + ft and 1,000 + ft, respectively.

Zero points for the purposes of recording distances will be:

1. On the highway at the first rail.
2. On the railroad (a) at the right side pavement edge for measurements to the right, and (b) at the left lane edge of the approach for measurements to the left.

Both *signatures* of the field crew will be affixed to the form prior to leaving the crossing. The signatures will indicate that all field work has been completed and nothing has been overlooked or omitted (Fig. D-3).

All forms will be *dated.*

A north arrow will appear on all plan views, as well as the other necessary data to reference it to the correct crossing, the correct approach, and the correct data form.

District ________ County ________ Route ________

Crossing No. ________ Railroad ________

Location ____

____

Approach ________ Train Speed ________MPH

Highway Speed Limit ________MPH Corresponding Distance No. 1 ________Ft.

Realistic Highway Speed ________MPH Corresponding Distance No. 2 ________Ft.

Sight Distance No. 1 ________ Ft.

Sight Distance No. 1L ________Ft. Sight Distance No. 1R ________Ft.

Sight Distance No. 2L ________Ft. Sight Distance No. 2R ________Ft.

Sight Distance No. 3L ________Ft. Sight Distance No. 3R ________Ft.

Sight Distance No. 4L ________Ft. Sight Distance No. 4R ________Ft.

No. of Approach Lanes ________ Lane Width ________Ft.

Total Approach Width ________Ft. Shoulder Width ________Ft.

Median Width ________Ft. Grade ________ (+, -) ________% for ________Ft.

Pavement Type ________

Pavement Markings:

Edge Line ________ RXR ________ No Passing Zone ________

Center Line ________ Lane Line ________ Other ________

Signs and Warning Devices ____

____

Driveways and Intersections ____

____

Angle of Crossing ________Degrees No. of Tracks ________

Length of Crossing ________Ft. Width of Crossing ________

Width of Pavement Adjacent to Crossing ________Ft.

Condition of Crossing ____________________________
(Very Rough, Rough, Average, Good, Very Good)

Comments ____

____

Signatures ____________________________

____

PLAN VIEW ATTACHED

Figure D-3. Railroad grade crossing survey form.

APPENDIX E

EXAMPLE OF SIGHT DISTANCE CALCULATIONS

For a highway speed of 50 mph, calculate perception-reaction distance, given that perception-reaction time is 2.5 sec.

Perception-reaction time =

$$50 \frac{\text{mi}}{\text{hr}} \times \frac{5{,}280 \text{ ft/mi}}{3{,}600 \text{ sec/hr}} \times 2.5 \text{ sec} = 183 \text{ ft}$$

Calculate braking distance and braking time, assuming deceleration on level wet concrete.

Braking distance,* =

$$\frac{V^2}{30f} = \frac{50^2}{30 \times 0.31} = 269 \text{ ft}$$

in which V is the initial speed, in mph, and f † is the coefficient of friction between tires and roadway.

Braking distance,* ft =

$$\frac{269 \text{ ft}}{\frac{1}{2} \times 50 \text{ mph} \times 1.467\left(\frac{\text{ft-hr}}{\text{mi sec}}\right)} = 7.4 \text{ sec}$$

Safe stopping distance = Perception-reaction dist. + Braking dist. = 183 + 269 = 452 ft

Add 20 ft to allow for distance between the driver's eye and the front bumper and clearance between the front bumper and the train; i.e., 452 + 20 = 472 ft (round to 470 ft). This represents the final distance before the crossing in which a driver can stop.

Safe stopping time = Braking time + Perception-reaction time = 7.4 sec + 2.5 sec = 9.9 sec

Calculate time to proceed:

At 50 mph, the driver can stop safely from a point 470 ft in advance of the crossing. In order to beat the train, however, he must travel more than 470 ft, because he must cross the tracks and also clear his vehicle. The distance of 60 ft, which includes the distance from the driver's eye to the vehicle's rear bumper, the length of a one-track crossing, and clearance, has been allowed for that purpose. An average speed of 50 mph has been assumed.

$$\text{Time to proceed} = \frac{470 \text{ ft} + 60 \text{ ft}}{50 \text{ mi/hr} \times 1.467 \frac{\text{ft hr}}{\text{mi sec}}} = 7.3 \text{ sec}$$

In order to beat the train, the driver must see the train at 470 ft from the crossing 7.3 sec before it reaches the crossing.

If the train is traveling 60 mph, calculate the distance from the crossing at which the driver must see it.

$$60 \text{ mi/hr} \times 1.467 \frac{\text{ft hr}}{\text{mi sec}} \times 7.3 \text{ sec} = 642 \text{ ft}$$

If the vehicle stops, the situation is slightly different. Assume that the design vehicle (a large loaded truck) can attain a speed of 10 mph by the time it is clear of the crossing and that acceleration is uniform, he must travel 80 ft (20 + 60) at an average speed of 5 mph.

$$\text{Time to proceed} = \frac{80 \text{ ft}}{5 \text{ mi/hr} \times 1.467 \frac{\text{ft hr}}{\text{mi sec}}} = 11.0 \text{ sec}$$

The following examples illustrate the use of Table D-1 to determine whether the existing sight distance is adequate.

Example 1

Given: One-track crossing, 65-mph highway speed limit, maximum train speed is 90 mph, crossing is visible 500 ft from the tracks on the highway because of a horizontal curve, at the following distances from the crossing the driver can see the given distances down the tracks:

DIST. ON HWY. FROM TRACKS (FT)	TRACK SIGHT DIST. (FT)	
	RIGHT	LEFT
965	0	0
840	0	0
745	0	0
640	0	0
560	0	100
470	100	200
395	200	300
330	300	400
270	400	500
215	500	600
165	600	700
125	700	800
95	800	900
65	900	1,000
20	1,000	1,100

Inasmuch as the driver is assumed to be traveling 65 mph, visibility of the crossing is required at 745 ft (from Table D-1). Upon finding that the crossing is not visible at this point, the possibility of removing the obstructions to the sight distance would be investigated. In this case, however, this is assumed to be so expensive as to be prohibitive. The problem is then one of determining what speed is safe.

Because the crossing first comes into view at 500 ft, it is obvious that the advisory speed should be reduced to at least 50 mph (from Table 20).

* *A Policy on Geometric Design of Rural Highways.* Am. Assn. of State Highway Officials (1951) p. 113.
† *Ibid.*, p. 436.

At 470 ft, one must determine the distances down the track at which a train would come into view. From Table 20, it is found that the driver should be able to see a train approaching at 90 mph at least 1,020 ft before it reaches the crossing. Further investigation shows that there is no safe speed at which a driver can approach this crossing because of the 90-mph train speed and the poor sight distance. In fact, even if the driver is stopped he can not safely proceed unless the train speed is below 62 mph. To make this crossing safe, the sight distance for stopped vehicles must be provided, or the train speed must be reduced. With a train speed of 62 mph, a vehicle could traverse the crossing safely at 35 mph (interpolating in Table 20). To allow a 40-mph operating speed, the train speed would have to be reduced to between 30 and 35 mph. A train speed of between 15 and 20 mph would allow 45-mph vehicle operation; 50 mph would not be safe without stopping the train.

The problem, then, is found to have the following solutions:

TRAIN SPEED (MPH)	VEHICLE SPEED (MPH)
1. 50	0 [a]
2. 45	15–20
3. 40	30–35
4. 35	62
5. 0 [a]	62

[a] Stopped.

In this case, the maximum vehicle speed was limited by the highway alignment; the maximum train speed was limited by the railroad alignment.

Choosing the correct solution becomes a matter of economics. On a very low-volume roadway, the correct solution would probably be to reduce the vehicle speed to 35 mph. On a high-volume roadway, the cost to the highway user of reducing his speed could be greater than the cost to the railroad of reducing train speed. The less the crossing is used by trains, the more likely this would be true.

APPENDIX F

ORGANIZATIONS AND AGENCIES CONTRIBUTING DATA TO THIS STUDY

State Highway Departments

Arizona	Maryland
Arkansas	Minnesota
California	Ohio
Colorado	Oregon
Connecticut	South Carolina
Delaware	Wyoming
Idaho	Vermont
Illinois	Virginia

Cities

Amarillo, Tex.
Chula Vista, Calif.
Houston, Tex.
Lincoln, Neb.
Richmond, Va.

Counties

Contra Costa Co., Calif.
Dade Co., Fla.
Dallas Co., Tex.
Sacramento Co., Calif.
St. Louis Co. Mo.

Railroads

Atlantic Coast Line
Baltimore and Ohio
Pennsylvania
Reading
Richmond, Fredericksburg, and Potomac
Seaboard Airline
Southern
Washington and Old Dominion

Others

Association of American Railroads
Calif. Public Utilities Commission
Interstate Commerce Commission
Professor Donald G. Newnan,
Dept. of Industrial Engineering,
San Jose State College, Calif.

APPENDIX G

SUMMARY OF APPENDIX ITEMS NOT PUBLISHED

Other appendix materials contained in the report as submitted by the research agency are not published herein, but are listed here for the convenience of qualified researchers in the subject area, who may obtain loan copies of any or all of the items by written request to the Highway Research Board. The items available are as follows:

1. Sample of letter and description of needed data sent to to cities, counties, and state highway departments.
2. (a) Copy of petition to and order of approval by the Interstate Commerce Commission for use of ICC railroad grade-crossing accident record cards for the years 1960-1964.
   (b) ICC data coding schedule.
3. (a) Table Generator System (AVTGS)

   The table generator system is a general framework for a computer job, into which the user supplies specific information for the generation of tables from a file of input records. The general job framework (physically) exists as a deck of punched cards into which the user information (also contained on punched cards) is inserted, thereby forming a specific job deck for input to a computer.

   User-supplied information, in the form of FORTRAN language statements, will direct the generation of tables. User specification statements, as a subset of the FORTRAN language, will allow for the power, flexibility, and ease of use which FORTRAN provides.

   During job execution, the input file is selectively mapped, one record at a time, into each of the tables defined for the job. When the entire input file has been processed, the information in each of the tables is summarized and printed.

   The following is an outline of the 45-page program description, discussion, and definitions:

   Description
   Job Composition and Organization
   Job Preparation
   Restrictions
   Input
   - Preparing a Non-Standard Function
   - Standard Summary Functions
   - Standard Print Functions
   - Input File
   - Preparing Parameter Information
   - Preparing Variable Format Information
   - Preparing Job Control Information

   Output
   Operations
   Error Messages (Stops)
   Example

   (b) Graph Generator System (AVGGS)

   The graph generator system furnishes from 1 to 6 plots from an input file too large to be contained in memory. During job execution the input file is mapped, one record at a time, into one of 6 plot areas defined for the job. When the entire input file has been processed, the information is printed (output).

   The following is an outline of the 6-page program description, discussion, and definitions:

   Identification and Language (CDC 3600 FORTRAN, scope monitor)
   Input
   Output
   Operations

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Highway Research Board
National Academy of Sciences
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Rep. No.	*Title*
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1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80
8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1,) 109 p., $6.00
18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
28	Surveillance Methods and Ways and Means of Communicating with Drivers (Proj. 3-2), 66 p., $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
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40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60

* Highway Research Board Special Report 80.

Rep. No.	*Title*
42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
44	Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
46	Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
47	Accident Rates As Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
48	Factors and Trends in Trip Lengths (Proj. 7-4), 72 p., $3.20
49	National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20
50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p. $5.20

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Example 2:

Daylight volume $= \frac{0.75 \times 5{,}000}{2{,}500} \times 5{,}000 = 7{,}500$ = ADT to be used for A-factor in Figure 24, from

0.009641 which $A = 0.07179$.

Dark volume $= \frac{0.25 \times 5{,}000}{2{,}500} \times 5{,}000 = 2{,}500$ = ADT to be used for A-factor in Figure 24, from which

0.003304 $A = 0.02486$.

Example 3:

Volume for 7:00 to 8:00 AM $= \frac{500}{208} \times 5{,}000 = 12{,}000$,

0.015012 and $A = 0.11081$, where 208 = average hourly volume for a 24-hr day when ADT = 5,000.

Volume for Noon to 1:00 PM $= \frac{300}{208} \times 5{,}000 = 7{,}200$,

0.009259 and $A = 0.06905$.

Volume for 1:00 to 2:00 AM $= \frac{100}{208} \times 5{,}000 = 2{,}400$,

and $A = 0.02388$. **0.003169**

The actual test of the predictive equation is not to apply it to an individual crossing and expect it to predict the exact number of accidents which have occurred there in the past three years. Accidents can not be scheduled or programmed to occur at certain times in the past or future for a precise time period.

However, based on mass data analysis of past history, the predictive equation should be a better indication of the number of accidents which will occur at a specific location than even that location's history. Too often, highway engineers are pressured into expending funds for "improvements" based on one or two spectacular accidents.

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

REPORT 50

"FACTORS INFLUENCING SAFETY AT HIGHWAY-RAIL GRADE CROSSINGS"

CORRECTIONS, CLARIFICATIONS, AND ADDITIONAL RESEARCH FINDINGS

1. Col. 2, page 49, contains one definition of p, whereas the last paragraph of Col. 1, page 50, contains a second definition of the same symbol (Eqs. 4 and 5). This re-definition has led to some confusion on the part of readers, but in *no way does it affect the validity* of the model and the subsequent regression analysis.

2. In Table 8, page 9, the total number of accidents during dark hours for motor vehicle speeds of 10-19 mph, given as "779," should read "799."

3. In Table 9, page 11, the entire third line should be replaced to read:
"10-19 1,022 380 1,402 27.1 731 554 1,285 43.1"

4. The equations on page 56 require a scaling factor of 1,000, which was omitted in the description of the equation but was included in all of the subsequent calculations. The last line on page 56 and the first line on page 57 should read:

   " X_{10} = probability of coincidental vehicle and train arrival scaled by 10^{-3}, or

   $$\frac{X_3}{86,400}\left(1-e^{-X_2/86,400}\right)\left(10^{-3}\right) \quad (40)"$$

5. Questions have been raised about the A-factors for hourly volumes near the bottom of Col. 2, page 60. These were obtained by multiplying the hourly volumes by 24 and entering the table on page 61 with this value. The procedure was not explained in the text.

6. On page 63, Col. 1, line 15 should read:
"0.01 deaths @ \$20,000 = \$200"
and line 18, given as \$4,000, should read:
"Total \$2,200"

7. The accident costs given in the report were based on then prevailing (1968) estimates of the costs of fatalities and injuries. In research subsequent to *NCHRP Report 50*[1/], new estimates of the costs of rail crossing accidents were developed based on revised values of fatalities and injuries. These estimates were:

Train-involved accidents	\$20,165
Nontrain-involved accidents	1,655

   Data also were gathered on accidents at urban crossings with flashing lights and automatic gates and the coefficients in the predictive equations were recalculated. The old and new coefficients are:

	NCHRP Report 50	New
Urban crossings with flashing lights	0.32	0.23
Urban crossings with automatic gates	0.32	0.08

1/ Program Definition Study for Grade Crossing Improvement, by Alan M. Voorhees & Associates, for the Federal Railroad Administration.

The sample size of the study is roughly equal to that in *NCHRP Report 50*, but the data are more recent. More research on this question would be helpful in finding a more definitive answer to the question of the relative effectiveness of flashing lights and automatic gates at urban grade crossings.
The original draft submission of *NCHRP Report 50* ended with line 32, Col. 2 page 63. At the request of the NCHRP reviewers, the example of the ten crossings which concludes Chapter 7 was added. The example was based on a number of simplifying assumptions that should not be used in a cost-benefit analysis.

8. Moreover, the selection of improvements should have been based on a net benefit or equivalent criterion. Thus, the three crossings—Nos. 2, 9, and 10—should have been treated as follows:

   - Crossing No. 2—only one improvement, flashing lights, produced benefits in excess of costs.

   - Crossing No. 9—flashing lights produced the greatest benefit and were therefore the preferred improvement at that crossing.

   - Crossing No. 10—gates produced a greater net benefit than either a grade separation or flashing lights.

   - If funds were available to make all of the improvements for which benefits were greater than costs, the priority of the improvements would be:

     Crossing No. 9—flashing lights
     Crossing No. 10—automatic gates
     Crossing No. 2—flashing lights

   - If only $39,000 were available, Crossings No. 9 and 10 would be improved in that order.

   - If only $26,000 were available, the indicated improvements and priorities would be:

     Crossing No. 9—flashing lights
     Crossing No. 10—flashing lights

   - If only $13,000 were available, only Crossing No. 9 would be improved with flashing lights.

   Cost benefit analysis requires careful evaluation of all costs and benefits and should not be undertaken without an understanding of the underlying principles. One report that readers could use for a reference has already been mentioned (see footnote 1). Another is Road User Benefit Analysis for Highway Improvements, AASHO.

9. Page 111, Col. 1, line 4 -- "time" should read "distance".
   line 14 -- "distance, *ft" should read "time, sec".
   Page 112, Col. 1, line 4 -- "1,020 ft" should read "964 ft".
   line 13 -- "35 mph" should read "25 mph".
   line 15 -- "35 mph" should read "25 mph".
   Col. 2, line 1 -- the tabular column headings should be transposed
   line 5 -- "35" (Col. 1) should read "25".

10. Corrections to page 62 were distributed with the original printing. To ensure that these corrections have not been misplaced, they are repeated here, as follows:

Col. 1, line 4 -- "A = 0.07179" should read "A = 0.009641".
line 7 -- "A = 0.02486" should read "A = 0.003304".
line 10 -- "A = 0.11081" should read "A = 0.015012".
line 13 -- "A = 0.06905" should read "A = 0.009259".
Col. 2, line 2 -- "A = 0.02388" should read "A = 0.003169".

HIGHWAY RESEARCH BOARD
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