FACTORS INFLUENCING SAFETY AT HIGHWAY-RAIL GRADE CROSSINGS
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FACTORS INFLUENCING SAFETY AT HIGHWAY-RAIL GRADE CROSSINGS

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS IN COOPERATION WITH THE BUREAU OF PUBLIC ROADS

SUBJECT CLASSIFICATION.
HIGHWAY DESIGN
MAINTENANCE, GENERAL
HIGHWAY SAFETY
TRAFFIC CONTROL AND OPERATIONS

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1968
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 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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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:

<table>
<thead>
<tr>
<th>Number of accidents</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of crossings</td>
<td>55</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

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

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

All other protection types

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

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.
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
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 involve-

ment 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 geometries, 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-
automatically 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.

### TABLE 4

<table>
<thead>
<tr>
<th>PROTECTION TYPE</th>
<th>TRUCK</th>
<th>TOTAL</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic gates</td>
<td>42</td>
<td>338</td>
<td>12.4</td>
</tr>
<tr>
<td>Manual gates</td>
<td>23</td>
<td>172</td>
<td>13.3</td>
</tr>
<tr>
<td>Watchman</td>
<td>10</td>
<td>133</td>
<td>7.5</td>
</tr>
<tr>
<td>Other employee</td>
<td>246</td>
<td>1,517</td>
<td>16.2</td>
</tr>
<tr>
<td>Aud. and vis. signal</td>
<td>282</td>
<td>1,629</td>
<td>17.3</td>
</tr>
<tr>
<td>Audible signal</td>
<td>287</td>
<td>1,454</td>
<td>19.7</td>
</tr>
<tr>
<td>Visual signal</td>
<td>262</td>
<td>1,246</td>
<td>21.1</td>
</tr>
<tr>
<td>Crossbuck</td>
<td>732</td>
<td>3,453</td>
<td>21.2</td>
</tr>
<tr>
<td>Advance warning sign</td>
<td>135</td>
<td>598</td>
<td>22.6</td>
</tr>
<tr>
<td>Unprotected</td>
<td>1,162</td>
<td>5,039</td>
<td>23.1</td>
</tr>
<tr>
<td>All</td>
<td>3,181</td>
<td>15,580</td>
<td>20.5</td>
</tr>
</tbody>
</table>

* Source: Interstate Commerce Commission, 1960-1964 nationwide data

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

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>MOVING VEHICLE</th>
<th>STALLED VEHICLE</th>
<th>STOPPED VEHICLE</th>
<th>HIT TRAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRAIN HIT</td>
<td>(NO.)</td>
<td>(%)</td>
<td>(NO.)</td>
<td>(%)</td>
</tr>
<tr>
<td>Auto</td>
<td>6,251</td>
<td>75.5</td>
<td>661</td>
<td>78.9</td>
</tr>
<tr>
<td>Bus</td>
<td>26</td>
<td>0.3</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Truck</td>
<td>1,983</td>
<td>24.0</td>
<td>175</td>
<td>20.9</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>16</td>
<td>0.2</td>
<td>1</td>
<td>0.1</td>
</tr>
</tbody>
</table>
TABLE 6
PARTS OF TRAINS INVOLVED IN ACCIDENTS IN THE UNITED STATES, 1960-1964 *

<table>
<thead>
<tr>
<th>ACCIDENT TYPE</th>
<th>ACCIDENTS (NO.)</th>
<th>ACCIDENTS (%)</th>
<th>LENGTH (FT)</th>
<th>LENGTH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hit by train</td>
<td>10,047</td>
<td>64.6%</td>
<td>64.6</td>
<td>64.6</td>
</tr>
<tr>
<td>Hit 1st unit</td>
<td>3,670</td>
<td>23.6%</td>
<td>50</td>
<td>88.2</td>
</tr>
<tr>
<td>Hit 1st quarter b</td>
<td>710</td>
<td>4.6%</td>
<td>482</td>
<td>92.8</td>
</tr>
<tr>
<td>Hit 2nd quarter</td>
<td>388</td>
<td>2.5%</td>
<td>532</td>
<td>97.1</td>
</tr>
<tr>
<td>Hit 3rd quarter</td>
<td>279</td>
<td>1.8%</td>
<td>532</td>
<td>97.1</td>
</tr>
<tr>
<td>Hit 4th quarter *</td>
<td>317</td>
<td>2.0%</td>
<td>482</td>
<td>99.1</td>
</tr>
<tr>
<td>Hit last unit</td>
<td>143</td>
<td>0.9%</td>
<td>50</td>
<td>100.0</td>
</tr>
<tr>
<td>All</td>
<td>15,554</td>
<td>100.0%</td>
<td>2130</td>
<td></td>
</tr>
</tbody>
</table>

* Source: Interstate Commerce Commission.

b Of longer train; or second, third, or fourth unit of train with less than five units.

* But not last unit.

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 7
DISTANCE TRAVELED FOR HIGHWAY VEHICLE SPEED OF 40 MPH AND 60 MPH

<table>
<thead>
<tr>
<th>TRAIN SPEED (MPH)</th>
<th>DIST./8 SEC (FT)</th>
<th>% OF AVG. LENGTH</th>
<th>DIST./11.6 SEC (FT)</th>
<th>% OF AVG. LENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>937</td>
<td>44.0%</td>
<td>1,360</td>
<td>63.8%</td>
</tr>
<tr>
<td>70</td>
<td>822</td>
<td>38.6%</td>
<td>1,190</td>
<td>55.8%</td>
</tr>
<tr>
<td>60</td>
<td>704</td>
<td>33.1%</td>
<td>1,020</td>
<td>47.8%</td>
</tr>
<tr>
<td>50</td>
<td>587</td>
<td>27.5%</td>
<td>850</td>
<td>39.9%</td>
</tr>
<tr>
<td>40</td>
<td>469</td>
<td>22.0%</td>
<td>680</td>
<td>31.9%</td>
</tr>
<tr>
<td>30</td>
<td>352</td>
<td>16.5%</td>
<td>510</td>
<td>23.9%</td>
</tr>
</tbody>
</table>

TABLE 8
VEHICLE-TRAIN ACCIDENTS BY LIGHT CONDITION, ACCIDENT TYPE, AND HIGHWAY SPEED

<table>
<thead>
<tr>
<th>MOTOR VEHICLE SPEED (MPH)</th>
<th>DAYLIGHT</th>
<th>DARK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STRUCK BY TRAIN</td>
<td>RAN INTO TRAIN</td>
</tr>
<tr>
<td>Standing</td>
<td>1,247</td>
<td>—</td>
</tr>
<tr>
<td>1 - 9</td>
<td>785</td>
<td>93</td>
</tr>
<tr>
<td>10 - 19</td>
<td>1,407</td>
<td>202</td>
</tr>
<tr>
<td>20 - 29</td>
<td>1,246</td>
<td>364</td>
</tr>
<tr>
<td>30 - 39</td>
<td>745</td>
<td>422</td>
</tr>
<tr>
<td>40 - 49</td>
<td>361</td>
<td>334</td>
</tr>
<tr>
<td>50 - 59</td>
<td>203</td>
<td>263</td>
</tr>
<tr>
<td>60 and over</td>
<td>110</td>
<td>259</td>
</tr>
<tr>
<td>High speed</td>
<td>24</td>
<td>42</td>
</tr>
<tr>
<td>Not reported</td>
<td>745</td>
<td>324</td>
</tr>
<tr>
<td>All</td>
<td>6,873</td>
<td>2,303</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>NO. OF ACCIDENTS</th>
<th>DAYLIGHT</th>
<th></th>
<th>DARK</th>
<th></th>
<th>% AT</th>
<th></th>
<th>% AT</th>
<th></th>
<th>% AT</th>
<th></th>
<th>% AT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STRUCK BY</td>
<td>RAN INTO</td>
<td>TRAIN</td>
<td>TOTAL</td>
<td>STRUCK BY</td>
<td>RAN INTO</td>
<td>TRAIN</td>
<td>TOTAL</td>
<td>STRUCK BY</td>
<td>RAN INTO</td>
<td>TRAIN</td>
<td>TOTAL</td>
</tr>
<tr>
<td>TRAIN SPEED (MPH)</td>
<td>TRAIN</td>
<td></td>
<td></td>
<td></td>
<td>TRAIN</td>
<td></td>
<td></td>
<td></td>
<td>TRAIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing</td>
<td>—</td>
<td>41</td>
<td>41</td>
<td>100</td>
<td>—</td>
<td>520</td>
<td>520</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - 9</td>
<td>542</td>
<td>330</td>
<td>872</td>
<td>37.8</td>
<td>696</td>
<td>1,170</td>
<td>1,866</td>
<td>62.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 - 19</td>
<td>1,407</td>
<td>202</td>
<td>1,609</td>
<td>12.6</td>
<td>571</td>
<td>228</td>
<td>799</td>
<td>28.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 - 29</td>
<td>1,280</td>
<td>501</td>
<td>1,781</td>
<td>28.1</td>
<td>530</td>
<td>385</td>
<td>915</td>
<td>42.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 - 39</td>
<td>1,207</td>
<td>394</td>
<td>1,601</td>
<td>24.6</td>
<td>362</td>
<td>261</td>
<td>623</td>
<td>41.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 - 49</td>
<td>1,085</td>
<td>298</td>
<td>1,383</td>
<td>21.5</td>
<td>321</td>
<td>203</td>
<td>504</td>
<td>38.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 - 59</td>
<td>715</td>
<td>170</td>
<td>885</td>
<td>19.2</td>
<td>219</td>
<td>84</td>
<td>303</td>
<td>27.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 - 69</td>
<td>448</td>
<td>90</td>
<td>538</td>
<td>16.7</td>
<td>148</td>
<td>29</td>
<td>177</td>
<td>16.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70 and over</td>
<td>370</td>
<td>99</td>
<td>469</td>
<td>14.8</td>
<td>167</td>
<td>26</td>
<td>193</td>
<td>13.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not reported</td>
<td>4</td>
<td>—</td>
<td>4</td>
<td>0</td>
<td>—</td>
<td>7</td>
<td>7</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>All</td>
<td>6,873</td>
<td>2,303</td>
<td>9,176</td>
<td>25.1</td>
<td>3,174</td>
<td>3,239</td>
<td>6,413</td>
<td>50.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>TRAIN SPEED (MPH)</th>
<th>1 - 9</th>
<th>10 - 19</th>
<th>20 - 29</th>
<th>30 - 39</th>
<th>40 - 49</th>
<th>50 - 59</th>
<th>&gt; 60</th>
<th>HIGH NOT STATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 9</td>
<td>30</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>10 - 19</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>150</td>
<td>150</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>20 - 29</td>
<td>150</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>250</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>30 - 39</td>
<td>150</td>
<td>250</td>
<td>250</td>
<td>300</td>
<td>350</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>40 - 49</td>
<td>200</td>
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Driver's Distance From Crossing (ft.)

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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

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<td>76</td>
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<td>50 - 59</td>
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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 com­
bination of factors must be causing or controlling the
distribution.

Figure 3. Accident index by month.

TABLE 13
ACCIDENTS IN WHICH THE VEHICLE STRUCK
THE TRAIN, BY LIGHT CONDITION

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Figure 3. Accident index by month.
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-
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
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<td>1,481</td>
<td>1,311</td>
<td>1,086</td>
<td>983</td>
<td>933</td>
<td>892</td>
<td>1,024</td>
<td>1,063</td>
<td>1,409</td>
<td>1,613</td>
<td>2,058</td>
<td>15,490</td>
</tr>
</tbody>
</table>
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 least 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 $\frac{9.8}{10} = 98$ 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.
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:

\[
\frac{\text{Annual crossing accidents}}{\text{Annual train accidents}} = \frac{\text{Illinois crossing accidents}}{\text{Illinois train accidents}}
\]

\[
\begin{align*}
\frac{\text{Annual crossing accidents}}{3,200} &= \frac{3,627}{1,113} \\
\text{Annual crossing accidents} &= 10,000
\end{align*}
\]

### TABLE 15

PERCENTAGE OF CROSSING ACCIDENTS WHICH INVOLVED TRAINS

<table>
<thead>
<tr>
<th>STATE</th>
<th>NO. OF YEARS</th>
<th>NO. OF CROSSINGS</th>
<th>INVOLVING TRAINS</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ariz.</td>
<td>4</td>
<td>44</td>
<td>15</td>
<td>34.1</td>
</tr>
<tr>
<td>Colo.</td>
<td>3.5</td>
<td>166</td>
<td>53</td>
<td>31.9</td>
</tr>
<tr>
<td>Conn.</td>
<td>6</td>
<td>94</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ill.</td>
<td>2.5</td>
<td>452</td>
<td>97</td>
<td>21.5</td>
</tr>
<tr>
<td>Ohio</td>
<td>5</td>
<td>1028</td>
<td>191</td>
<td>18.6</td>
</tr>
<tr>
<td>Vt.</td>
<td>5</td>
<td>108</td>
<td>19</td>
<td>17.6</td>
</tr>
<tr>
<td>Total</td>
<td>1892</td>
<td>375</td>
<td>19.8</td>
<td></td>
</tr>
</tbody>
</table>

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

### TABLE 16

DISTRIBUTION OF ACCIDENTS AT CROSSINGS BY PRESENCE AND INVOLVEMENT OF TRAIN

<table>
<thead>
<tr>
<th>TRAIN INVOLVEMENT</th>
<th>ACCIDENTS</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involved</td>
<td>1113</td>
<td>30.7</td>
</tr>
<tr>
<td>Present, not involved</td>
<td>1339</td>
<td>36.9</td>
</tr>
<tr>
<td>Not present</td>
<td>1175</td>
<td>32.4</td>
</tr>
<tr>
<td>Total</td>
<td>3627</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* Source: Illinois Division of Highways, covering State highways, county roads, and city streets in entire State.
### TABLE 17
TYPES OF ACCIDENTS AT RAILROAD CROSSINGS

<table>
<thead>
<tr>
<th>TYPE OF ACCIDENT</th>
<th>TRAIN INVOLVED</th>
<th>TRAIN PRESENT</th>
<th>TRAIN NOT PRESENT</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO.</td>
<td>%</td>
<td>NO.</td>
<td>%</td>
</tr>
<tr>
<td>Ran off roadway</td>
<td>4</td>
<td>0.4</td>
<td>29</td>
<td>2.2</td>
</tr>
<tr>
<td>Overturned in roadway</td>
<td>5</td>
<td>0.4</td>
<td>17</td>
<td>1.4</td>
</tr>
<tr>
<td>Pedestrian</td>
<td></td>
<td></td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Motor vehicle in traffic</td>
<td>15</td>
<td>1.3</td>
<td>1213</td>
<td>90.6</td>
</tr>
<tr>
<td>Parked motor vehicle</td>
<td></td>
<td></td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Railroad train</td>
<td>1091</td>
<td>98.0</td>
<td>6</td>
<td>0.4</td>
</tr>
<tr>
<td>Bicyclist</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed object</td>
<td>3</td>
<td>0.3</td>
<td>67</td>
<td>5.0</td>
</tr>
<tr>
<td>Other object</td>
<td></td>
<td></td>
<td>13</td>
<td>1.0</td>
</tr>
<tr>
<td>Other non-collision</td>
<td></td>
<td></td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>All</td>
<td>1113</td>
<td>100.0</td>
<td>1339</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* Source: Illinois Division of Highways.
* But not involved.

### TABLE 18
ACCIDENTS AT CROSSINGS BY MANNER OF COLLISION

<table>
<thead>
<tr>
<th>MANNER OF COLLISION</th>
<th>TRAIN INVOLVED</th>
<th>TRAIN PRESENT</th>
<th>TRAIN NOT PRESENT</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO.</td>
<td>%</td>
<td>NO.</td>
<td>%</td>
</tr>
<tr>
<td>Rear-end or sideswipe, same direction</td>
<td>15</td>
<td>1.3</td>
<td>1169</td>
<td>87.3</td>
</tr>
<tr>
<td>Head-on or sideswipe, opposite direction</td>
<td></td>
<td></td>
<td>31</td>
<td>2.3</td>
</tr>
<tr>
<td>Angle collision</td>
<td></td>
<td></td>
<td>15</td>
<td>1.1</td>
</tr>
<tr>
<td>Collision with pedestrian</td>
<td></td>
<td></td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Other collision</td>
<td>1094</td>
<td>98.3</td>
<td>71</td>
<td>5.3</td>
</tr>
<tr>
<td>Non-collision</td>
<td>4</td>
<td>0.4</td>
<td>49</td>
<td>3.7</td>
</tr>
<tr>
<td>Others and not known</td>
<td></td>
<td></td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>All</td>
<td>1113</td>
<td>100.0</td>
<td>1339</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* Source: Illinois Division of Highways.
* But not involved.

Annual deaths at crossings = Illinois deaths at crossings
Deaths with trains = Illinois deaths with trains

Annual deaths at crossings = 1,200
Annual deaths at crossings = 315
Annual injuries at crossings = 1,305
Annual injuries at crossings = 3,400
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
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,
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 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 would vary from driver to driver and with time at the same location.

All events are not related to the driving task. Individuals "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 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 should 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 result in safe driving.

As indicated by Platt (20), approximately one time in every 40 decisions the average driver will make the wrong decision. Furthermore, 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.

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

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

The driving task may end with a collision. If no collision results, 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 be noted that an event may require 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 rural situation and 127 in an urban situation.

Because, as stated previously, the driver is limited to only 16 observations per sec, approximately 3 sec of observation time would 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 up the
Figure 14. Basic order of traffic situations at railroad grade crossings.
The 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 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

Precising 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.

**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.

### Table 24

**General Principles for Development of Warning Systems**

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Take into account the full range of human characteristics; i.e., do not use only the &quot;normal&quot; or &quot;average&quot; driver in specifying design requirements.</td>
</tr>
<tr>
<td>B.</td>
<td>Minimize uncertainty in decision-making by making alternative courses of action as few and as simple as possible.</td>
</tr>
<tr>
<td>C.</td>
<td>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.</td>
</tr>
<tr>
<td>D.</td>
<td>Avoid the presentation of any extraneous or irrelevant information that could interfere with attention to the important cues.</td>
</tr>
<tr>
<td>E.</td>
<td>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.</td>
</tr>
<tr>
<td>F.</td>
<td>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 multichannel stimulation (e.g., rumble strips in addition to signs).</td>
</tr>
<tr>
<td>G.</td>
<td>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.</td>
</tr>
<tr>
<td>H.</td>
<td>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).</td>
</tr>
<tr>
<td>I.</td>
<td>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.</td>
</tr>
</tbody>
</table>
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 visibility 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 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.
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 yellow 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 \( \text{Y} \)-\( \text{R} \). 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 hierarchy 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 X 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

<table>
<thead>
<tr>
<th>PROTECTION TYPE</th>
<th>NO. OF CROSSINGS</th>
<th>NUMBER OF ACCIDENTS PER YEAR</th>
<th>ACCIDENTS PER CROSSING PER YEAR</th>
<th>PROBABILITY X 10^-6 PER CROSSING</th>
<th>ACCIDENTS PER CROSSING PER PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossbucks</td>
<td>5541</td>
<td>231</td>
<td>0.0417</td>
<td>0.406</td>
<td>0.103</td>
</tr>
<tr>
<td>Stop signs</td>
<td>728</td>
<td>68</td>
<td>0.0935</td>
<td>1.552</td>
<td>0.060</td>
</tr>
<tr>
<td>Wigwags</td>
<td>303</td>
<td>124</td>
<td>0.4100</td>
<td>11.690</td>
<td>0.035</td>
</tr>
<tr>
<td>Flashing lights</td>
<td>795</td>
<td>186</td>
<td>0.2340</td>
<td>11.110</td>
<td>0.021</td>
</tr>
<tr>
<td>Gates</td>
<td>128</td>
<td>33</td>
<td>0.2580</td>
<td>22.900</td>
<td>0.011</td>
</tr>
</tbody>
</table>

TABLE 26
COMPARISON OF EXPECTED AND OBSERVED DISTRIBUTION OF ACCIDENTS

<table>
<thead>
<tr>
<th>TYPE OF PROTECTION</th>
<th>TYPE OF DISTRIBUTION</th>
<th>0 ACC.</th>
<th>1 ACC.</th>
<th>2 ACC.</th>
<th>3 ACC.</th>
<th>4 ACC.</th>
<th>5 ACC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No protection</td>
<td>Expected</td>
<td>366</td>
<td>3</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>367</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Passive protection, one side only</td>
<td>Expected</td>
<td>1385</td>
<td>40</td>
<td>1</td>
<td>+ +</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>1385</td>
<td>41</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Passive protection, both sides</td>
<td>Expected</td>
<td>3723</td>
<td>284</td>
<td>1</td>
<td>+ +</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>3773</td>
<td>207</td>
<td>29</td>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Stop sign protection, one side</td>
<td>Expected</td>
<td>91</td>
<td>7</td>
<td>1</td>
<td>+ +</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>91</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Stop sign protection, both sides</td>
<td>Expected</td>
<td>536</td>
<td>80</td>
<td>6</td>
<td>1</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>545</td>
<td>65</td>
<td>11</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Active warning devices</td>
<td>Expected</td>
<td>313</td>
<td>91</td>
<td>13</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Observed</td>
<td>319</td>
<td>84</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

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 geometries 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 1 + + 
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:

\[ P = R(K + p) \]  \hspace{1cm} (1) \n
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 probability 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

\[ P = rK + Rp \]  

(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

\[ P = C(rK + Rp) \]  

(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

\[ P = CRp \]  

(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,

\[ p = ab \]  

(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 \( h \)th 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 \( e^{-V_h/T_t} \), in which \( T_t \) is the number of seconds in an hour. Therefore, the probability of having at least one arrival in a randomly chosen second is \( 1 - e^{-V_h/T_t} \). 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

\[ b_h = 1 - e^{-V_h/3600} \]  

(6)
and

\[ a_h = Z_t/T_t \]  

(7)
in which the time period, \( t \), covers the \( h \) hour.

The term \( a b \) is then determined as follows:

\[ a b = \sum_{h=1}^{24} a_h b_h \]  

(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 \( a_h = 0 \). 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,

$$P(y) = \binom{N}{y_1} (P_1)^{y_1} (1 - P_1)^{N-y_1} \binom{N}{y_2} (P_2)^{y_2} (1 - P_2)^{N-y_2}$$

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 $NP$ is less than 5. Considering the fact that three or four accidents are rarely observed in a 5-year period (indicating that $NP$ 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 $NP$. And it is easily shown that

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

(10)

This indicates that the convolution is closely approximated by a single Poisson distribution whose parameter $NP$ is equal to $NP_1 + NP_2$, the sum of the probabilities of the independent distributions. That is,

$$NP = NP_1 + NP_2$$

$$= C [N(R_d a_d b_d) + N(R_a a_n b_n)]$$  

(11a)

or

$$P = C [R_d a_d b_d + R_a a_n b_n]$$

(11b)

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

$$P = C (R_d + R_a) a b$$

(11c)

Eq. 11c simply says that the effects of night and day can be approximated if the day and night splits 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 $J$th group of devices with a known $a b$ is

$$P_J = C \left(1 - K_{0J} \pm \epsilon_j - K_{1J} X_1 - K_{2J} X_2 \ldots \right) a b$$

(12)

in which $K_0$ is the “basic awareness”; $\epsilon$ is the “error” representing the variability in the “basic awareness”; $K_1, K_2 \ldots$ are the coefficients which indicate the effects of geometric numbers 1, 2, $\ldots$ as measured by $X_1, X_2, \ldots$, 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

$$P(y) = \binom{NP}{y} (P)^y (1 - P)^{NP-y}$$

(13a)

or can be accurately approximated by

$$P(y) = \frac{(NP)^y e^{-NP}}{y!}$$

(13b)

in which $y$ is the number of accidents and $NP$ 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 $P = 4 \times 10^{-5}$, 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.
Estimating Coefficients in the Risk Equation

In estimating the effects of different types of warning devices and geometries 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 $y_i$ totals in the $N_i$ trials, all in the same group of data, is given by

$$L = \left( \frac{N_1}{y_1} \right)^{y_1} (1 - P_1)^{N_1 - y_1} \left( \frac{N_2}{y_2} \right)^{y_2} (1 - P_2)^{N_2 - y_2} \left( \frac{N_3}{y_3} \right)^{y_3} (1 - P_3)^{N_3 - y_3}$$  \hspace{2cm} (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 $C_i = \left( \frac{N_i}{y_i} \right)$, is

$$\ln L = \sum_i [\ln C_i + y_i \ln P_i + (N_i - y_i) \ln (1 - P_i)]$$

$$= \sum_i \left[ \ln C_i + y_i \ln (a_i + bX) + (N_i - y_i) \ln (1 - a_i - bX) \right]$$  \hspace{2cm} (15)

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

$$\frac{d \ln L}{db} = \sum_i \left( 0 + \frac{y_i X}{(a_i + bX)} - \frac{(N_i - y_i) X}{(1 - a_i - bX)} \right) = 0$$  \hspace{2cm} (16)

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

$$\frac{d \ln L}{db} = \sum_i \left( \frac{X (y_i - N_i a_i - N_i b X)}{(a_i + b X)} (1 - a_i - b X) \right) = 0$$

$$= \sum_i \frac{N_i X (y_i / N_i - a_i - b X)}{(a_i + b X) (1 - a_i - b X)} = 0$$  \hspace{2cm} (17)

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

$$A_j = A_o + G_j + e_j$$  \hspace{2cm} (18)

Then letting

$$\frac{y_i}{N_i} = A_o + G_j + b X + e_j$$  \hspace{2cm} (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 of the model 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

\[
y_j/N_j = A_o + G_j + b X_j + e_j
\]

or, in actual form,

\[
y_j/N_j = (1 - K_o - K_1 G_j - K_2 X_j + \epsilon_j) a_j b_j
\]

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 \( K'_o = 1 - K_o \) in Eq. 21, the predictive equation,

\[
\left(\frac{y/N}{a b}\right) = K'_o - K_1 X_1 - K_2 X_2 - K_m X_m
\]

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 \( A_o \) (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

\[
\left(\frac{y/N}{a b}\right) = K'_o X_1 K'_1 X_2 K'_2 \ldots X_m K'_m
\]

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 \( VT \) as the basic variable in a hazard index. There are certain similarities between this term and the \( ab \) term.

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

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

For matters of presentation, let

\[
X = V/(24 \times 3,600) = V/86,400
\]

Now the series expansions become

\[
e^{-x} = 1 - x + \frac{x^2}{2!} - \frac{x^3}{3!} + \frac{x^4}{4!} - \ldots
\]

and

\[
(1 - e^{-x}) = x - \frac{x^2}{2!} + \frac{x^3}{3!} - \frac{x^4}{4!} + \ldots
\]

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

$$0.40 + 32.5 \left( X - \frac{X^2}{21} \right)$$

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-Dimick 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,

$$\sum_{a=1}^{n} (a, b)$$

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:

<table>
<thead>
<tr>
<th>VARIABLE NUMBER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Accidents: number of vehicle-train accidents times 100, expressed on a per-year basis.</td>
</tr>
<tr>
<td>2</td>
<td>ADT: average daily highway traffic.</td>
</tr>
<tr>
<td>3</td>
<td>Average number of trains per day.</td>
</tr>
<tr>
<td>4</td>
<td>Sight distance: minimum of the four quadrants measured 300 to 500 ft from the railroad on the highway approach.</td>
</tr>
<tr>
<td>5</td>
<td>Angle: acute angle of intersection of tracks and roadway.</td>
</tr>
<tr>
<td>6</td>
<td>Number of lanes in both directions.</td>
</tr>
<tr>
<td>7</td>
<td>Maximum approach gradient: generally an average of the area within 100 ft from the crossing measured as a percent.</td>
</tr>
<tr>
<td>8</td>
<td>Number of tracks: number of mainline (but occasionally including spur and switch) tracks.</td>
</tr>
<tr>
<td>9</td>
<td>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.</td>
</tr>
</tbody>
</table>

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:

\[
\text{Accidents per year} = K_i + \sum_{i=1}^{n} K_i V_i
\]

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:

\[
V_i = V_{10} (38.90)
\]

in which \(V_i\) 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

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.99</td>
<td>5.94</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>123.40</td>
<td>66.70</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>4.05</td>
<td>6.12</td>
<td>-2.64</td>
<td>1.41</td>
</tr>
<tr>
<td>5</td>
<td>68.45</td>
<td>19.43</td>
<td>0.47</td>
<td>0.42</td>
</tr>
<tr>
<td>7</td>
<td>2.84</td>
<td>3.30</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>1.14</td>
<td>0.55</td>
<td>16.84</td>
<td>15.90</td>
</tr>
<tr>
<td>11</td>
<td>38.90</td>
<td>422.40</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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

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

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

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.04</td>
<td>35.56</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>2967.03</td>
<td>4131.93</td>
<td>-0.0021</td>
<td>0.0014</td>
</tr>
<tr>
<td>3</td>
<td>4.16</td>
<td>6.45</td>
<td>-1.697</td>
<td>0.960</td>
</tr>
<tr>
<td>5</td>
<td>59.70</td>
<td>22.59</td>
<td>0.163</td>
<td>0.220</td>
</tr>
<tr>
<td>7</td>
<td>2.35</td>
<td>7.36</td>
<td>-1.815</td>
<td>1.878</td>
</tr>
<tr>
<td>8</td>
<td>1.39</td>
<td>1.08</td>
<td>-1.345</td>
<td>5.047</td>
</tr>
<tr>
<td>11</td>
<td>30.35</td>
<td>125.21</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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.

SUMMARY OF EQUATIONS

Crossbucks:
- Highway volume below 500 per day:
  \[ X_1 = X_{10} [38.90] \]  
- Highway volume greater than 500 per day:
  \[ X_1 = X_{10} [30.57] \]  

Stop signs:
- Highway volume below 500 per day:
  \[ X_1 = X_{10} [45.13 + 2.51 X_7 + 13.5 X_8] \]  
- Highway volume greater than 500 per day:
  \[ X_1 = X_{10} [11.44] \]  

Wigwags:
\[ X_1 = X_{10} [6.06 + 0.02 X_7 + 0.40 X_8] \]  

Flashing light signals:
- Urban
  \[ X_1 = X_{10} [3.23] \]  
- Rural
  \[ X_1 = X_{10} [9.30] \]  

Gates:
- Urban
  \[ X_1 = X_{10} [3.23] \]  
- Rural
  \[ X_1 = X_{10} [1.93] \]  

in which
- \( X_{10} \) = accidents per year, scaled by 100;
- \( X_7 \) = ADT;
- \( X_8 \) = angle of crossing, acute angle measured in degrees;
- \( X_9 \) = total number of highway lanes;
- \( X_{10} \) = maximum absolute approach gradient within 100 ft of crossing; and
- \( X_{10} \) = probability of coincidental vehicle and train arrival, or

TABLE 30

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

Intercept = 65.43; \( R = 0.2263; \) \( F = 2.235; \) \( N = 425 \).

TABLE 31

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.02</td>
<td>39.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4395.48</td>
<td>5386.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8.36</td>
<td>10.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>288.12</td>
<td>281.52</td>
<td>0.014</td>
<td>0.007</td>
</tr>
<tr>
<td>5</td>
<td>52.73</td>
<td>27.31</td>
<td>0.141</td>
<td>0.078</td>
</tr>
<tr>
<td>6</td>
<td>2.21</td>
<td>0.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2.12</td>
<td>2.64</td>
<td>-1.963</td>
<td>1.052</td>
</tr>
<tr>
<td>8</td>
<td>1.55</td>
<td>1.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>11.44</td>
<td>30.51</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Intercept = 20.228; \( R = 0.0512; \) \( F = 1.498; \) \( N = 303 \).

TABLE 32

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40.76</td>
<td>70.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>9773.</td>
<td>8807.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11.50</td>
<td>11.56</td>
<td>-0.113</td>
<td>0.080</td>
</tr>
<tr>
<td>4</td>
<td>242.57</td>
<td>255.80</td>
<td>0.004</td>
<td>0.006</td>
</tr>
<tr>
<td>5</td>
<td>63.75</td>
<td>21.17</td>
<td>0.200</td>
<td>0.096</td>
</tr>
<tr>
<td>6</td>
<td>2.98</td>
<td>1.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2.08</td>
<td>1.65</td>
<td>4.04</td>
<td>1.08</td>
</tr>
<tr>
<td>8</td>
<td>1.41</td>
<td>0.94</td>
<td>-10.830</td>
<td>5.868</td>
</tr>
<tr>
<td>9</td>
<td>21.79</td>
<td>14.21</td>
<td>-0.142</td>
<td>0.082</td>
</tr>
<tr>
<td>11</td>
<td>7.03</td>
<td>15.45</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Intercept = 15.90; \( R = 0.4356; \) \( F = 5.659; \) \( N = 303 \).
TABLE 33
FLASHING LIGHT SIGNALS AT URBAN CROSSINGS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.67</td>
<td>47.47</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>11,126.04</td>
<td>10,680.19</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>13.90</td>
<td>14.63</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>3.38</td>
<td>1.30</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>1.82</td>
<td>3.23</td>
<td>—0.521</td>
<td>0.367</td>
</tr>
<tr>
<td>8</td>
<td>2.15</td>
<td>1.35</td>
<td>—0.093</td>
<td>0.144</td>
</tr>
<tr>
<td>9</td>
<td>27.87</td>
<td>17.59</td>
<td>—0.026</td>
<td>0.331</td>
</tr>
<tr>
<td>11</td>
<td>3.23</td>
<td>8.50</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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

TABLE 34
FLASHING LIGHT SIGNALS AT RURAL CROSSINGS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21.49</td>
<td>38.43</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>431.11</td>
<td>4801.10</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>15.07</td>
<td>16.84</td>
<td>0.213</td>
<td>0.115</td>
</tr>
<tr>
<td>6</td>
<td>2.36</td>
<td>0.88</td>
<td>—2.713</td>
<td>2.245</td>
</tr>
<tr>
<td>7</td>
<td>1.60</td>
<td>2.76</td>
<td>—0.180</td>
<td>0.613</td>
</tr>
<tr>
<td>8</td>
<td>1.38</td>
<td>1.04</td>
<td>—1.992</td>
<td>1.642</td>
</tr>
<tr>
<td>9</td>
<td>37.02</td>
<td>18.12</td>
<td>—0.164</td>
<td>0.106</td>
</tr>
<tr>
<td>11</td>
<td>9.30</td>
<td>34.84</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Intercept = 31.069; R = 0.1967; F = 2.865; N = 434.

TABLE 35
GATES AT URBAN CROSSINGS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.952</td>
<td>45.311</td>
<td>—</td>
<td>—</td>
</tr>
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<td>2</td>
<td>8483.80</td>
<td>6118.67</td>
<td>0.099</td>
<td>0.110</td>
</tr>
<tr>
<td>3</td>
<td>24.297</td>
<td>17.972</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>3.000</td>
<td>1.316</td>
<td>—0.953</td>
<td>1.513</td>
</tr>
<tr>
<td>7</td>
<td>2.721</td>
<td>6.341</td>
<td>—0.100</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
<td>2.590</td>
<td>1.415</td>
<td>0.136</td>
<td>1.428</td>
</tr>
<tr>
<td>9</td>
<td>45.108</td>
<td>23.104</td>
<td>0.160</td>
<td>0.090</td>
</tr>
<tr>
<td>11</td>
<td>3.23</td>
<td>15.859</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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

TABLE 36
GATES AT RURAL CROSSINGS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STD. DEV.</th>
<th>COEFF.</th>
<th>STD. ERROR</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>2</td>
<td>2576.35</td>
<td>1527.04</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>35.36</td>
<td>15.88</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>2.400</td>
<td>0.809</td>
<td>—1.583</td>
<td>0.717</td>
</tr>
<tr>
<td>7</td>
<td>2.767</td>
<td>2.913</td>
<td>—0.158</td>
<td>0.207</td>
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<tr>
<td>8</td>
<td>2.378</td>
<td>0.777</td>
<td>0.295</td>
<td>1.017</td>
</tr>
<tr>
<td>9</td>
<td>56.067</td>
<td>11.181</td>
<td>0.037</td>
<td>0.068</td>
</tr>
<tr>
<td>11</td>
<td>1.928</td>
<td>3.815</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Intercept = —3.580; R = 0.3703; F = 1.589; N = 45.

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:

\[
\frac{X_8}{86,400} (1 - e^{-x_2/86,400})
\]

in which

\[X_8 = \text{trains per day; and}\]
\[X_3 = \text{highway vehicles per day.}\]

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.

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...
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:

\[ X_{1t} = \frac{\text{Accidents}}{\text{ADT}/100} = K_n + K_i V_i \ldots K_w V_w \]  

(41)

The following variables were included in the analysis:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Average daily traffic</td>
</tr>
<tr>
<td>2</td>
<td>Number of daily trains</td>
</tr>
<tr>
<td>3</td>
<td>Highway speed</td>
</tr>
<tr>
<td>4</td>
<td>Crossbuck protection</td>
</tr>
<tr>
<td>5</td>
<td>Stop-sign protection</td>
</tr>
<tr>
<td>6</td>
<td>Wigwag protection</td>
</tr>
<tr>
<td>7</td>
<td>Flashing light signal protection</td>
</tr>
<tr>
<td>8</td>
<td>Automatic gate protection</td>
</tr>
<tr>
<td>9</td>
<td>Accidents per year</td>
</tr>
<tr>
<td>10*</td>
<td>Accidents per year/ADT/100</td>
</tr>
</tbody>
</table>

* Dependent variable.

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

\[ X_{10} = 0.00499 + 0.00036 X_2 + 0.00656 X_8 \]  

(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

\[ X_{10} = 0.00866 + 0.00036 X_2 \]  

(43)

or

### TABLE 37

| SIMPLE CORRELATION OF INDEPENDENT VARIABLES WITH PROTECTION COEFFICIENT |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| INDEPENDENT VARIABLE | COEFFICIENT FOR PROTECTION * | 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         | -0.051                        | -0.043        | -0.144        | +0.046        | +0.098        | +0.037        |               |               |               |               |               |
| Angle                  | 0.019                         | 0.057         | 0.057         | 0.045         | 0.046         | 0.120         |               |               |               |               |               |
| No. of lanes           | -0.019                        | -0.057        | -0.022        | 0.054         | -0.070        | -0.051        | -0.053        | -0.122        | -0.296        |               |               |
| Gradient               | 0.019                         | -0.031        | -0.015        | 0.036         | -0.015        | 0.081         | -0.003        | -0.053        | 0.108         | 0.144         |               |
| No. of tracks          | 0.009                         | -0.019        |               |               | -0.056        | -0.009        | -0.097        | -0.085        | 0.199         |               |               |

* 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.

**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 |

...
where EA represents expected nontrain-involved accidents of the equations which predict expected train-involved accidents, allows prediction of the total number of 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.

**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:

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

All other protection types

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

or

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

where EA represents expected nontrain-involved accidents per year.

Use of 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 type 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
Example 2:

Daylight volume \( = \frac{0.75 \times 5,000 \times 5,000}{2,500} = 7,500 \)

\( = \text{ADT to be used for } A \)-factor in Figure 24, from which \( A = 0.07179 \).

Dark volume \( = \frac{0.25 \times 5,000 \times 5,000}{2,500} = 2,500 \) = 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.

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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 2 1/2-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
- **Total** = $4,000

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

- **Flashers**
  - Cost = $10,000;
  - Amortization = $1,000/year

- **Gates**
  - Cost = $20,000;
  - Amortization = $2,000/year

- **Grade separation**
  - Cost = $200,000;
  - Amortization = $10,000/year

**Annual maintenance costs:**

<table>
<thead>
<tr>
<th>Device</th>
<th>Cost per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashers</td>
<td>$300</td>
</tr>
<tr>
<td>Gates</td>
<td>$600</td>
</tr>
</tbody>
</table>

**Annual costs:**

<table>
<thead>
<tr>
<th>Device</th>
<th>Cost per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashers</td>
<td>$1,300</td>
</tr>
<tr>
<td>Gates</td>
<td>$2,600</td>
</tr>
<tr>
<td>Grade separation</td>
<td>$10,000</td>
</tr>
</tbody>
</table>

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

\[
\frac{8,000 \text{ (EA saved/yr)}}{1,300} \geq 1 \quad \text{and} \quad \frac{8,000 \text{ (EA saved/yr)}}{2,600} \geq 1 \\
\frac{8,000 \text{ (EA saved/yr)}}{10,000} \geq 1
\]

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:

<table>
<thead>
<tr>
<th>CROSSING NO.</th>
<th>URBAN OR RURAL</th>
<th>PROTECTION TYPE</th>
<th>TRAIN VOL.</th>
<th>COINCIDENT HIGHWAY VOLUME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rural</td>
<td>Wigways</td>
<td>20</td>
<td>10,000</td>
</tr>
<tr>
<td>2</td>
<td>Urban</td>
<td>Crossbucks</td>
<td>10</td>
<td>5,000</td>
</tr>
<tr>
<td>3</td>
<td>Rural</td>
<td>Crossbucks</td>
<td>12</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>Rural</td>
<td>Gates</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>5</td>
<td>Urban</td>
<td>Gates</td>
<td>25</td>
<td>25,000</td>
</tr>
<tr>
<td>6</td>
<td>Rural</td>
<td>Crossbucks</td>
<td>5</td>
<td>5,000</td>
</tr>
<tr>
<td>7</td>
<td>Urban</td>
<td>Flashing lights</td>
<td>2</td>
<td>30,000</td>
</tr>
<tr>
<td>8</td>
<td>Rural</td>
<td>Flashing lights</td>
<td>15</td>
<td>4,000</td>
</tr>
<tr>
<td>9</td>
<td>Urban</td>
<td>Crossbucks</td>
<td>25</td>
<td>25,000</td>
</tr>
<tr>
<td>10</td>
<td>Rural</td>
<td>Crossbucks</td>
<td>30</td>
<td>15,000</td>
</tr>
</tbody>
</table>

* See sample calculations of coincident volumes in Chapter Six.
* Adjusted for day and night train arrivals; see Chapter Six.
* 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:
Figure 25. Warrants for improved protection.
Possible improvements at each crossing are then listed, along with their costs, corresponding savings in accident costs, and the ratio of benefit to cost.

<table>
<thead>
<tr>
<th>CROSSING NO.</th>
<th>POSSIBLE IMPROVEMENTS</th>
<th>ADD'L. COST PER 10 YEARS ($)</th>
<th>ACCIDENT SAVINGS ($)</th>
<th>BENEFIT/COST RATIO</th>
<th>PRIORITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flashing lights</td>
<td>5,000</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>18,000</td>
<td>15,008</td>
<td>0.84</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>18,856</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Flashing lights</td>
<td>13,000</td>
<td>14,280</td>
<td>1.00*</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>26,000</td>
<td>14,280</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>15,952</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Flashing lights</td>
<td>13,000</td>
<td>1,184</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>26,000</td>
<td>1,472</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>1,552</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Grade sep.</td>
<td>100,000</td>
<td>552</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Grade sep.</td>
<td>100,000</td>
<td>18,592</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Flashing lights</td>
<td>13,000</td>
<td>5,472</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>26,000</td>
<td>7,400</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>7,896</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Gates</td>
<td>13,000</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>1,776</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Gates</td>
<td>13,000</td>
<td>4,624</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>5,808</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Flashing lights</td>
<td>13,000</td>
<td>159,112</td>
<td>12.23*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>26,000</td>
<td>159,112</td>
<td>6.16*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>177,776</td>
<td>1.78*</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Flashing lights</td>
<td>13,000</td>
<td>92,888</td>
<td>7.14*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>26,000</td>
<td>125,592</td>
<td>3.57*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade sep.</td>
<td>100,000</td>
<td>134,040</td>
<td>1.34*</td>
<td></td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>CROSSING NO.</th>
<th>IMPROVEMENT</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Flashing lights</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Grade separation</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Grade separation</td>
<td>2</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>CROSSING NO.</th>
<th>IMPROVEMENT</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Flashing lights</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Grade separation</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Gates</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>CROSSING NO.</th>
<th>IMPROVEMENT</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Flashing lights</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Gates</td>
<td>2</td>
</tr>
</tbody>
</table>

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.
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 knowledgeable 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 consistent 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

7. “Conflicts at Grade Crossings, a Theoretical Analysis.” Contra Costa County (Calif.) Highway Dept. (Unpubl.)

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

\[ \text{Index of Hazard} = V \cdot T \cdot (1 + F_1 + F_2 + F_3) + P \cdot T \]

\[ (1 + F_4) \]  

(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, 2; night trains, 2; 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

\[ H. I. = \frac{V P}{100} (10L + 20Y + 30H) + (4m - 5e) \]

\[ + N (F_s + F_{tr}) \]

in which

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

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 create three times as much hazard as a train traveling less than 30 mph; the hours of the day were divided into three time periods.

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

\[ \text{Index of hazard} = V A \]

in which

\[ V = v_1 t_1 \rho + 1.4 v_2 t_2 p \]
\[ A = \frac{a_1}{a_2} \]
\[ v_1 = \text{vehicle movements during daylight hours}; \]
\[ v_2 = \text{vehicle movements during dark hours}; \]
\[ t_1 = \text{train movements during daylight hours}; \]
\[ t_2 = \text{train movements during dark hours}; \]
\[ p = \text{protection factor} (1.0 \text{ for cross-buck signs}; 0.8 \text{ for wigwag signals; 0.6 \text{ for flashing lights}; and 0.1 \text{ for automatic gates});} \]
\[ a_1 = \text{actual number of accidents which occurred in a 5-year period}; \] and
\[ a_2 = \text{predicted number of accidents which occurred in a 5-year period}. \]
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:

\[
\text{Predicted accidents (5 yr)} = 0.25 + 8.03 \times 10^{-3} \cdot v \cdot t \cdot p \cdot d - 1.58 \times 10^{-10} \cdot v \cdot t \cdot p \cdot d^2
\]

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**

\[
R + 1 = F(2.764G^{0.37})
\]

\[
F = 1.0937 + 0.06034Q - 0.003652A
\]

**For flashing lights**

\[
R + 1 = F(1.690G^{0.258})
\]

\[
F = 0.81124 + 0.06986Q
\]

**For gates**

\[
R + 1 = F(1.205G^{0.178})
\]

\[
F = 0.7788 + 0.081553K
\]

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.
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.
15. Darkness.
17. Alcohol.
18. Male driver.
19. Drive age.
20. Personal injury.
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. 56. Average car speed.
55. ADT. 57. Sum of 44, 45, and 47.

Factor analysis and regression analysis were performed independently. The equation resulting from factor analysis is as follows:

\[ IH = 0.545 + 0.498 (-0.242F_{AA} + 0.245F_{BB}) + 0.253F_{DD} + 0.194F_{FP} \]  \hspace{1cm} (A-26)

in which

\[ F_{AA} = -0.136Z_9 - 0.251Z_{11} - 0.224Z_{15} - 0.214Z_{41} - 0.166Z_{43} - 0.263Z_{56} \]  \hspace{1cm} (A-27)

\[ F_{BB} = +0.86Z_{10} - 0.112Z_{42} + 0.229Z_{61} + 0.302Z_{59} + 0.317Z_{54} \]  \hspace{1cm} (A-28)

\[ F_{DD} = +0.215Z_{39} - 0.494Z_{19} + 0.420Z_{11} + 0.124Z_{15} - 0.140Z_{56} \]  \hspace{1cm} (A-29)

\[ F_{FP} = -0.148Z_{40} - 0.132Z_{11} - 0.449Z_{44} + 0.270Z_{15} + 0.430Z_{47} - 0.428Z_{56} \]  \hspace{1cm} (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:

\[ IH = 0.185 + 0.079X_{40} + 0.021X_{41} + 0.011X_{54} + 0.013X_{55} + 0.024X_{57} \]  \hspace{1cm} (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.

Newman (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:

\[ Acc./2 \text{ yr} = 0.1956 + 0.0028A + 0.0037C + 0.0329D + 0.0193E + 0.0307G \]  \hspace{1cm} (A-32)

Standard wigwag:

\[ Acc./2 \text{ yr} = 0.315 + 0.0042A + 0.569B + 0.0373D - 0.0897F \]  \hspace{1cm} (A-33)

Other wigwag, rotating and flashing lights:

\[ Acc./2 \text{ yr} = -0.4634 - 0.0022A + 0.0357C + 0.0139D + 0.1897G \]  \hspace{1cm} (A-34)

Flashing lights:

\[ Acc./2 \text{ yr} = 0.0262 + 0.0018A + 0.0290B + 0.0217D + 0.0356F + 0.0302G \]  \hspace{1cm} (A-35)

Automatic gates:

\[ Acc./2 \text{ yr} = -0.493 - 0.0037A - 0.0843B + 0.0186C + 0.0192D + 0.1625G \]  \hspace{1cm} (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 1/4 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 predictive equations and the theory on which they are based have been attacked.

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 VT 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:

\[ C = T Z (1 - e^{-t/1+0Z}) \]  
(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

\[ C = \sum Z (1 - e^{-t/100Z}) \]  
(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:

<table>
<thead>
<tr>
<th>TYPE OF PROTECTION</th>
<th>RELATIVE HAZARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossbucks</td>
<td>1.00</td>
</tr>
<tr>
<td>Flashing light signals</td>
<td>0.23</td>
</tr>
<tr>
<td>Flashing light signals and gates</td>
<td>0.22</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>TYPE OF PROTECTION</th>
<th>RELATIVE HAZARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossbucks</td>
<td>1.00</td>
</tr>
<tr>
<td>Wigwags</td>
<td>0.6 - 0.8</td>
</tr>
<tr>
<td>Flashing lights</td>
<td>0.3 - 0.6</td>
</tr>
<tr>
<td>Automatic gates</td>
<td>0.1 - 0.2</td>
</tr>
</tbody>
</table>

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 H, 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>
<thead>
<tr>
<th>TYPE OF PROTECTION</th>
<th>RELATIVE HA ZARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic gates</td>
<td>0.0925</td>
</tr>
<tr>
<td>Manual gates, full time</td>
<td>0.1513</td>
</tr>
<tr>
<td>Flashing light signals, single track</td>
<td>0.1773</td>
</tr>
<tr>
<td>Flashing light signals, multiple track</td>
<td>0.3044</td>
</tr>
<tr>
<td>Wigwag</td>
<td>0.2936</td>
</tr>
<tr>
<td>Manual gates, part time</td>
<td>0.3520</td>
</tr>
<tr>
<td>Watchman</td>
<td>0.3581</td>
</tr>
<tr>
<td>Automatic bell</td>
<td>0.3941</td>
</tr>
<tr>
<td>ReflectORIZED crossbucks, AREA</td>
<td>0.4450</td>
</tr>
<tr>
<td>Painted crossbucks</td>
<td>0.5038</td>
</tr>
<tr>
<td>ReflectORIZED crossbucks (Michigan)</td>
<td>0.8156</td>
</tr>
</tbody>
</table>

### Table A-1

<table>
<thead>
<tr>
<th>TYPE OF PROTECTION</th>
<th>FINAL ACCIDENT QUOTIENT</th>
<th>RELATIVE HAZARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic gates</td>
<td>0.0925</td>
<td>0.184</td>
</tr>
<tr>
<td>Manual gates, full time</td>
<td>0.1513</td>
<td>0.301</td>
</tr>
<tr>
<td>Flashing light signals, single track</td>
<td>0.1773</td>
<td></td>
</tr>
<tr>
<td>Flashing light signals, multiple track</td>
<td>0.3044</td>
<td></td>
</tr>
<tr>
<td>Wigwag</td>
<td>0.2936</td>
<td>0.583</td>
</tr>
<tr>
<td>Manual gates, part time</td>
<td>0.3520</td>
<td>0.699</td>
</tr>
<tr>
<td>Watchman</td>
<td>0.3581</td>
<td>0.712</td>
</tr>
<tr>
<td>Automatic bell</td>
<td>0.3941</td>
<td>0.783</td>
</tr>
<tr>
<td>ReflectORIZED crossbucks, AREA</td>
<td>0.4450</td>
<td></td>
</tr>
<tr>
<td>Painted crossbucks</td>
<td>0.5038</td>
<td>1.000</td>
</tr>
<tr>
<td>ReflectORIZED crossbucks (Michigan)</td>
<td>0.8156</td>
<td></td>
</tr>
</tbody>
</table>

### Table A-2

<table>
<thead>
<tr>
<th>TYPE OF PROTECTION</th>
<th>ACCIDENTS PER VT</th>
<th>RELATIVE HAZARD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossbucks</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Automatic signals</td>
<td></td>
<td>0.333</td>
</tr>
<tr>
<td>Automatic gates</td>
<td></td>
<td>0.133</td>
</tr>
</tbody>
</table>

### Table A-3

**RESULTS OF ILLINOIS 1965 GRADE CROSSING STUDY**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>FLAS HING LIGHT SIGNALS a</th>
<th>FLAS HING LIGHT SIGNALS AND GATES b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BEFORE</td>
<td>AFTER</td>
</tr>
<tr>
<td>Accidents</td>
<td>143</td>
<td>33</td>
</tr>
<tr>
<td>Fatalities</td>
<td>57</td>
<td>4</td>
</tr>
<tr>
<td>Injuries</td>
<td>88</td>
<td>11</td>
</tr>
</tbody>
</table>

a 177 crossings, 9,276 crossing-months. b 123 crossings, 9,276 crossing-months.
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 run-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
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**

<table>
<thead>
<tr>
<th>STUDY DATE</th>
<th>PERIOD</th>
<th>TRAIN-VEHICLE ACCIDENTS</th>
<th>DEATHS</th>
<th>INJURIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 18, 1961</td>
<td>1951-60</td>
<td>62</td>
<td>85</td>
<td>83</td>
</tr>
<tr>
<td>Apr. 1, 1963</td>
<td>1951-62</td>
<td>60</td>
<td>90</td>
<td>84</td>
</tr>
<tr>
<td>Oct. 1, 1964</td>
<td>1954-63</td>
<td>57</td>
<td>89</td>
<td>88</td>
</tr>
</tbody>
</table>

### Table A-9

**SUMMARY OF EFFECTIVENESS OF AUTOMATIC GATES AT GRADE CROSSINGS, BY TYPE OF PROTECTION PRIOR TO GATE INSTALLATION (75)**

<table>
<thead>
<tr>
<th>PRIOR PROTECTION</th>
<th>ACCIDENTS PER CROSSING YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BEFORE a</td>
</tr>
<tr>
<td>Crossbucks</td>
<td>0.427</td>
</tr>
<tr>
<td>Watchman</td>
<td>1.789</td>
</tr>
<tr>
<td>Wigwag</td>
<td>0.589</td>
</tr>
<tr>
<td>Flashing light signals</td>
<td>0.531</td>
</tr>
<tr>
<td>Manual gates</td>
<td>0.693</td>
</tr>
</tbody>
</table>

*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)**

<table>
<thead>
<tr>
<th>PRIOR PROTECTION</th>
<th>ACCIDENTS PER CROSSING YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BEFORE</td>
</tr>
<tr>
<td>Crossbucks</td>
<td>0.267</td>
</tr>
<tr>
<td>Watchman</td>
<td>1.021</td>
</tr>
<tr>
<td>Wigwag</td>
<td>0.649</td>
</tr>
<tr>
<td>Flashing light signals</td>
<td>0.658</td>
</tr>
<tr>
<td>Manual gates</td>
<td>0.344</td>
</tr>
</tbody>
</table>

### Table A-11

**RESULTS OF STOP-SIGN OBSERVANCE AT RAILROAD CROSSINGS AND NEARBY INTERSECTION**

<table>
<thead>
<tr>
<th>VEHICLES AT INTER-SECTION</th>
<th>AT RAILROADS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>%</td>
</tr>
<tr>
<td>Full stop</td>
<td>178</td>
</tr>
<tr>
<td>Almost stop (0-3 mph)</td>
<td>312</td>
</tr>
<tr>
<td>Entered slowly (4-15 mph)</td>
<td>67</td>
</tr>
<tr>
<td>Entered fast (over 15 mph)</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>561</td>
</tr>
</tbody>
</table>
REFERENCES

14. "Conflicts at Grade Crossings: A Theoretical Analysis." Contra Costa County (Calif.) Highway Dept. (unpub.).
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. Chapinis (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 distinctively 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 surroundings, 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 headlightst 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, unstable, 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 (71).

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 over-emphasis 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 (59), 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 $\frac{1}{2}$° (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 2½ 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, lumiance, 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:

\[ X = \frac{S}{10} + \frac{V}{100} (N + 6) \]  
\[ H = \frac{4}{3} \left( \frac{S}{10} + \frac{V}{100} (N + 6) \right) \]

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:

\[ T = 1.47 \times 11.5V_i \]  

Total warning time for stopping:

\[ T = 1.47V_i \times 3.5 + 1.08V_i/4 \]

Legibility distance:

\[ L = X - A \]
Letter height: \[ H = \frac{L}{l} \] (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 background 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 headlights. 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.
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/cm²), 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 efficiently 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, tactile 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
lus 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 cutaneous 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 vibrations 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 reverse 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., kinesthesia, 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.,

$$R = f(P, W)$$  \hspace{1cm} (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 sign leading to a traffic STOP 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 railroad 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 re-
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 reaction 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 presentation. 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 reaction 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., 143) 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 has 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 is discovered that the 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.

NEW WARNING SYSTEMS

Utilization of any or all of these phenomena in designing new crossing 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.

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.

* 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.
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.

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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-3
RESPONSES TO PROPOSALS FOR OTHER SIGNS AT GRADE CROSSINGS WITH PASSIVE PROTECTION (PART II)

<table>
<thead>
<tr>
<th>SIGN DESCRIPTION</th>
<th>RESPONSES (NO.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FIG. NO.</td>
</tr>
<tr>
<td>Reduce Speed</td>
<td>20</td>
</tr>
<tr>
<td>View of Trains Limited</td>
<td>20</td>
</tr>
</tbody>
</table>

TABLE C-5
COLOR PREFERENCE OF SURVEY SUBJECTS FOR USE ON GRADE CROSSING PROTECTION SIGNS (PART II)

<table>
<thead>
<tr>
<th>COLOR</th>
<th>PREFERENCES (NO.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>10</td>
</tr>
<tr>
<td>Brilliant yellow-green</td>
<td>11</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
</tr>
</tbody>
</table>

* Still pictures only.  ^ Brilliant yellow-green.
### TABLE C-2

**ORDER RANKING OF PROPOSALS FOR ADVANCE GUIDE SERIES (PART II)**

<table>
<thead>
<tr>
<th>SIGN DESCRIPTION</th>
<th>FIG. NO.</th>
<th>NO. OF CHOICES</th>
<th>RANK 1</th>
<th>RANK 2</th>
<th>RANK 3</th>
<th>RANK 4</th>
<th>RANK 5</th>
<th>VOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) CROSSING WITH ACTIVE PROTECTION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-X-R Signal Ahead</td>
<td>17</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Railroad Signal Ahead</td>
<td>17</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Railroad (Symbol) Ahead</td>
<td>17</td>
<td>5</td>
<td>12</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Symbol only</td>
<td>17</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Existing round R-X-R</td>
<td>5</td>
<td></td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>(b) CROSSING WITH PASSIVE PROTECTION, FIRST SIGN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track angle, white road</td>
<td>18</td>
<td>4</td>
<td>15</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Track angle, black road</td>
<td>18</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Train Crossing</td>
<td>20</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>12</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Existing round R-X-R</td>
<td>4</td>
<td></td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>(c) CROSSING WITH PASSIVE PROTECTION, SECOND SIGN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>← Look for Trains →</td>
<td>16</td>
<td>2</td>
<td>17</td>
<td>5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1*</td>
</tr>
<tr>
<td>Symbol only</td>
<td>18</td>
<td>2</td>
<td>5</td>
<td>17</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1*</td>
</tr>
</tbody>
</table>

* Other sign preferred.

### TABLE C-4

**ORDER RANKING OF PROPOSALS FOR AT-CROSSING SERIES ON GRADE CROSSINGS WITH PASSIVE PROTECTION (PART II)**

<table>
<thead>
<tr>
<th>SIGN DESCRIPTION</th>
<th>FIG. NO.</th>
<th>RANK 1</th>
<th>RANK 2</th>
<th>RANK 3</th>
<th>RANK 4</th>
<th>RANK 5</th>
<th>OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triang. target, large crossbuck</td>
<td>15</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Triang. target, small crossbuck</td>
<td>15</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Lg. square target with crossbuck</td>
<td>19</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Sm. square target with crossbuck</td>
<td>19</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Trains Cross Here ↓ — End of Xing</td>
<td>22</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Existing crossbuck, no background</td>
<td>—</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

### 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>
<thead>
<tr>
<th>TABLE D-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAFE STOPPING DISTANCE PLUS CLEARANCE FOR VARIOUS HIGHWAY SPEEDS, DESIGN VALUES</td>
</tr>
<tr>
<td>HIGHWAY SPEED (MPH)</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>45</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>55</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>65</td>
</tr>
<tr>
<td>70</td>
</tr>
<tr>
<td>75</td>
</tr>
</tbody>
</table>

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.
The number 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 abbreviations 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: Dv. 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 $15^\circ$.

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.
<table>
<thead>
<tr>
<th>District</th>
<th>County</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossing No.</td>
<td>Railroad</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Approach</th>
<th>Train Speed</th>
<th>MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway Speed Limit</td>
<td>MPH</td>
<td>Corresponding Distance No. 1</td>
</tr>
<tr>
<td>Realistic Highway Speed</td>
<td>MPH</td>
<td>Corresponding Distance No. 2</td>
</tr>
</tbody>
</table>

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 = \( \frac{50 \text{ mi}}{5280 \text{ ft/mi}} \times \frac{3600 \text{ sec/hr}}{2.5 \text{ sec}} = 183 \text{ ft} \)

Calculate braking distance and braking time, assuming deceleration on level wet concrete.

Braking distance, \( * \) = \( \frac{V^2}{2f \times \text{mi/hr} \times 1.467 \text{ ft/hr} \times 7.3 \text{ sec}} = 269 \text{ ft} \)

in which \( V \) is the initial speed, in mph, and \( f \) is the coefficient of friction between tires and roadway.

Braking distance, \( * \) = \( \frac{269 \text{ ft}}{\frac{1}{2} \times 50 \text{ mph} \times 1.467 \text{ ft/hr} \times \text{mi/ sec}} = 7.4 \text{ sec} \)

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.

Time to proceed = \( \frac{470 ft + 60 ft}{50 \text{ mi/hr} \times 1.467 \text{ ft/hr} \times 7.3 \text{ sec}} = 7.3 \text{ sec} \)

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.

\( 60 \text{ mi/hr} \times 1.467 \text{ ft/hr} \times 7.3 \text{ sec} = 642 \text{ ft} \)

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.

Time to proceed = \( \frac{80 ft}{5 \text{ mi/hr} \times 1.467 \text{ ft/hr} \times \text{mi/sec}} = 11.0 \text{ sec} \)

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:

<table>
<thead>
<tr>
<th>DIST. ON HWY. FROM TRACKS (FT)</th>
<th>TRACK SIGHT DIST. (FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>965</td>
<td>0</td>
</tr>
<tr>
<td>840</td>
<td>0</td>
</tr>
<tr>
<td>745</td>
<td>0</td>
</tr>
<tr>
<td>640</td>
<td>0</td>
</tr>
<tr>
<td>560</td>
<td>0</td>
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<tr>
<td>470</td>
<td>100</td>
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<tr>
<td>395</td>
<td>200</td>
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<td>330</td>
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<td>270</td>
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<td>95</td>
<td>800</td>
</tr>
<tr>
<td>65</td>
<td>900</td>
</tr>
<tr>
<td>20</td>
<td>1,000</td>
</tr>
</tbody>
</table>

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).

---


† 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:

<table>
<thead>
<tr>
<th>TRAIN SPEED (MPH)</th>
<th>VEHICLE SPEED (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 50</td>
<td>0 ${}^a$</td>
</tr>
<tr>
<td>2. 45</td>
<td>15–20</td>
</tr>
<tr>
<td>3. 40</td>
<td>30–35</td>
</tr>
<tr>
<td>4. 35</td>
<td>62</td>
</tr>
<tr>
<td>5. 0 ${}^a$</td>
<td>62</td>
</tr>
</tbody>
</table>

* 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**

<table>
<thead>
<tr>
<th>State Highway Departments</th>
<th>Cities</th>
<th>Railroads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td></td>
<td>Atlantic Coast Line</td>
</tr>
<tr>
<td>Arkansas</td>
<td></td>
<td>Baltimore and Ohio</td>
</tr>
<tr>
<td>California</td>
<td></td>
<td>Pennsylvania</td>
</tr>
<tr>
<td>Colorado</td>
<td></td>
<td>Reading</td>
</tr>
<tr>
<td>Connecticut</td>
<td></td>
<td>Richmond, Fredericksburg, and Potomac</td>
</tr>
<tr>
<td>Delaware</td>
<td></td>
<td>Seaboard Airline</td>
</tr>
<tr>
<td>Idaho</td>
<td></td>
<td>Southern</td>
</tr>
<tr>
<td>Illinois</td>
<td></td>
<td>Washington and Old Dominion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Association of American Railroads</td>
</tr>
<tr>
<td>Calif. Public Utilities Commission</td>
</tr>
<tr>
<td>Interstate Commerce Commission</td>
</tr>
<tr>
<td>Professor Donald G. Newnan, Dept. of Industrial Engineering, San Jose State College, Calif.</td>
</tr>
</tbody>
</table>
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 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
Published reports of the NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM are available from:
Highway Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

<table>
<thead>
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<th>Rep. No.</th>
<th>Title</th>
<th>Pages</th>
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</tr>
</thead>
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<tr>
<td>1</td>
<td>Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8)</td>
<td>56 p.</td>
<td>$2.80</td>
</tr>
<tr>
<td>2</td>
<td>An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1)</td>
<td>19 p.</td>
<td>$1.80</td>
</tr>
<tr>
<td>2A</td>
<td>Guidelines for Satellite Studies of Pavement Performance, 85 p.</td>
<td>4 app.</td>
<td>$3.00</td>
</tr>
<tr>
<td>3</td>
<td>Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5)</td>
<td>36 p.</td>
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<tr>
<td>4</td>
<td>Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2)</td>
<td>74 p.</td>
<td>$3.20</td>
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<tr>
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<td>Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3)</td>
<td>48 p.</td>
<td>$2.00</td>
</tr>
<tr>
<td>6</td>
<td>Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4)</td>
<td>56 p.</td>
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<tr>
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<td>Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2)</td>
<td>29 p.</td>
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<tr>
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<td>Synthetic Aggregates for Highway Construction (Proj. 4-4)</td>
<td>13 p.</td>
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<tr>
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<td>Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2)</td>
<td>28 p.</td>
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<tr>
<td>10</td>
<td>Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4)</td>
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<tr>
<td>11</td>
<td>Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6)</td>
<td>107 p.</td>
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<tr>
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<td>Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1))</td>
<td>47 p.</td>
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<tr>
<td>13</td>
<td>Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5)</td>
<td>43 p.</td>
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<tr>
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<td>Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-3)</td>
<td>32 p.</td>
<td>$3.00</td>
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<tr>
<td>15</td>
<td>Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2))</td>
<td>66 p.</td>
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<tr>
<td>16</td>
<td>Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3)</td>
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<td>17</td>
<td>Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1)</td>
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<tr>
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<td>Community Consequences of Highway Improvement (Proj. 2-2)</td>
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<td>Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1)</td>
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<tr>
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<td>Economic Study of Roadway Lighting (Proj. 5-4)</td>
<td>77 p.</td>
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<td>Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5)</td>
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<tr>
<td>22</td>
<td>Factors Influencing Flexible Pavement Performance (Proj. 1-3(2))</td>
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<tr>
<td>23</td>
<td>Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4)</td>
<td>22 p.</td>
<td>$1.40</td>
</tr>
<tr>
<td>24</td>
<td>Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1)</td>
<td>116 p.</td>
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<td>25</td>
<td>Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7)</td>
<td>48 p.</td>
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<td>Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1)</td>
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<td>Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5)</td>
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<td>Surveillance Methods and Ways of Communicating with Drivers (Proj. 3-2)</td>
<td>66 p.</td>
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<td>Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2)</td>
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<td>Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2))</td>
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<td>A Review of Transportation Aspects of Land-Use Control (Proj. 8-5)</td>
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<td>Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5)</td>
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<td>Values of Time Savings of Commercial Vehicles (Proj. 2-4)</td>
<td>74 p.</td>
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<td>Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2)</td>
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<td>Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3))</td>
<td>117 p.</td>
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THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by President Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

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Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE HIGHWAY RESEARCH BOARD, organized November 11, 1920, as an agency of the Division of Engineering, is a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the Board are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.
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.
1. Col. 2, page 49, contains one definition of \( p_j \), 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:

\[
\begin{array}{ccccccc}
10-19 & 1,022 & 380 & 1,402 & 27.1 & 731 & 554 & 1,285 & 43.1 \\
\end{array}
\]

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:

\[ X_{10} = \text{probability of coincidental vehicle and train arrival scaled by } 10^{-3}, \]

or

\[
\frac{X_3}{86,400} \left(1-e^{-X_2/86,400} \right)(10^{-3})
\]

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:

<table>
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<td>Urban crossings with flashing lights</td>
<td>0.32</td>
</tr>
<tr>
<td>Urban crossings with automatic gates</td>
<td>0.32</td>
</tr>
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\(^1\) 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".