EVALUATION OF SAFETY 001455
*AT RAILROAD - GRADE
CROSSINGS*

SEPTEMBER, 1967

NO. 23

by
W.D. BERG
T.G. SCHULTZ
and
J.C. OPPENLANDER

*Joint
Highway
Research
Project*

*PURDUE UNIVERSITY
LAFAYETTE INDIANA*

Technical Paper

EVALUATION OF SAFETY AT RAILROAD - GRADE CROSSINGS

To: G. A. Leonards, Director
Joint Highway Research Project

September 27, 1967

File No.: 8-4-31

From: H. L. Michael, Associate Director
Joint Highway Research Project

Project No.: C-36-17EE

The attached Technical Paper entitled "Evaluation of Safety at Railroad - Grade Crossings" has been authored by Messrs. W. D. Berg and T. G. Schultz formerly members of our staff and Professor J. C. Oppenlander of our staff. The paper is a summary of the two research reports entitled "Evaluation of Safety at Railroad-Highway Grade Crossings" (by T. G. Schultz) and "Evaluation of Safety at Railroad-Highway Grade Crossings in Urban Areas" (by W. D. Berg) which were presented to the Advisory Board at previous meetings.

The paper has been offered to the Highway Research Board for presentation at the 1968 Annual Meeting. It is presented to the Advisory Board for approval of publication if it is accepted by the HRSB for publication.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

ELM:s1j

Attachment

Copy: F. L. Ashbacher
W. L. Dolch
W. H. Goetz
W. L. Gresco
G. E. Hallock
M. E. Herr

R. H. Harrell
J. A. Havers
V. E. Harvey
J. F. McLaughlin
F. B. Mendenhall
R. D. Miles
J. C. Oppenlander

C. F. Scholer
H. B. Scott
W. T. Spencer
H. R. J. Walsh
K. B. Woods
E. J. Yoder

Technical Paper

EVALUATION OF SAFETY AT RAILROAD-GRADE CROSSINGS

by

W. D. Berg, Graduate Assistant
T. G. Schultz, Graduate Assistant
J. C. Oppenlander, Research Engineer

Joint Highway Research Project

File No: 8-5-9
Project No: C-36-59I

Purdue University
Lafayette, Indiana
September 27, 1967

EVALUATION OF SAFETY AT RAILROAD-HIGHWAY GRADE CROSSINGS

INFORMATIVE ABSTRACT

The purpose of this research investigation was to determine the relative effects of those factors which significantly influence the accident patterns at railroad-highway grade crossings; to develop mathematical models that measure the relative safety or hazard of grade crossings; and to establish a priority rating system, based on the models, for determining protection improvements.

The mathematical techniques of regression analysis and discriminant analysis were utilized to develop models for predicting the relative hazard at railroad-highway grade crossings. The models were functionally related to factors and variables which were descriptive of environment, topography, geometry of the crossing, and rail and highway traffic patterns.

For rural grade crossings, a regression model was formulated to express relative hazard as a function of average daily highway traffic, average daily train traffic, roadside distractions, pavement width, and number of tracks. Warrants based on current levels of protection in Indiana were developed for selecting the recommended type of protective device at rural grade crossings.

For urban grade crossings, a discriminant model with linearly assigned probabilities expressed potential hazard as a function of protective device, average daily highway traffic, average daily train traffic, degree of effective sight distance, and roadside distractions. A methodology was

developed for selecting a minimum level of grade crossing protection and establishing priorities for the improvement of protection at urban railroad-highway grade crossings.

INTRODUCTION

Railroads and highways are the two primary networks of surface transportation serving the entire nation. Both systems are essential to the public interest. However, exposure to potential collisions between trains and motor vehicles at some 224,000 railroad-highway grade crossings throughout the United States has created a serious problem with regard to the convenience and safety of highway travel (8)*. This problem has grown tremendously during the past few decades because of the rapid growth in vehicle-miles of travel. Accidents which occur at these crossings, although a numerically small part of the overall highway accident problem, are usually severe and result in a relatively high number of deaths.

It is usually difficult to assign a particular cause to railroad-highway grade crossing accidents. Rather, numerous influences appear to exist which vary in importance for different combinations of factors. Accidents may be caused by an error in perception, judgment, or action by the motor vehicle driver (4). Such factors as weather conditons, distractions, obstructions, railroad and highway traffic and operational features, geometry of the railroad, roadway, and grade crossing, and type of protective device may be related to the caused of an accident.

Possible solutions to the grade crossing problem have included better enforcement of laws and regulations which apply to motor vehicle drivers at grade crossings, improvement of the level of grade crossing protection, and construction of grade separations. Application of the latter two alternatives by highway and traffic engineers is economically limited. Based upon engineering principles, a feasible solution is to

*Numbers in parentheses refer to articles listed in the Bibliography.

develop some type of priority rating system for the improvement of the level of grade crossing protection. However, criteria and warrants for protective devices have yet to be developed for application on a national basis. The general warrants used by many states result in priority ratings based on subjective judgment, not on hazard.

The objectives of this research investigation were:

1. To determine the relative effects of those factors which significantly influence the accident patterns at railroad-highway grade crossings.
2. To develop mathematical models that measure the relative safety or hazard of grade crossings.
3. To establish a priority rating system, based on the models, for determining protection improvements.

The results of this study allow a systematic reduction in hazard at grade crossings by the utilization of protection improvement warrants and priorities. An insight into the grade crossing problem is offered, as well as an indication of what segment of the problem lies within the working province of the engineer. By applying the results of this research, it may be possible to substantially improve the safety of highway travel at railroad-highway grade crossings.

REVIEW OF LITERATURE

Today there exists an overall uniformity in the design and use of both signs and signals at railroad crossings. Most types of protection have been standardized by the Association of American Railroads and the National Joint Committee on Uniform Traffic Control Devices (2, 3, 19). The following types of protection are included in these specifications and standards:

1. Painted crossbuck,
2. Reflectorized crossbuck,
3. Flasher,
4. Flasher and bell,
5. Gate and flasher,
6. Gate, flasher, and bell,
7. Manual gate, and
8. Watchman.

The degree of warning offered by grade crossing protective devices can be separated into two basic categories (1). In the case of either a painted or reflectorized crossbuck sign, the driver determines whether or not there are train movements for which he should stop. For automatic signals and gates the driver is given a more positive indication of when to stop. Nevertheless, automatic signals do not completely eliminate the necessity of driver decision.

Clearly, public compliance of automatic protective devices is directly related to grade crossing accidents. If all drivers of motor vehicles complied with existing laws and regulations and exercised proper caution at grade crossings, there would be fewer motor vehicle-train

collisions. Because it is assumed that automatic protective devices provide adequate warning to drivers, in many cases driver compliance remains as the determining factor (7).

Stop signs have been recommended and incorporated at some railroad-highway grade crossings (10, 13, 16, 21). The application of this device is based on the reasoning that the best protective devices must be signs or signals that drivers are conditioned to obey by reflex. Because the majority of motor vehicle drivers have developed this conditioned response to the stop sign, this traffic control device is often assumed to be a panacea for the grade crossing problem. Contrary conclusions were observed in a recent study of stop sign protection at railroad-highway grade crossings conducted by the Traffic Engineering Department of the City of Lincoln, Nebraska. Driver compliance to stop signs at railroad-highway grade crossings was inadequate, and it was concluded that such installations encourage willful violations and create contempt and disrespect for all stop signs. Therefore, the investigators recommended that stop signs should not be used as a grade crossing protective device (6).

Protection Coefficients

Protection coefficients are comparative numerical ratings of the measure of protection afforded by various devices and are usually expressed as a function of either accident rates or reductions in accident rates. The Automotive Safety Foundation has summarized the results of several reported studies which developed protection coefficients (4). The crosssbuck was assigned a reference index of unity.

Indices which indicated the number of accidents likely to occur at a crossing with a particular type of protective device in place were developed for other forms of protection. The composite coefficients, with ranges to compensate for various numbers of tracks, are as follows:

Crossbucks	1.0
Flashers	0.3 - 0.6
Gates	0.1 - 0.2

The above protection coefficients indicate the relative effectiveness of various protective devices. Because the experimental conditions varied for each study, any conclusions based on these values should be qualitative in nature.

Accident Prediction and Hazard Equations

Accident prediction and hazard equations have been formulated to express the antithesis of safety as a measure of various variables. Accident prediction equations are concerned with accident rates, while hazard equations relate influencing factors to an established scale. Among those variables included in previous research investigations are:

1. Average daily traffic volume,
2. Average daily train volume,
3. Type of protection,
4. Daylight or darkness,
5. Number of tracks,
6. Train speeds,
7. Vehicle speeds,
8. Type of highway,

9. Geometrics of the crossing (sight distance, crossing alinement, etc.),
10. Pavement width and number of lanes,
11. Type of highway surface,
12. Distractive influences,
13. Visibility,
14. Illumination, and
15. Vehicle and driver characteristics.

Previously developed accident prediction and hazard equations, based on combinations of the above factors, have had only limited reliability when used to evaluate the relative safety of railroad-highway grade crossings.

Warrants and Priority Rating Systems

Limited funds are available for expenditure toward reducing the hazard at railroad-highway grade crossings. Because of the large number of grade crossings and the high cost of modern protective devices, provision of the maximum protection at every location is not always possible. There is general agreement that a need exists for a priority rating system which would indicate both relative hazard, and the minimum level of protection necessary to reduce this hazard effectively.

Numerical warrants and criteria for type of protection at grade crossings have been developed and used by many different agencies. However, no universally acceptable criteria have been adopted for evaluating hazard or for specifying the minimum required level of protection. Judgment values assigned to various selected influencing factors have resulted in distorted ratings from one locality to another. Many

states rely on subjective judgment rather than a type of numerical rating (12).

The development of economic warrants has frequently been proposed (11, 12, 15). The suggested procedure usually is to evaluate whether or not a grade crossing has a minimum level of protection consistent with existing conditions. Then by numerically assessing the possible alternatives with respect to both accident potential and installation and operational requirements, select the alternative with the greatest economic justification. This approach is limited by the inadequate techniques available for estimating the true economic value of safety.

PROCEDURE

This research investigation was performed in two successive phases. The first phase was concerned with grade crossings located in rural portions of the State of Indiana (17), while the second portion pertained to grade crossings situated in urban areas of Indiana. (5) Because the rural and urban studies were performed separately with different methods of analysis, each study is presented and discussed individually.

Rural Grade Crossings

Because previous research investigations had achieved only a limited degree of success in predicting grade crossing accident rates, accident locations were compared to non-accident locations in an attempt to develop realistic correlations between hazard and various grade crossing characteristics. The 289 accident locations, which included most of the rural crossings in Indiana with at least one accident in 1962 and 1963, were established by using the traffic accident reports of the Indiana State Police. The 241 non-accident locations were randomly selected in the following manner:

1. The railroad lines were outlined on a state map;
2. Railroad mileage for each county was measured on the map;
3. By simple proportion based on railroad mileage, each county was allocated a number of the total non-accident locations to be investigated; and
4. The allocated number of railroad crossings in each county was selected from county maps.

To ascertain that each non-accident crossing represented an accident-

free location, the nearest available residents to the crossing were asked about accidents at the proposed study location. If an accident had occurred at the location, the crossing was eliminated from the analysis. The railroads also checked their records for accidents at these non-accident locations.

Many possible variables were selected, and all those which could be realistically evaluated were investigated. Many variables were evaluated subjectively by use of dichotomous values (0 or 1) representing absence or presence of a situation. The information for the following 56 selected variables came primarily from police accident reports, field investigations, and railroad correspondence.

Accident Data (Accident Locations Only)

1. Vehicle type (0 if car, 1 if truck).
2. Age of vehicle-years.
3. Out-of-county vehicles (0 if in-county, 1 if out-of-county).
4. Out-of-state vehicle (0 if in-state, 1 if out-of-state).
5. Number of occupants-driver plus passengers. This variable was included because of the possible distraction caused by passengers.
6. Actual car speed - mph. The speed of the car was not always listed on the accident report. The car speed was then established by driving the approach to the crossing at the speed the investigator considered a maximum safe speed for the highway and subtracting 10 mph.
7. Actual train speed - mph.

8. Vehicle defects (0 if no defects, 1 if defects were indicated).
This variable indicated whether or not mechanical defects were a contributing factor to the accident.
- 9-11. Surface type - portland cement concrete, asphalt, or gravel (0 if absent, 1 if present for each type). These three variables were also applicable to the non-accident locations and the data for them were obtained from field observations.
12. Dry pavement (0 if dry, 1 if wet or covered with ice or snow).
13. Ice or snow (0 if dry, 1 if covered with ice or snow).
14. Clear weather (0 if clear, 1 if cloudy).
15. Darkness (0 if daylight, 1 if darkness). This variable was defined as darkness if the accident occurred between 6:00 p.m. and 6:00 a.m.
16. Window position (0 if window down, 1 if window rolled up).
Often the officers reported the windows were up (and/or radio playing), and the driver possibly could not hear either the warning bells or train whistle. If the accident report did not indicate this information, the time of day, time of year, and reported weather conditions were used as guides.
17. Drinking driver (0 if not drinking, 1 if drinking).
18. Male-female driver (0 if female, 1 if male).
19. Driver age - years.
20. Personal injury (0 if no personal injury, 1 if personal injury).
A fatality was considered a personal injury for this variable.
21. Fatality (0 if no fatality, 1 if fatality).
- 22-28. Day of the week (0 if not on a certain day, 1 if on the day).

Field Data (All Locations)

The Field data were recorded for the approach quadrant where an accident occurred at accident locations and for one randomly selected quadrant at non-accident locations. Variables 29 to 35 were coded as 0 if not existing, 1 if existing.

29. Painted crossbuck.
30. Reflectorized crossbuck.
31. Flasher.
32. Gate.
33. No protection.
34. Stop sign.
35. White edge line.
36. Highway gradient - percent.
37. Railroad gradient - percent.
38. Highway curvature - degrees.
39. Railway curvature - degrees.
40. Number of tracks - pairs.
41. Pavement width - feet.
42. Advance warning sign (0 if not existing, 1 if existing).
43. Pavement crossing markings (0 if not existing, 1 if existing).
44. Number of businesses. This variable represents the number of business establishments located a distance of one-half mile along the approach to the crossing on both sides of the roadway.
45. Number of advertising signs - measured similarly to variable number 44.

46. Presence of minor obstructions (0 if not obstructed, 1 if partially obstructed). This variable considered such things as brush or trees which would partially obstruct the view of an approaching train but would not completely block its view.
47. Line of sight. This variable represents the angle at which a motorist could first view an approaching train when the vehicle is at a distance from the crossing equal to the stopping sight distance as determined either by the speed limit or maximum safe speed of the highway. The sine of the angle included between the highway and the first view of an approaching train was recorded to three decimal places.
49. Intersection angle - degrees.

Railroad Data (All Locations)

50. Average number of passenger trains per day.
51. Average number of freight trains per day.
52. Average freight train speed - mph.
53. Average passenger train speed - mph.
54. Average number of trains per day - TPD.

Vehicular Traffic Data (All Locations)

55. Average daily traffic - ADT. The files of the Indiana State Highway Commission were used as a reference for collection of these data.
56. Average car speed - mph. Determined as described in discussion of variable number 6.

Summary statistics were developed for all study variables. Regression analysis was then performed on the 28 variables common to both accident and non-accident locations. Three other common variables - railway gradient, stop sign, and no protection - were not included due to insufficient data. The dependent variable was accident occurrence, a dichotomous variable representing occurrence or non-occurrence of an accident (0 if a non-accident location, 1 if an accident location). Relative hazard was defined as the functional relationship between the dependent variable and the independent variables.

The regression analysis which was utilized is often referred to as "buildup" or "stepwise" regression. The independent variables were selected in order of their ability to predict the dependent variable. However, the program allowed the ordering of the variables and thus permitted the development of practical models. For all equations, train and highway traffic volumes were ordered to permit their inclusion in the multiple regression expressions.

The regression models were then used to develop warrants for selecting the type of protection device recommended at rural grade crossings, based on current levels of protection in Indiana.

URBAN GRADE CROSSINGS

As a result of the experience gained from the initial study of rural grade crossings, a different type of analysis was performed in the subsequent urban study. The two investigations were quite similar with respect to data collection and the mathematical techniques which were employed. However, there was a substantial difference in the conceptual development and formulation of the hazard models.

The hypothesis assumed in the urban study was that railroad-highway grade crossings can be classified as either accident prone or non-accident prone. If an accident was experienced during an arbitrary period of time, a grade crossing was considered as a representative member of the accident prone group. If a crossing did not experience an accident, it was classified as a representative member of the non-accident prone group. This approach permitted safety or, conversely, hazard to be assessed in terms of a dichotomous variable representing membership in either the accident prone or non-accident prone group.

A two-year period, 1963 through 1964, was selected for investigation, and the study was limited to those railroad-highway grade crossings located within incorporated areas in the State of Indiana. For the purposes of the urban study, hazard was defined as the probability of membership in the accident prone group expressed as a function of various characteristics of the grade crossing.

A large number of variables were selected for analysis to minimize the possibility of overlooking any statistically significant hazard predictors. Only those variables which can be evaluated realistically were retained for field investigation. Many variables are identified by a dichotomous measure (0 or 1) representing absence or presence of a situation. A summary of the study variables is listed below. Each variable name is followed by the units of its measurement.

Accident Data (Accident Locations Only)

1. Driver age - years.
2. Driver sex (0 if female, 1 if male).

3. Out of town driver (0 if in-town, 1 if out-of-town).
4. Out-of-county driver (0 if in-county, 1 if out-of-county).
5. Out-of-state driver (0 if in-state, 1 if out-of-state).
6. Drinking driver (0 if not drinking, 1 if drinking).
7. Vehicle type (0 if truck, 1 if car).
8. Vehicle age - years.
9. Vehicle defects (0 if no defects, 1 if defects were indicated in the accident report).
10. Fatality (0 if no fatality, 1 if fatality).
11. Personal injury (0 if no personal injury, 1 if personal injury)
a fatality was not considered a personal injury for this variable.
12. Property damage loss - dollars/100.
13. Car speed - mph.
14. Speeding driver (0 if not speeding, 1 if speeding).
15. Train speed - mph.
16. Wet pavement (0 if dry, 1 if wet).
17. Ice or snow (0 if pavement was dry, 1 if covered with ice or snow).
18. Vehicle out of control (0 if under control, 1 if out of control)
- a skidding vehicle was considered out of control.
19. Darkness (0 if daylight, 1 if darkness) - dawn and dusk were coded as darkness.
20. Clear weather (0 if precipitating, 1 if clear).
21. Stalled vehicle (0 if not stalled, 1 if stalled).
22. Unaware driver (0 if driver was aware of automatic warning signals or train, 1 if not aware).

23. Disregarded warning (0 if driver complied with automatic warning signals, 1 if disregarded).
24. Year of accident (3 if 1963, 4 if 1964).

Field Data (All Locations)

Variables 25 to 39, 41 to 43, 45 to 53, 56 to 59, 62 to 67, and 80 to 84 were coded as 0 if not existing, 1 if existing.

25. Painted crossbuck - good condition.
26. Painted crossbuck - poor condition.
27. Reflectorized crossbuck - good condition.
28. Reflectorized crossbuck - poor condition.
29. Warning bell and crossbuck.
30. Warning bell, crossbuck, and stop sign.
31. Flasher.
32. Flasher and warning bell.
33. Gate and flasher.
34. Gate, flasher, and warning bell.
35. Manual gate.
36. Flagman.
37. Stop sign.
38. Traffic signal coordinated with train movements.
39. No protection.
40. Speed limit - mph.
41. Railroad advance warning sign.
42. Railroad pavement marking.
43. Two-way street.
44. Number of lanes.

45. Local street classification.
46. Collector street classification.
47. Arterial street classification.
48. Painted center line.
49. Curb and gutter.
50. Curb parking.
51. Bus stop - this variable represented bus loading zones adjacent to a grade crossing.
52. Traffic signal - this variable was restricted to traffic signals located within 200 ft. of the grade crossing.
53. Illuminated roadway.
54. Pavement width - feet.
55. Average lane width - feet.
56. Portland cement concrete pavement.
57. Asphalt pavement.
58. Brick pavement.
59. Gravel pavement.
60. Number of tracks.
61. Number of mainline tracks.
62. Rough crossing - judgment was based on a test drive and field observation of driver reactions while traversing the crossing.
63. Railroad yards.
64. Passenger station.
65. Illuminated crossing.
66. Tracks located parallel to the centerline and within the pavement of the roadway.

67. Grade - judgment was used to evaluate this qualitative dichotomous variable.
68. Number of businesses on the approach - this variable represented the number of business establishments and all other non-residential structures which were located a distance of 500 ft. along the approach to the crossing on both sides of the roadway.
69. Number of advertising signs on the approach - this variable included all signs capable of being read by a motorist and located along the roadway section described for variable No. 68.
70. Number of dwellings on the approach - measured similarly to variable No. 68.
71. Number of access points on the approach - measured similarly to variable No. 68. This variable represented all intersecting streets, alleys, driveways, and business entrances.
72. Number of intersecting streets on the approach - measured similarly to variable No. 68.
73. Number of loading zones on the approach - measured similarly to variable No. 68. This variable represented the number of curb loading zones as well as off-street loading docks or loading facilities visible to a motorist.
74. Number of businesses beyond the crossing - measured similarly to variable No. 68 except that the roadway under consideration was the section extending 200 ft. beyond the grade crossing relative to the approach direction.
75. Number of advertising signs beyond the crossing - measured similarly to variable No. 74.

76. Number of dwellings beyond the crossing - measured similarly to variable No. 74.
77. Number of access points beyond the crossing - measured similarly to variable No. 74.
78. Number of intersecting streets beyond the crossing - measured similarly to variable No. 74.
79. Number of loading zones beyond the crossing - measured similarly to variable No. 74.
80. Residential locality.
81. Commercial locality.
82. Industrial locality.
83. Minor obstruction - this variable represented objects such as brush, trees, or temporary obstructions which would obscure the view of an approaching train.
84. Adjacent high volume intersection - this variable represented the existence of a high volume roadway adjacent and parallel to the railroad right-of-way.
85. Population - measured in thousands. This variable represented the population of the incorporated urban area where a grade crossing was located.
86. Angle of intersection - degrees.
87. Line of sight - this variable represented the ratio of the actual corner sight angle to the minimum desirable corner sight angle. The actual corner sight angle was defined as the angle at which a motorist can first view an approaching train when the vehicle is at a distance from the crossing equal to the stopping sight

distance (as determined by the posted speed limit of the roadway). The minimum desirable corner sight angle was defined as the minimum angle (measured at the same location described above) at which a motorist can first view the fastest approaching train and bring his vehicle to a stop in advance of the tracks before the train (traveling at a constant speed) reached the crossing. A mathematical derivation of this variable is presented in the Appendix.

88. Traffic volume - ADT.

Railroad Data (All Locations)

- 89. Average passenger train speed - mph.
- 90. Average freight train speed - mph.
- 91. Average switching movement speed - mph.
- 92. Average train speed - mph.
- 93. Average number of passenger trains per day.
- 94. Average number of freight trains per day.
- 95. Average number of switching movements per day.
- 96. Average number of trains per day - TPD.
- 97. Percentage of non-scheduled trains per day - this variable expressed the number of switching movements per day as a percent of TPD.
- 98. Speed of fastest train - mph.

Indiana State Police traffic accident reports for the years 1963 and 1964 were used as the data source for all accident variables. Data were obtained for 295 grade crossing accidents which occurred in urban areas during the two-year period.

For statistical purposes it was desirable to select an approximately equal number of grade crossings representative of the non-accident group. The 281 non-accident locations were randomly chosen in the following manner:

1. The railroad track mileage in each incorporated area in the State of Indiana was measured on a county map.
2. The scaled mileages were recorded and summed.
3. Using random number tables, 281 numbers were selected from the numerical range of the cumulative scaled mileage.
4. Each number represented a non-accident location to be investigated in a specific urban area.
5. The grade crossings in each designated urban area were assigned consecutive numbers.
6. Using random number tables, the required number of grade crossings in each urban area was then selected from the numerically ordered crossings for that area.

To reduce the possibility that a selected non-accident grade crossing was not a representative member of the non-accident prone group, it was specified that the location must not have experienced a vehicle-train accident for a minimum of five years prior to the date of field investigation. To ascertain if the above requirement was fulfilled, the local police department, railroad agencies, and nearest available residents to the crossing were questioned with respect to each proposed location. If an accident had occurred, the site was rejected, and a different grade crossing was randomly selected as a replacement.

Each grade crossing selected for investigation actually represented four possible collision paths between motor vehicles and trains. As a

result, data were recorded for a single quadrant representing unique vehicle and train approach directions. At the accident locations the selected quadrant was the one in which the accident occurred. Quadrants at the non-accident locations were selected with respect to a repetitive ordering of geographically designated quadrants (NE, SE, SW, NW, NE, etc).

A correlation analysis program was used to develop sums, means, standard deviations, and correlation coefficients for the study variables. The computer program also permitted combinations of variables to be transgenerated into the following new variables:

99. Painted crossbuck - sum of variable No. 25 and 26.
100. Reflectorized crossbuck - sum of variable No. 27 and 28.
101. Flasher - sum of variable No. 31 and 32.
102. Gate - sum of variable No. 33, 34, and 35.
103. Number of businesses - sum of variable No. 68 and 74.
104. Number of businesses and advertising signs - sum of variable No. 69, 75, and 103.
105. Number of businesses, advertising signs, and dwellings - sum of variable No. 70, 76, and 104.
106. Number of businesses, advertising signs, dwellings, and access points - sum of variable No. 71, 77, and 105.
107. Number of businesses, advertising signs, dwellings, and intersecting streets - sum of variable No. 72, 78, and 105.
108. Number of businesses, advertising signs, dwellings, access points, and loading zones - sum of variable No. 73, 79, and 106.
109. Exposure rate (ADT x TPD) - product of variable No. 88 and 96.

Highly associated variables were examined, and the variables judged to be the less applicable parameter of a given grade crossing characteristic

were eliminated. Means and standard deviations aided in the deletion of those variables which were observed at only a very small percentage of the sample locations.

Hazard was previously defined as being a problem of binary assignment; that is, a selected grade crossing was classified as a member of either the accident prone or non-accident prone group. Both groups were assumed to be characterized by a unique distribution of influencing variables. The purpose was to discriminate between the two groups with a minimum chance of misclassification.

Discriminant analysis techniques, which have been applied to the choice of mode problem in urban transportation planning, were conveniently adapted to the analysis of grade crossing hazard (18, 20). By formulating a linear discriminant model of important explanatory variables, a statistical rule was available to indicate those discriminant scores, or hazard values, for which a given location can be classified as either accident prone or non-accident prone.

The linear discriminant model was initially defined as:

$$F = a_0 + \sum_{i=1}^n a_i X_i$$

where F = discriminant score,

X_i = an explanatory variable,

a_0 = constant,

a_i = constant coefficient, and

n = the number of explanatory variables.

For the discriminant model to be useful, it was necessary to choose coefficients which maximized the separation between the density functions

representing expected discriminant scores for the accident prone and non-accident prone groups. However, the above model was restricted to the prediction of a dichotomous classification. It was not statistically possible to distinguish the relative association with either of the two groups. To indicate the change in likelihood of association with either group, linear probabilities were assigned to the above discriminant model under the following constraints:

$$\text{Pr [observation is from accident prone group]} = \begin{cases} 0, & \text{if } F < 0, \\ F, & \text{if } 0 \leq F \leq 1, \text{ and} \\ 1, & \text{if } 1 < F. \end{cases}$$

The linear relationship was selected because of its mathematical simplicity and its reasonable description of the sample data. This technique permitted the discrimination of hazard to be expressed as a continuous, rather than dichotomous, function of the explanatory variables. Thus, potential hazard was expressed as the probability of being classified as a member of the population of accident prone grade crossings.

The success of the discriminant model was defined as the ability to correctly assign group membership. This success was determined by applying the model to the study sample and then computing the percentage of correct classifications of the accident and non-accident grade crossings relative to a classification criterion of 50-percent probability of membership in the accident prone group.

As a check on the appropriateness of the linear assignment of probabilities, the sample locations were separated into ranges of similar discriminant scores. The proportion in each range whose true value belonged to the accident prone group was graphically compared to the

linear probability curve described by the discriminant model. This comparison permitted a visual verification of the linear assignment of probabilities.

A methodology, based on the selection of a maximum tolerable accident prone probability, was developed to determine a minimum level of grade crossing protection. Maximum tolerable probability levels were related to the errors resulting from misclassification and to the success of the discriminant model. The misclassification errors expressed the likelihood of overprotection or underprotection. Overprotection was defined as the probability that a non-accident prone grade crossing will be classified as a member of the accident prone group. Similarly, underprotection was defined as the probability that an accident prone grade crossing will be classified as a member of the non-accident prone group. The error probabilities were computed by assigning the sample observations to accident and non-accident prone groups and then determining the proportion of misclassifications in each group. The errors were functionally expressed as:

$$A = \frac{M_a}{N_n} \quad \text{and,} \quad B = \frac{M_n}{N_a}$$

where, A = probability of underprotection,

B = probability of overprotection,

M_a = number of accident locations which were assigned to the non-accident prone group,

M_n = number of non-accident locations which were assigned to the accident prone group,

N_a = total number of grade crossings assigned to the accident prone group, and

M_n = total number of grade crossings assigned to the non-
accident prone group.

A chart was then developed to permit the selection of a maximum tolerable accident prone probability based on the error of underprotection. This chart was constructed by computing the probability of underprotection associated with various levels of maximum tolerable accident prone probability. Each probability level represented a different criterion for assigning the group membership of the sample data.

Compliance Study

To provide an additional insight into the effectiveness of grade crossing protective devices, a compliance study was performed at existing flasher and gate installations. Drivers at numerous grade crossings were observed from the engine of a moving train. The survey considered only those motorists who were confronted with a choice of observing or disregarding an actuated signal. If a vehicle was already stopped at the crossing, all other vehicles approaching in that lane were excluded from the study.

RESULTS

The results of this research investigation are presented and discussed relative to the respective studies of rural and urban grade crossings. (5, 17) All variable number designations were retained for convenient referencing.

Rural and Urban Summary Statistics

Descriptive statistics of grade crossings located throughout the State of Indiana were developed from the results of each phase of the investigation.

Several predominant patterns were observed when urban and rural grade crossing accidents were analyzed with respect to the statistics listed in Table 1. Male drivers were involved in most of the grade crossing accidents, while the percentage of female drivers who had accidents was greater in urban areas than in rural areas. Most grade crossing accidents occurred within the city or county in which a motorist resided. Each of these facts can be attributed to driver exposure; that is, most drivers in both urban and rural area are male, and the percentage of female motorists is greater in urban areas than in rural areas. In addition, most vehicle trips are made within close proximity of the driver's place of residence.

Drinking drivers were more frequently involved in motor-vehicle-train accidents in urban areas than in rural areas. This may be a result of the greater number of taverns and bars in urban areas.

TABLE 1
CHARACTERISTICS OF SAMPLED RAILROAD-HIGHWAY
GRADE CROSSING ACCIDENTS

Variable	Urban Locations	Rural Locations
1. Driver		
a. Average driver age	37 yr	36 yr
b. Drivers who were male	78 %	86 %
c. Drivers who resided in the city in which the accident occurred	65 %	-
d. Drivers who resided in the county in which the accident occurred	85 %	72 %
e. Drivers who resided in the State of Indiana	96 %	94 %
f. Accident reports which indicated the driver had been drinking	11 %	6 %
g. Accidents in which the driver apparently was unaware of the train or an automatic warning signal	38 %	-
h. Accidents in which the driver apparently disregarded an automatic warning signal or a flagman	27 %	-
i. Accidents which resulted in at least one personal injury	39 %	48 %
j. Accidents which resulted in at least one fatality	10 %	14 %

TABLE 1 (cont'd.)

Variable	Urban Locations	Rural Locations
k. Average property damage loss	\$871	-
2. Vehicle		
a. Trucks	12 %	27 %
b. Average vehicle age	5.1 yr	5.2 yr
c. Accidents in which the vehicle skidded or was out of control	21 %	-
d. Vehicles which evidenced contributing mechanical defects	3 %	17 %
3. Environmental		
a. Accidents which occurred during clear weather	76 %	74 %
b. Accidents which occurred during the hours of darkness	45 %	36 %
c. Pavement surface condition		
1) Dry	60 %	57 %
2) Wet	20 %	16 %
3) Covered with ice or snow	20 %	27 %

In approximately 65 percent of the urban accidents, drivers apparently were unaware of the presence of a train or willfully disregarded an automatic warning device. The high severity of all grade crossing accidents was shown by the fact that a fatality or personal injury occurred in 62 percent of the rural accidents and 49 percent of the urban accidents. This difference in severity was probably due to higher train and vehicle speeds in the rural areas.

The percentage of trucks involved in grade crossing accidents was more than twice as high in rural areas than in urban areas. This result can be attributed to the higher percentage of trucks traveling on rural highways. Contributing mechanical defects in a motor vehicle were more frequent in rural accidents, although the average vehicle age was almost identical for each group.

The importance of environmental conditions was quite apparent. Although approximately 25 percent of the accidents occurred during some form of precipitation, about 40 percent took place on a pavement that was wet or covered with ice or snow. Also, there was a higher frequency of grade crossing accidents during the period from dusk till dawn when vehicle and train volumes are usually low. Both of these facts indicate the influence of poor visibility.

The data presented as Table 2 represent a summary of the physical features and characteristics of the accident and non-accident grade crossings investigated in both the rural and urban studies. The frequency of an occurrence is represented by a percentage, and all other measures represent means.

TABLE 2
COMPARISON OF SAMPLED RAILROAD-HIGHWAY
GRADE CROSSING CHARACTERISTICS

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
1. Protective device				
a. Painted cross-buck	20 %	19 %	53 %	69 %
b. Reflectorized crossbuck	11 %	11 %	23 %	20 %
c. Flasher	48 %	44 %	18 %	9 %
d. Gate	8 %	15 %	4 %	1 %
2. Roadway characteristics				
a. Speed limit	27 mph	26 mph	-	-
b. Railroad advance warning sign	21 %	21 %	69 %	72 %
c. Railroad pavement marking	5 %	6 %	10 %	4 %
d. Number of lanes	2.3	2.1	-	-
e. Painted center line	47 %	24 %	-	-
f. Curb and gutter	58 %	47 %	-	-
g. Curb parking	56 %	67 %	-	-
h. Traffic signal within 200 ft of crossing	7 %	1 %	-	-

TABLE 2 (cont'd.)

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
i. Illuminated roadway	19 %	7 %	-	-
j. Pavement width	32 ft	27 ft	20 ft	17 ft
k. Pavement type:				
1) Portland cement concrete	14 %	9 %	7 %	1 %
2) Asphalt	83 %	86 %	75 %	43 %
3) Brick	1 %	3 %	-	-
4) Gravel	2 %	2 %	18 %	56 %
l. Local classification	31 %	60 %	-	-
m. Collector classification	43 %	28 %	-	-
n. Arterial classification	26 %	12 %	-	-
3. Roadside characteristic				
a. Residential locality	30 %	57 %	-	-
b. Commercial locality	36 %	28 %	-	-
c. Industrial locality	34 %	15 %	-	-
d. Minor obstruction	49 %	41 %	70 %	77 %
e. Adjacent high volume intersection	10 %	3 %	-	-

TABLE 2 (cont'd.)

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
f. Number of businesses	5.0	3.1	1.6*	0.8*
g. Number of advertising signs	4.8	2.5	0.6*	0.1*
h. Number of dwellings	5.5	7.9	3.1*	1.9*
i. Number of access points	8.5	8.6	-	-
j. Number of streets	2.2	2.6	-	-
k. Number of loading zones	0.8	0.6	-	-
4. Railroad crossing characteristic				
a. Number of tracks	2.4	2.0	1.4	1.2
b. Number of main-line tracks	1.4	1.3	-	-
c. Rough crossing	58 %	67 %	-	-
d. Railroad yards	16 %	4 %	-	-
e. Passenger station	4 %	4 %	-	-
f. Illuminated crossing	3 %	2 %	-	-
g. Tracks located parallel to center line and within the pavement of a roadway	5 %	5 %	-	-

TABLE 2 (cont'd.)

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
h. Grade	10 %	7 %	-	-
i. Angle of inter- section	93 deg	89 deg	94 deg	90 deg
j. Line of sight ratio	1.19	1.25	-	-
5. Traffic characteristic				
a. Average daily traffic	4,861	2,299	1,185	342
b. Average passenger train speed	18 mph	16 mph	44 mph	41 mph
c. Average freight train speed	23 mph	25 mph	40 mph	39 mph
d. Average switching movement speed	6 mph	5 mph	-	-
e. Average passenger trains per day	3.4	2.6	2.9	1.8
f. Average freight trains per day	11.0	8.0	9.8	7.0
g. Average switching movements per day	10.0	2.9	-	-
h. Average train speed	21 mph	24 mph	41 mph	39 mph
i. Average trains per day	24.3	13.4	12.7	8.8

TABLE 2 (cont'd.)

Variable	Urban Locations		Rural Locations	
	Accident	Non-Accident	Accident	Non-Accident
j. Average speed of fastest trains	27 mph	28 mph	-	-
k. Percentage of non-scheduled trains per day	35 %	26 %	-	-
l. Exposure rate	132.7	28.0	-	-

* Measured along one-half mile, both sides of roadway, for one approach to the crossing.

RURAL GRADE CROSSINGS

Regression analyses were performed on the 28 variables measured at both accident and non-accident locations. The dependent variable for each equation was accident occurrence; that is, whether or not an accident occurred at the location during the two-year study period.

An equation was developed to account for the various protection devices, train and highway volumes and those additional variables which significantly influenced accident occurrence. This analysis produced the following prediction equation:

$$1. \quad IH = +0.149 - 0.376X_{29} - 0.300X_{30} - 0.383X_{31} - 0.331X_{32} + 0.082X_{40} \\ + 0.0223X_{41} + 0.011X_{54} + 0.0142X_{55} + 0.024X_{57}$$

where IH = index of hazard (accident occurrence)

X_{29} = presence of a painted crossbuck (0, 1),

X_{30} = presence of a reflectorized crossbuck (0, 1),

X_{31} = presence of a flasher (0, 1),

X_{32} = presence of a gate (0, 1),

X_{40} = number of track pairs,

X_{41} = pavement width in feet,

X_{54} = TPD,

X_{55} = ADT/1000, and

X_{57} = sum of distractions.

In addition to the protection variables, Equation 1 also includes variables which are a measure of train and highway volumes. The type of rail and highway operations are represented by the variables designated as number of track pairs and pavement width. The number of roadside distractions also proved significant. The sum of the three distraction

variables, houses, businesses and advertising signs, was more important than the individual distraction variables. The coefficient of determination, R^2 , for Equation 1 was 19.3 percent.

The regression coefficients of the four protective devices were remarkably similar. It might be inferred from this fact that hazard was relatively independent of the type of protective device. To ascertain the statistical significance of the coefficients for the protection variables, a second multiple regression equation was developed which excluded the four types of crossing protection and included the remaining variables. The coefficient of determination for Equation 2, presented below, was 18.3 percent.

$$2. \quad IH = 0.185 = 0.079X_{40} + 0.021X_{41} + 0.011X_{54} + 0.013X_{55} + 0.024X_{57}$$

where IH = index of hazard,

X_{40} = number of track pairs,

X_{41} = pavement width in feet,

X_{54} = TPD,

X_{55} = ADT/1000, and

X_{57} = sum of distractions.

An F-test was used to test the hypothesis that the coefficients for the four protective devices as presented in Equation 1 were not significantly different from zero. The calculated F-value was 1.61 as compared to a critical value of 2.39 for the 95-percent level of confidence. Because the calculated value is less than the critical value, the hypothesis that the protection coefficients are equal to zero was not rejected.

This analysis did not show that protection devices had a significant influence on the prediction of hazard at grade crossings. Although the protection device variables can be eliminated from the prediction equation, the result of this significance test does not warrant the conclusion that protection devices have no influence on reducing hazard. This finding is restricted by the limited variability of the field conditions for the four types of protection investigated.

Because the inclusion of the protection variables did not materially improve the estimation of hazard and because the types of protection device were equally weighted, the nomograph shown as Figure 1 was developed from Equation 2. In an attempt to correlate the index of hazard with the present standard of installing protection devices at grade crossings, the mean indices of hazard were calculated for the study crossings protected with reflectorized crossbucks, flashers, and gates. These mean values were, respectively, 0.523, 0.774, and 0.828. A suggested warrant for the selection of at-grade protection was established by computing the average value between the mean index of hazard for the various protection devices. Flashers would be recommended if the index of hazard is greater than 0.65, and gates would be recommended for indices greater than 0.80. The values suggested for these warrants are based on current levels of protection in Indiana. Painted crossbucks were not included in the nomograph because all crossbucks are required to be reflectorized by state law. Although many painted crossbucks are presently in service, these devices are to be replaced with reflectorized crossbucks when necessary.

FIGURE 1. PROTECTION NOMOGRAPH - GRADE CROSSINGS LOCATED IN RURAL AREAS OF INDIANA

When the nomograph is used to evaluate a grade crossing, each approach direction to the crossing must be considered. The approach requiring the highest type of protective device, as indicated by the suggested warrants, establishes the protective device recommended for that railroad-highway grade crossing.

To check the adequacy of Equation 2, the average calculated indices of hazard for the crossings studied were compared to the actual hazard as defined by the number of accident locations, A, per number of locations investigated, N, for each type of protection. The comparison is given below:

<u>Type of Protection</u>	<u>Calculated Average IH</u>	<u>A/N</u>	<u>Actual IH</u>	<u>Difference</u>	<u>Percent Variation</u>
Painted crossbuck	0.502	155/320	0.484	0.018	3
Reflectorized crossbuck	0.523	66/115	0.574	0.051	9
Flasher	0.774	51/73	0.699	0.075	11
Gate	0.828	12/14	0.857	0.029	3

The percentage of variation was determined by comparing the difference in the calculated index of hazard and the actual index of hazard, to the actual index of hazard. The average error for all crossings investigated amounted to approximately 5.5 percent. The low average error thus verified the reasonability of the suggested protection warrants based on Equation 2.

URBAN GRADE CROSSINGS

The analysis of urban grade crossing hazard was restricted to locations protected by a painted crossbuck, reflectorized crossbuck, flasher, or gate. The sample consisted of 243 accident locations and 222 non-accident locations, or a total sample size of 465 grade crossings.

Development of the Discriminant Model

Several discriminant models with linearly assigned probabilities were developed by the mechanics of regression analysis. These models were formulated for various combinations of explanatory variables to obtain the most successful discriminant model capable of being evaluated from measurements that are readily and conveniently available to the engineer. The success of each model was assessed by determining the percentage of correct classifications for the sampled grade crossings. The basic classification criterion was a discriminant score equivalent to the 50-percent probability of membership in the accident prone group. A probability greater than 50 percent was indicative of a location that was likely to be a member of the accident prone group. A probability less than 50 percent represented a greater likelihood of membership in the non-accident prone group.

The most practical and successful discriminant model was:

$$\begin{aligned} 3. \quad F = & 0.41227 - 0.03276 X_{87} + 0.02384 X_{88} + 0.00728 X_{96} \\ & - 0.02109 X_{100} - 0.19494 X_{101} - 0.52512 X_{102} + 0.01281 X_{104} \end{aligned}$$

where, F = discriminant score,

X_{87} = line of sight ratio,

X_{88} = ADT/1000,

X_{96} = TPD,

X_{100} = presence of a reflectorized crossbuck (0, 1),

X_{101} = presence of a flasher (0, 1),

X_{102} = presence of a gate (0, 1), and

X_{104} = sum of distractions (number of businesses and advertising signs, on both sides of the roadway, along a section extending 500 ft. from the crossing to 200 ft. beyond the crossing for one approach direction).

Potential hazard, or the probability of membership in the accident prone group, was related to the discriminant model under the following constraints:

$$4. \Pr[\text{observation is from accident prone group}] = \begin{cases} 0, & \text{if } F < 0, \\ F, & \text{if } 0 \leq F \leq 1, \\ 1, & \text{if } 1 < F, \text{ and} \end{cases}$$

where F = discriminant score.

This model was 74 percent successful in discriminating between the accident and non-accident grade crossings in the study sample.

The explanatory variables appearing in the discriminant model represent easily measured predictors of grade crossing characteristics. The line of sight ratio is a function of maximum actual train speed, angle of intersection, speed limit of the roadway, and the actual corner sight angle. Curves shown as Figures 7 through 12 in the Appendix permit a graphical solution for the line of sight ratio variable. The average daily traffic and the average trains per day variables are measures of relative exposure to potential collisions. The sum of distractions variable measures the number of possible roadside distractions along the roadway on both sides of the crossing. Each of the four types of protective devices are included in the discriminant model. To calculate the potential hazard at a location with a given type of protection, the

remaining protection variables are assigned a value of zero. Because the painted crossbuck represents the lowest form of protective device, only the remaining three protective devices appear as variables in the model.

The relative effectiveness of each type of protective device is indicated by the magnitude of the respective variable coefficients appearing in the discriminant model. These coefficients, as shown in Table 3, represent the reduction in potential hazard (probability of membership in the accident prone group) for a particular type of protective device. The hazard reductions were expressed relative to the level of protection offered by the painted crossbuck. As evidenced by the coefficients, the reflectorized crossbuck offers a very small improvement over the painted crossbuck. This improvement is probably due to the benefits of reflectorization realized during the hours of darkness. However, the automatic flasher is almost ten times more effective than the reflectorized crossbuck, while gate protection is approximately 2.5 times more effective than flasher protection.

Appropriateness of the Discriminant Model

As a check on the appropriateness of the discriminant model with linearly assigned probabilities, the function was graphically compared with actual probabilities of group membership for the sample data. The graph of the linear discriminant model and the points representing the computed actual probabilities for the sample grade crossings are illustrated in Figure 2. The relatively close scatter of points about the line indicates that the discriminant model with linearly assigned probabilities can offer a reasonable estimate of potential hazard.

TABLE 3
RAILROAD-HIGHWAY GRADE CROSSING
PROTECTION COEFFICIENTS

Protective Device	Relative Protection
Painted crossbuck	0.000
Reflectorized crossbuck	0.021
Flasher	0.195
Gate	0.525

FIGURE 2. COMPARISON OF THE LINEAR ASSIGNMENT OF PROBABILITIES WITH THE ACTUAL PROBABILITIES FOR THE SAMPLE DATA

Criteria for Minimum Levels of Protection

If the potential hazard at a specific grade crossing can be defined as the probability of its membership in the accident prone group, criteria can be established for judging the minimum level of grade crossing protection. This procedure involves the specification of a maximum tolerable accident prone probability for urban railroad-highway grade crossings. The minimum level of protection is then defined as the lowest level of protection yielding a probability less than the tolerable value.

The selection of a maximum tolerable accident prone probability is dependent on several factors. Consideration must be given to misclassification errors which result in overprotection or underprotection. The error which leads to underprotection may be considered more critical. Thus, by decreasing the maximum tolerable accident prone probability, the chance of underprotection is reduced. However, a disadvantage of lowering the maximum tolerable accident prone probability is the increased number of grade crossings which require a higher level of protection. The greater protection requirements are directly related to the increased chance of overprotection and to the decreased chance of underprotection. If limited funds are available for the improvement of grade crossing protection, a decrease in the maximum tolerable probability also results in a reduction in the number of improvement projects which can be financed. This reduction is due to the substantially greater cost of the higher types of protective devices.

The final selection of a maximum tolerable accident prone probability must revert to subjective judgment of an acceptable and economically realistic error of underprotection. The curve shown as Figure 3 was

developed to aid engineers and public officials in making this decision. The error, or probability, or underprotection is plotted as a function of maximum tolerable accident prone probability. Utilization of the graph requires that an acceptable probability of underprotection be predetermined. This probability is then used to select the corresponding maximum tolerable accident prone probability indicated by the graph.

Protection Nomograph

The estimation of potential hazard (probability of membership in the accident prone group) at any urban grade crossing is facilitated by the nomograph shown as Figure 4. In addition, the nomograph can be used to determine a minimum level of protection. This procedure requires that a maximum tolerable accident prone probability be selected from Figure 3. The minimum level of protection is then specified as the lowest level of protection which yields an accident prone probability less than the maximum tolerable value.

Because the sum of distractions and the line of sight ratio variables are referenced to one approach direction and one corner sight triangle, respectively, the nomograph must be evaluated for each grade crossing quadrant. The highest type of protection required in any quadrant is the recommended protective device for that particular grade crossing.

Protection Improvement Priorities

The discriminant model with linearly assigned probabilities also permits the establishment of protection improvement priorities based on potential hazard. Warranted grade crossing protection improvement projects can be ordered relative to their existing accident prone probabilities. The

FIGURE 3. RELATION BETWEEN MAXIMUM TOLERABLE ACCIDENT PRONE PROBABILITY AND PROBABILITY OF UNDERPROTECTION

FIGURE 4. PROTECTION NOMOGRAPH - GRADE CROSSINGS LOCATED IN URBAN AREAS OF INDIANA

projects with the greatest potential hazard (probability of membership in the accident prone group) are then assigned the highest priorities for improvement.

Compliance Study

As evidenced by the results of the compliance study, driver attitudes and characteristics are germane to highway safety. Motorists approaching railroad-highway grade crossings which are protected with an automatic warning device often showed complete disregard for an actuated signal. The study sample was comprised of 153 observed motorists. A graphic representation of the statistical results is illustrated in Figure 5. Only 46-percent compliance was observed at flasher installations; however, there was 90-percent compliance at gate locations. The importance of these statistics is supported by the fact that in 27 percent of the accidents analyzed in the urban study, the driver was reported to have disregarded an automatic warning device or a flagman. Thus, improvement of driver education and better enforcement of laws and regulations which apply to motor vehicle drivers at grade crossings appear to be warranted as a means of improving highway safety.

FLASHER PROTECTION

GATE PROTECTION

FIGURE 5. DRIVER OBSERVANCE OF RAILROAD - HIGHWAY
GRADE CROSSING PROTECTIVE DEVICES

CONCLUSIONS

The following conclusions concerning hazard at rural railroad-highway grade crossings summarize the findings of the first phase of this research investigation.

1. The accident victims are predominantly young male drivers residing in the county in which the accident occurred. They are usually not under the influence of alcohol. More than one half of them are injured, and about one out of seven are killed.
2. Trucks account for more than one quarter of the accident vehicles. Seventeen percent of all vehicles involved in accidents have evidence of mechanical defects. The majority of accidents occur at moderate train speeds.
3. Most accidents occur during the favorable driving conditions of clear weather, daylight hours, and dry pavements. However, the number of accidents per unit time and per unit exposure is probably greater for ice and snow conditions and for wet pavements than for dry pavement conditions.
4. The hazard model developed by multiple linear regression (Equation 2) identifies number of track pairs, highway pavement width, train volume, average daily traffic volume, and the sum of distractions (number of houses, businesses, and advertising signs) as important variables for the prediction of index of hazard. Type of protection was not a statistically significant variable. This model explains 18 percent of the variation in accident occurrence..

5. Warrants for the installation of protective devices at rail-highway crossings, based on the current standard of protection used in Indiana, are indices of hazard of below 0.65 for reflectorized crossbucks, 0.65 to 0.80 for flashers, and above 0.80 for gates. These values are applicable for crossings rated by Equation 2.

The findings of the investigation of safety at urban railroad-highway grade crossings in the State of Indiana are summarized below.

1. Most accidents involved male drivers who resided in the city and county in which the accident occurred. Approximately one out of ten accident drivers had been drinking, and about one out of every two grade crossing accidents resulted in a personal injury or fatality.
2. Trucks represented 12 percent of the accident vehicles. Few vehicles evidenced contributing mechanical defects, although 21 percent skidded or were out of control at the time of impact.
3. Three-quarters of the accidents occurred during clear weather, and almost one-half took place during the hours of darkness. Pavements were wet or were covered with ice or snow in 40 percent of the collisions.
4. Motorists apparently were unaware of the presence of a train or willfully disregarded an automatic warning device in 65 percent of the accidents.
5. The development of a discriminant model with linearly assigned probabilities permitted potential hazard to be expressed as the probability that a grade crossing can be considered accident prone.

- The discriminant model related potential hazard to type of protective device, average daily highway traffic, average daily train traffic, a measure of effective sight distance, and a measure of roadside distractions.
6. The linear discriminant model was 74-percent successful in assigning the sample grade crossings into accident and non-accident groupings. Therefore, the model was considered to be a reliable predictor of potential hazard.
 7. The suggested procedure for establishing a minimum level of protection was to determine the minimum protection requirement for each grade crossing quadrant relative to a selected maximum tolerable accident prone probability. The recommended protective device for that particular grade crossing was the highest type of protection required in any quadrant. Protection improvement priorities can be established on the basis of the existing accident prone probabilities.
 8. The relative effectiveness of the protective devices were measured by the coefficients of the protective device variables appearing in the discriminant model. These coefficients are indicative of the reductions in potential hazard relative to the level of protection offered by a painted crossbuck:

a. Painted crossbuck	0.000
b. Reflectorized crossbuck	0.021
c. Flasher	0.195
d. Gate	0.525

9. The results of a compliance study at urban grade crossings protected with an automatic protective device indicated approximately 46-percent observance of actuated flashers and 90-percent observance of actuated gates.

BIBLIOGRAPHY

1. American Association of State Highway Officials, A Policy on Geometric Design of Rural Highways, Washington, D. C., 1954.
2. American Railway Engineering Association, Engineering Division, Association of American Railroads, Manual of Recommended Practice, Chapter 9, Parts 1 to 5, Washington, D. C., 1962.
3. Association of American Railroads, "Recommended Standards and Practices for Railroad-Highway Grade Crossing Protection," Bulletin No. 5, Washington, D. C., 1955.
4. Automotive Safety Foundation, Traffic Control and Roadway Elements, Their Relationship to Highway Safety, U. S. Bureau of Public Roads, Washington, D. C., 1963.
5. Berg, William D., "Evaluation of Safety at Railroad-Highway Grade Crossings in Urban Areas," a Thesis submitted to Purdue University for the degree of Master of Science in Civil Engineering, January 1967.
6. Bezkorovainy, G. and Holsinger, R. G., "The Use of Stop Signs at Railroad Crossings," Traffic Engineering Department, City of Lincoln, Nebraska, 1966.
7. Hays, Joseph H., "The ICC Report on Prevention of Grade-Crossing Collisions," Annual Meeting of American Railway Engineering Association, Chicago, Illinois, March 23, 1965.
8. Hays, Joseph H., "Can Government Curb Grade Crossing Accidents?", Traffic Safety, Chicago, Illinois, April 1964.
9. Interstate Commerce Commission, "Rail-Highway Grade-Crossing Accidents," Statement No. 6305, Washington, D. C., 1963.
10. Iowa State Commerce Commission, Summary, Highway Railroad Grade Crossing Accidents in the State of Iowa, Des Moines, Iowa, 1958.
11. Marks, Harold, "Railroad Crossing Protection: How Much Is Justified?" Proceedings, The Twelfth California Street and Highway Conference, The Institute of Traffic and Transportation Engineering, University of California, Berkeley, California, 1960.
12. McLaughlin, W. A., "Highway-Railway Grade Crossing Treatments," Technical Publication No. 13, Canadian Good Roads Association, Ottawa, Canada, 1960.
13. Michigan Railroads Association, "Study of Michigan Crossing Accidents," Detroit, Michigan, 1961.

14. National Safety Council, Accident Facts, Chicago, Illinois, 1965.
15. Newman, Donald G., "An Economic Analysis of Railway Grade Crossings on the California State Highway System," Report EEP-16, Institute in Engineering-Economic Systems, Stanford University, June 1965.
16. Ohio Legislative Service Commission, "Grade Crossings in Ohio," Staff Research Report No. 23, Columbus, Ohio, 1957.
17. Schultz, Thomas G., "Evaluation of Safety at Railroad-Highway Grade Crossings," a Thesis submitted to Purdue University for the degree of Doctor of Philosophy, August, 1965.
18. The Port of New York Authority Engineering Department, Research and Development Division, "Some Techniques for the Evaluation of Ground Service to Air Travelers," Report 63-5, October 1963.
19. United States Bureau of Public Roads, Manual on Uniform Traffic Control Devices for Streets and Highways, U. S. Department of Commerce, Washington, D. C., 1961.
20. Warner, Stanley Leon, Stochastic Choice of Mode in Urban Travel: A Study in Binary Choice, The Transportation Center at Northwestern University, Northwestern University Press, 1962.
21. Wyatt, George H., Testimony, Interstate Commerce Commission, No. 33440, Washington, D. C., 1964.

APPENDIX

LINE OF SIGHT RATIO DERIVATION AND CURVES

This appendix contains the derivation of the line of sight ratio variable, information for obtaining the necessary field measurements, and curves for determining the numerical value of the line of sight ratio.

The derivation of the line of sight ratio is based on the following definitions:

V_c = assumed vehicle speed for a given posted speed limit - mph,

SSD = minimum stopping sight distance - feet,

D_b = braking distance - feet,

t_1 = perception-reaction time - seconds,

t_2 = time required for a driver to bring his vehicle to a stopped position within the minimum stopping sight distance - seconds,

V_t = speed of fastest train - mph,

D_t = distance traveled by fastest train - feet,

ϕ = angle of intersection - degrees, and

θ = actual corner sight angle - degrees, and

Δ = minimum desirable corner sight angle - degrees.

The geometry of the line of sight triangle is shown in Figure 6. Thus, for a generalized configuration, the time and distance relationships are:

$$\begin{aligned} t_2 &= t_1 + \frac{2 D_b}{1.47 V_c} \\ &= 2.5 + \frac{2 D_b}{1.47 V_c}, \text{ and} \end{aligned}$$

FIGURE 6. GEOMETRY OF THE CORNER SIGHT TRIANGLE

$$D_t = 1.47 V_t t_2$$

Therefore, by the Sine Law, the minimum desirable corner sight angle is expressed as:

$$\frac{\sin \Delta}{D_t} = \frac{\sin (180 - \phi - \Delta)}{SSD}$$

The determination of Δ requires a trial and error solution of the above expression. The line of sight ratio is then equivalent to the actual corner sight angle divided by the minimum desirable corner sight angle.

Computation of the line of sight ratio is facilitated by the curves shown as Figures 7 through 12. These figures also permit a graphical solution of the minimum desirable corner sight angle. The development of the curves was based on the above derivation and the relationships listed in Table 4 (1). The table also provides the minimum stopping sight distances necessary for field measurement of the actual ratio for any grade crossing quadrant is illustrated by the following example:

Given: 20-mph posted speed limit; 90-deg intersection angle; and
speed of fastest train = 50 mph.

1. The minimum stopping sight distance of 97 ft is obtained from Table 4.
2. At a distance of 97 ft from the grade crossing, the maximum corner sight angle is measured for the given quadrant. This angle represents the actual corner sight angle, .
3. On Figure 7, a horizontal line is extended from the fastest train speed value of 50 mph to the curve representing an angle of intersection of 90 deg.

20 MPH SPEED LIMIT

ANGLE OF INTERSECTION (ϕ)

FIGURE 7. LINE OF SIGHT RATIO CURVES

25 MPH SPEED LIMIT

ANGLE OF INTERSECTION (ϕ)

FIGURE 8. LINE OF SIGHT RATIO CURVES

FIGURE 9. LINE OF SIGHT RATIO CURVES

35 MPH SPEED LIMIT

ANGLE OF INTERSECTION (ϕ)

FIGURE 10. LINE OF SIGHT RATIO CURVES

40 MPH SPEED LIMIT

ANGLE OF INTERSECTION (ϕ)

FIGURE II. LINE OF SIGHT RATIO CURVES

45 MPH SPEED LIMIT

ANGLE OF INTERSECTION (ϕ)

FIGURE 12. LINE OF SIGHT RATIO CURVES

TABLE 4

MINIMUM STOPPING SIGHT DISTANCE RELATIONSHIPS

Posted Speed Limit	V_c (mph)	D_b (ft)	SSD (ft)
20	18	31	97
25	23	51	136
30	28	73	176
35	32	106	223
40	36	131	263
45	40	168	314

4. From this point, a vertical line is extended to the minimum desirable corner sight angle, 75 deg.
5. From the intersection of the vertical line and the curve representing the actual corner sight angle, a horizontal line is extended to the line of sight ratio axis.
6. This intersection point is the line of sight ratio for the given conditions.
7. For an actual corner sight angle of 50 deg, the line of sight ratio is 0.67.