

EVALUATION OF METHODS FOR PREDICTING RAIL-
HIGHWAY CROSSING HAZARDS

by

Ardeshir Faghri
Research Scientist Assistant

and

Michael J. Demetsky
Faculty Research Scientist

(The opinions, findings, and conclusions expressed in this
report are those of the authors and not necessarily those of
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ABSTRACT

The need for improvement at a rail/highway crossing typically is based on the Expected Accident Rate (EAR) in conjunction with other criteria carrying lesser weight. In recent years new models for assessing the need for improvements have been developed, and in the research reported here five such models selected from a list established from a literature review and a user survey were evaluated. The selected models--the DOT, Peabody-Dimmick, NCHRP No. 50, Coleman-Stewart, and New Hampshire--were evaluated using a data base maintained by the Virginia Department of Highways and Transportation. Additionally, the performance of the methods in predicting the EAR were compared using the chi-square test and the power factor. The results indicated that the DOT formula outperformed the other four methods in both the evaluative and comparative analyses, and thus was recommended for use. The priority list produced by this formula is only one criterion used in determining the need to improve conditions at any crossing. It must be supplemented with information obtained by regular site inspections and with qualitative data that cannot feasibly be incorporated into a mathematical formula.

TABLE OF CONTENTS

| | <u>Page</u> |
|--|-------------|
| STANDARD TITLE PAGE..... | i |
| ABSTRACT..... | iii |
| INTRODUCTION..... | 1 |
| PROBLEM STATEMENT..... | 2 |
| PURPOSE..... | 3 |
| IDENTIFICATION OF NATIONALLY RECOGNIZED MODELS | |
| FOR PREDICTING HAZARD POTENTIAL..... | 4 |
| THE MODELS SELECTED FOR EVALUATION..... | 5 |
| NCHRP #50..... | 6 |
| New Hampshire..... | 10 |
| DOT..... | 10 |
| Coleman-Stewart..... | 13 |
| Peabody-Dimmick..... | 18 |
| VIRGINIA DATA BASE..... | 25 |
| EVALUATION OF THE MODELS..... | 29 |
| Methodology..... | 29 |
| Results..... | 31 |
| RECOMMENDATIONS..... | 34 |
| ACKNOWLEDGEMENTS..... | 37 |
| REFERENCES CITED..... | 39 |
| SELECTED REFERENCES..... | 41 |
| APPENDIX A - Hazard Index Formulae..... | A-1 |
| APPENDIX B - Computer Analysis..... | B-1 |
| APPENDIX C - The Power Factors for Different..... | C-1 |
| Percentiles of Hazard | |
| APPENDIX D - Summary of the DOT Resource Allocation Model..... | D-1 |

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INTRODUCTION

Safety at highway/railroad grade crossings is an important issue throughout the United States. Federal Railroad Administration figures show that nationally 3,067 people were killed in 42,206 automobile/train collisions from 1979 to 1983. In Virginia, there were 162 such collisions with 8 fatalities at the 1,536 rural public crossings on roads from 1980 to 1984.

The Highway Safety Acts of 1973 and 1976 and the Surface Transportation Assistance Acts of 1978 and 1982 provide federal funding to states for safety improvement projects at public rail-highway crossings. To promote effective use of these funds, states are required to establish procedures for ranking crossings and then use such rankings in an allocation process. The objective is to allocate funds to improvements of crossings and warning devices in a manner that achieves the greatest accident reduction.(1)

In 1983, responsibility for inventorying grade crossings and establishing preliminary priorities for improvement projects in Virginia was assigned to the Rail and Public Transportation Division. The division identifies potential improvement needs based on an Expected Accident Rate (EAR) and lists the crossings in terms of this rate. It then uses the EAR listing and other criteria to identify a preliminary list of needed improvements.

The model used in Virginia to estimate the EAR is documented in NCHRP Report No. 50 and is a modified version of the New Hampshire model.(2,3) This model was used previously by the Highway and Traffic Safety Division and passed to the Rail and Public Transportation Division when it assumed this responsibility.

Virginia maintains a grade crossing inventory based on the format used by the Federal Highway Administration (FHWA), Federal Railroad Administration (FRA), and the Association of American Railroads (AAR). Part of the information in the inventory is maintained in a computerized data base, and the remainder in written form.(2) The computer data base supports the presently used prediction method, but data can be added for use in an alternative method.

PROBLEM STATEMENT

The New Hampshire model represents one of the early attempts to measure hazard potentials at rail-highway crossings. The primary reference to the model given by the Rail and Public Transportation Division is NCHRP Report No. 50, p. 60. There is no reference to the model as the "New Hampshire Model" in that source, where a detailed graphical solution is provided. There, it is called the "Train Involved Accident Model."

In recent years, new methods such as the U.S. Department of Transportation (DOT) accident prediction formula(1) and the Coleman-Stewart model(4) have been developed. With the availability of these methods, the Rail and Public Transportation Division of the Virginia Department of Highways and Transportation requested that several of the methods deemed most promising for its use be evaluated in conjunction with both state and U.S. data bases (DOT - AAR national rail-highway crossing inventory and FRA accident files). Also, it was thought that variables such as sight distance and the number of school buses using a crossing would be appropriate for inclusion in the methods to be evaluated and should be examined for their significance. Accordingly, the request from the Rail and Public Transportation Division stipulated that the available methods be examined in light of certain practical criteria and that the best approach to predicting the relative hazard potential at rail-highway crossings in Virginia be recommended.

PURPOSE

This study was conducted to (a) establish a list of the nationally recognized models, (b) evaluate representative models for their ability to use available data to show hazard potentials at crossings, and (c) recommend whether the currently used method, a modification of it, or a different method should be used by the Rail and Public Transportation Division to predict the accident potential at a crossing.

IDENTIFICATION OF NATIONALLY RECOGNIZED MODELS FOR
PREDICTING HAZARD POTENTIAL

Through a literature review the 13 models listed in Table 1 were determined to be used nationwide. Information obtained for 7 of these models--the Coleman-Stewart, Peabody-Dimmick, New Hampshire, Oregon, Utah, City of Detroit, and DOT--provided full documentation on their development, testing, verification, and application. The information found for the remaining 6 was limited to the basic format and the variables they used. Idaho and Mississippi have dropped their original models and now use the DOT model. Ohio, Wisconsin, and North Dakota use modified versions of their original models. Since no states ever used the Contra Costa County model, it could also be dismissed. Of the 7 remaining models, only 6 differ in their basic forms, as the City of Detroit and Utah models use the same formulation.

Table 1

Nationally Recognized Models for Predicting Hazard Potential

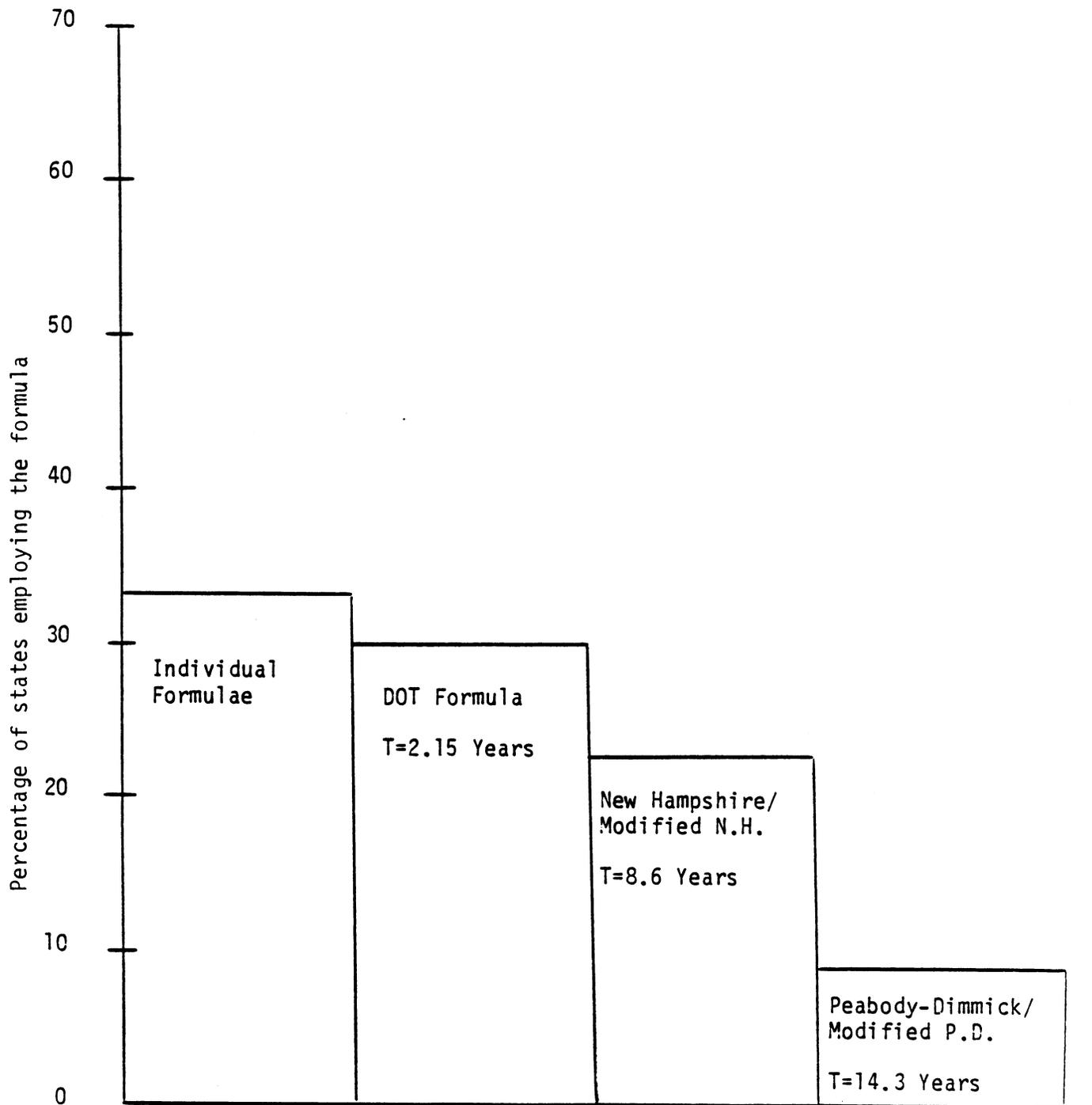
Coleman-Stewart
Peabody-Dimmick
Mississippi
New Hampshire
Ohio
Wisconsin
Contra Costa County
Oregon
North Dakota Rating System
Idaho
Utah
City of Detroit
DOT

In addition to the information collected on the 13 models as noted above, data were obtained through a survey questionnaire sent to the departments of transportation in the other 49 states and the District of Columbia to determine the formulae and methods they use to predict accidents at public rail-highway crossings. The current utilization of models by the states is summarized in Figure 1, and the factors considered in the formulae used are listed in Table 2.

THE MODELS SELECTED FOR EVALUATION

The empirical formulae for calculating hazard indexes can be categorized into two basic groups. In one group are relative formulae that provide a measure of the relative hazards or the accident expectations at various types of railway crossings. These may be used to rank a large number of crossings in order of priority for improvement, the crossing with the highest index being regarded as potentially the most dangerous and hence the most in need of attention. The second group consists of absolute formulae that forecast the number of accidents likely to occur at a crossing or a number of crossings over a certain time period, and the number of accidents that may be prevented by making improvements at these crossings.

Based on the information obtained from the literature on the 13 aforementioned models and the results of the survey questionnaire to the states, 5 formulae were selected for testing and evaluation. The DOT, Peabody-Dimmick, NCHRP No. 50, and Coleman-Stewart represent the absolute formulae. The Coleman-Stewart model, which is relatively new, was included in the evaluation since little is known about its performance. The New Hampshire represented relative formulae.



Rail-Highway Accident Prediction Formulae Employed By States

Figure 1. Utilization of models to predict rail/highway crossing hazards by various states. (n=45 states, T=average number of years the formula has been used)

Table 2

Factors Considered in the Formulae as Determined
in Questionnaire Survey

| <u>Factor Considered</u> | <u>Number of Formulae Containing the Factor (n=13)</u> | <u>Number of States Using the Factor in Their Formulae (n=45)</u> |
|--|--|---|
| Vehicles per day | 13 | 43 |
| Trains per day | 13 | 43 |
| Existing protection | 10 | 37 |
| Sight distance | 7 | 14 |
| Train speed | 6 | 13 |
| Number of tracks | 9 | 22 |
| Highway vehicular speed | 5 | 22 |
| Accident records | 5 | 23 |
| Condition or type of crossing | 3 | 20 |
| Condition of approaches | 3 | 6 |
| Type of train | 3 | 5 |
| Approach gradient | 2 | 6 |
| Angle of crossing | 2 | 5 |
| Pedestrian hazard | 2 | 1 |
| Distribution of vehicular and/or train volumes throughout the day | 3 | 14 |
| Time crossing is blocked | 1 | 1 |
| Darkness | 1 | 1 |
| Number of traffic lanes | 2 | 15 |
| School buses and/or carriers of hazardous materials | 0 | 5 |

The 5 selected models are discussed below and the remaining 8 are given in Appendix A.

NCHRP No. 50

For predicting the expected number of accidents per year at each public grade crossing, the Virginia Department of Highways and Transportation is currently employing the methodology that was documented in NCHRP Report No. 50.(3) This report, which was prepared by Alan M. Voorhees & Associates in 1968, is a comprehensive document that interprets and analyzes highway-rail grade crossing data for the United States. It also gives the development of a mathematical model for predicting accidents. The model was based on accident data obtained from a 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 5-year period.

This study used data from 7,500 crossings and developed a statistical procedure that permits calculation of a probable accident rate for a railroad grade crossing. This procedure (summarized in Figure 2) takes into consideration the number of trains, traffic volume, type of protection, environment (urban or rural), and, for certain types of protection, the gradient, number of traffic lanes, and angle of crossing.

Figure 2 presents the accident prediction model in a simple graphic form that allows easy computation of accidents per year at any type of railroad crossing. The equation can be used on (1) an average daily vehicular traffic and daily train volume basis, (2) a partial-day basis, or (3) an hourly basis.

| VEHICLES PER DAY | 'A' FACTOR |
|------------------|------------|
| 250 | .000347 |
| 500 | .000694 |
| 1000 | .001377 |
| 2000 | .002627 |
| 3000 | .003981 |
| 4000 | .005208 |
| 5000 | .006516 |
| 6000 | .007720 |
| 7000 | .009005 |
| 8000 | .010278 |
| 9000 | .011435 |
| 10000 | .012574 |
| 12000 | .015012 |
| 14000 | .017315 |
| 16000 | .019549 |
| 18000 | .021736 |
| 20000 | .023877 |
| 25000 | .029051 |
| 30000 | .034157 |

EXAMPLE:
ASSUME

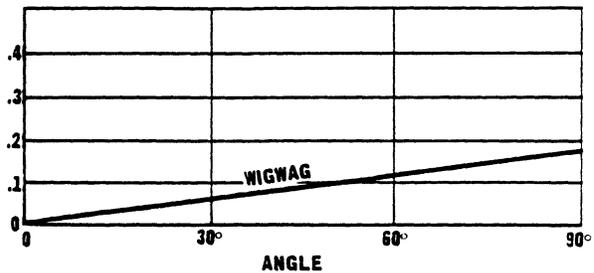
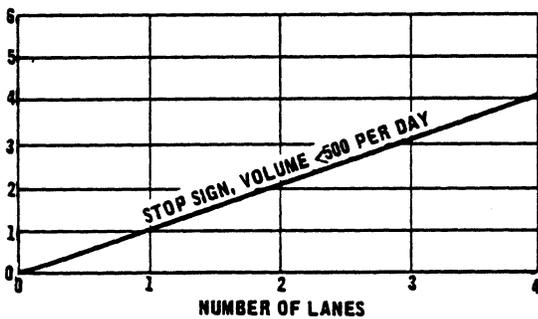
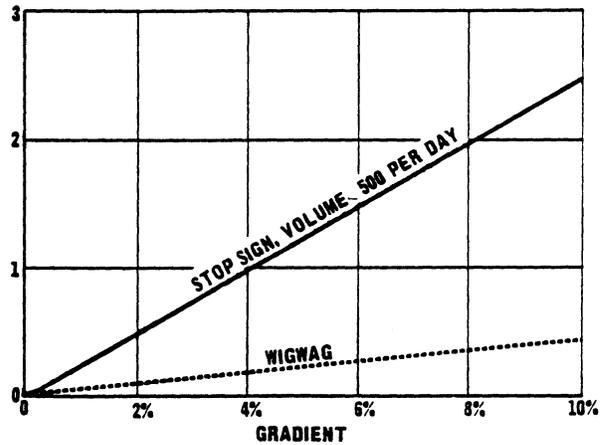
URBAN AREA
CROSSBUCK PROTECTION
5000 VEHICLES PER DAY
5 TRAINS PER DAY

EXPECTED ACCIDENTS

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

'B' FACTOR COMPONENTS
(**'B' FACTOR = BASIC VALUE + ADJUSTMENTS¹**)

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



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

Figure 2. Calculation of expected accidents.
(From reference 3)

New Hampshire Formula

Despite the varying degrees of refinement and the large number of variables they may incorporate, some of the simplest formulae give results very close to the mean results obtained from all formulae. In a test to see whether different hazard index formulae gave significantly different priorities, Bezkorovainy used several well-known formulae to rank 180 level crossings in Lincoln, Nebraska.(5) He found that the hazard index rank order obtained as the average from all formulae was most closely approximated by the rank order obtained from the New Hampshire formula, which is stated simply as

$$\text{Hazard Index} = VT P_f, \quad (1)$$

where

V = average 24-hour traffic volume,

T = average 24-hour train volume, and

P_f = protection factor (gates = 0.1; flashing lights = 0.6; signs only = 1.0).

DOT Accident Prediction Formula

The availability of both inventory and accident data for crossings influenced the development of the DOT accident prediction formula.(1) The method is described in Figure 3. The formula calculates the expected annual number of accidents at a crossing on the basis of characteristics of the crossing described in the inventory and the accident experience of the crossing described in the FRA Railroad Accident Incident Reporting System (RAIRS).

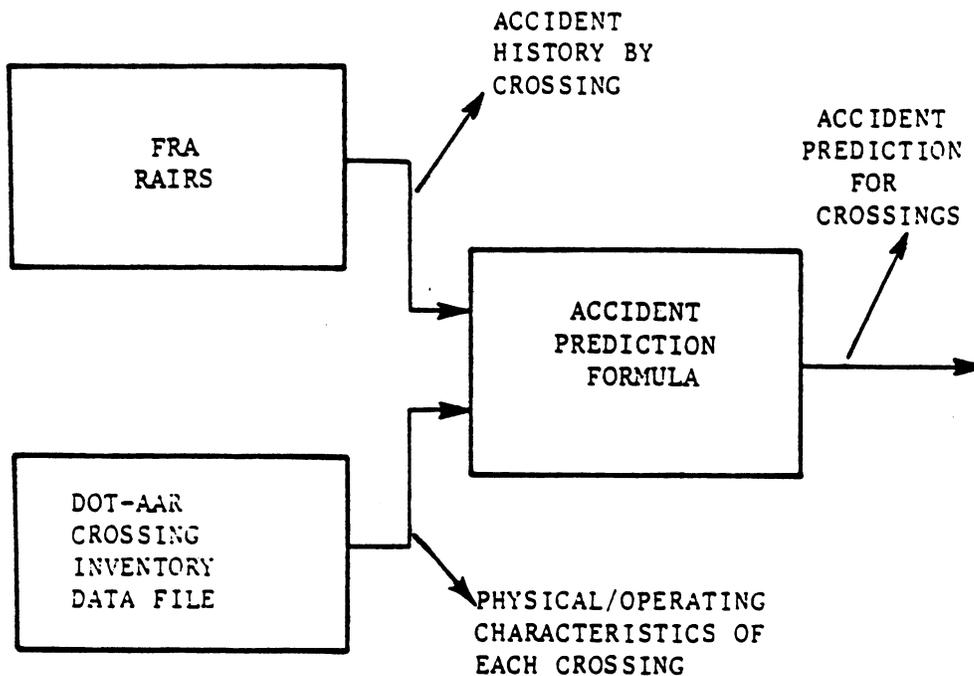


Figure 3. DOT rail-highway crossing accident prediction formula.
(From reference 1)

The DOT formula is of the absolute type since it estimates the number of accidents. The formula combines two independent predictions of the number of accidents for a crossing to produce the prediction for use. The two independent predictions are obtained from the following two sources:

1. A "basic" formula (equation 2) provides an initial prediction of accidents on the basis of the characteristics of the crossing as described in the inventory. This formula predicts crossing accidents through a calculation similar to that used in other common formulae, such as the Peabody-Dimmick and New Hampshire. It is

$$a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL, \quad (2)$$

where

- a = initial accident prediction, accidents per year at the crossing,
- K = constant for initialization of factor values at 1.00,
- EI = factor for exposure index based on product of highway and train traffic,
- MT = factor for number of main tracks,
- DT = factor for number of thru trains per day during daylight,
- HP = factor for highway paved (yes or no),
- MS = factor for maximum timetable speed,
- HT = factor for highway type, and
- HL = factor for number of highway lanes.

2. The second prediction is equal to the observed accident history at a crossing. It assumes that future accidents per year will be the same as the average historical accident rate. It is referred to as the accident history of the crossing, and is equal to the total observed accidents divided by the number of years over which the observations were made.

The DOT accident prediction formula can be expressed as

$$A = \frac{T_0}{T_0 + T} (a) + \frac{T}{T_0 + T} \left(\frac{N}{T}\right), \quad (3)$$

where

- A = final accident prediction, accidents per year at the crossing,
- $\frac{N}{T}$ = accident history prediction, accidents per year, where N is the number of observed accidents in T years at the crossing, and

$$T_o = \text{formula weighting factor} = \frac{1}{0.05 + a} .$$

The DOT formula calculates a weighted average of the predicted accidents at a crossing from the basic formula (a) and accident history ($\frac{N}{T}$). The two formula weights, $\frac{T_o}{T_o + T}$ and $\frac{T}{T_o + T}$, add to the value 1.0.

The basic formula in equation 2 was developed by applying nonlinear multiple regression techniques to crossing characteristics stored in the August 1976 inventory and 1976 accident data contained in the FRA RAIRS. Half of the file was used to determine the formula coefficients by regression and iteration (data set A), and the other half for testing the formula (data set B). Data sets A and B were disjoint, of equal size, and comprised of a random sample of records from the inventory, including all records for which accident data existed in the RAIRS file. Each data set was categorized into two groups of accident and non-accident crossings. The resulting basic formula can be expressed as a series of factors which, when multiplied together, yield the initial predicted accidents per year (a) at a crossing. Each factor in the formula represents a characteristic of the crossing described in the inventory.

It must be noted that in this study only the basic DOT formula was tested and compared with the available 5-year accident data. This provided a more meaningful basis than the DOT final accident prediction formula for comparing and selecting the best of the five models evaluated.

Coleman-Stewart Model

The Coleman-Stewart formula is an absolute type formula and determines the probable average number of accidents per crossing year. It was developed by Janet Coleman and Gerald R. Stewart of the FHWA.(4) In

developing it, they obtained data for accidents that involved trains at grade crossings and inventory data from 45 states. Because of difficulties in matching accident data with crossing inventory data, only data from 37,230 grade crossings in 15 states could be used in the final data base. In the tabulation of accident data, crossings were classified according to the number of tracks (single or multiple), the location (urban or rural), and the type of warning device (automatic gates, flashing lights, other active, crossbucks, stop signs, or none). A summary of these data is given in Table 3.

Table 3
Accident Data According to Type of Crossing

| <u>Crossing Type</u> | <u>Percent Grade Crossing</u> | <u>Percent Reported Accidents</u> |
|-------------------------------|-----------------------------------|---------------------------------------|
| Single track | | |
| Urban | | |
| Percentage of total | 23 | 26 |
| Percentage of single tracks | 68 | 50 |
| Rural | | |
| Percentage of total | 48 | 26 |
| Percentage of single tracks | 68 | 50 |
| | <u>71</u> | <u>52</u> |
| Multiple track | | |
| Urban | | |
| Percentage of total | 16 | 32 |
| Percentage of multiple tracks | 54 | 67 |
| Rural | | |
| Percentage of total | 13 | 15 |
| Percentage of multiple tracks | 46 | 33 |
| | <u>29</u> | <u>47</u> |

Source: Reference 4.

The sample crossings were then stratified according to the volume ranges of highway and train traffic given in Table 4.

Table 4

Volume Ranges of Highway and Train Traffic

| <u>Average Vehicles Per Day</u> | <u>Average Trains Per Day</u> |
|---------------------------------|-------------------------------|
| 1 to 250 | 1 to 2 |
| 251 to 500 | 3 to 5 |
| 501 to 1,000 | 6 to 10 |
| 1,001 to 5,000 | 11 to 20 |
| 5,001 to 10,000 | 21 to 40 |
| 10,001 to 40,000 | 41 to 100 |

Source: Reference 4.

This stratification yielded 24 sets of two-way tables. For each cell within these tables, the following information was tabulated:

- N = number of grade crossings
- N* = number of crossing years of data
(cumulative years of available accident data)
- A = total number of accidents reported for the N* crossing years
- \bar{A} = the average number of accidents per crossing year (A/N*)
- \bar{V} = the weighted average daily traffic volume for the N crossings (the weights are the number of years of available accident data for each of the N crossings)
- \bar{T} = the weighted average train volume for the N crossings (the weights are the numbers of years of available accident data for the N crossings)

The distribution characteristics of the 37,230 sample grade crossings and 9,490 accidents were shown in Table 3.

For purposes of generalization, it was assumed that each crossing within a group had an accident potential equivalent to the average rate

(\bar{A}) for that group; therefore, the development of accident prediction equations focused on the relations between observed accident rates for groups of crossings with similar physical characteristics and the associated average daily highway and train volumes. As a group, crossings are considered to be similar if they fall within a common range of such characteristics as location, number of tracks, warning device, and highway and train volumes.

Seventy percent of the sample data base was randomly selected for testing alternative models for multiple linear regression, and the remaining data were reserved for validation purposes. The following models were both found to offer a reasonable and statistically significant explanation of the observed accident rates for the grouped data.

Model 1

$$\text{Log}_{10}\bar{A} = C_0 + C_1 \text{Log}_{10}\bar{V} + C_2 \text{Log}_{10}\bar{T}. \quad (4)$$

Model 2

$$\text{Log}_{10}\bar{A} = C_0 + C_1 \text{Log}_{10}\bar{V} + C_2 \text{Log}_{10}\bar{T} + C_3 (\text{Log}_{10}\bar{T})^2. \quad (5)$$

In some situations, the additional term $C_3 (\text{Log}_{10}\bar{T})^2$ enabled model 2 to achieve an improved fit for accident rates in the higher volume categories. For this reason, the model 2 regression results given in Table 5 represent the preferred accident prediction equations. With a few exceptions, the signs of the coefficients correspond to expectations.

Table 5
Model 2 Regression Results

| Item | C ₀ | C ₁ | C ₂ | C ₃ | R ² | Item | C ₀ | C ₁ | C ₂ | C ₃ | R ² |
|---------------------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|----------------|----------------|----------------|----------------|----------------|
| Single-track urban | | | | | | Multiple-track urban | | | | | |
| Automatic gates | -2.17 | 0.16 | 0.96 | -0.35 | 0.186 | Automatic gates | -2.58 | 0.23 | 1.30 | -0.42 | 0.396 |
| Flashing lights | -2.85 | 0.37 | 1.16 | -0.42 | 0.729 | Flashing lights | -2.50 | 0.36 | 0.68 | -0.09 | 0.691 |
| Crossbucks | -2.38 | 0.26 | 0.78 | -0.18 | 0.684 | Crossbucks | -2.49 | 0.32 | 0.63 | -0.02 | 0.706 |
| Other active | -2.13 | 0.30 | 0.72 | -0.30 | 0.770 | Other active | -2.16 | 0.36 | 0.19 | 0.08 | 0.65 |
| Stop signs | -2.98 | 0.42 | 1.96 | -1.13 | 0.590 | Stop signs | -1.43 | 0.09 | 0.18 | 0.16 | 0.35 |
| None | -2.46 | 0.16 | 1.24 | -0.56 | 0.24 | None | -3.00 | 0.41 | 0.63 | -0.02 | 0.58 |
| Single-track rural | | | | | | Multiple-track rural | | | | | |
| Automatic gates | -1.42 | 0.08 | -0.15 | 0.25 | 0.200 | Automatic gates | -1.63 | 0.22 | -0.17 | 0.05 | 0.142 |
| Flashing lights | -3.56 | 0.62 | 0.92 | -0.38 | 0.857 | Flashing lights | -2.75 | 0.38 | 1.02 | -0.36 | 0.674 |
| Crossbucks | -2.77 | 0.40 | 0.89 | -0.29 | 0.698 | Crossbucks | -2.39 | 0.46 | -0.50 | 0.53 | 0.780 |
| Other active | -2.25 | 0.34 | 0.34 | -0.01 | 0.533 | Other active | -2.32 | 0.33 | 0.80 | -0.35 | 0.31 |
| Stop signs | -2.97 | 0.61 | -0.02 | 0.29 | 0.689 | Stop signs | -1.87 | 0.18 | 0.67 | -0.34 | 0.32 |
| None | -3.62 | 0.67 | 0.22 | 0.26 | 0.756 | None | - | - | - | - | - |

*Insufficient data.

Source: Reference 4.

It is important to note that the regression results give predicted logarithms of accident rates. Since the equations would be used in terms of expected numbers of accidents rather than the logarithms of accident rates, correlations between the observed and predicted numbers of accidents were calculated and are given in Table 6.

Table 6
Model 2 Validation Results

| Item | Correlation Between Accidents | | Item | Correlation Between Accidents | |
|---------------------------|-------------------------------|-----------------|-----------------------------|-------------------------------|-----------------|
| | Regression Data | Validation Data | | Regression Data | Validation Data |
| Single-track urban | | | Multiple-track urban | | |
| Automatic gates | 0.7916 | 0.5959 | Automatic gates | 0.8954 | 0.8705 |
| Flashing lights | 0.9183 | 0.7309 | Flashing lights | 0.9129 | 0.7567 |
| Crossbucks | 0.9308 | 0.7963 | Crossbucks | 0.8775 | 0.7629 |
| Other active | 0.9421 | 0.7564 | Other active | 0.9130 | 0.6046 |
| Stop signs | 0.7377 | 0.8451 | Stop signs | 0.9142 | 0.5565 |
| None | 0.6804 | 0.4938 | None | 0.4548 | -0.2921 |
| Single-track rural | | | Multiple-track rural | | |
| Automatic gates | 0.7107 | -0.4573 | Automatic gates | 0.8027 | 0.7443 |
| Flashing lights | 0.9640 | 0.8564 | Flashing lights | 0.6728 | 0.4148 |
| Crossbucks | 0.9229 | 0.8892 | Crossbucks | 0.7670 | 0.6570 |
| Other active | 0.8675 | 0.7652 | Other active | 0.9442 | 0.9898 |
| Stop signs | 0.7976 | 0.7414 | Stop signs | 0.9081 | 0.7952 |
| None | 0.7490 | 0.8095 | None | - | - |

*Insufficient data.

Source: Reference 4.

The 30% sample of crossing data originally withheld were used for a cross validation of the model 2 equation. The results are also given in Table 6. In a cross-validation procedure, the regression results from the analysis are applied to a separate independent sample of validation data to obtain predicted values of the dependent variable. The correlation between the observed and predicted values is an estimate of the validity of the derived regression results. One may conclude from the results in Tables 5 and 6 that the accident prediction equations for crossbucks, flashing lights, and other active devices will generally be reliable for translating the train and vehicle volume characteristics for grouped crossings into predicted numbers of accidents. On the other hand, the relation between volume characteristics and accidents seems to be much weaker in the case of automatic gates. Also the prediction equations for stop signs are weak, except for the case of single-track crossings.

Peabody-Dimmick Formula

The Peabody-Dimmick formula, an absolute type, determines the probable number of accidents in 5 years at any crossing. It was developed by L. E. Peabody and T. B. Dimmick of the Bureau of Public Roads in 1941.(6)

The data base they used consisted of a large amount of information, collected by various highway planning surveys from all sections of the country, on rural crossings at which accidents had occurred. Data concerning 3,563 such crossings were furnished by the planning survey organizations of 29 states. This information consisted of a description and sketch of the crossing, a statement of the highway and railway traffic using the crossing, and a description of the accidents that had occurred in a 5-year period.

The description of the crossing included the clear view distances measured along the tracks from points on the highway 300 feet from the crossing, the gradient of the highway on both sides of the crossing, the alignment of the highway at the crossing, the surface type, the number of tracks crossed, the angle of intersection of the highway with the railway, and other special features that might affect the safety of the crossing. Any type of protection that had been installed at the location was described. Data concerning the average daily highway and train traffic were generally subdivided to show the division between passenger car and commercial traffic on the highways and the division between high-speed, medium-speed, and standing or switching trains on the railroads. Finally, the number of accidents, including the number of persons killed and the number injured, was given and the accident causes that could be determined were reported. This information covered a period of 5 years, generally from 1932 to 1936 inclusive, and furnished a basis for determining the relations between the number of accidents and some of the factors contributing to these accidents.

The formula for rating crossings derived herein is general and does not completely take into account special local conditions that greatly affect the true hazards at a given crossing. For example, there were crossings where every train movement was guarded by brakemen who served as flagmen. These crossings showed a statistical movement of a certain number of trains per day, while from the standpoint of true hazard (because of the protection given each train movement), there are actually no trains per day.

Another problem involved in the derivation of the formula was whether to include in the analysis crossings for which no accidents were reported during the period covered by the study. It is possible that at these crossings there may have been an accident very soon after the close of the period under observation, or there may have been an accident in

the period just prior to that for which data were reported. Five years, the period used in the study covered by this report, is a rather short time for the establishment of true accident ratings, and a rating of 0.2 on the basis of 5 years' experience might become a rating of 0.8 on 25 years' experience. Because of this relatively high variability and the relative shortness of the experience, it was decided to omit from consideration altogether data for crossings at which no accidents were reported within the 5 years studied.

A study was made of the data to determine if there were any relationships between the numbers of accidents and the various items concerning the crossings. This study indicated that for traffic, both highway and train, and type of protection, there was a relationship. Other items, although they probably influenced the safety or hazard at individual crossings, when considered in combination indicated no average trend or one too indefinite for practical use. The results of this preliminary study indicated, therefore, that traffic and protection were the only dependable factors for use in rating the crossings on an average accident basis.

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

Preliminary coefficients were determined for the various common types of protection by determining the average number of "exposure units" which passed over all crossings having each type of protection for each accident which had occurred at those crossings. The exposure units were

obtained by multiplying the average daily highway traffic by the average daily train traffic. These products were divided by 100 to reduce the size of the figure. The coefficient for each type of protection was determined as

$$P = \frac{1}{N} \sum \left(\frac{H \times T}{100 A} \right) = \frac{1}{100 N} \sum \left(\frac{H \times T}{A} \right), \quad (6)$$

where

- P = the protection coefficient for a type of protection,
- N = the number of crossings in a type group,
- H = the highway traffic at each crossing,
- T = the train traffic at each crossing, and
- A = the number of accidents.

Using equation 6, the protection coefficients given in Table 7 were determined.

Using the highway traffic, the train traffic, and the protection coefficient as independent variables and the number of accidents as the dependent variable, a correlation was made of the data using the equation

$$I = C \frac{H^a \times T^b}{P^c} + K, \quad (7)$$

where

- I = probable number of accidents in a 5-year period (this figure to be used as the hazard rating),
- H = highway traffic--average daily number of vehicles,
- T = train traffic--trains per day,
- P = protection type coefficient,
- C = constant,
- K = additional parameter, and
- a, b, and c = fractional exponents.

Table 7

Protection Coefficients for the Peabody-Dimmick Formula

| <u>Type of Protection</u> | <u>Preliminary Protection Coefficient</u> |
|------------------------------------|---|
| Signs | 19 |
| Bells | 29 |
| Wigwag | 56 |
| Wigwag and bells | 63 |
| Flashing lights | 96 |
| Flashing lights and bells | 114 |
| Wigwag and flashing lights | 121 |
| Wigwag, flashing lights, and bells | 147 |
| Watchman, 8 hours | 119 |
| Watchman, 16 hours | 180 |
| Watchman, 24 hours | 228 |
| Gates, 24 hours | 241 |
| Gates, automatic | 333 |

Source: Reference 6.

The probable number of accidents which would occur at a crossing in a 5-year period was assumed to be a sufficient index of the hazard at the crossing. From the correlation made, it was found that the index could be calculated as

$$I = 1.28 \frac{H^{0.170} \times T^{0.151}}{p^{0.171}} + K. \quad (8)$$

Once the accident contribution factors H^a , T^b , and P^c are inserted, the formula may be reduced to

$$I = I_u + K, \quad (9)$$

where

I = probable number of accidents in a 5-year period (the hazard rating),

I_u = an unbalanced rating, and

K = an additional parameter.

The factor K can be obtained from Figure 4, which gives the variation of this factor for values of the unbalanced rating I_u . The product of H^a , T^b , and C divided by P^c , plus K , gives the probable number of accidents which will occur in a period of 5 years and a number used in this study as the hazard rating.

To test the reliability of the formula, it was used to develop ratings with data for 123 crossings not used in its derivation. A large majority of these crossings were relatively safe, having experienced no more than three recorded accidents during the 5-year reporting period, while some had experienced from six to eight accidents. The estimated numbers of accidents are compared with the actual numbers of accidents recorded at these 123 locations in Table 8.

The probable number of accidents which will occur at any crossing cannot be obtained by means of this formula with a high degree of accuracy. While the factors used account for a large part of the variation in the accident probability, there are other variables that were not reported but probably have a definite influence.

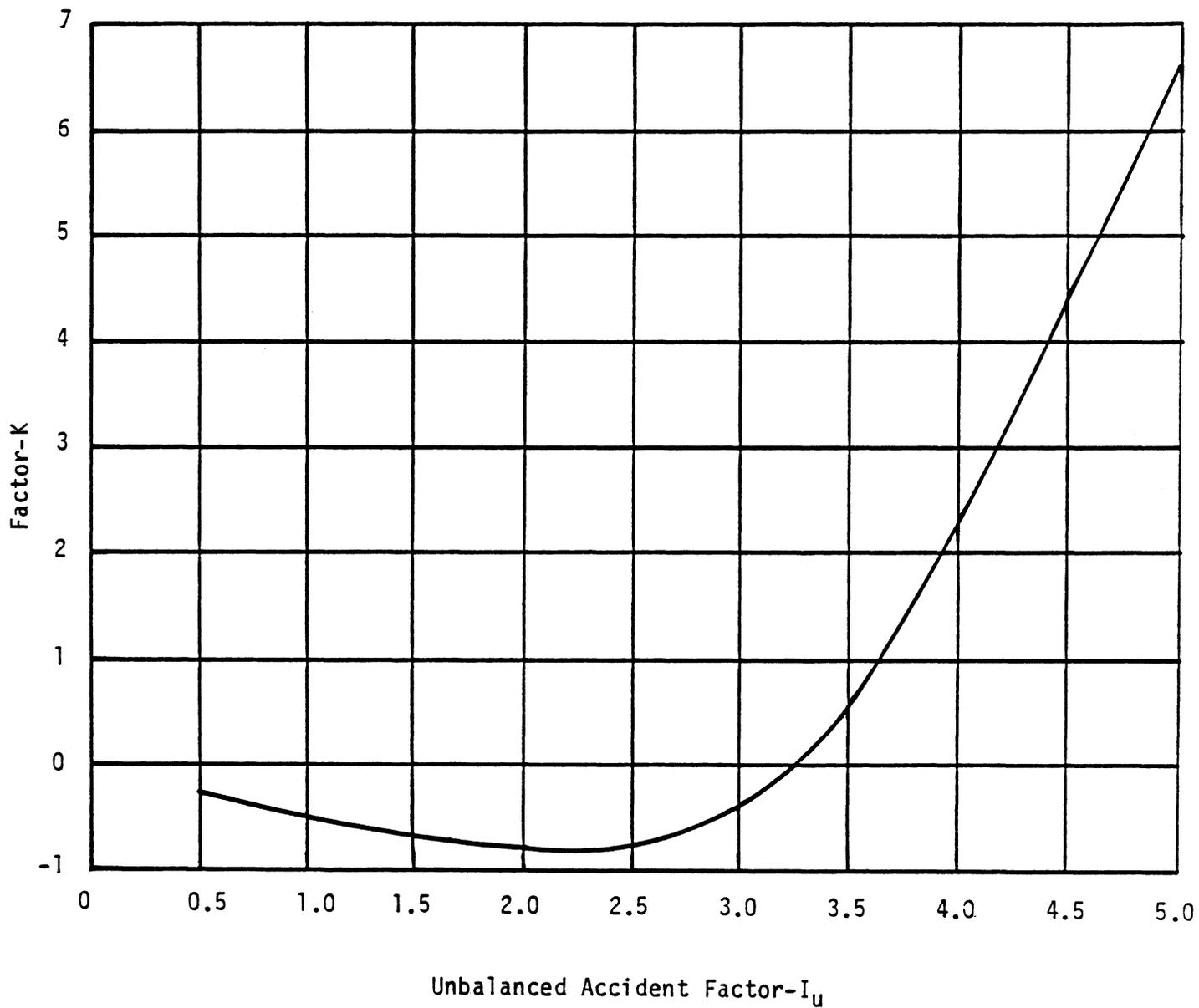


Figure 4. Relation between unbalanced accident factor computed from formula I_u as compared to smoothing factor, K . (From reference 6)

Table 8

Average Computed Number of Accidents Using
Peabody-Dimmick Formula in 10 States Compared to
Actual Number of Accidents Recorded at Those Crossings

| <u>Number of Crossings</u> | <u>Actual Number of Accidents</u> | <u>Average Computed Accidents</u> |
|----------------------------|-----------------------------------|-----------------------------------|
| 15 | 1 | 1.21 |
| 47 | 2 | 1.84 |
| 39 | 3 | 3.05 |
| 11 | 4 | 3.69 |
| 3 | 5 | 5.20 |
| 5 | 6 | 6.18 |
| 1 | 7 | 7.36 |
| 2 | 8 | 8.37 |

VIRGINIA DATA BASE

As noted previously, the Rail and Public Transportation Division maintains a grade crossing inventory program which was developed by the FHWA, FRA, and AAR. Each crossing is assigned a unique inventory number, and relevant information is collected and tabulated. Part of the information used for predictive purposes is maintained in a computer data base (Table 9) and the remainder in written form. Virginia's inventory form is presented in Figure 5.

The computer data base is sufficient for computing the New Hampshire, Peabody-Dimmick, and NCHRP #50 models, but must be supplemented to compute the DOT and Coleman-Stewart models. The supplemental data items include number of through trains per day during daylight hours, maximum timetable speed for each crossing, and highway type. Data on the number of school buses per day per crossing and the sight distance for each crossing were also included to permit further analysis.

Table 9
Existing Virginia Grade Crossing Inventory
Computer Data Base
(From reference 2)

| <u>COLUMN</u> | <u>CONTENTS</u> |
|---------------|---|
| 1 | Department district code |
| 2-4 | City or county code |
| 5-16 | Route number or street name and suffix, if applicable |
| 17-19 | Crossing number on the route (sequential) |
| 20-21 | Highway functional class code |
| 22-25 | Federal aid number of road |
| 26-32 | DOT-AAR inventory number |
| 33-48 | Location |
| 49-54 | Railroad code |
| 55-58 | Number of tracks - main, branch, siding, total |
| 59 | Advance warning sign type code |
| 60 | Crossbuck type code |
| 61 | Pavement marking type code |
| 62 | Warning device type code |
| 63-64 | Number of daily fast trains |
| 65-66 | Total number of trains |
| 67 | Number of reported accidents in 5 years |
| 68 | Number of fatalities |
| 69-74 | Average daily traffic |
| 75 | Number of lanes |
| 76-77 | Total road width |
| 78 | Pavement code |
| 79 | Rural/urban code |
| 80 | Highway system code |

Figure 5. Railroad grade crossing inventory. (From reference 2)

**VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
RAILROAD GRADE CROSSING INVENTORY
IN COOPERATION WITH THE
FEDERAL HIGHWAY ADMINISTRATION**

DOT-AAR NO. _____

HWY-R.R. NO. _____ FA NO. _____ CITY OR COUNTY _____ RAILROAD COMPANY _____

Part I Location and Classification of All Crossings

1. Railroad Operating Company _____ 2. Railroad Division or Region _____ 3. Railroad Subdivision or District _____

4. State _____ 5. County _____ 6. County Map Ref. No. _____

7. City _____ 8. Nearest City _____ 9. Highway Type and No. _____

10. Street or Road Name _____ 11. RR I. D. No. _____

12. Nearest RR. Timetable Station _____ 13. Branch or Line Name _____ 14. Railroad Mile Post _____

15. Pedestrian Crossing
 1. at grade
 2. RR under
 3. RR over

16. Private Vehicle Crossing
 A. 1. Farm 2. Residential 3. Recreational 4. Industrial
 B. 5. at grade 6. RR under 7. RR over
 C. 8. signal-specify _____
 9. signal-specify _____

17. Public Vehicle Crossing
 1. at grade
 2. RR under
 3. RR over

18. Location _____

Part II Detailed Information for Public Vehicular Grade Crossing

1A. Typical Number of Daily Train Movements

| Daylight (6AM to 6 PM) | | Night (6PM to 6AM) | |
|------------------------|-----------------|--------------------|-----------------|
| thru trains _____ | switching _____ | thru trains _____ | switching _____ |

18. Check if Less Than One Movement Per Day

2A. Speed of Train at Crossing - Maximum time table speed _____

2B. Typical Speed Range over Crossing from _____ to _____ mph

3A. Type and Number of Tracks
 main _____ other _____
 branch _____ if other specify _____

3B. Width of Crossing _____

3C. Length of Crossing _____

3D. Condition of Crossing _____

4. Does Another RR Operate a Separate Track at Crossing?
 Yes No Specify: RR _____

5. Does Another RR Operate Over Your Track at Crossing?
 Yes No Specify: RR _____

6. Type of Protection at Crossing

A. Signs

| Crossbucks | | Standard Highway Stop Sign | Other Stop Signs |
|--|-----------------------------------|----------------------------|------------------|
| reflectORIZED Number _____ | non-reflectORIZED Number _____ | | |
| Other Signs: Specify Number _____ Number _____ | | | |

B. Train Activated Devices

| Gates | | Cantilevered Flashing Lights | | Mast Mounted Flashing Lights |
|--|-------------------------------|---|---------------------------------------|------------------------------|
| red & white reflectORIZED Number _____ | other colored Number _____ | over traffic lane Number _____ | not over traffic lane Number _____ | |
| Other Flashing Lights Specify: Number _____ | | Highway Traffic Signals Number _____ | Wignaps Number _____ | Bells Number _____ |

C. Specify Special Protection not Train Activated _____ (Not in instructions)

D. No Signs or Signals

7. Is Commercial Power Available? Yes No

8. Does Crossing Signal Provide Speed Selection for Trains? Yes No N/A

9. Method of Signaling for Train Operation: Is Track Equipped with Signals? Yes No

10. Protection Code _____

Part III Physical Data

1. Type of Development 1. Open Sp. 2. Res. 3. Comm. 4. Ind. 5. Inst.

2. Smallest Crossing Angle 0°20' 30° 59' 60° 90°

3. Number of Traffic Lanes Crossing Railroad
 Divided Undivided Number _____

4. Are Truck Pullout Lanes Present? Yes No

5. Is Highway Paved? Yes No

6. Crossing Surface
 1. Sec. Timber 6. Rubber
 2. Full Wd. Plank 7. Metal Sections
 3. Asphalt 8. Other Metal
 4. Concrete Slab 9. Unconsolidated
 5. Concrete Pave.

6A. Pavement Markings
 Stoplines RR Xing Sym. None
 Edgelines Center Line

6B. Pavement Width _____

7. Are RR Advance Warning Signs Present?
 Yes No

8. Does Track Run Down A Street
 Yes No

9. Nearby Intersection Highway?
 Yes No

10. Is Crossing Illuminated? (Street Lights Within 100') Yes No

Part IV Highway Department Information

1. Highway System _____

2. Is Crossing on State Highway System? Yes No

3. Functional Classification of Road over Crossing _____

4. Estimated AADT _____

5. Estimated Percent Trucks _____

6. Posted Speed _____

7. Crossing Speed _____

8. No. Accidents (Last 5 Years) _____

9. No. Fatalities (Last 5 Years) _____

FIGURE 11

For this study, the data base was recorded on an NBI (384k) micro-computer. Three computer programs were written to (1) compute the 5-year accident record for each crossing according to the four absolute models and the hazard index for the New Hampshire model, (2) perform the chi-square statistical testing for the models, and (3) compute the power factors of the models. The computed numbers of accidents, as well as the hazard index, for all the crossings determined by each of the models were saved on the data diskette. The computer programs used to accomplish this data set and the subsequent analyses are described in Appendix B.

EVALUATION OF THE MODELS

Methodology

The two methods described below were employed to evaluate the representative models.

1. A statistical chi-square formula of the form

$$\sum_{i=1}^{1,536} \frac{(AO_i - AC_i)^2}{AC_i}, \quad (10)$$

where AO is the number of observed accidents and AC is the number of computed accidents for each of the 1,536 crossings was used to determine the goodness of fit of the four absolute formulae. The computed number of accidents according to each of the four representative absolute formulae (DOT, NCHRP #50, Coleman-Stewart, Peabody-Dimmick) were determined and tested.

In ancillary tests, data were obtained on 9 crossings that had restricted sight distances and 913 crossings that carried school bus

traffic. These data were examined through a simple statistical test for possible significance.

2. The primary tool for the comparison of the representative relative formula (the New Hampshire model) and the four absolute formulae is the power factor, which is defined as follows: The 10% power factor is the percentage of accidents which occur at the 10% most hazardous crossings (as determined by the given hazard index) divided by 10%. (7) The same sort of definition holds for the 5% power factor, etc. Thus, if $PF(5\%) = 3.0$, then 5% of the crossings account for 15% ($3 \times 5\% = 15\%$) of the accidents (when the 5% referred to is the 5% most hazardous according to the hazard index in question).

The power factor can be seen as a direct primary measure of the efficacy of a hazard index for the relative ranking of crossings. Thus, suppose 10% of a certain group of crossings is to be selected for improvement, and assume that one wishes to select the most hazardous crossings for this purpose. Then, if a given hazard index is used, the 10% most hazardous crossings will be selected according to that hazard index. The number of accidents that may be expected at these selected crossings in any period of time is proportional to the power factor for the given hazard index. The greater the proportion of the total accidents that would occur at the crossings selected as most hazardous, the more effective is the hazard index as evidenced by the power factor; in fact, for some purposes, the payoff, or benefit, will be proportional to the number (or proportion) of accidents that would occur at the selected crossings, as these accidents may be partially or totally prevented. Consequently, when the hazard index is to be used for selecting the 10% most hazardous crossings, the 10% power factor seems to be the most direct measure of its effectiveness. The same would hold for the 20% power factor if 20% of the crossings were to be selected, etc.

Results

In the comparison of the computed and observed numbers of accidents, the chi-square tests on the four absolute models showed that the number computed by the basic DOT formula had the closest fit to the actual number of accidents at all the crossings. The summations of chi-squares for all the crossings by the four absolute models are shown in Table 10.

Table 10
Chi-Square Statistics

| <u>Model</u> | <u>Chi-squares</u> |
|-----------------|--------------------|
| NCHRP #50 | 3810.222 |
| Peabody-Dimmick | 2175.609 |
| Coleman-Stewart | 961.166 |
| DOT | 833.096 |

In the ancillary tests, the effect of inadequate sight distances was determined not to be significant, since the 5-year accident data did not show an accident on any of these crossings. A summary of the statistics regarding the school bus traffic on the 913 crossings is presented in Table 11.

Table 11
School Bus Data

| <u>No. of Accidents</u> | <u>Frequency (Total No. Crossings)</u> | <u>Frequency (No. Crossings with Bus Traffic)</u> | <u>Average % School Bus/ Total Traffic</u> | <u>Range</u> |
|-----------------------------|--|---|--|--------------|
| 0 | 1392/1536 = 90.60% | 816/1392 = 58.6% | -- | |
| 1 | 130/1536 = 8.40% | 91/130 = 70.0% | 1.54% | 0.10%-7.14% |
| 2 | 10/1536 = 0.65% | 5/10 = 50.0% | 0.74% | 0.46%-0.96% |
| 3 | 4/1536 = 0.26% | 1/4 = 25.0% | 1.94% | 1.94% |

As can be seen from Table 11, of all crossings that experienced one accident during the last 5 years, 70% had an average of 1.54% daily school bus traffic. Fifty percent of all crossings that experienced two accidents had an average of 0.74% daily school bus traffic, and 25% of the crossings with three accidents had 1.94% daily school bus traffic.

It can thus be concluded that the effects of sight distance and school bus traffic are not statistically significant, and that their inclusion in the final hazard prediction formula would not alter the final results. However, since school buses do present a potential accident severity greater than that experienced in the typical incident, consideration of this factor should be included in the final site evaluation process.

The performances of all five representative models in the second type of test (the power factor) are summarized in Table 12.

Table 12

Ranking of the Representative Models in the Power Factor Test (#1 has the highest power factor, #5 the lowest)

| <u>% Crossing</u> | <u>Rank</u> | | | | |
|-------------------|-------------|-----------|-----------|-----------|-----------|
| | <u>#1</u> | <u>#2</u> | <u>#3</u> | <u>#4</u> | <u>#5</u> |
| 1 | DOT | N.H. | NCHRP #50 | P-D | C-S |
| 2 | DOT | N.H. | NCHRP #50 | P-D | C-S |
| 3 | DOT | NCHRP #50 | N.H. | P-D | C-S |
| 6 | NCHRP #50 | DOT | P-D | C-S | N.H. |
| 10 | N.H. | NCHRP #50 | DOT | P-D | C-S |
| 20 | DOT | P-D | NCHRP #50 | N.H. | C-S |
| 40 | DOT | C-S | P-D | NCHRP #50 | N.H. |

The complete set of power factors computed at each percentile of hazard (when the percentile of hazard is defined as the percent more hazardous, and the small order percentiles thus indicate higher hazards) is given in Appendix C. Table 12 indicates the stability of the basic DOT formula as compared to the other four. Research results have also indicated that once the accident history is incorporated into the basic DOT formula, i.e., the main DOT formula is employed, the DOT power factors for different percentiles of hazard will be significantly better than those of any other model.(7)

Thus, even though the chi-square and power factor tests are different in their use and interpretation of data, both have shown the DOT model to perform better for their respective criteria than the other models.

RECOMMENDATIONS

As was shown in this study, the DOT accident prediction formula outperformed the other four nationally recognized accident prediction formulae, including the one (NCHRP #50) currently employed by the Rail and Public Transportation Division of the Virginia Department of Highways and Transportation. It is, therefore, recommended that the division discontinue the use of NCHRP #50 formula and start employing the DOT formula for prioritizing the rail/highway crossings in the state. The DOT formula is fully documented in reference 1. Also described in reference 1 is a resource allocation model that can be used with the accident prediction formula to provide an automated and systematic means of making a cost-effective allocation of funds among individual crossings and available improvement options. A summary of the resource allocation model is shown in Appendix D. The FRA will run the DOT models for states, if requested, upon receiving an updated version of their inventory file.

The DOT accident prediction formula takes into account the most important variables that are statistically significant in predicting accidents at rail/highway crossings. However, it must be noted that there is no general consensus as to which of the site characteristics are the most important ones. Consequently, the priority list that is produced by using this formula must serve as only one of the criteria for improving conditions at any crossing. This list must be supplemented with information obtained by regular site inspections and with qualitative data that cannot feasibly be incorporated into a mathematical formula. For example, limited sight distances and the presence of school buses create situations for which criteria cannot be conveniently included in the formula, but these variables may have a significant influence on the allocation of funds for grade improvements.

The DOT resource allocation model could be used by the Department in conjunction with the DOT hazard prediction model, if the Department elected to use the same criteria that the model uses to prioritize rail/highway crossings for improvement.

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APPENDIX A

HAZARD INDEX FORMULAE

Mississippi Formula:

$$H.I. = \frac{\frac{SDR}{8} + A5}{2}$$

where H.I. = Hazard Index

SDR = Sight Distance Rating

A5 = Expected number of accidents in five years

The Ohio Method:

$$H.I. = A_f + B_f + G_f + L_f + N_f + SDR$$

where H.I. = Hazard Index

A_f = Accident Probability Factor

B_f = Train Speed Factor

G_f = Approach Gradient Factor

L_f = Angle of Crossing Factor

N_f = Number of Tracks Factor

SDR = Sight Distance Rating

The Wisconsin Method:

$$H.I. = \frac{T\left(\frac{V}{20} + \frac{P^1}{50}\right)}{5} + SDR + Ae$$

where H.I. = Hazard Index

T = Average 24-hour train volume

V = Average 24-hour traffic volume

P¹ = Number of pedestrians in 24 hours

SDR = Sight distance rating

Ae = Accident Experience

Contra Costa County Method:

$$H.I. = TZ \left[1 - \exp\left(\frac{-Vt}{1440Z}\right) \right]$$

where H.I. = Hazard Index

T = Average 24-hour train volume

Z = Number of traffic lanes

V = Average 24-hour traffic volume

t = Time crossing is blocked

The Oregon Method:

$$H.I. = [V_1 T_1 P_f + 1.4 V_2 T_2 P_f] \frac{Ae}{A5}$$

where H.I. = Hazard Index

V_1 = Average daylight traffic volume

T_1 = Average daylight train volume

P_f = Protection factor

V_2 = Average traffic volume during dark hours

T_2 = Average train volume during dark hours

Ae = Accident experience

$A5$ = Expected number of accidents in 5 years

North Dakota Rating System:

$$H.I. = (N_f + L_f) + (P_f + D_f + G_f + X_f) + (VT_f) + SDR$$

where H.I. = Hazard Index

N_f = Number of tracks factor

L_f = Angle of crossing factor

P_f = Protection factor

D_f = Alignment of track and highway factor

G_f = Approach gradient factor

X_f = Condition of crossing factor

V = Average 24-hour traffic volume

T_f = Train volume factor

SDR = Sight distance rating

Idaho Formula

$$H.I. = V_f \times T_f (CB_f + SDR + N_f + Y_f)$$

where H.I. = Hazard Index

V_f = Traffic volume factor

T_f = Train volume factor

CB_f = Type and speed of train factor

SDR = Sight distance rating

N_f = Number of tracks factor

Y_f = Severity factor

Utah Formula:

$$H.I. = \frac{V}{1000} \left(\frac{P}{10} + \frac{F}{20} + \frac{S}{30} \right) + SDR + N_f + X_f + R_f$$
$$+ 2 Ae + \frac{P^1}{100,000} \left(\frac{P}{10} + \frac{F}{20} + \frac{S}{30} \right) - P_f$$

where H.I. = Hazard Index

V = Average 24-hour traffic volume

P = Number of passenger trains in 24 hours

F = Number of freight trains in 24 hours

S = Number of switch trains in 24 hours

SDR = Sight distance rating

N_f = Number of tracks factor

X_f = Condition of crossing factor

R_f = Road approach factor

Ae = Accident experience

P^1 = Number of pedestrians in 24 hours

P_f = Protection factor

City of Detroit Formula:

$$H.I. = \frac{V}{1000} \left(\frac{P}{10} + \frac{F}{20} + \frac{S}{30} \right) + SDR + N_f + X_f + R_f (100\% - \%P_f) + 2 Ae$$

where H.I. = Hazard Index

V = Average 24-hour traffic volume

P = Number of passenger trains in 24 hours

F = Number of freight trains in 24 hours

S = Number of switch trains in 24 hours

SDR = Sight distance rating

N_f = Number of tracks factor

X_f = Condition of crossing factor

R_f = Road approach factor

P_f = Protection factor

APPENDIX B

COMPUTER ANALYSIS

The required data base for this study was recorded as a sequential data file on an NBI (384K) microcomputer. A sequential data file is characterized by the fact that the individual items are arranged sequentially, one after another. Such a file consists of several lines of data, each line beginning with a line number. The line numbers are arranged sequentially in the order of increasing line numbers. The data items in a given line can be numbers, strings, or a combination of the two, separated by either commas or blank spaces. In this study, each line represents one crossing. The original data file consisted of the basic information (such as the identification number for each crossing) and all the variables for each crossing that the five models required. The lines had the following format: crossing number, classification code, identification number, number of main tracks, number of total tracks, protective device, total number of trains in 24 hours, total number of accidents in 5 years, average daily traffic, number of highway lanes, highway paved, classification system, expected accident rate (by NCHRP #50 method), number of through trains during daylight, and the maximum timetable speed. The recorded data file was checked manually and the errors were corrected by the EDLIN command.

Three separate computer programs were written in basic language to perform the following tasks:

- 1) Compute the 5-year accident data for each crossing according to the four absolute models and the hazard index for the New Hampshire model. There were two difficulties at this point. One was with the K-factor associated with the Peabody-Dimmick formula. This factor had been obtained experimentally and could not be formulated into an

algebraic form of high precision. As a result, the basic Peabody-Dimmick 5-year accident data for each crossing was determined by the computer, and then the K-factor was manually added to the results. The final results were added to the data file by using the EDLIN command. The second problem had to do with the interpretation of the model requirements. For example, protection type appears in all hazard rating models, yet the protection types described in the file may not agree with the types defined for the model. As a result, some subjective judgements were used to define the proper protection type. The 5-year accident data for the four absolute models and the hazard index for the relative model were saved on the data diskette for testing and evaluation.

- 2) Perform the chi-square statistical testing for the models to determine the relative goodness of fit of the four absolute models. The formula used for this test has the form

$$\sum_{i=1}^{1536} \frac{(AO_i - AC_i)^2}{AC_i}$$

where AO is the number of observed accidents and AC is the number of computed accidents for each of the 1,536 crossings.

- 3) Determine the 1%, 2%, 3%, 6%, 10%, 20%, and 40% power factors of the five representative models. For doing this, a programmable sorting and merging utility called MS-SORT was employed. MS-SORT accepts data files and arranges the records contained in these files in the assigned order. The recorded data file was sorted in a decreasing order according to the results for each of the five representative models, and the power factors for the previously mentioned percentages of hazards were substantially determined. Examples of the data file, the programs, and the computer outputs are presented in the following pages of this appendix.

| | | | | | | | | | | | | | | | |
|---|-----|----------|---|---|---|----|---|-------|---|---|----|--------|----|----|------|
| 1 | ,16 | ,905892D | 0 | 1 | 0 | 1 | 0 | 1389 | 2 | 2 | RS | ,0.008 | 0 | 10 | 0.12 |
| 1 | ,16 | ,905893K | 1 | 1 | 0 | 4 | 0 | 6730 | 2 | 2 | RS | ,0.109 | 4 | 25 | 0.44 |
| 1 | ,19 | ,905894S | 1 | 1 | 0 | 4 | 0 | 52 | 2 | 0 | RS | ,0.005 | 4 | 25 | 0.06 |
| 1 | ,16 | ,714334G | 2 | 3 | 6 | 28 | 0 | 13642 | 2 | 2 | RS | ,0.092 | 16 | 79 | 0.44 |
| 2 | ,7 | ,714341S | 2 | 2 | 6 | 26 | 0 | 3144 | 2 | 2 | RS | ,0.026 | 16 | 79 | 0.33 |
| 1 | ,16 | ,714337C | 2 | 2 | 6 | 26 | 3 | 2422 | 2 | 0 | RS | ,0.020 | 16 | 79 | 1.65 |
| 1 | ,16 | ,714335N | 2 | 2 | 6 | 26 | 1 | 9289 | 2 | 2 | RS | ,0.063 | 16 | 79 | 0.93 |
| 1 | ,17 | ,714326P | 0 | 1 | 8 | 6 | 1 | 10144 | 2 | 2 | RS | ,0.273 | 0 | 15 | 0.94 |
| 2 | ,17 | ,714322M | 0 | 1 | 8 | 6 | 0 | 3909 | 2 | 2 | RS | ,0.095 | 0 | 15 | 0.34 |
| 1 | ,19 | ,714324B | 0 | 1 | 8 | 2 | 0 | 2030 | 2 | 2 | RS | ,0.024 | 0 | 15 | 0.24 |
| 1 | ,19 | ,714321F | 0 | 3 | 8 | 6 | 0 | 2119 | 2 | 2 | RS | ,0.072 | 0 | 15 | 0.30 |
| 1 | ,6 | ,714367U | 1 | 1 | 6 | 4 | 1 | 2700 | 2 | 2 | RP | ,0.003 | 4 | 25 | 0.49 |
| 1 | ,2 | ,714363S | 1 | 1 | 6 | 4 | 0 | 17225 | 4 | 2 | RP | ,0.017 | 4 | 25 | 0.30 |
| 1 | ,7 | ,714370C | 1 | 1 | 6 | 4 | 0 | 2530 | 2 | 2 | RP | ,0.003 | 4 | 25 | 0.16 |
| 1 | ,7 | ,714611N | 2 | 3 | 6 | 28 | 0 | 2738 | 2 | 2 | RS | ,0.021 | 16 | 79 | 0.32 |
| 1 | ,9 | ,714360W | 1 | 1 | 4 | 4 | 1 | 1373 | 2 | 2 | RS | ,0.010 | 4 | 25 | 0.75 |
| 1 | ,9 | ,714365F | 1 | 1 | 4 | 4 | 0 | 503 | 2 | 2 | RS | ,0.005 | 4 | 25 | 0.25 |
| 1 | ,16 | ,860600A | 2 | 2 | 6 | 24 | 0 | 2110 | 2 | 2 | RS | ,0.018 | 11 | 70 | 0.29 |
| 1 | ,7 | ,714614J | 2 | 2 | 2 | 26 | 0 | 2500 | 2 | 2 | RS | ,0.020 | 16 | 79 | 0.52 |
| 1 | ,9 | ,714359C | 1 | 1 | 4 | 4 | 0 | 716 | 2 | 2 | RS | ,0.005 | 4 | 25 | 0.27 |
| 1 | ,7 | ,714356G | 1 | 1 | 6 | 4 | 0 | 6470 | 2 | 2 | RS | ,0.007 | 4 | 25 | 0.20 |
| 1 | ,7 | ,714361D | 1 | 1 | 4 | 4 | 0 | 4077 | 2 | 2 | RS | ,0.024 | 4 | 25 | 0.38 |
| 1 | ,9 | ,714369H | 1 | 1 | 4 | 4 | 0 | 72 | 2 | 2 | RS | ,0.001 | 4 | 25 | 0.16 |
| 1 | ,17 | ,860598B | 2 | 2 | 6 | 24 | 1 | 4703 | 2 | 2 | RS | ,0.030 | 11 | 70 | 0.83 |
| 1 | ,9 | ,714364Y | 1 | 2 | 6 | 8 | 0 | 1321 | 2 | 2 | RS | ,0.004 | 4 | 25 | 0.16 |
| 1 | ,9 | ,482046T | 1 | 1 | 3 | 8 | 1 | 1514 | 2 | 2 | RS | ,0.020 | 2 | 20 | 0.83 |
| 1 | ,7 | ,471499E | 1 | 1 | 3 | 8 | 0 | 3707 | 2 | 2 | RS | ,0.039 | 2 | 20 | 0.41 |
| 1 | ,9 | ,482056Y | 1 | 1 | 3 | 8 | 0 | 551 | 2 | 2 | RS | ,0.010 | 2 | 20 | 0.29 |
| 1 | ,9 | ,482058M | 1 | 1 | 3 | 8 | 0 | 572 | 2 | 2 | RS | ,0.010 | 2 | 20 | 0.29 |
| 1 | ,9 | ,482100J | 1 | 1 | 0 | 6 | 1 | 70 | 2 | 0 | RS | ,0.008 | 2 | 20 | 0.33 |
| 1 | ,8 | ,482074W | 1 | 1 | 6 | 2 | 0 | 652 | 2 | 2 | RS | ,0.001 | 0 | 20 | 0.09 |
| 1 | ,8 | ,482074W | 1 | 1 | 0 | 6 | 0 | 1266 | 2 | 2 | RS | ,0.048 | 2 | 20 | 0.27 |

Figure B-1. Sample copy of the computer output used for models evaluation.

```

1 DIM F$(25)
2 F$(1)="H ":F$(2)="HH ":F$(3)=" \ \":F$(4)=" H":F$(5)=" H":F$(6)=" H ":F$(7)
="HH":F$(8)=" H ":F$(9)="HHHHH"
3 F$(10)=" H":F$(11)=" H":F$(12)=" \ \ ":F$(13)="H.HHH":F$(14)="HH":F$(15)="HH":F
$(16)="H.HH":F$(17)="H.HH":F$(18)="HHHHHH.HH"
4 F$(19)="HH.HH"
5 DIM F(25)
7 LOT=LOG (10)
20 N=1536
30 OPEN "i", #1, "ARDESHIR"
40 OPEN "o", #2, "COST"
50 FOR I = 1 TO N
60 INPUT #1, F(1),F(2),F3$,F(4),F(5),F(6),F(7),F(8),F(9),F(10),F(11),F12$,F(13),
F(14),F(15),F(16),F(17),F(18)
70 IF F(5)<>1 THEN 90
72 ON F(6) + 1 GOTO 74,75,76,77,78,79,80,81,82,83
74 C0=-2.77:C1=.4:C2=.89:C3=--.29:GOTO 110
75 C0=-2.77:C1=.4:C2=.89:C3=--.29:GOTO 110
76 C0=-2.77:C1=.4:C2=.89:C3=--.29:GOTO 110
77 C0=-3.56:C1=.62:C2=.92:C3=--.38:GOTO 110
78 C0=-3.56:C1=.62:C2=.92:C3=--.38:GOTO 110
79 C0=-3.56:C1=.62:C2=.92:C3=--.38:GOTO 110
80 C0=-1.42:C1=.08:C2=--.15:C3=--.25:GOTO 110
81 C0=-3.56:C1=.62:C2=.92:C3=--.38:GOTO 110
82 C0=-3.56:C1=.62:C2=.92:C3=--.38:GOTO 110
83 C0=-3.56:C1=.62:C2=.92:C3=--.38:GOTO 110
90 ON F(6)+1 GOTO 91,92,93,94,95,96,97,98,99,100
91 C0=-2.39:C1=.46:C2=--.5:C3=.53:GOTO 110
92 C0=-2.39:C1=.46:C2=--.5:C3=.53:GOTO 110
93 C0=-2.39:C1=.46:C2=--.5:C3=.53:GOTO 110
94 C0=-2.75:C1=.38:C2=1.02:C3=--.36:GOTO 110
95 C0=-2.75:C1=.38:C2=1.02:C3=--.36:GOTO 110
96 C0=-2.75:C1=.38:C2=1.02:C3=--.36:GOTO 110
97 C0=-1.63:C1=.22:C2=--.17:C3=.05:GOTO 110
98 C0=-2.75:C1=.38:C2=1.02:C3=--.36:GOTO 110
99 C0=-2.75:C1=.38:C2=1.02:C3=--.36:GOTO 110
100 C0=-2.75:C1=.38:C2=1.02:C3=--.36:GOTO 110
110 IF F(7)<=0! OR F(9)<= 0! THEN F(19) =0! : GOTO 130
120 F(19)=5*10^(C0+C1*LOG(F(9))/LOT + C2*LOG(F(7))/LOT+C3 *(LOG(F(7))/LOT)^2)
130 FOR J=1 TO 19
133 IF J=3 THEN PRINT#2, USING F$(3);F3$;:GOTO 138
134 IF J=12 THEN PRINT#2, USING F$(12);F12$;:GOTO 138
135 PRINT#2, USING F$(J);F(J);
138 IF J < 19 THEN PRINT#2, ", ";
139 NEXT J: PRINT#2,
140 NEXT I
150 CLOSE
160 END

```

Figure B-2. Coleman-Stewart basic program.

```

1 DIM F$(25)
2 F$(1)="# ":F$(2)="## ":F$(3)=" \      \":F$(4)=" #":F$(5)=" #":F$(6)=" # ":F$(7)
="##":F$(8)=" # ":F$(9)="#####"
3 F$(10)=" #":F$(11)=" #":F$(12)=" \ \ ":F$(13)="#-###":F$(14)="##":F$(15)="##":F
$(16)="#-##":F$(17)="#-##":F$(18)="#####-##"
4 F$(19)="##.##": F$(20)="##.##"
5 DIM F(25),SUM(4),CSQ(4)
7 LOT=LOG (10)
10 FOR I=1 TO 4 : SUM(I)=0! : NEXT I
20 N=1536
30 OPEN "i", #1, "COST"
40 OPEN "o", #2, "DOT"
50 FOR I = 1 TO N
60 INPUT #1, F(1),F(2),F3$,F(4),F(5),F(6),F(7),F(8),F(9),F(10),F(11),F12$,F(13),
F(14),F(15),F(16),F(17),F(18),F(19)
65 IF F(6) <> 0 THEN GOTO 80
67 ON F(2) GOTO 68,69,80,80,80,70,71,72,73,80,68,69,80,70,80,71,72,80,73
68 HT=1:GOTO 74
69 HT=2:GOTO 74
70 HT=3:GOTO 74
71 HT=4:GOTO 74
72 HT=5:GOTO 74
73 HT=6
74 IF F(11)=0 THEN HP = 2 ELSE IF F(11)=1 OR F(11)=2 THEN HP = 1
75 X=.3839 * LOG(F(9)*F(7)+.2)/LOT + .1538 * LOG(F(14)+.2)/LOT - .308 * HP + .00
3855 * F(15) - .04991 * HT + .1047 * F(4)
76 LITA = 9.840001E-03 * EXP (2 * X):GOTO 100
80 IF F(6) <> 6 THEN 90
81 X=.3588 * LOG (F(9) * F(7) + .2) / LOT + .1456 * F(4) + .0518 * F(10)
82 LITA = .00162 * EXP (2 * X): GOTO 100
90 X=.34 * LOG(F(9) * F(7) + .2)/LOT + .05415 * LOG (F(14) + .2) / LOT
+ .05442 * F(4) + .069 * F(10)
91 LITA = .00551 * EXP (2 * X): GOTO 100
100 F(20) = 5 * (-LITA + F(8) * (.05 + LITA) ) / ( 1.25 + 5 * LITA)
103 IF F(16) <> 0 THEN CSQ (1) = (F(16) - F(8))^2 / F(16): SUM(1) = SUM (1) + CS
Q(1)
104 IF F(17) <> 0 THEN CSQ (2) = (F(17) - F(8))^2 / F(17): SUM(2) = SUM (2) + CS
Q(2)
105 IF F(19) <> 0 THEN CSQ (3) = (F(19) - F(8))^2 / F(19): SUM(3) = SUM (3) + CS
Q(3)
106 IF F(20) <> 0 THEN CSQ (4) = (F(20) - F(8))^2 / F(20): SUM(4) = SUM (4) + CS
Q(4)
130 FOR J=1 TO 20
133 IF J=3 THEN PRINT#2, USING F$(3);F3$;:GOTO 138
134 IF J=12 THEN PRINT#2, USING F$(12);F12$;:GOTO 138
135 PRINT#2, USING F$(J);F(J);
138 IF J < 20 THEN PRINT#2, ", ";
139 NEXT J: PRINT#2,
140 IF I MOD 25 = 0 THEN PRINT ". ";
142 NEXT I
150 CLOSE
155 FOR J=1 TO 4: LPRINT SUM(J),: NEXT J : LPRINT
160 END

```

Figure B-3. DOT and the Chi-Square basic programs.

APPENDIX C

THE POWER FACTORS FOR DIFFERENT PERCENTILES OF HAZARD

| Model | % Crossing | Incremental Accidents | Cumulative Accidents | % Accidents | Power Factor |
|-----------------|------------|-----------------------|----------------------|-------------|--------------|
| DOT | 1 | 5 | 5 | 3.10 | 3.10 |
| | 2 | 6 | 11 | 6.83 | 3.42 |
| | 3 | 3 | 14 | 8.69 | 2.90 |
| | 6 | 11 | 25 | 15.52 | 2.58 |
| | 10 | 11 | 36 | 22.36 | 2.24 |
| | 20 | 30 | 66 | 40.99 | 2.05 |
| | 40 | 42 | 108 | 67.08 | 1.68 |
| NCHRP #50 | 1 | 4 | 4 | 2.48 | 2.48 |
| | 2 | 6 | 10 | 6.21 | 3.10 |
| | 3 | 3 | 13 | 8.07 | 2.69 |
| | 6 | 14 | 27 | 16.77 | 2.79 |
| | 10 | 11 | 38 | 23.60 | 2.36 |
| | 20 | 27 | 65 | 40.37 | 2.01 |
| | 40 | 33 | 98 | 60.86 | 1.52 |
| New Hampshire | 1 | 5 | 5 | 3.10 | 3.10 |
| | 2 | 5 | 10 | 6.21 | 3.10 |
| | 3 | 0 | 10 | 6.21 | 2.07 |
| | 6 | 9 | 19 | 11.80 | 1.96 |
| | 10 | 20 | 39 | 24.22 | 2.42 |
| | 20 | 25 | 64 | 39.75 | 1.98 |
| | 40 | 33 | 97 | 60.25 | 1.51 |
| Coleman-Stewart | 1 | 2 | 2 | 1.24 | 1.24 |
| | 2 | 5 | 7 | 4.34 | 2.17 |
| | 3 | 3 | 10 | 6.21 | 2.07 |
| | 6 | 10 | 20 | 12.42 | 2.07 |
| | 10 | 12 | 32 | 19.87 | 1.98 |
| | 20 | 31 | 63 | 39.13 | 1.96 |
| | 40 | 44 | 107 | 66.45 | 1.66 |
| Peabody-Dimmick | 1 | 4 | 4 | 2.48 | 2.48 |
| | 2 | 3 | 7 | 4.34 | 2.17 |
| | 3 | 3 | 10 | 6.21 | 2.07 |
| | 6 | 10 | 20 | 12.42 | 2.07 |
| | 10 | 15 | 35 | 21.74 | 2.17 |
| | 20 | 30 | 65 | 40.37 | 2.02 |
| | 40 | 37 | 102 | 63.35 | 1.58 |

APPENDIX D

SUMMARY OF THE DOT RESOURCE ALLOCATION MODEL (Reference 1)

Introduction

The resource allocation model is designed to provide an initial recommended list of crossing improvements that result in the greatest accident reduction benefits on the basis of cost-effectiveness considerations for a given budget limit. This initial recommendation may then be used by states to guide the on-site inspection of crossings by diagnostic teams. Updated results obtained by the diagnostic teams then form a useful set of recommendations upon which state and local officials can finalize their crossing safety improvement plans.

Input to the resource allocation model includes predicted accidents for the crossings being considered, costs and effectiveness of the different safety improvement options (e.g., flashing lights and gates), and the budget level available for safety improvement. Accident predictions for crossings can come from any accident prediction formula which computes number of accidents per year. The DOT accident prediction formula was developed for this purpose.

Cost data for the warning device options can be of several different types. They may be life cycle costs (the sum of procurement, installation, and maintenance), the costs associated with a particular phase of a project (e.g., procurement or installation or maintenance) or some fraction of these costs. In any case, comparable figures are needed for the following categories of improvement actions currently considered by the model: flashing lights for a previously passive crossing, and gates at a crossing previously equipped with flashing lights.

Warning device effectiveness required by the resource allocation model is defined as the decimal fraction by which accidents are expected to be reduced by installation of a warning device. Effectiveness is a relative measure involving both existing and proposed warning systems at a crossing to be upgraded. If automatic gates have an effectiveness of 0.84 when installed at a crossing with a passive warning device, the accident rate at the crossing will be reduced by 84%. Automatic gates installed at a crossing with flashing lights would have a lower effectiveness. An improvement which completely eliminates accidents, such as grade separations or closures, would have an effectiveness of 1.0; it is 100% effective. Values of effectiveness for different warning device improvement combinations are presented in the "warning device effectiveness data" section of this report.

The budget level for crossing improvements, used as input to the resource allocation model, should include the total multiyear funding.

Description of Resource Allocation Model--Model Algorithm

Three categories of crossings, representing all warning device classes in the inventory, are considered by the resource allocation algorithm, and are the same categories evaluated by the accident prediction formula. Warning device classes 1 through 4 are grouped together and called "passive" warning systems, meaning that they are not train-activated devices. Passive warning systems include no signs or signals, stop signs, other signs or crossbucks. Classes 5, 6, and 7 are grouped together and called "flashing lights," since public crossings which are equipped with flashing lights predominate this category. The flashing lights group also include flagmen, highway signals, wigwags, or bells. Class 8 remains as a separate warning device category called "gates." This group contains automatic gates with flashing lights as well.

Table D-1 is a matrix showing the effectiveness and cost symbols for the three warning device groupings used in describing the resource allocation algorithm. The matrix reflects the possible combinations of crossing warning device improvements currently considered by the model. For passive crossings, single track, two upgrade options exist: flashing lights or gates. For passive, multiple-track crossings, the model allows only the gate option to be considered in accordance with federal regulations. For flashing light crossings, the only improvement option is gates. The model can be modified by extending the basic logic to include other options, such as grade separations and closures. It is also necessary to determine the costs and effectiveness of any additional options that are considered.

Table D-1
Effectiveness/Cost Symbol Matrix

| Existing Warning Device | Proposed Warning Device | | | |
|-------------------------------|----------------------------|-------------------|----------------------------|-------------------|
| | Flashing Lights | | Automatic Gates | |
| | Equipment Effectiveness | Equipment Cost | Equipment Effectiveness | Equipment Cost |
| Passive | E1 | C1 | E2 | C2 |
| Flashing Lights | -- | -- | E3 | C3 |

For any given crossing and/or proposed warning device, a pair of parameters (E_j , C_j), as shown in Table D-1, must be provided for the resource allocation algorithm, where $j = 1$ for flashing lights installed at a passive crossing, $j = 2$ for gates installed at a passive crossing, and $j = 3$ for gates installed at a crossing with flashing lights. The first parameter (E_j) is the effectiveness of installing a proposed warning device at a crossing with a lower class warning device. The second parameter (C_j) is the corresponding cost of the proposed warning

device. Table D-1 shows the six warning device parameters (E_1 , C_1 , E_2 , C_2 , E_3 , C_3) that are needed to use the resource allocation algorithm.

The resource allocation model considers all crossings with either passive or flashing light warning devices for improvements. If, for example, a single-track passive crossing, i , is considered it could be upgraded with either flashing lights, with an effectiveness E_1 , or gates, with an effectiveness of E_2 . The number of predicted accidents at crossing i is A_i ; hence, the reduced accidents per year is $A_i E_1$ for the flashing light option and $A_i E_2$ for the gate option. The corresponding costs for these two improvements are C_1 and C_2 . The accident reduction/cost ratios for these improvements are $A_i E_1 / C_1$ for flashing lights and $A_i E_2 / C_2$ for gates. The rate of increase in accident reduction versus the results from changing an initial decision to install flashing lights with a decision to install gates, at crossing i , is referred to as the incremental accident reduction/cost ratio and is equal to $A_i (E_2 - E_1) / (C_2 - C_1)$. The incremental accident reduction/cost ratio is used by the algorithm to compare the cost-effectiveness of a decision to further upgrade a passive crossing from flashing lights to gates with an alternative decision to upgrade another crossing instead. If a passive multiple-track crossing, i , is considered, the only improvement option allowable would be installation of gates, with an effectiveness of E_2 , a cost of C_2 and an accident reduction/cost ratio of $A_i E_2 / C_2$. If crossing i was originally a flashing light crossing, the only improvement option available would be installation of gates, with an effectiveness of E_3 , a cost of C_3 and an accident reduction/cost ratio of $A_i E_3 / C_3$.

The resource allocation algorithm systematically computes the accident reduction/cost ratios, including incrementals, of all allowable improvement options for all crossings under consideration. The individual accident reduction/cost ratios which are associated with these improvements are selected by the algorithm in an efficient manner to

produce the maximum accident reduction which can be obtained for a predetermined total cost. This total cost is the sum of an integral number of equipment costs (C1, C2 and C3). The total, maximum accident reduction is the sum of the individual accident reductions of the form $A_i E_j$.

A flow diagram describing the logic of the resource allocation algorithm is shown in Figure D-1. The input to this program consists of the set of crossings for which the model is to apply, the accidents predicted per year for these crossings, the six warning device parameters (E_1 , E_2 , E_3 , C1, C2, C3), and the funding level (CMAX) which determines where the calculation is to stop.

The algorithm, described in Figure D-1, proceeds according to the following steps in computing optimal resource allocations:

Step 1: The reasonable assumption is made for the algorithm that $E_2 > E_1$ and $C2 > C1$. This assumes that gates are more effective at passive crossings than flashing lights and that gates cost more. However, the effectiveness/cost ratio for flashing lights ($E_1/C1$) could be greater or less than that for gates ($E_2/C2$). If $E_1/C1 > E_2/C2$, the algorithm computes incremental accident reduction/cost ratios for all allowable improvements at each crossing according to the procedure outlined in Step 2A below. Step 2A is based on the assumption that flashing lights have a greater effectiveness/cost ratio than gates. If the opposite is true--that gates have an effectiveness/cost ratio equal to or greater than flashing lights ($E_1/C1 \leq E_2/C2$)--then step 2B is followed for computing the improvement accident reduction/cost ratios. Step 2B assumes that gates will always be installed at passive crossings.

Step 2A: In Step 2A, two accident reduction/cost ratios are calculated for each single-track passive crossing, $A_i E_1/C1$ and the

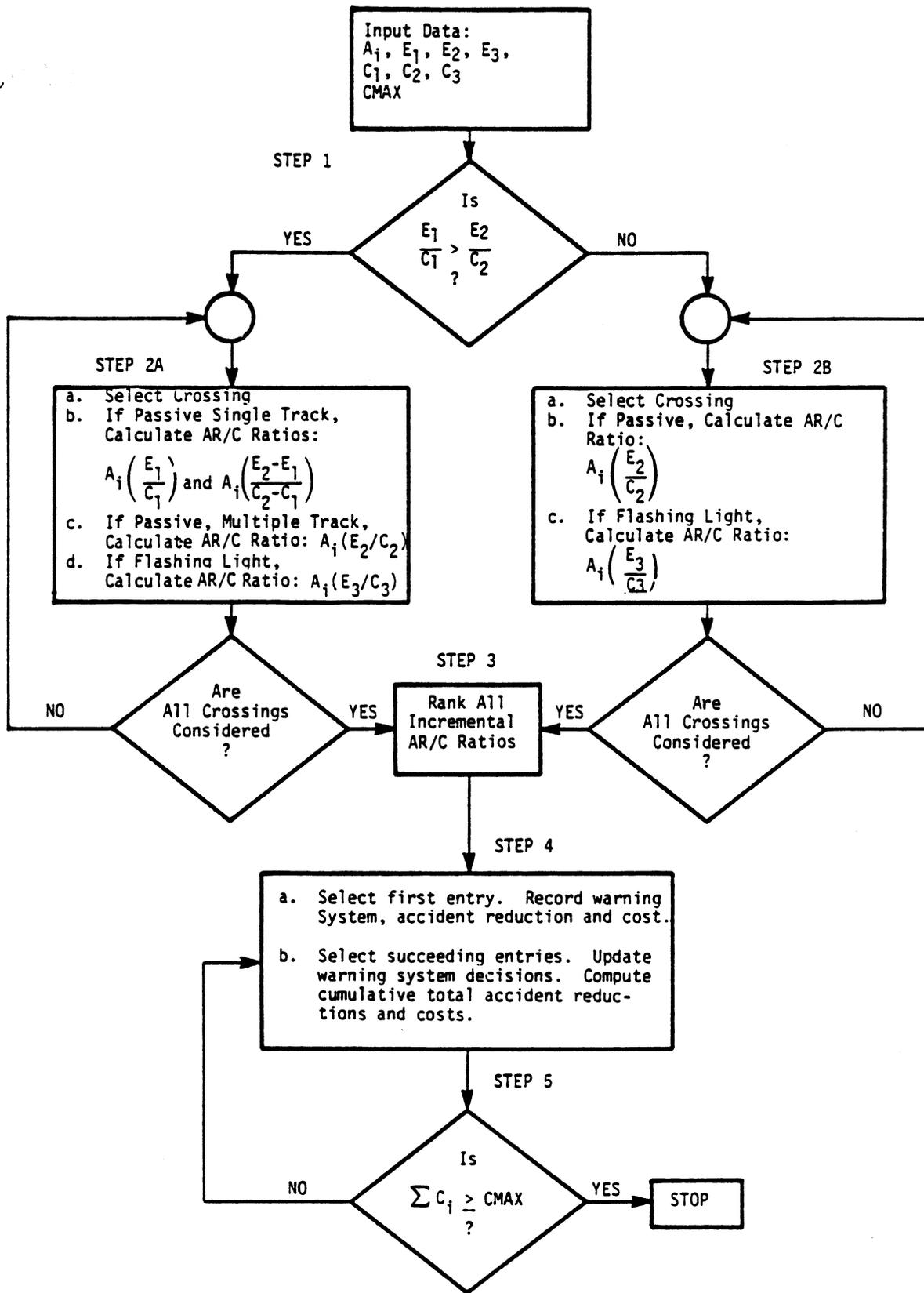


Figure D-1. Resource allocation algorithm.
 (from Reference 1)

incremental ratio $A_i(E_2-E_1)/(C_2-C_1)$, where A_i is the number of accidents predicted per year for the crossing. These two ratios correspond to the two actions available for single-track passive crossings, either to install flashing lights or a revised decision to install gates. For multiple-track passive crossings, only the accident reduction/cost ratio for installation of gates is calculated ($A_i E_2/C_2$), to conform with federal regulations. For each crossing equipped with flashing lights, the algorithm computes $A_i E_3/C_3$, corresponding to an upgrading from flashing lights to gates. The accident reduction/cost ratio is presented in units of accidents prevented per year per dollar.

Step 2B: The algorithm computes the accident reduction/cost ratio $A_i E_2/C_2$ for passive crossings and the ratio $A_i E_3/C_3$ for crossings with flashing lights. These accident reduction/cost ratios are associated with installing only gates at crossings. For the step 2B case, these actions are always optimal to the alternative of installing flashing lights, since the accident reduction/cost ratio and the absolute cost of gates are greater than for flashing lights.

Step 3: Regardless of whether step 2A or 2B is followed, all of the accident reduction/cost ratios calculated by the algorithm are ranked with the largest first. The list of accident/reduction cost ratios represents a sequence of optimal decisions starting with the top of the list.

Step 4: This step consists of a set of iterations, where the algorithm progresses down the list of ranked accident reduction/cost ratios. This process is equivalent to making the optimum decision of achieving the maximum accident reduction for each additional increment in cost incurred. If the accident reduction/cost ratio at any given step on the list is calculated as $A_i E_1/C_1$, a decision is made to install flashing lights at a passive crossing, with an accident reduction of $A_i E_1$ and cost

of C1. If the accident reduction/cost ratio is $A_i(E_2-E_1)/(C2-C1)$, a previous decision to install flashing lights is changed to installation of gates at a passive crossing. The incremental accident reduction of changing the previous decision is $A_i(E_2-E_1)$, and the incremental cost is $C2-C1$. If the accident reduction/cost ratio is $A_iE_2/C2$, then a decision is made to install gates at a passive crossing without prior consideration of flashing lights. The accident reduction is A_iE_2 at a cost of C2. If the accident reduction/cost ratio is $A_iE_3/C3$, then a decision is made to install gates at a crossing which had flashing lights. The accident reduction is A_iE_3 at a cost of C3. The total accident reduction at each step is the sum of the previous accident reductions and the total cost is the sum of the previous costs. In addition to determining the total accident reduction and cost at each step, the algorithm also determines the particular warning systems which are to be installed at particular crossings. Since the crossings which were affected are known, the accident prediction, accidents, location, and all other information in the inventory for those crossings are also known. Thus, the output of the program could include any of this information and any computations based on this information.

Step 5: The cumulative total cost of each step, proceeding down the list of accident reduction/cost ratios, is compared with the total funding limit specified as input to the algorithm. When the total cost equals or exceeds this limit, the program ends. Otherwise, the sequential procedure described in Step 4 continues.

Warning Device Effectiveness Data

Two investigations have been performed to determine the effectiveness of warning devices in reducing accidents at rail-highway

crossings. The most recent study used information in the Inventory and the FRA accident reporting system. This study compared the accident rates at crossings both before and after warning device improvements had been made to determine their effectiveness during the period from 1975 to 1978. An earlier study was performed in 1974 by the California Public Utilities Commission. This study examined accident rates before and after upgrades at 1,552 California crossings over the period from 1960 to 1970. The results of these studies are shown in Table D-2 in terms of the effectiveness values, E_1 , E_2 and E_3 for the three improvement options considered by the resource allocation model.

Table D-2
Effectiveness of Warning Device Improvements

| Warning Device Improvement Option | DOT Study 1980 | California Study 1974 |
|-----------------------------------|----------------|-----------------------|
| passive to flashing lights, E_1 | 0.65 | 0.64 |
| passive to gates, E_2 | 0.84 | 0.88 |
| flashing lights to gates, E_3 | 0.64 | 0.66 |

The effectiveness values resulting from the two studies are quite similar. In fact, the average values from the California study all fall within the 95% confidence interval of the DOT study results. The question arises as to which set of values to use for the resource allocation model. As with the cost data, any set of values which the user believes accurately reflect the situation being evaluated may be used. Without other information to the contrary, the effectiveness values from the DOT study are recommended, since they were most recently developed and used the largest data base of national scope. The DOT results are being recalculated, using a data base expanded with data

added to the inventory and accident files since the previous study was completed. It is expected that the effectiveness values shown in Table D-2 may change slightly as a result of this work. These values should, therefore, not be thought of as constants.