EVALUATION OF METHODS FOR PREDICTING RAIL-HIGHWAY CROSSING HAZARDS

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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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 assess-

reported here five such models selected from a list established from a

EVALUATION OF METHODS FOR PREDICTING RAIL-

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INTRODUCTION

Safety at highway/railroad grade crossings is an important issue throughout the United States. Federal Railroad Administration figures

In 1983, responsibility for inventorying grade crossings and establishing preliminary priorities for improvement projects in Virginia was

[illegible]

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.

[illegible]

In recent years, new methods such as the U.S. Department of Transportation (DOT) accident prediction formula(1) and the

[illegible]

Coleman-Stewart model(4) have been developed. With the availability of

[illegible]

Virginia Department of Highways and Transportation requested that several of the methods deemed most promising for its use be evaluated in

[illegible]

rail-highway crossing inventory and FRA accident files). Also, it was thought that variables such as sight distance and the number of school

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

modified versions of their original models. Since no states ever used the Contra Costa County model, it could also be dismissed. Of the 7

[illegible]

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.

by [illegible] the formula

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

NCHRP No. 50

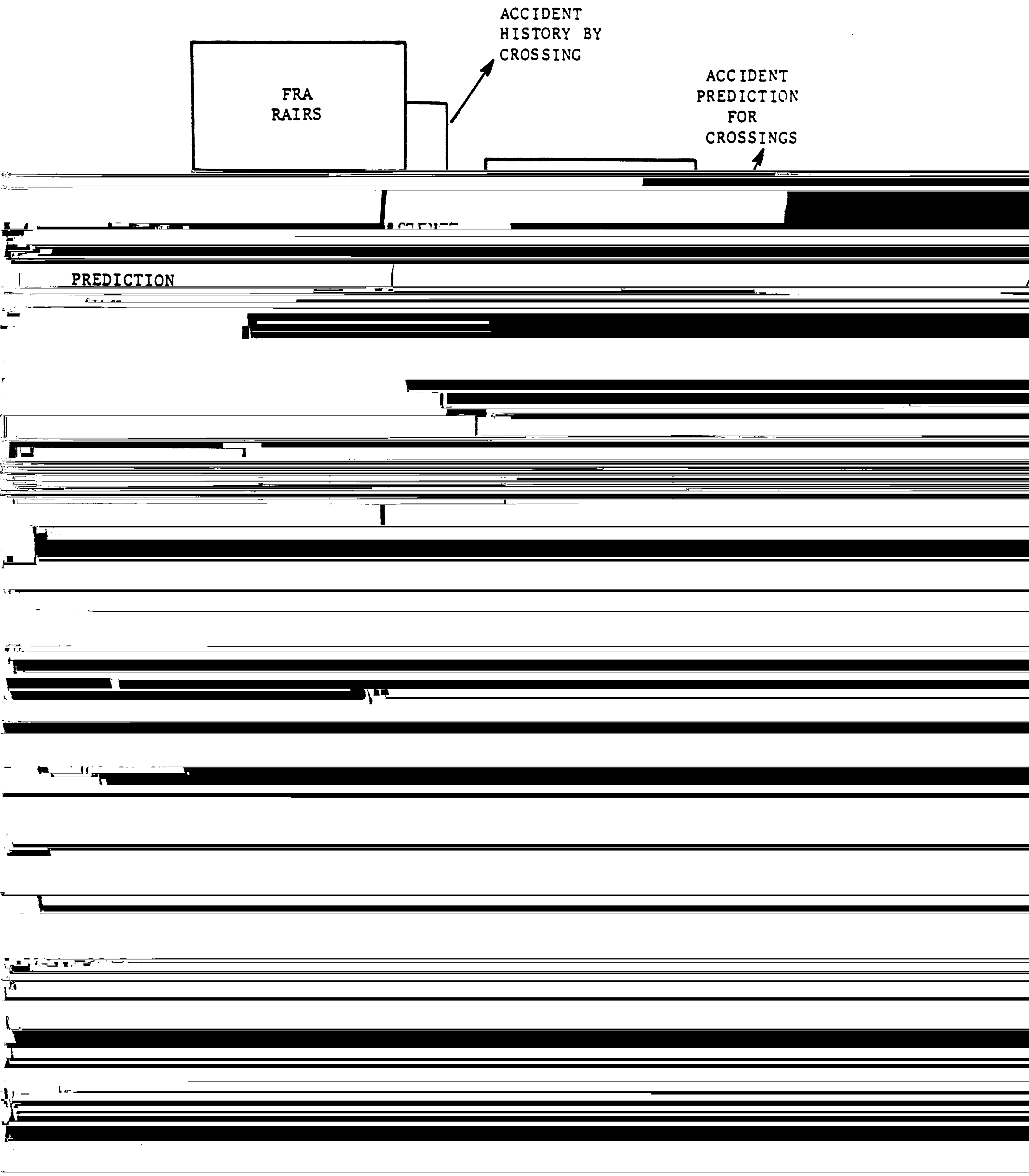
public grade crossing, the Virginia Department of Highways and Transportation is currently employing the methodology that was documented in NCHRP Report No. 50.(3) This report, which was prepared by Alan M.

EA PER YEAR= AxBxTRAINS PER DAY

VEHICLES	'A' FACTOR	EXAMPLE:

New Hampshire Formula

[illegible]


FRA
RAIRS
ACCIDENT
HISTORY BY
CROSSING
ACCIDENT
PREDICTION
FOR
CROSSINGS
PREDICTION

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

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,

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.

T_o = formula weighting factor = $\frac{1}{\ldots}$

accidents at a crossing from the basic formula (a) and accident history ($\frac{N}{T}$). The two formula weights, $\frac{T_o}{\ldots}$ and $\frac{T}{\ldots}$, 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 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 [illegible]

[illegible]

base. In the tabulation of accident data, crossings were classified [illegible]

[illegible]

(urban or rural), and the type of warning device (automatic gates,

Table 4

Volume Ranges of Highway and Train Traffic

Average Vehicles Per Day	Average Trains Per Day
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 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 [illegible]

($\bar{A}$) 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, [redacted] 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 [redacted]

Table 5

Model 2 Regression Results

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 [illegible]

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 devel-

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 [illegible]

preliminary study indicated, therefore, that traffic and protection were the only dependable factors for use in rating the crossings on an average 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

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

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

Using the highway traffic, the train traffic, and the protection coefficient as independent variables and the number of accidents as the depen-

Table 7

Protection Coefficients for the Peabody-Dimmick Formula

Type of Protection	Preliminary Protection Coefficient
Signs	[illegible]
Bells	29
Wigwag	56
Wigwag and bells	63
Flashing lights	96
Flashing lights and bells	114
Watchman, 8 hours	119
Watchman, 16 hours	180

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.

[illegible]

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

7

Table 8

Average Computed Number of Accidents Using

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

Number of Crossings	Actual Number of Accidents	Average Computed Accidents
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

Table 9

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

COLUMN	CONTENTS
1	Department district code
2-4	City or county code
5-16	Route number or street name and suffix, if applicable
22-25	Federal aid number of road

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

Figure 5. (continued)

For this study, the data base was recorded on an NBI (384k) microcomputer. 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 [illegible]

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

[illegible]

traffic. These data were examined through a simple statistical test

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 x 5% = 15%) of the accidents (when the 5% referred to is the 5% most hazardous according to the hazard index in question).

Results

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

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 [redacted]

It can thus be concluded that the effects of sight distance and [redacted]

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, [illegible] ent 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 [illegible] 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

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:

SDR + A5 ... =

SDR = Sight Distance Rating

The Ohio Method:

The Wisconsin Method:

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

T = Average 24-hour train volume

V = Average 24-hour traffic volume

P^1 = Number of pedestrians in 24 hours

SDR = Sight distance rating

Ae = Accident Experience

Contra Costa County Method:

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

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:

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:

City of Detroit Formula:

[illegible]

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

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 algebraic form of high precision. As a result, the basic Peabody-Dimmick 5-year accident data for each crossing was [illegible] determined by the computer, and then the K-factor was manually added [illegible] to the results. The final results were added to the data file by [illegible]

[illegible] 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

$$\sum^{1536} \frac{(AO_i - AC_i)^2}{[illegible]}$$

[illegible]

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

[redacted]

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

[redacted]

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
	9	482058M	1	1	3	8	0	572	2	2	RS	0.010	2	20	0.29
	9	482100J	1	1	0	6	1	70	2	0	RS	0.008	2	20	0.33
	8	482074W	1	1	6	2	0	652	2	2	RS	0.001	0	20	0.09
	[illegible]	[illegible]	[illegible]	1	0	6	0	1266	2	2	RS	0.048	2	20	0.27

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

```
1 DIM F$(25)
2 F$(1)="# ":F$(2)="## ":F$(3)="\        \":F$(4)=" #":F$(5)=" #":F$(6)=" # ":F$(7)
="##":F$(8)=" # ":F$(9)="#####"
```

```
4 F$(19)="##.##"
5 DIM F(25)
7 LOT=LOG (10)
20 N=1536
30 OPEN "i", #1, "ARDESHIR"
40 OPEN "o", #2, "COST"
50 FOR I = 1 TO N
60 INPUT #1, F(1),F(2),F3$,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
```

```
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
```

APPENDIX C

THE POWER FACTORS FOR DIFFERENT PERCENTILES OF HAZARD

	2	6	11	6.83	3.42
	3	3	14	8.69	2.90
DOT	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
	1	4	4	2.48	2.48
	2	6	10	6.21	3.10
	3	3	13	8.07	2.69
NCHRP #50	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

APPENDIX D

SUMMARY OF THE DOT RESOURCE ALLOCATION MODEL

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

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

installed at a crossing with flashing lights would have a lower effectiveness. An improvement which completely eliminates accidents,

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

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

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

[illegible]

example, a single-track passive crossing, i, is considered it could be upgraded with either flashing lights, with an effectiveness E_1, or gates,

[illegible]

crossing i is A_i; hence, the reduced accidents per year is A_iE_1 for the

[illegible]

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

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

Input Data:
A_i, E_1, E_2, E_3,
C_1, C_2, C_3
CMAX

incremental ratio $A_i(E_2-E_1)/(C2-C1)$, where A_i is the number of accidents

[illegible]

predicted per year for the crossing. These two ratios correspond to the two actions available for single-track passive crossings, either to

[illegible]

install flashing lights or a revised decision to install gates. For

[illegible]

for installation of gates is calculated $(A_iE_2/C2)$, to conform with federal regulations. For each crossing equipped with flashing lights 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. It 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

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

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