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**Federal Railroad
Administration**

Summary of the DOT Rail-Highway Crossing Resource Allocation Procedure - Revised

Office of Safety
Office of Safety Analysis
Washington DC 20590

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16. Abstract

The Highway Safety Acts of 1973 and 1976, and the Surface Transportation Assistance Acts of 1978 and 1982 provide funding authorizations to individual states to improve safety at public rail-highway crossings. The installation of active motorist warning devices, such as flashing lights or flashing lights with gates, is an important part of crossing safety improvements. The U.S. Department of Transportation (DOT) assists states and railroads in determining effective allocations of Federal funds for rail-highway crossing safety improvements. This report is a revision of a previous report which describes the resource allocation procedure developed to assist in the allocation of funds among crossings to achieve maximum crossing safety benefits for a given level of funding.

The procedure consists of two parts. The first is an accident and severity prediction formula which computes the expected number of accidents at each crossing, based on information from the U.S. DOT-AAR National Rail-Highway Crossing Inventory and the Railroad Accident/Incident Reporting System (RAIRS). The second part is a resource allocation model designed to nominate crossings for improvement consideration on a cost-effective basis and to suggest the type of warning device to be installed.

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PREFACE

The Department of Transportation's (DOT) rail-highway crossing accident prediction formula and resource allocation model were developed at the Transportation Systems Center (TSC) under the sponsorship of the Federal Railroad Administration's (FRA) Office of Safety Analysis and the Federal Highway Administration's (FHWA) Office of Research. When used together, these procedures provide a systematic means of assisting in making a preliminary, optimum allocation of funds among individual crossings, considering available improvement options. These procedures provide a ranked listing of crossings which can then be used as a guide for selecting crossings for on-site visits by diagnostic teams. States and railroads are invited to contact the FRA, FHWA, or the author of this report for assistance in using the resource allocation procedures.

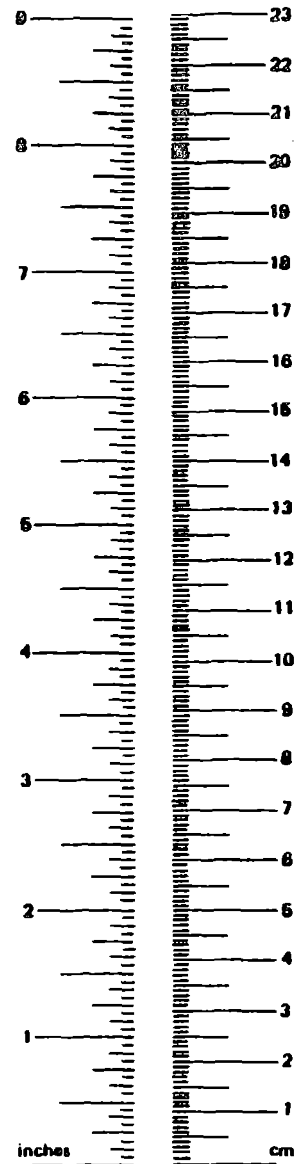
This report provides an overview of the use and output of these procedures. The author had the major role in formulating the resource allocation model while Dr. Peter H. Mengert/TSC had the primary role in developing the DOT rail-highway crossing accident prediction formula.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

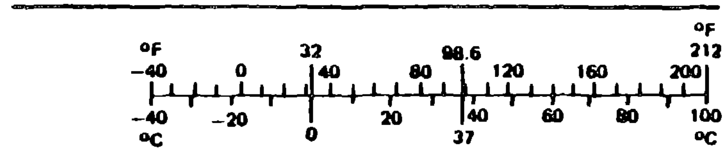
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF SYMBOLS

A = final predicted number of accidents per year

a = initial predicted number of accidents per year

c = number of highway vehicles per day

d = number of through trains per day during daylight

DT = factor for number of through trains per day during daylight

EI = exposure index factor based on the product of the number of highway vehicles and trains per day

hl = number of highway lanes

HL = factor for number of highway lanes

hp = highway paved?, yes = 1.0, no = 2.0

HP = factor for highway paved

K = basic accident prediction formula constant

ms = maximum timetable speed (mph)

MS = factor for maximum timetable speed

mt = number of main tracks

MT = factor for number of main tacks

N = number of accidents recorded for a crossing in T years

t = number of trains per day

tt = number of through trains per day

TT = factor for number of through trains per day

ts = number of switch trains per day

TS = factor for number of switch trains per day

T = number years of recorded accident data

T_o = weighting factor in DOT accident prediction formula

ur = 1 for urban crossings, 0 for rural crossings

UR = factor for urban-rural

1. INTRODUCTION

This report is a revision of a previous report with the same title. (1) The present report contains a revised accident prediction formula based on recent inventory data and recent accident experience. The report also contains formulas which calculate severity prediction; it contains extended warning device effectiveness data; and it contains the inclusion of the stop sign option in the resource allocation model.

Under Section 203 of the Highway Safety Acts of 1973 and 1976 and the Surface Transportation Assistance Acts of 1978 and 1982, Congress provided funding authorizations for individual states to improve safety at public rail-highway crossings. Included in these authorizations is funding for the installation of active motorist warning devices, such as flashing lights or flashing lights with gates. These devices are an important part of crossing safety improvements. In support of these safety efforts, several projects have been undertaken by the U.S. Department of Transportation (DOT) to assist states and railroads in determining effective allocations of funds for rail-highway crossing safety improvement. One project is the development of a resource allocation procedure which assists in nominating and ranking crossings for safety improvements to assure maximum safety benefits for a given level of funding. DOT's resource allocation procedure is based on two analytical tools: an accident prediction formula and a resource allocation model. The purpose of this report is to describe these tools in non-technical language and to explain the applications for the resource allocation procedure.

A joint U.S. DOT-AAR National Rail-Highway Crossing Inventory (DOT Crossing Inventory) was completed in 1976. Updated inventory data are published annually. (2) The DOT Crossing Inventory contains characteristics of all rail-highway crossings in the United States, gives uniform information on each crossing, and provides an improved basis for rail-highway crossing accident prediction.

A number of crossing hazard formulas have been developed and used extensively in dealing with solutions to the rail-highway crossing safety problem. (3) The DOT accident prediction formula is based on the extensive data in the DOT Crossing Inventory and is an improvement over other hazard formulas.

A flow diagram of the DOT accident and severity prediction formulas, showing the data bases employed, is described in Figure 1. Further information on these procedures is contained in another DOT report. (4) The theory underlying the formulas is contained in a separate report. (5)

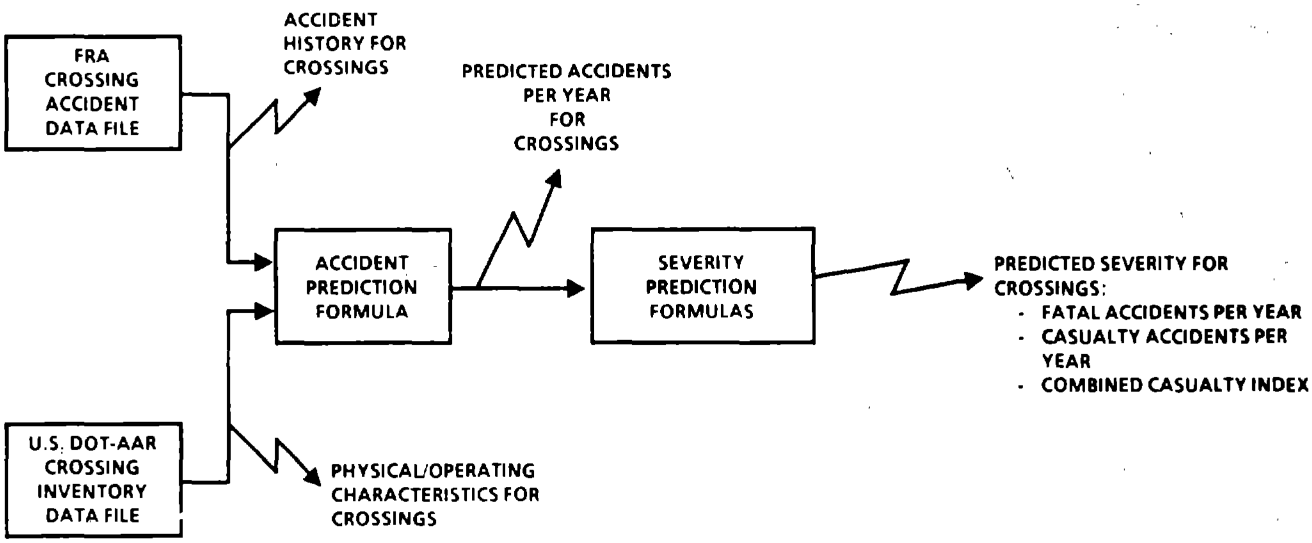

FIGURE 1. DOT RAIL-HIGHWAY CROSSING ACCIDENT AND SEVERITY PREDICTION FORMULAS

2. DOT ACCIDENT PREDICTION FORMULA

The DOT accident prediction formula was developed using the data shown in Figure 1. Three formulas are used to calculate predicted accidents: a basic formula which contains factors from the crossing inventory, a second formula which incorporates accident history as an explicit factor, and a third formula which involves a normalizing constant. The three formulas, given in a general form, are shown in equations [1], [2], and [3] respectively. The output of equation [1] is an input to equation [2]. The output of equation [2] is the input to equation [3]. The output of equation [3] is the predicted accidents per year for the crossing of interest.

$$a = K \times EI \times DT \times MS \times MT \times HP \times HL \qquad [1]$$

$$B = \frac{T_O}{T_O + T}(a) + \frac{T}{T_O + T}(N/T), \quad T_O = 1/(0.05 + a) \qquad [2]$$

$$A = \begin{cases} .8644B & \text{Passive Devices} \\ .8887B & \text{Flashing Lights} \\ .8131B & \text{Gates} \end{cases} \qquad [3]$$

The basic formula [1] was developed using a nonlinear multiple regression technique as applied to crossing characteristics contained in the DOT Crossing Inventory and to accident data contained in RAIRS. The basic formula consists of a number of multiplicative factors, each factor representing a characteristic of the crossing described in the DOT Crossing Inventory. The numerical value of each factor is related to the statistical influence which the specific crossing characteristic has on the predicted number of accidents. The values of (a) calculated from equation [1] could be considered accident predictions, but they have not been normalized properly. Three sets of equations are used to determine the values of each factor, corresponding to the following categories of warning devices: passive warning devices, flashing lights, and flashing lights with automatic gates. Specific equations for the crossing characteristic factors by the three warning device categories are shown in Appendix B. Each set of factor equations should only be used for crossings with the warning device category for which it was designed. To calculate the value of (a) at a crossing with crossbucks, for example, the passive set of equations should be used. In lieu of using the actual equations in Appendix B, a very good approximation can be achieved by using the range values for each factor. These values are tabulated in Appendix C.

The predictive capacity of the basic formula is limited because certain important crossing characteristics, such as site distance at the crossing, are not included in the DOT Crossing Inventory. Inclusion of actual accident history at crossings, as is done in equation [2], dramatically improves the predictive capabilities of the formula. Equation [2] calculates a value (B) which is a weighted average of two separately derived predictions. The two predictions are the value (a) from equation [1], which provides a prediction on the basis of a crossing's characteristics (as described in the DOT Crossing Inventory), and the actual accident history at a crossing, which is equal to the number of previous accidents (N) divided by the number of years of data (T). The value of (T) is usually taken to be five. To get the final predicted accidents (A), (B) is multipled by one of three constants as indicated by [3]. The particular constant depends on whether the crossing has a passive device (e.g., crossbuck), a flashing light, or a gate. These constants adjust the predictions to reflect more recent levels of accident experience. They will be recalculated periodically and published annually in FRA's Rail-Highway Crossing Accident/Incident and Inventory Bulletin starting with Bulletin No. 10 to be published in 1988 for Calendar Year 1987.

Values for (B) from equation [2] are tabulated in Appendix A for different values of (a) from equation [1], and the number of accidents (N) for five years of accident history data. The most recent five years of accident history data should be used to ensure good performance from the formula. Accident history information older than five years may be misleading because of changes in crossing characteristics. Tables for one, two, three and four years of accident history are published in the User's Guide, Third Edition 4 . Referring to the table in Appendix A, the value of (B) is determined from the intersection of the appropriate column and row for the values of (a) and (N). For example, if a = 0.10 and N = 1 for five years of data, the value of (B) is 0.143.

Use of the DOT accident prediction formula is illustrated below. Characteristics of a sample crossing from the DOT Crossing Inventory and RAIRS are shown in Table 1.

TABLE 1. CHARACTERISTICS OF SAMPLE CROSSING

CHARACTERISTIC	VALUE
Present warning device	Crossbucks
Annual average daily highway traffic	350
Total number of train movements per day	15
Total number of through trains per day	10
Total number of switch trains per day	5
Number of main tracks	2
Total number of tracks (main and other)	2
Number of through trains per day during daylight	5
Highway paved?	yes
Maximum timetable speed, mph	40
Number of highway lanes	2
Urban - rural location	Rural
Number of years accident data (T)	5
Number of accidents (N) in (T) years	2

The basic formula [1] is first used to determine the value of (a). The values of the formula factors for a passive crossing are determined from Table C-1: K = 0.0006938; EI = 42.39; DT = 1.79; MS = 1.36; MT = 1.00; HP = 1.00 and HL = 1.00. Substituting the factor values in the basic formula yields:

$$a = K \times EI \times DT \times MS \times MT \times HP \times HL$$
$$= 0.0006938 \times 42.39 \times 1.79 \times 1.36 \times 1.00 \times 1.00 \times 1.00$$
$$= 0.072$$

The value of (B) is determined by combining the value of (a) with the crossing's accident history, using either equation [2] or the table in Appendix A for five years of accident data. From Appendix A, with a = 0.072 and an accident history of two accidents (N = 2) during the past five years, the value of (B) is 0.196.* Thus, the final accident prediction value (A) from Formula [3] is A = 0.8644 X 0.196 = 0.169 accidents per year. This could be interpreted as one accident in six years.

The accident prediction formula was compared with other rail-highway crossing accident prediction models. Statistical tests which compared these models indicated that the accuracy of DOT's formula is superior for ranking crossings by predicted accident levels. Since the DOT formula is based on the DOT Crossing Inventory, a common data base of crossing characteristics is available to formula users. As the DOT Crossing Inventory is updated and the RAIRS data is expanded, the DOT accident prediction formula will reflect the latest information.

*Linear interpolation was used to obtain this value.

3. DOT SEVERITY PREDICTION FORMULAS

The DOT severity prediction formulas were developed using the data shown in Figure 1. Two basic kinds of severity predictions can be made: fatal accidents per year and casualty accidents per year. Fatal accidents are accidents which result in a fatality, and casualty accidents are accidents which result in either a fatality or an injury. Both kinds of accidents are reported annually by the FRA. (1)

In order to determine fatal accidents per year, given that an accident occurred, the probability that a fatal accident occurred, denoted P(FA|A), is first calculated using the formula:

$$P(FA|A) = 1/(1 + KF \times MS \times TT \times TS \times UR). \qquad [4]$$

The equation for P(FA|A) and numerical values for the multiplicative factors in the denominator are given in Appendix D. The number of fatal accidents per year (FA) is then obtained by the formula FA = A X P(FA|A).

In order to determine casualty accidents per year, given that an accident occurred, the probability that a casualty accident occurred, denoted P(CA|A), is first calculated using the formula:

$$P(CA|A) = 1/(1 + KC \times MS \times TK \times UR) \qquad [5]$$

The equation for P(CA|A) and numerical values for the multiplicative factors in the denominator are given in Appendix D. The number of casualty accidents per year (CA) is then obtained by the formula CA = A X P(CA|A).

In addition to these two predictions of crossing accident severity, a combined casualty index (CCI) can be calculated. If this measure is specified, the user must provide a constant which establishes how many injury accidents are equivalent to a fatal accident overall. If it is assumed that 50 injury accidents provide the same societal loss as one fatal accident, noting that CA - FA is the number of injury accidents per year, then

$$\begin{aligned} CCI &= 50\ FA + CA - FA \qquad [6] \\ &= 49\ FA + CA \end{aligned}$$

Use of the DOT severity prediction formulas is illustrated by the example in Table 1. From Table D-1 values of the factors needed to calculate the fatal accident probability are: KF = 440.9, MS = 0.025, TT = 0.811, TS = 1.169, and UR = 1.000. Substituting in formula [4] yields:

$$P(FA|A) = 1/(1 + 440.9 \times 0.025 \times 0.811 \times 1.169 \times 1.000) = .087.$$

This produces:

$$FA = A \times P\ (FA|A) = 0.16 \times 0.087 = 0.014 \text{ fatal accidents per year.}$$

This could be interpreted as one fatal accident in 71 years.

From Table D-2, values of the factors needed to calculate the casualty accident probability are: KC = 4.481, MS = 0.282, TK = 1.259, and UR = 1.000. Substituting in formula [5] yields:

$$P(CA|A) = 1/(1 + 4.481 \times 0.282 \times 1.259 \times 1.000) = 0.386$$

This produces:

$$CA = A \times P(CA|A) = 0.16 \times 0.386 = 0.062 \text{ casualty accidents per year.}$$

This could be interpreted as one casualty accident in 16 years.

Using the value of 50 injury accidents being equivalent to one fatal accident, the combined casualty index, using [6], is:

$$\begin{aligned} CCI &= 49\ FA + CA \\ &= 0.75 \end{aligned}$$

This value of CCI could be interpreted as being equivalent to one injury accident every 1.3 years.

4. RESOURCE ALLOCATION MODEL

The resource allocation model, shown as part of the resource allocation procedure in Figure 2, is designed to nominate crossings for improvement and suggest installation of the types of warning devices which maximize safety in the most cost effective manner. (6) Input to the resource allocation model includes the number of accidents predicted for each crossing, the severity predictions, the cost and effectiveness of different safety improvement options, and the budget level available for crossing safety improvement. Accident predictions can be made for a crossing by using any accident prediction formula which computes the expected number of accidents per year.

The resource allocation model requires estimated costs for flashing lights at a passive crossing, flashing lights and gates at a passive crossing, and for gates at a crossing already equipped with flashing lights. The required cost data may be specified by the user of the model, or data from a recent DOT study, shown in Table 2, may be used. (7) The cost data may be total life-cycle costs - the sum of procurement, installation, and maintenance - or those associated with a particular component of life-cycle costs. The cost data may also be installation costs.

TABLE 2. COST PARAMETERS FOR CROSSING WARNING DEVICES IN 1983 DOLLARS

IMPROVEMENT ACTION	LIFE CYCLE COSTS	INSTALLATION COSTS
Passive to Flashing Lights	$54,500	$43,800
Passive to Flashing Lights with Gates	$84,000	$65,300
Flashing Lights to Flashing Lights with Gates	$77,400	$58,700

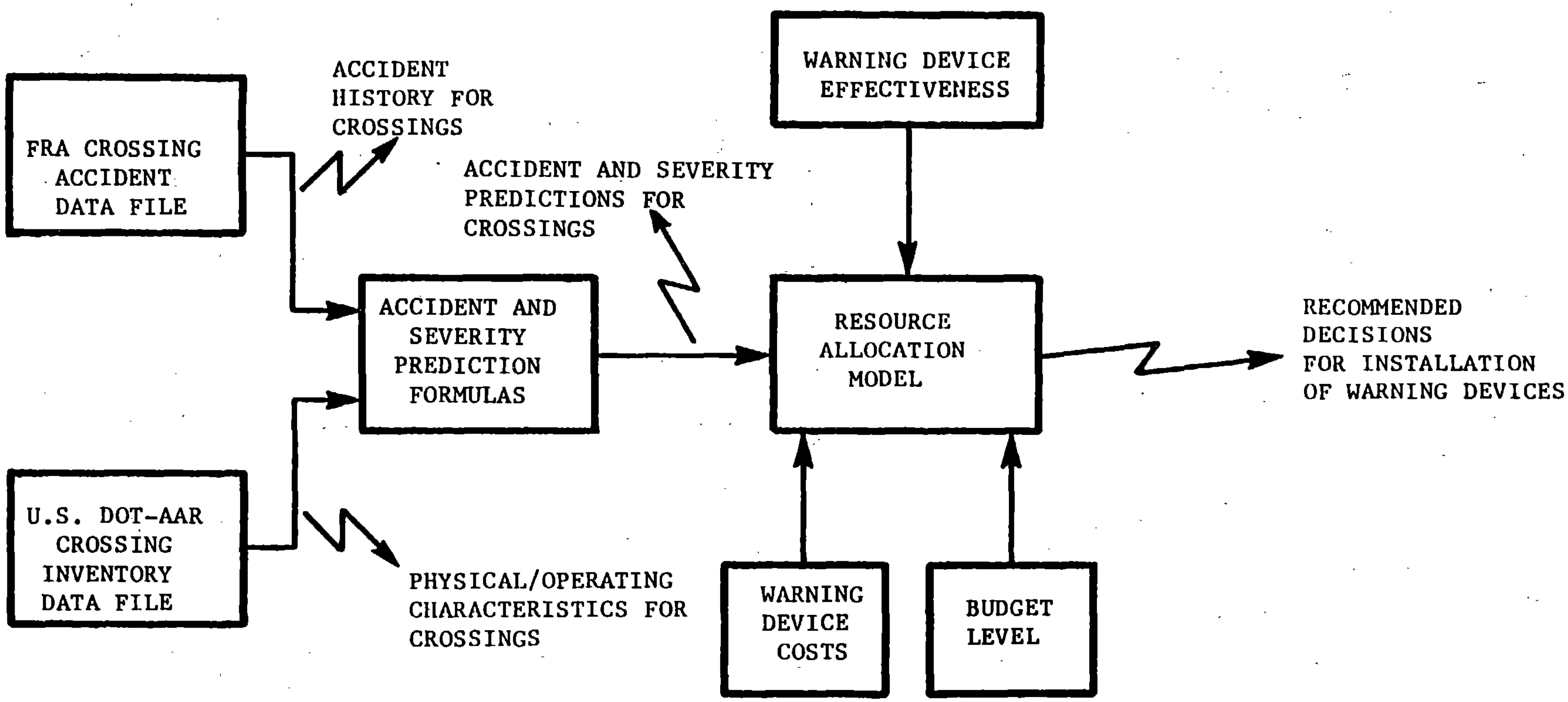

FIGURE 2. RAIL-HIGHWAY CROSSING RESOURCE ALLOCATION PROCEDURE

Similarly, the effectiveness of these warning device improvement options must be specified. Effectiveness is the decimal amount by which accidents are reduced with installation of the given warning device. Values of warning device effectiveness have been obtained by the DOT study. (7) Three standard effectiveness values have been determined which are based only on the present warning devices and the proposed warning devices. In addition, twelve extended effectiveness values have been determined which depend on the present and proposed warning devices, on whether the crossing has a single track or multiple tracks, and whether the number of trains per day is less than or equal to 10 or greater than or equal to 11. The user of the resource allocation model can choose which set of values to use. The DOT effectiveness values are shown in Table 3. Alternatively, if users have other effectiveness values which they believe are preferable, these may be specified in either the standard or extended format.

TABLE 3. EFFECTIVENESS VALUES FOR CROSSING WARNING DEVICES

IMPROVEMENT ACTION	STANDARD EFFECTIVENESS	EXTENDED EFFECTIVENESS			
		TRAINS $\leq$ 10		TRAINS $\geq$ 11	
		SINGLE TRACK	MULTIPLE TRACK	SINGLE TRACK	MULTIPLE TRACK
Passive to Flashing Lights	.70	.75	.65	.61	.57
Passive to Flashing Lights with Gates	.83	.90	.86	.80	.78
Flashing Lights to Flashing Lights with Gates	.69	.89	.65	.69	.63

The resource allocation model is used initially to develop a ranked list of benefit/cost ratios, representing improvement project decisions for each of the crossings and options under consideration. For a crossing with multiple tracks, the model specifies gates as the only improvement option. The benefit is the predicted number of accidents prevented per year, the predicted number of fatal accidents prevented per year, or the predicted reduced combined casualty index.

The cost is that specified for the warning device to be installed. The model is an aid for the decision maker in his/her determination of the most cost-beneficial crossing improvements. Using the model, the decision-maker is provided with a list of possible improvement projects that maximize estimated benefits for the available funding.

An example of an application of the resource allocation model is shown in Table 4. This table shows the results for a given set of crossings for a budget of $1,000,000, assuming the installation costs of Table 2 and the extended effectiveness values of Table 3. The list shows the recommended improvements sorted by benefit/cost ratio, where benefit is the expected accident reduction. The ID, the present warning device, the predicted accidents per year, and the improvement costs for each crossing are also included. The sum of the improvement costs is $994,400, which is just under the budget of $1,000,000. If one more crossing improvement were added to the list, the budget would be exceeded.

These results are indicative of the computer output that is available. Software is available that will show additional crossing characteristics that enter into the model. The software will also produce the output list sorted by crossing ID and provide a convenient summary of all the input parameters (4).

An optional feature has been added to the resource allocation model pertaining to stop signs. In the DOT study it was found that stop signs, when installed at passive crossings, have an effectiveness of 0.35 and an average installation cost of $400. (7) The FHWA has established guidelines for the selection of candidate crossings for stop signs. (8) With such a high benefit/cost ratio it is important to know which crossings meet these guidelines. Therefore the resource allocation procedure identifies passive crossings which satisfy the following criteria:

1. Less than 400 AADT for rural roads. Less than 1500 AADT for urban roads.
2. Single track.
3. Greater than 10 trains per day.

Crossings so identified may also be recommended for an active warning device by the resource allocation model. The judgment of the crossing diagnostic team would be used at this point to make the best improvement decision.

TABLE 4. RAIL-HIGHWAY CROSSING RESOURCE ALLOCATION RESULTS

Crossing ID	Benefit/Cost Ratio	Recommended Improvement	Improvement Cost	Present Warning Device	Predicted Acc./Year
284M	3.60	Gate	$58,700	Flashing Lt.	.306
636R	2.68	Gate	65,300	Passive	.195
368H	2.61	Gate	58,700	Flashing Lt.	.172
365M	2.61	Gate	58,700	Flashing Lt.	.172
358C	2.44	Gate	58,700	Flashing Lt.	.161
639L	1.95	Flashing Lt.	43,800	Passive	.114
249Y	1.89	Flashing Lt.	43,800	Passive	.111
377G	1.45	Gate	58,700	Flashing Lt.	.095
382D	1.44	Gate	58,700	Flashing Lt.	.095
175X	1.39	Gate	65,300	Passive	.105
337J	1.25	Gate	58,700	Flashing Lt.	.082
158G	1.21	Flashing Lt.	43,800	Passive	.070
164K	1.21	Flashing Lt.	43,800	Passive	.070
651T	1.21	Flashing Lt.	43,800	Passive	.087
631G	1.21	Flashing Lt.	43,800	Passive	.087
389B	1.18	Flashing Lt.	43,800	Passive	.069
640F	1.12	Flashing Lt.	43,800	Passive	.066
370J	1.06	Gate	58,700	Flashing Lt.	.070
158M	0.98	Flashing Lt.	43,800	Passive	.058

APPENDIX A

TABLE VALUES FOR ACCIDENT HISTORY FORMULA

Table A-1 gives the value of (B) for a crossing from equation [2] based on the output (a) of equation [1] and the crossing's five year accident history. For example, if the value of (a) is 0.20 and the crossing experienced two accidents during the past five years, the value of (B) would be 0.311.

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TABLE A-1. VALUES OF (B) CALCULATED FROM VALUES OF (a) AND ACCIDENT HISTORY (FIVE YEARS OF ACCIDENT DATA)

PREDICTION FROM BASIC MODEL* (a)	NUMBER OF ACCIDENTS (N)														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.00	0.000	0.040	0.080	0.120	0.160	0.200	0.240	0.280	0.320	0.360	0.400	0.440	0.480	0.520	0.560
0.01	0.008	0.054	0.100	0.146	0.192	0.238	0.285	0.331	0.377	0.423	0.469	0.515	0.562	0.608	0.654
0.02	0.015	0.067	0.119	0.170	0.222	0.274	0.326	0.378	0.430	0.481	0.533	0.585	0.637	0.689	0.741
0.03	0.021	0.079	0.136	0.193	0.250	0.307	0.364	0.421	0.479	0.536	0.593	0.650	0.707	0.764	0.821
0.04	0.028	0.090	0.152	0.214	0.276	0.338	0.400	0.462	0.524	0.586	0.648	0.710	0.772	0.834	0.897
0.05	0.033	0.100	0.167	0.233	0.300	0.367	0.433	0.500	0.567	0.633	0.700	0.767	0.833	0.900	0.967
0.06	0.039	0.110	0.181	0.252	0.323	0.394	0.465	0.535	0.606	0.677	0.748	0.819	0.890	0.961	1.032
0.07	0.044	0.119	0.194	0.269	0.344	0.419	0.494	0.569	0.644	0.719	0.794	0.869	0.944	1.019	1.094
0.08	0.048	0.127	0.206	0.285	0.364	0.442	0.521	0.600	0.679	0.758	0.836	0.915	0.994	1.073	1.152
0.09	0.053	0.135	0.218	0.300	0.382	0.465	0.547	0.629	0.712	0.794	0.876	0.959	1.041	1.124	1.206
0.10	0.057	0.143	0.229	0.314	0.400	0.486	0.571	0.657	0.743	0.829	0.914	1.000	1.086	1.171	1.257
0.20	0.089	0.200	0.311	0.422	0.533	0.644	0.756	0.867	0.978	1.089	1.200	1.311	1.422	1.533	1.644
0.30	0.109	0.236	0.364	0.491	0.618	0.745	0.873	1.000	1.127	1.255	1.382	1.509	1.636	1.764	1.891
0.40	0.123	0.262	0.400	0.538	0.677	0.815	0.954	1.092	1.231	1.369	1.508	1.646	1.785	1.923	2.062
0.50	0.133	0.280	0.427	0.573	0.720	0.867	1.013	1.160	1.307	1.453	1.600	1.747	1.893	2.040	2.187
0.60	0.141	0.294	0.447	0.600	0.753	0.906	1.059	1.212	1.365	1.518	1.671	1.824	1.976	2.129	2.282
0.70	0.147	0.305	0.463	0.621	0.779	0.937	1.095	1.253	1.411	1.568	1.726	1.884	2.042	2.200	2.358
0.80	0.152	0.314	0.476	0.638	0.800	0.962	1.124	1.286	1.448	1.610	1.771	1.933	2.095	2.257	2.419
0.90	0.157	0.322	0.487	0.652	0.817	0.983	1.148	1.313	1.478	1.643	1.809	1.974	2.139	2.304	2.470
1.00	0.160	0.328	0.496	0.664	0.832	1.000	1.168	1.336	1.504	1.672	1.840	2.008	2.176	2.344	2.512
1.10	0.163	0.333	0.504	0.674	0.844	1.015	1.185	1.356	1.526	1.696	1.867	2.037	2.207	2.378	2.548
1.20	0.166	0.338	0.510	0.683	0.855	1.028	1.200	1.372	1.545	1.717	1.890	2.062	2.234	2.407	2.579
1.30	0.168	0.342	0.516	0.690	0.865	1.039	1.213	1.387	1.561	1.735	1.910	2.084	2.258	2.432	2.606
1.40	0.170	0.345	0.521	0.697	0.873	1.048	1.224	1.400	1.576	1.752	1.927	2.103	2.279	2.455	2.630
1.50	0.171	0.349	0.526	0.703	0.880	1.057	1.234	1.411	1.589	1.766	1.943	2.120	2.297	2.474	2.651
1.60	0.173	0.351	0.530	0.708	0.886	1.065	1.243	1.422	1.600	1.778	1.957	2.135	2.314	2.492	2.670
1.70	0.174	0.354	0.533	0.713	0.892	1.072	1.251	1.431	1.610	1.790	1.969	2.149	2.328	2.508	2.687
1.80	0.176	0.356	0.537	0.717	0.898	1.078	1.259	1.439	1.620	1.800	1.980	2.161	2.341	2.522	2.702
1.90	0.177	0.358	0.540	0.721	0.902	1.084	1.265	1.447	1.628	1.809	1.991	2.172	2.353	2.535	2.716
2.00	0.178	0.360	0.542	0.724	0.907	1.089	1.271	1.453	1.636	1.818	2.000	2.182	2.364	2.547	2.729
2.10	0.179	0.362	0.545	0.728	0.911	1.094	1.277	1.460	1.643	1.826	2.009	2.191	2.374	2.557	2.740
2.20	0.180	0.363	0.547	0.731	0.914	1.098	1.282	1.465	1.649	1.833	2.016	2.200	2.384	2.567	2.751
2.30	0.180	0.365	0.549	0.733	0.918	1.102	1.286	1.471	1.655	1.839	2.024	2.208	2.392	2.576	2.761
2.40	0.181	0.366	0.551	0.736	0.921	1.106	1.291	1.475	1.660	1.845	2.030	2.215	2.400	2.585	2.770
2.50	0.182	0.367	0.553	0.738	0.924	1.109	1.295	1.480	1.665	1.851	2.036	2.222	2.407	2.593	2.778

*For values of (a) between those listed, linear interpolation is recommended.

APPENDIX B

EQUATIONS FOR BASIC FORMULA

Table B-1 lists equations for determining values of crossing characteristic factors used in the basic formula [1]. A different set of equations is provided for each of the warning device categories: passive, flashing lights, and gates. Each set of factor equations should only be used for crossings with the warning device category for which it was designed. To calculate (a) at a crossing with crossbucks, for example, the passive set of equations would be used. For cases indicated in the table where the equation is shown as a constant 1.0, it was found that the characteristic did not have a statistical relationship to predicting crossing accidents.

If the warning devices at a particular crossing were upgraded in the last five years, it is preferable to use the set of equations for the warning device existing prior to upgrading and multiply the resulting value of (a) by the appropriate effectiveness factor from Table 3. In calculating (B) for such a crossing, only accident history since the upgrading should be considered. For example, if the warning devices at a crossing were upgraded from crossbucks to gates two years ago, the value of (a) should be calculated using the equation for "passive" crossings and the result should be multiplied by 1 - 0.83 = 0.17. Though five years of accident history may be available, only the accidents and the time elapsed since the upgrade (T = 2) should be used in arriving at a value of (B). The final accident prediction (A) would be obtained from the equation A = 0.8131 X B.

TABLE B-1. EQUATIONS FOR CROSSING CHARACTERISTIC FACTORS

GENERAL FORM OF BASIC FORMULA: a = K x EI x DT x MS x MT x HP x HL

CROSSING CHARACTERISTIC FACTORS							
CROSSING CATEGORY	FORMULA CONSTANT	EXPOSURE INDEX FACTOR	DAY THROUGH TRAINS FACTOR	MAXIMUM SPEED FACTOR	MAIN TRACKS FACTOR	HIGHWAY PAVED FACTOR	HIGHWAY LANES FACTOR
	K	EI	DT	MS	MT	HP	HL
PASSIVE	0.0006938	$((c \times t + 0.2)/0.2)^{0.37}$	$((d + 0.2)/0.2)^{0.178}$	$e^{0.0077ms}$	1.0	$e^{-0.5966(hp-1)}$	1.0
FLASHING LIGHTS	0.0003351	$((c \times t + 0.2)/0.2)^{0.4106}$	$((d + 0.2)/0.2)^{0.1131}$	1.0	$e^{0.1917mt}$	1.0	$e^{0.1826(hl-1)}$
GATES	0.0005745	$((c \times t + 0.2)/0.2)^{0.2942}$	$((d + 0.2)/0.2)^{0.1781}$	1.0	$e^{0.1512mt}$	1.0	$e^{0.1420(hl-1)}$

c = number of highway vehicles per day

t = number of trains per day

mt = number of main tracks

d = number of through trains per day during daylight

hp = highway paved? yes = 1.0 and no = 2.0

ms = maximum timetable speed, mph

hl = number of highway lanes

APPENDIX C

TABLE VALUES FOR BASIC FORMULA FACTORS

Tables C-1, C-2, and C-3 provide numerical values for the crossing characteristic factors of the basic formula [1] for the various characteristic levels. A different table is provided for each of the categories: passive, flashing lights, and gates. The values are to be used only for crossings with the warning device category for which it was designed. To calculate the value of (a) at a crossing with flashing lights, Table C-2 would be used to obtain the factor values for substitution into the basic formula.

If the warning devices at a particular crossing were upgraded in the last five years, it is preferable to use the set of equations for the warning device existing prior to upgrading and multiply the resulting value of (a) by the appropriate effectiveness factor from Table 3. In calculating (B) for such a crossing, only accident history since the upgrading should be considered. For example, if the warning device at a crossing were upgraded from crossbucks to gates two years ago, the value of (a) should be developed using Table C-1 and the result should be multiplied by 1 - 0.83 = 0.17. Though five years of accident history may be available, only the accidents and the time elapsed since the upgrade (T = 2) should be used in arriving at a value of (B). The final accident prediction (A) would be obtained from the equation A = 0.8131 X B.

TABLE C-1. FACTOR VALUES FOR CROSSINGS WITH PASSIVE WARNING DEVICES

GENERAL FORM OF BASIC FORMULA: a = K x EI x DT x MS x MT x HP x HL

K	"c" x "t"	EI	Day Through Trains	DT	Maximum Timetable Speed	MS	Main Tracks	MT	Highway Paved	HP	Highway Lanes	HL
0.0006938	0*-	1.00	0	1.00	0	1.00	0	1.00	1 (yes)	1.00	1	1.00
	1 - 5	2.43	1	1.37	5	1.04	1	1.00			2	1.00
	6 - 10	3.95	2	1.53	10	1.08	2	1.00	2 (no)	0.55	3	1.00
	11 - 20	4.96	3	1.64	15	1.12	3	1.00			4	1.00
	21 - 30	5.99	4	1.72	20	1.17	4	1.00			5	1.00
	31 - 50	7.12	5	1.79	25	1.21	5	1.00			6	1.00
	51 - 80	8.51	6	1.84	30	1.26	6	1.00			7	1.00
	81 - 120	9.98	7	1.89	35	1.31					8	1.00
	121 - 200	11.88	8	1.94	40	1.36					9	1.00
	201 - 300	14.00	9	1.98	45	1.41						
	301 - 400	15.85	10	2.01	50	1.47						
	401 - 500	17.39	11-10	2.16	55	1.53						
	501 - 600	18.73	21-30	2.37	60	1.59						
	601 - 700	19.93	31-40	2.51	65	1.65						
	701 - 1000	22.01	41-60	2.67	70	1.71						
	1001 - 1300	24.61			75	1.78						
	1301 - 1600	26.81			80	1.85						
	1601 - 2000	29.05			85	1.92						
	2001 - 2500	31.28			90	2.00						
	2501 - 3000	33.98										
	3001 - 4000	37.15										
	4001 - 6000	42.39										
	6001 - 8000	48.01										
	8001 - 10000	52.69										
	10001 - 15000	59.49										
	15001 - 20000	67.38										
	20001 - 25000	73.95										
	25001 - 30000	79.65										
	30001 - 40000	87.08										
	40001 - 50000	95.57										
	50001 - 60000	102.93										
	60001 - 70000	109.50										
	70001 - 90000	118.24										
	90001 - 110000	128.42										
	110001 - 130000	137.38										
	130001 - 180000	151.02										
	180001 - 230000	167.48										
	230001 - 300000	187.14										
	300001 - 370000	200.86										

K = formula constant
"c" x "t" - number of highway vehicles per day, "c", multiplied by the number of trains per day, "t"
EI = exposure index factor
MT = main tracks factor
DT = day through trains factor
HP = highway paved factor
MS = maximum timetable speed factor
HL = highway lanes factor

*Less than one train per day.

TABLE C-2. FACTOR VALUES FOR CROSSINGS WITH FLASHING LIGHT WARNING DEVICES

GENERAL FORM OF BASIC FORMULA: a = K x EI x DT x MS x MT x HP x HL

K	"c" x "t"	EI	Day Through Trains	DT	Maximum Timetable Speed	MS	Main Tracks	MT	Highway Paved	HP	Highway Lanes	HL
0.0003351	0*-	1.00	0	1.00	0	1.00	0	1.00	1 (yes)	1.00	1	1.00
	1 - 5	3.12	1	1.22	5	1.00	1	1.21			2	1.20
	6 - 10	4.59	2	1.31	10	1.00	2	1.47	2 (no)	1.00	3	1.44
	11 - 20	5.92	3	1.37	15	1.00	3	1.78			4	1.72
	21 - 30	7.28	4	1.41	20	1.00	4	2.15			5	2.08
	31 - 50	8.82	5	1.45	25	1.00	5	2.61			6	2.49
	51 - 80	10.76	6	1.47	30	1.00	6	3.16			7	2.99
	81 - 120	12.54	7	1.50	35	1.00					8	3.59
	121 - 200	15.57	8	1.52	40	1.00					9	4.31
	201 - 300	18.70	9	1.54	45	1.00						
	301 - 400	21.46	10	1.56	50	1.00						
	401 - 500	23.79	11-20	1.63	55	1.00						
	501 - 600	25.84	21-30	1.73	60	1.00						
	601 - 700	27.67	31-40	1.79	65	1.00						
	701 - 1000	30.89	41-60	1.87	70	1.00						
	1001 - 1300	34.97			75	1.00						
	1301 - 1600	38.47			80	1.00						
	1601 - 2000	42.04			85	1.00						
	2001 - 2500	46.07			90	1.00						
	2501 - 3000	50.03										
	3001 - 4000	55.23										
	4001 - 6000	63.94										
	6001 - 8000	73.42										
	8001 - 10000	81.40										
	10001 - 15000	93.15										
	15001 - 20000	106.95										
	20001 - 25000	118.58										
	25001 - 30000	128.76										
	30001 - 40000	142.17										
	40001 - 50000	157.62										
	50001 - 60000	171.16										
	60001 - 70000	183.31										
	70001 - 90000	199.62										
	90001 - 110000	218.78										
	110001 - 130000	235.78										
	130001 - 180000	261.91										
	180001 - 230000	293.77										
	230001 - 300000	326.42										
	300001 - 370000	359.40										

K = formula constant
"c" x "t" = number of highway vehicles per day, "c", multiplied by the number of trains per day, "t"
EI = exposure index factor
MT = main tracks factor
DT = day through trains factor
HP = highway paved factor
MS = maximum timetable speed factor
HL = highway lanes factor

*Less than one train per day.

TABLE C-3. FACTOR VALUES FOR CROSSINGS WITH GATE WARNING DEVICES

GENERAL FORM OF BASIC FORMULA: a = K x EI x DT x MS x MT x HP x HL

K	"c" x "t"	EI	Day Through Trains	DT	Maximum Timetable Speed	MS	Main Tracks	MT	Highway Paved	HP	Highway Lanes	HL
0.0005745	0*-	1.00	0	1.00	0	1.00	0	1.00	1 (yes)	1.00	1	1.00
	1 - 5	2.26	1	1.38	5	1.00	1	1.16			2	1.15
	6 - 10	2.98	2	1.53	10	1.00	2	1.35	2 (no)	1.00	3	1.32
	11 - 20	3.57	3	1.64	15	1.00	3	1.57			4	1.53
	21 - 30	4.15	4	1.72	20	1.00	4	1.83			5	1.76
	31 - 50	4.76	5	1.79	25	1.00	5	2.13			6	2.03
	51 - 80	5.99	6	1.84	30	1.00	6	2.48			7	2.34
	81 - 120	6.23	7	1.89	35	1.00					8	2.70
	121 - 200	7.15	8	1.94	40	1.00					9	3.11
	201 - 300	8.15	9	1.98	45	1.00						
	301 - 400	9.00	10	2.01	50	1.00						
	401 - 500	9.69	11-20	2.16	55	1.00						
	501 - 600	10.28	21-30	2.37	60	1.00						
	601 - 700	10.79	31-40	2.51	65	1.00						
	701 - 1000	11.68	41-60	2.68	70	1.00						
	1001 - 1300	12.77			75	1.00						
	1301 - 1600	13.67			80	1.00						
	1601 - 2000	14.57			85	1.00						
	2001 - 2500	15.55			90	1.00						
	2501 - 3000	16.20										
	3001 - 4000	17.71										
	4001 - 6000	19.67										
	6001 - 8000	21.72										
	8001 - 10000	23.39										
	10001 - 15000	25.76										
	15001 - 20000	28.44										
	20001 - 25000	30.67										
	25001 - 30000	32.49										
	30001 - 40000	34.87										
	40001 - 50000	37.55										
	50001 - 60000	39.83										
	60001 - 70000	41.84										
	70001 - 90000	44.48										
	90001 - 110000	47.49										
	110001 - 130000	50.11										
	130001 - 180000	54.03										
	180001 - 230000	58.24										
	230001 - 300000	63.26										
	300001 - 370000	67.78										

K = formula constant
"c" x "t" = number of highway vehicles per day, "c", multiplied by the number of trains per day, "t"
EI - exposure index factor
MT = main tracks factor
DT = day through trains factor
HP = highway paved factor
MS = maximum timetable speed factor
HL = highway lanes factor

*Less than one train per day.

APPENDIX D

EQUATIONS AND TABLE VALUES FOR SEVERITY PREDICTION FORMULAS

The equation for P(FA|A) is:

$$P(FA|A) = 1/(1 + KF \times MS \times TT \times TS \times UR),$$

where

$$KF = 440.9,\ MS = ms^{-0.9981},\ TT = (tt + 1)^{-0.0872},$$
$$TS = (ts + 1)^{0.0872},\ UR = e^{0.3571ur}$$

The equation for P(CA|A) is:

$$P(CA|A) = 1/(1 + KC \times MS \times TK \times UR),$$

where

$$KC = 4.481,\ MS = ms^{-0.343},\ TK = e^{0.1153tk},\ UR = e^{0.2960ur}$$

Tables D-1 and D-2 provide the numerical values of the severity prediction formulas [4] and [5]. These formulas apply to all crossings regardless of the type of warning device present.

TABLE D-1. FACTOR VALUES FOR FATAL ACCIDENT PROBABILITY FORMULA

Fatal Accident Probability Formula: P(FA|A) = 1/(1 + KF x MS x TT x TS x UR)

FORMULA CONSTANT KF	MAXIMUM TIMETABLE TRAIN SPEED	MS	THROUGH TRAINS PER DAY	TT	SWITCH TRAINS PER DAY	TS	URBAN RURAL CROSSING	UR
440.9	1	1.000	0	1.000	0	1.000	0 (rural)	1.000
	5	0.201	1	0.941	1	1.062	1 (urban)	1.344
	10	0.100	2	0.908	2	1.101		
	15	0.067	3	0.886	3	1.128		
	20	0.050	4	0.869	4	1.151		
	25	0.040	5	0.855	5	1.169		
	30	0.034	6	0.844	6	1.185		
	40	0.025	7	0.834	7	1.199		
	50	0.020	9	0.818	9	1.222		
	60	0.017	10	0.811	10	1.233		
	70	0.014	20	0.767	20	1.304		
	80	0.013	30	0.741	30	1.349		
	90	0.011	40	0.723	40	1.382		
	100	0.010	50	0.710	50	1.409		

TABLE D-2. FACTOR VALUES FOR CASUALTY ACCIDENT PROBABILITY FORMULA

CASUALTY ACCIDENT PROBABILITY FORMULA: P(CA|A) = 1/(1 + KC x MS X TK x UR)

FORMULA CONSTANT KC	MAXIMUM TIMETABLE TRAIN SPEED	MS	TOTAL NUMBER OF TRACKS	TK	URBAN-RURAL CROSSING	UR
4.481	1	1.000	0	1.000	0 (rural)	1.000
	5	0.576	1	1.122	1 (urban)	1.429
	10	0.454	2	1.259		
	15	0.395	3	1.413		
	20	0.358	5	1.780		
	25	0.332	6	1.997		
	30	0.308	7	2.241		
	40	0.282	8	2.515		
	50	0.261	9	2.823		
	60	0.246	10	3.168		
	70	0.233	15	5.638		
	80	0.222	20	10.034		
	90	0.214				
	100	0.206				

GLOSSARY

AAR - Association of American Railroads

accident prediction formula - A hazard function which calculates predicted accidents per year at a crossing.

active warning device - A warning device activated by an approaching train; e.g., gates, flashing lights, highway signals, wig-wags, and bells.

basic accident prediction formula - Provides an initial prediction of a crossing's accidents based on its characteristics in the DOT Crossing Inventory. Results of the basic formula are used as input for the DOT accident prediction formula.

benefit/cost ratio - Ratio of benefit expressed in the number of accidents, fatalities, or casualties prevented per year to the cost of the warning systems ($).

combined casualty index (CCI) - A measure of accident severity which combines fatal and injury accidents into a single index.

effectiveness - Accident reduction factor for a warning device relative to the present warning device. It is a number between zero and one; zero means no effectiveness and one is total effectiveness.

flashing lights - An active warning device consisting of flashing red lights that are either cantilevered or mast-mounted.

gates - An active warning device consisting of automatic gates and flashing lights.

hazard function - Any function which gives a numerical value of the likelihood of a motor vehicle/train collision at a rail-highway crossing.

life-cycle costs - The total net present value that is needed to procure, install, and maintain a warning device over its useful service.

optimum safety improvement - An improvement which maximizes safety benefits, in terms of reduced accidents, fatalities, or casualties, for a given amount of funding.

passive warning device - A warning device not activated by an approaching train.

RAIRS - Railroad Accident/Incident Reporting System

severity prediction formula - A formula which calculates predicted fatal accidents per year or predicted casualty accidents per year.

warning device - A device which warns highway users that the roadway crosses railroad trackage.

warning device categories - The following types of warning devices are included in the three warning device categories established for the DOT resource allocation procedure:

1. passive warning devices: crossbucks, stop signs, other signs, and no signs or signals. These devices are classes 1, 2, 3 and 4 in the DOT Crossing Inventory.

2. flashing light warning devices: flashing lights, both cantilevered and post-mounted; highway signals, wig-wags, or bells; and special warnings such as flagmen. These devices are classes 5, 6, and 7 in the DOT Crossing Inventory.

3. gate warning devices: automatic gates with flashing lights. This device is class 8 in the DOT Crossing Inventory.

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