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# Summary of the Department of Transportation Rail-Highway Crossing Accident Prediction Formulas and Resource Allocation Model

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16. Abstract


The Highway Safety Acts of 1973 and 1976, and the Surface Transportation Assistance Act of 1978, 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 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 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).[1] 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.

[1] Association of American Railroads (AAR)


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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 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 authors of this report for assistance in using the resource allocation procedures.

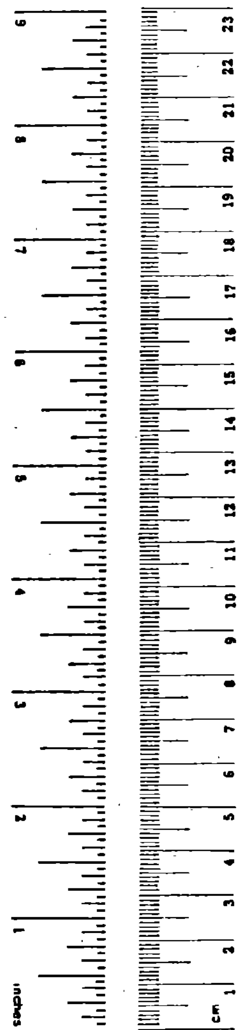
This report provides an overview of the use and output of these procedures. Dr. Peter H. Mengert/TSC had the primary role in developing the DOT rail-highway accident prediction formula, and Dr. Edwin H. Farr/TSC had the major role in formulating the resource allocation model.

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

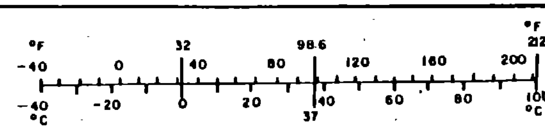
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 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 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights 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 |



CONTENTS

# 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

ht = highway type value

HT = factor for highway type*

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 tracks

N = number of historical accidents recorded for a crossing

t = number of trains per day

T = number years of recorded accident data

$T_o$ = weighting factor in DOT accident prediction formula

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* New formula factors not included in the previous version of the basic formula described by Peter Mengert in Rail-Highway Crossing Hazard Prediction Research Results.

# 1. INTRODUCTION

The Highway Safety Acts of 1973 and 1976 and the Surface Transportation Assistance Act of 1978 provide funding authorizations for 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. 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 paper is to describe these tools 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.[1] 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. The DOT accident prediction formula is an improvement over other hazard formulas.

[1] Association of American Railroads (AAR)

## 2. THE DOT ACCIDENT PREDICTION FORMULA

The DOT accident prediction formula, illustrated in Figure 1, can be used to predict the annual average number of accidents at crossings.

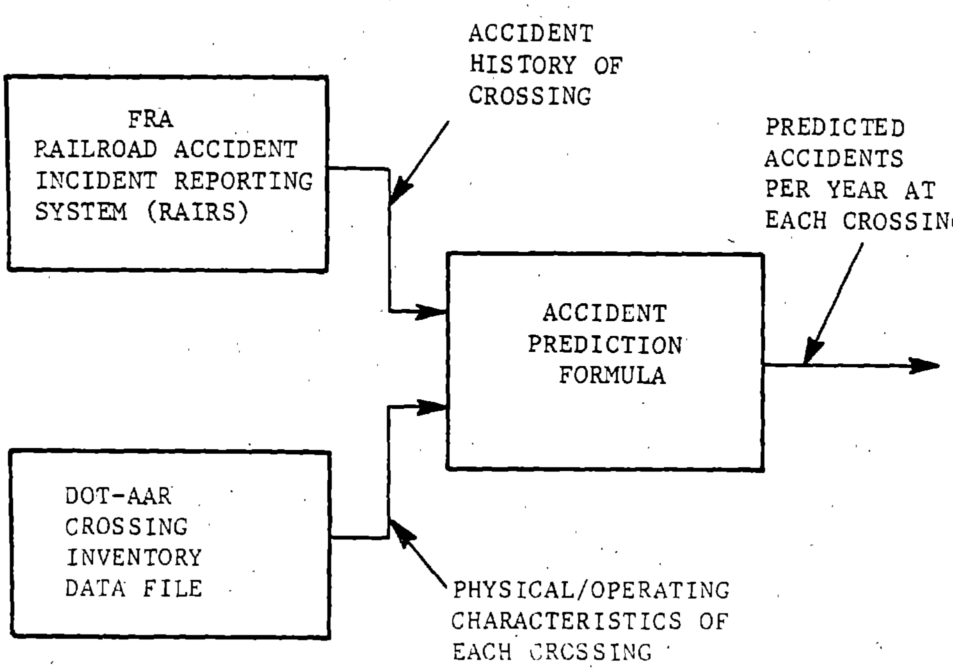


FIGURE 1. ILLUSTRATION OF THE DOT RAIL-HIGHWAY CROSSING ACCIDENT PREDICTION FORMULA

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[1] Federal Highway Administration, Railroad-Highway Grade Crossing Handbook, (Washington, D.C.: U.S. Department of Transportation, August 1978).

The initial prediction of crossing accidents (a) is determined from the basic formula described in equation 1. The basic formula was developed by applying nonlinear, multiple regression techniques to crossing characteristics stored in the DOT Crossing Inventory and to accident data contained in RAIRS. Using the basic formula, a crossing's predicted number of accidents per year is calculated by multiplying a series of 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 general expression of the basic formula is shown below:

$$a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL \qquad \text{(equation 1)}$$

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 predict the number of accidents at a crossing with crossbucks for example, the passive set of equations should be used. Numerical values of the factors for different crossing characteristics 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 dramatically improves the predictive capabilities of the formula. The improved DOT accident prediction formula is based on a weighted average of two separately derived predictions. The two separate predictions are obtained from: the "basic formula" (equation 1) which provides a prediction of accidents (a) on the basis of a crossing's characteristics, as described in the DOT Crossing Inventory; and the actual accident history at a crossing equal to the number of previous accidents (N) divided by the number of years of data (T). These two predictions are combined in the DOT accident prediction formula as follows:

$$A = \frac{T_0}{T_0 + T}(a) + \frac{T}{T_0 + T}\frac{N}{T} \qquad \text{(equation 2)}$$

where: $T_0$ = formula weighting factor = 1.0 / (0.05 + a).

Values for the final accident prediction (A), obtained from the DOT accident prediction formula (equation 2), are tabulated in Appendix A for different values of the initial predictions (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. Referring to the table in Appendix A, the value of A 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 predicted number of accidents is A = 0.143.

Use of the DOT accident prediction formula is illustrated in this section. 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 | 500 |
| Total number of trains per day | 13 |
| Number of main tracks | 2 |
| Number of thru trains per day during daylight | 6 |
| Highway paved? | Yes |
| Maximum timetable speed (mph) | 40 |
| Highway type | rural minor arterial (inventory code 06) |
| Number of highway lanes | 2 |
| Number of years accident data | 5 |
| Number of accidents in T years | 2 |

The basic formula (equation 1) is first used to determine the initial accident prediction (a). The values of the formula factors for a passive crossing are determined from Table C-1: K = 0.002268; EI = 32.73; MT = 1.52; DT = 1.58; HP = 1.00; MS = 1.36; HT = 0.82; and HL = 1.00. Substituting the factor values in the basic formula yields:

$$\begin{aligned} a &= K \times EI \times MT \times DT \times HP \times MS \times HT \times HL \\ &= 0.002268 \times 32.73 \times 1.52 \times 1.58 \times 1.00 \times 1.36 \times 0.82 \times 1.00 \\ &= 0.20 \text{ accidents per year.} \end{aligned}$$

The final accident prediction (A) in accidents per year is determined by combining the initial prediction (a) with the crossing's accident history, using either the DOT accident prediction formula (equation 1) or the table in Appendix A for five years of accident data. With an initial accident prediction (a = 0.20) and an accident history of two accidents during the past five years, the final accident prediction (A) is 0.31 accidents per year.

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.[1] 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.

## 3. 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 type of warning device which is cost effective and most safe. Input to the resource allocation model includes the number of accidents predicted for each crossing, 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.

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[1] Peter Mengert, Rail-Highway Crossing Hazard Prediction Research Results, (Washington, D.C.: U.S. Department of Transportation, March 1980).

N.B.: The performance of the DOT formula described in this report is an improved version of the one described in Dr. Mengert's report.

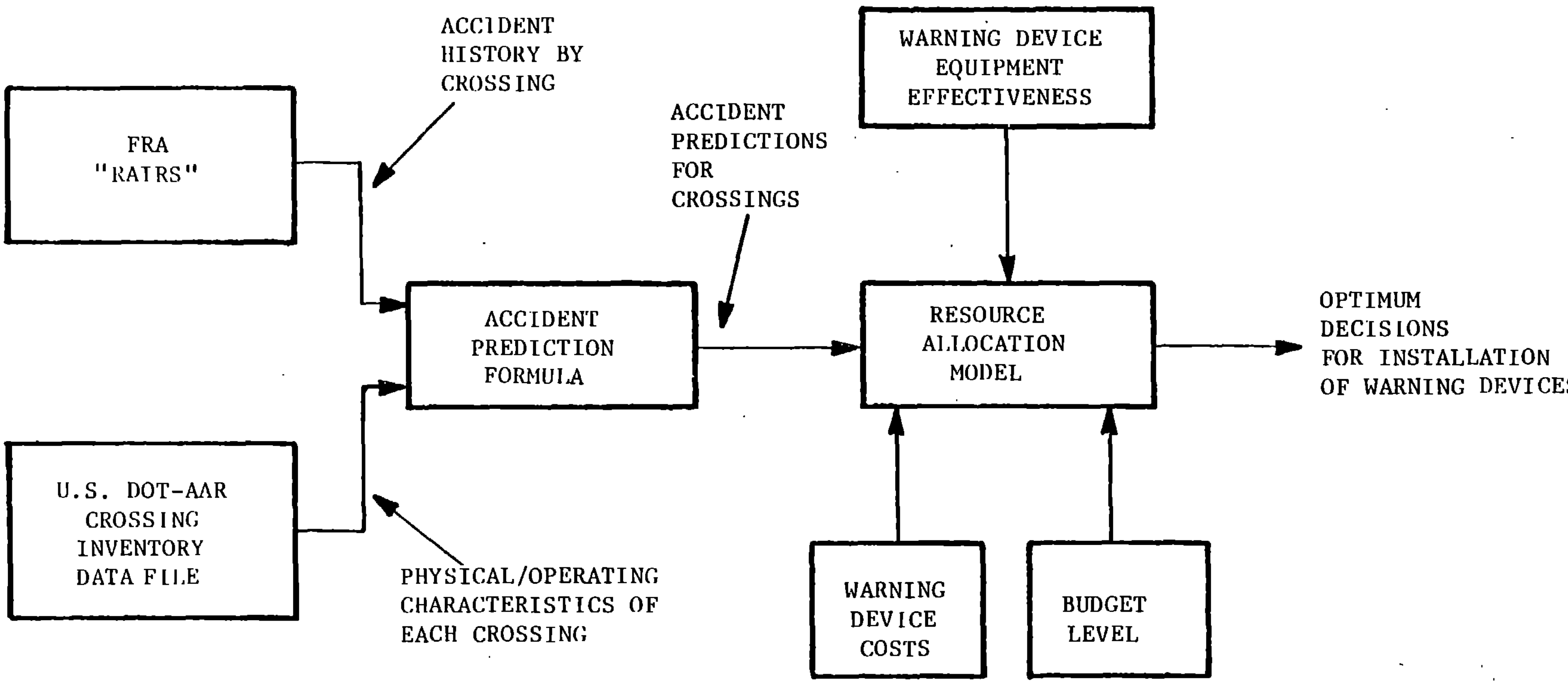


FIGURE 2. ILLUSTRATION OF THE RAIL-HIGHWAY CROSSING RESOURCE ALLOCATION PROCEDURE

The resource allocation model requires improvement costs for flashing lights at a passive crossing, flashing lights and gates at a passive crossing, and gates at a crossing 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.[1] 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. Similarly, the effectiveness of these warning device improvement options must be specified by the decimal fraction by which accidents are reduced with the installation of the warning device. Values for warning device effectiveness, determined from another DOT study, are listed in Table 2.[2]

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 shows gates as the only improvement option. The benefit is the number of predicted accidents prevented per year, and the cost

TABLE 2. COST AND EFFECTIVENESS PARAMETERS FOR CROSSING WARNING DEVICES IN 1980 DOLLARS ADJUSTED BY INFLATION FACTOR (1.36)[3]

| IMPROVEMENT ACTION | EFFECTIVENESS | LIFE CYCLE COST |
|---|---|---|
| Passive to Flashing Lights | 0.65 | $58,100 |
| Passive to Flashing Lights with Gates | 0.84 | $88,500 |
| Flashing Lights to Flashing Lights with Gates | 0.64 | $83,300 |

[1] J. Heisler and J. Morrissey, Rail-Highway Crossing Warning Device Life Cycle Cost Analysis, (Washington, D.C.: U.S. Department of Transportation, March 1980).

[2] J. Morrissey, The Effectiveness of Flashing Lights and Flashing Lights with Gates in Reducing Accident Frequency At Public Rail-Highway Crossings, (Washington, D.C.: U.S. Department of Transportation, April 1980).

[3] ibid., J. Heisler and J. Morrissey.

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 the results of resource allocation model application is shown in Table 3. The resource allocation model was used for a series of funding levels. For each funding level, the table presents the number of crossings nominated for improvement consideration with flashing lights and flashing lights with gates, and the expected number of accidents prevented per year. Although not shown in this example, the model also identifies each crossing by identification number and the suggested type of warning device which should be installed. The resource allocation model can be applied on a nationwide basis or for any defined set of crossings, such as those of a particular State, railroad, or region.

TABLE 3. RESOURCE ALLOCATION RESULTS FOR VARIOUS FUNDING LEVELS

| TOTAL FUNDING LEVEL BASED ON 1977 LIFE CYCLE COSTS ($) | BENEFIT | NUMBER OF CROSSINGS UPGRADED | | |
|---|---|---|---|---|
| | ACCIDENTS PREVENTED PER YEAR | PASSIVE TO FLASHING LIGHTS | PASSIVE TO GATES | FLASHING LIGHTS TO GATES |
| 87,400,000 | 599 | 771 | 73 | 812 |
| 145,300,000 | 858 | 1,388 | 153 | 1,247 |
| 183,500,000 | 1,008 | 1,716 | 236 | 1,547 |
| 268,000,000 | 1,304 | 2,443 | 426 | 2,218 |
| 346,500,000 | 1,548 | 3,181 | 597 | 2,802 |
| 456,000,000 | 1,851 | 4,096 | 955 | 3,570 |
| 606,900,000 | 2,218 | 5,248 | 1,541 | 4,608 |
| 817,600,000 | 2,664 | 7,109 | 2,229 | 6,017 |
| 1,133,300,000 | 3,228 | 9,380 | 3,778 | 7,940 |

# APPENDIX A

Table A-1 gives the final accident prediction (A) for a crossing from the DOT accident prediction formula (equation 1) based on an initial prediction (a) from the basic formula (equation 2) and the crossing's five year accident history.

If the initial accident prediction (a) is 0.20 and the crossing experienced two accidents during the past five years, the final accident prediction (A) would be 0.311 accidents per year.

TABLE A-1 FINAL ACCIDENT PREDICTION PER YEAR FROM INITIAL PREDICTION AND ACCIDENT HISTORY (FIVE YEARS OF ACCIDENT DATA)

| INITIAL 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 |

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APPENDIX B

Table B-1 lists equations for determining values of crossing characteristic factors used in the basic accident prediction formula (equation 2). 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 predict the number of accidents 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 basic accident prediction (a) by the appropriate effectiveness factor from Table 2. In developing the final prediction (A) 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, a basic accident prediction (a) should be developed using the equation for "passive" crossings and the result should be multiplied by 0.84. 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 final accident prediction (A).

# TABLE B-1 EQUATIONS FOR CROSSING CHARACTERISTIC FACTORS

GENERAL FORM OF BASIC ACCIDENT PREDICTION FORMULA: $a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL$

| CROSSING CATEGORY | FORMULA CONSTANT | CROSSING CHARACTERISTIC FACTORS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | EXPOSURE INDEX FACTOR | MAIN TRACKS FACTOR | DAY THRU TRAINS FACTOR | HIGHWAY PAVED FACTOR | MAXIMUM SPEED FACTOR | HIGHWAY TYPE FACTOR | HIGHWAY LANES FACTOR |
| | K | EI | MT | DT | HP | MS | HT | HL |
| PASSIVE | 0.002268 | $((c \times t + 0.2)/0.2)^{0.3334}$ | $e^{0.2094mt}$ | $((d + 0.2)/0.2)^{0.1336}$ | $e^{-0.6160(hp-1)}$ | $e^{0.0077ms}$ | $e^{-0.1000(ht-1)}$ | 1.0 |
| FLASHING LIGHTS | 0.003646 | $((c \times t + 0.2)/0.2)^{0.2953}$ | $e^{0.1088mt}$ | $((d + 0.2)/0.2)^{0.0470}$ | 1.0 | 1.0 | 1.0 | $e^{0.1380(hl-1)}$ |
| GATES | 0.001088 | $((c \times t + 0.2)/0.2)^{0.3116}$ | $e^{0.2912mt}$ | 1.0 | 1.0 | 1.0 | 1.0 | $e^{0.1036(hl-1)}$ |

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c = number of highway vehicles per day

t = number of trains per day

mt = number of main tracks

d = number of thru trains per day during daylight

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

ms = maximum timetable speed, mph

ht = highway type value

hl = number of highway lanes

| HIGHWAY TYPE | INVENTORY CODE | ht VALUE |
|---|---|---|
| **RURAL** | | |
| Interstate | 01 | 1 |
| Other principal arterial | 02 | 2 |
| Minor arterial | 06 | 3 |
| Major collector | 07 | 4 |
| Minor collector | 08 | 5 |
| Local | 09 | 6 |
| **URBAN** | | |
| Interstate | 11 | 1 |
| Other freeway and expressway | 12 | 2 |
| Other principal arterial | 14 | 3 |
| Minor arterial | 16 | 4 |
| Collector | 17 | 5 |
| Local | 19 | 6 |

# APPENDIX C

Tables C-1, C-2, and C-3 provide numerical values for the crossing characteristic factors of the basic accident prediction formula (equation 2) for 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 predict the number of accidents 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 basic accident prediction (a) by the appropriate effectiveness factor from Table 2. In developing the final prediction (A) 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, a basic accident prediction (a) should be developed using Table C-1 and the result should be multiplied by 0.84. 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 final accident prediction (A).

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

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

| K | "c" x "t" | EI | Main Tracks | MT | Day Thru Trains | DT | Highway Paved | HP | Maximum Timetable Speed | MS | Highway Type Code** | HT | Highway Lanes | HL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.002268 | 0* | 1.00 | 0 | 1.00 | 0 | 1.00 | 1 (yes) | 1.00 | 0 | 1.00 | 01&11 | 1.00 | 1 | 1.00 |
| | 1 5 | 2.22 | 1 | 1.23 | 1 | 1.27 | | | 5 | 1.04 | | | 2 | 1.00 |
| | 6- 10 | 3.30 | 2 | 1.52 | 2 | 1.38 | 2 (no) | 0.54 | 10 | 1.08 | 02&12 | 0.90 | 3 | 1.00 |
| | 11- 20 | 4.24 | 3 | 1.87 | 3 | 1.45 | | | 15 | 1.12 | | | 4 | 1.00 |
| | 21- 30 | 5.01 | 4 | 2.31 | 4 | 1.50 | | | 20 | 1.17 | 06&14 | 0.82 | 5 | 1.00 |
| | 31- 50 | 5.86 | 5 | 2.85 | 5 | 1.55 | | | 25 | 1.21 | | | 6 | 1.00 |
| | 51- 80 | 6.89 | 6 | 3.51 | 6 | 1.58 | | | 30 | 1.26 | 07&16 | 0.74 | 7 | 1.00 |
| | 81- 120 | 7.95 | | | 7 | 1.61 | | | 35 | 1.31 | | | 8 | 1.00 |
| | 121- 200 | 9.29 | | | 8 | 1.64 | | | 40 | 1.36 | 08&17 | 0.67 | 9 | 1.00 |
| | 201- 300 | 10.78 | | | 9 | 1.67 | | | 45 | 1.41 | | | | |
| | 301- 400 | 12.06 | | | 10 | 1.69 | | | 50 | 1.47 | 09&19 | 0.61 | | |
| | 401- 500 | 13.11 | | | 11-20 | 1.78 | | | 55 | 1.53 | | | | |
| | 501- 600 | 14.02 | | | 21-30 | 1.91 | | | 60 | 1.59 | | | | |
| | 601- 700 | 14.82 | | | 31-40 | 2.00 | | | 65 | 1.65 | | | | |
| | 701- 1000 | 16.21 | | | 41-60 | 2.09 | | | 70 | 1.71 | | | | |
| | 1001- 1300 | 17.93 | | | | | | | 75 | 1.78 | | | | |
| | 1301- 1600 | 19.37 | | | | | | | 80 | 1.85 | | | | |
| | 1601- 2000 | 20.81 | | | | | | | 85 | 1.92 | | | | |
| | 2001- 2500 | 22.42 | | | | | | | 90 | 2.00 | | | | |
| | 2501- 3000 | 23.97 | | | | | | | | | | | | |
| | 3001- 4000 | 25.98 | | | | | | | | | | | | |
| | 4001- 6000 | 29.26 | | | | | | | | | | | | |
| | 6001- 8000 | 32.73 | | | | | | | | | | | | |
| | 8001- 10000 | 35.59 | | | | | | | | | | | | |
| | 10001- 15000 | 39.71 | | | | | | | | | | | | |
| | 15001- 20000 | 44.43 | | | | | | | | | | | | |
| | 20001- 25000 | 48.31 | | | | | | | | | | | | |
| | 25001- 30000 | 51.65 | | | | | | | | | | | | |
| | 30001- 40000 | 55.98 | | | | | | | | | | | | |
| | 40001- 50000 | 60.87 | | | | | | | | | | | | |
| | 50001- 60000 | 65.08 | | | | | | | | | | | | |
| | 60001- 70000 | 68.81 | | | | | | | | | | | | |
| | 70001- 90000 | 73.74 | | | | | | | | | | | | |
| | 90001- 110000 | 79.44 | | | | | | | | | | | | |
| | 110001- 130000 | 84.42 | | | | | | | | | | | | |
| | 130001- 180000 | 91.94 | | | | | | | | | | | | |
| | 180001- 230000 | 100.92 | | | | | | | | | | | | |
| | 230001- 300000 | 109.94 | | | | | | | | | | | | |
| | 300001- 370000 | 118.87 | | | | | | | | | | | | |

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 thru trains factor
HP = highway paved factor
MS = maximum timetable speed factor
HT = highway type factor
HL = highway lanes factor

* Less than one train per day.
** For definition of highway type codes, see Table B-1.

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

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

| K | "c" x "t" | EI | Main Tracks | MT | Day Thru Trains | DT | Highway Paved | HP | Maximum Timetable Speed | MS | Highway Type Code** | HT | Highway Lanes | HL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.003646 | 0* | 1.00 | 0 | 1.00 | 0 | 1.00 | 1 (yes) | 1.00 | 0 | 1.00 | 01&11 | 1.00 | 1 | 1.00 |
| | 1- 5 | 2.27 | 1 | 1.11 | 1 | 1.09 | | | 5 | 1.00 | | | 2 | 1.15 |
| | 6- 10 | 2.99 | 2 | 1.24 | 2 | 1.12 | 2 (no) | 1.00 | 10 | 1.00 | 02&12 | 1.00 | 3 | 1.32 |
| | 11- 20 | 3.59 | 3 | 1.39 | 3 | 1.14 | | | 15 | 1.00 | | | 4 | 1.51 |
| | 21- 30 | 4.17 | 4 | 1.55 | 4 | 1.15 | | | 20 | 1.00 | 06&14 | 1.00 | 5 | 1.74 |
| | 31- 50 | 4.79 | 5 | 1.72 | 5 | 1.17 | | | 25 | 1.00 | | | 6 | 1.99 |
| | 51- 80 | 5.52 | 6 | 1.92 | 6 | 1.18 | | | 30 | 1.00 | 07&16 | 1.00 | 7 | 2.29 |
| | 81- 120 | 6.27 | | | 7 | 1.18 | | | 35 | 1.00 | | | 8 | 2.63 |
| | 121- 200 | 7.20 | | | 8 | 1.19 | | | 40 | 1.00 | 08&17 | 1.00 | 9 | 3.02 |
| | 201- 300 | 8.22 | | | 9 | 1.20 | | | 45 | 1.00 | | | | |
| | 301- 400 | 9.07 | | | 10 | 1.20 | | | 50 | 1.00 | 09&19 | 1.00 | | |
| | 401- 500 | 9.77 | | | 11-20 | 1.23 | | | 55 | 1.00 | | | | |
| | 501- 600 | 10.37 | | | 21-30 | 1.26 | | | 60 | 1.00 | | | | |
| | 601- 700 | 10.89 | | | 31-40 | 1.28 | | | 65 | 1.00 | | | | |
| | 701- 1000 | 11.79 | | | 41-60 | 1.30 | | | 70 | 1.00 | | | | |
| | 1001- 1300 | 12.89 | | | | | | | 75 | 1.00 | | | | |
| | 1301- 1600 | 13.80 | | | | | | | 80 | 1.00 | | | | |
| | 1601- 2000 | 14.71 | | | | | | | 85 | 1.00 | | | | |
| | 2001- 2500 | 15.72 | | | | | | | 90 | 1.00 | | | | |
| | 2501- 3000 | 16.67 | | | | | | | | | | | | |
| | 3001- 4000 | 17.91 | | | | | | | | | | | | |
| | 4001- 6000 | 19.89 | | | | | | | | | | | | |
| | 6001- 8000 | 21.97 | | | | | | | | | | | | |
| | 8001- 10000 | 23.66 | | | | | | | | | | | | |
| | 10001- 15000 | 26.08 | | | | | | | | | | | | |
| | 15001- 20000 | 28.80 | | | | | | | | | | | | |
| | 20001- 25000 | 31.02 | | | | | | | | | | | | |
| | 25001- 30000 | 32.91 | | | | | | | | | | | | |
| | 30001- 40000 | 35.34 | | | | | | | | | | | | |
| | 40001- 50000 | 38.06 | | | | | | | | | | | | |
| | 50001- 60000 | 40.39 | | | | | | | | | | | | |
| | 60001- 70000 | 42.43 | | | | | | | | | | | | |
| | 70001- 90000 | 45.11 | | | | | | | | | | | | |
| | 90001- 110000 | 48.18 | | | | | | | | | | | | |
| | 110001- 130000 | 50.85 | | | | | | | | | | | | |
| | 130001- 180000 | 54.84 | | | | | | | | | | | | |
| | 180001- 230000 | 59.56 | | | | | | | | | | | | |
| | 230001- 300000 | 64.25 | | | | | | | | | | | | |
| | 300001- 370000 | 68.86 | | | | | | | | | | | | |

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 thru trains factor
HP = highway paved factor
MS = maximum timetable speed factor
HT = highway type factor
HL = highway lanes factor

* Less than one train per day.
** For definition of highway type codes, see Table B-1.

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

GENERAL FORM OF BASIC ACCIDENT PREDICTION FORMULA: $a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL$

| K | "c" x "t" | EI | Main Tracks | MT | Day Thru Trains | DT | Highway Paved | HP | Maximum Timetable Speed | MS | Highway Type Code** | HT | Highway Lanes | HL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.001088 | 0* | 1.00 | 0 | 1.00 | 0 | 1.00 | 1 (yes) | 1.00 | 0 | 1.00 | 01&11 | 1.00 | 1 | 1.00 |
| | 1- 5 | 2.37 | 1 | 1.34 | 1 | 1.00 | | | 5 | 1.00 | | | 2 | 1.11 |
| | 6- 10 | 3.18 | 2 | 1.79 | 2 | 1.00 | 2 (no) | 1.00 | 10 | 1.00 | 02&12 | 1.00 | 3 | 1.23 |
| | 11- 20 | 3.86 | 3 | 2.40 | 3 | 1.00 | | | 15 | 1.00 | | | 4 | 1.36 |
| | 21- 30 | 4.51 | 4 | 3.21 | 4 | 1.00 | | | 20 | 1.00 | 06&14 | 1.00 | 5 | 1.51 |
| | 31- 50 | 5.22 | 5 | 4.29 | 5 | 1.00 | | | 25 | 1.00 | | | 6 | 1.68 |
| | 51- 80 | 6.07 | 6 | 5.74 | 6 | 1.00 | | | 30 | 1.00 | 07&16 | 1.00 | 7 | 1.86 |
| | 81- 120 | 6.94 | | | 7 | 1.00 | | | 35 | 1.00 | | | 8 | 2.07 |
| | 121- 200 | 8.03 | | | 8 | 1.00 | | | 40 | 1.00 | 08&17 | 1.00 | 9 | 2.29 |
| | 201- 300 | 9.23 | | | 9 | 1.00 | | | 45 | 1.00 | | | | |
| | 301- 400 | 10.25 | | | 10 | 1.00 | | | 50 | 1.00 | 09&19 | 1.00 | | |
| | 401- 500 | 11.08 | | | 11-20 | 1.00 | | | 55 | 1.00 | | | | |
| | 501- 600 | 11.80 | | | 21-30 | 1.00 | | | 60 | 1.00 | | | | |
| | 601- 700 | 12.43 | | | 31-40 | 1.00 | | | 65 | 1.00 | | | | |
| | 701- 1000 | 13.51 | | | 41-60 | 1.00 | | | 70 | 1.00 | | | | |
| | 1001- 1300 | 14.84 | | | | | | | 75 | 1.00 | | | | |
| | 1301- 1600 | 15.96 | | | | | | | 80 | 1.00 | | | | |
| | 1601- 2000 | 17.07 | | | | | | | 85 | 1.00 | | | | |
| | 2001- 2500 | 18.30 | | | | | | | 90 | 1.00 | | | | |
| | 2501- 3000 | 19.48 | | | | | | | | | | | | |
| | 3001- 4000 | 21.00 | | | | | | | | | | | | |
| | 4001- 6000 | 23.46 | | | | | | | | | | | | |
| | 6001- 8000 | 26.06 | | | | | | | | | | | | |
| | 8001- 10000 | 28.18 | | | | | | | | | | | | |
| | 10001- 15000 | 31.22 | | | | | | | | | | | | |
| | 15001- 20000 | 34.67 | | | | | | | | | | | | |
| | 20001- 25000 | 37.49 | | | | | | | | | | | | |
| | 25001- 30000 | 39.91 | | | | | | | | | | | | |
| | 30001- 40000 | 43.03 | | | | | | | | | | | | |
| | 40001- 50000 | 46.53 | | | | | | | | | | | | |
| | 50001- 60000 | 49.53 | | | | | | | | | | | | |
| | 60001- 70000 | 52.18 | | | | | | | | | | | | |
| | 70001- 90000 | 55.67 | | | | | | | | | | | | |
| | 90001- 110000 | 59.68 | | | | | | | | | | | | |
| | 110001- 130000 | 63.16 | | | | | | | | | | | | |
| | 130001- 180000 | 68.41 | | | | | | | | | | | | |
| | 180001- 230000 | 74.63 | | | | | | | | | | | | |
| | 230001- 300000 | 80.85 | | | | | | | | | | | | |
| | 300001- 370000 | 86.98 | | | | | | | | | | | | |

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 thru trains factor
HP = highway paved factor
MS = maximum timetable speed factor
HT = highway type factor
HL = highway lanes factor

* Less than one train per day.
** For definition of highway type codes, see Table B-1.

## GLOSSARY

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 prevented per year to the cost of the warning systems ($).

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, for a given amount of funding.

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

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.

2. flashing light warning devices: flashing lights, both cantilevered and post-mounted; highway signals, wig-wags, or bells; and special warnings such as flagmen.

3. gate warning devices: automatic gates with flashing lights.

## BIBLIOGRAPHY


Farr, E.H. Rail-Highway Crossing Resource Allocation Model. Washington, D.C.: U.S. Department of Transportation, April 1981.

Federal Highway Administration. Railroad-Highway Grade Crossing Handbook. Washington, D.C.: U.S. Department of Transportation, August 1978.

Federal Railroad Administration. Rail-Highway Crossing Accident/Incident and Inventory Bulletin. No. 1, 1978. Washington, D.C.: U.S. Department of Transportation, October 1979.

Heisler, J. and J. Morrissey. Rail-Highway Crossing Warning Device Life Cycle Cost Analysis. Washington, D.C.: Department of Transportation, September 1980.

Mengert, Peter. Rail-Highway Crossing Hazard Prediction Research Results. Washington, D.C.: U.S. Department of Transportation, March 1980.

Morrissey, J. The Effectiveness of Flashing Lights and Flashing Lights with Gates in Reducing Accident Frequency at Public Rail-Highway Crossing. Washington, D.C.: U.S. Department of Transportation, April 1980.

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