9.0 DOT HIGHWAY-RAIL CROSSING ACCIDENT PREDICTION AND RESOURCE ALLOCATION PROCEDURE

The DOT Highway-Rail Crossing accident prediction formula is an accident and severity prediction calculation which computes the expected number of accidents at a crossing, based on information from the U.S. DOT-AAR National Highway-Rail Crossing Inventory and the Railroad Accident Reporting System (RAIRS) data files.

The DOT Highway-Rail Crossing resource allocation procedure is a computer model designed to nominate crossings for improvement consideration on a cost-effective basis and to suggest the type of warning device to be installed, given the cost of crossing improvements and an available budget level.

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

9.1 Background

The Highway Safety Acts of 1973 and 1976, the Surface Transportation Assistance Acts of 1978 and 1982, the Surface Transportation and Uniform Relocation Assistance Act of 1987, and the Intermodal Surface Transportation Efficiency Act of 1991 provide funding authorizations to individual States to improve safety at public highway-rail 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 highway-rail crossing safety improvements by use of 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 Highway-Rail 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.

The DOT Highway-Rail Crossing accident prediction formula and resource allocation model were developed at the Transportation Systems Center (TSC) under the sponsorship of the Federal Railroad Administration (FRA) Office of Safety Analysis and the Federal Highway Administration (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.

The formula and procedures were reviewed and slightly revised in 1986 and 1987. While some improvements were implemented, the basic formulas remain the same as those originally developed in 1976. A subsequent review is planned for the 1996-1997 period.

9.2 DOT Accident Prediction Formula

The availability of both inventory and accident data for crossings influenced the development of the DOT accident prediction formula. This formula calculates the expected annual number of accidents at a crossing on the basis of physical and operational characteristics of the crossing as described in the Inventory and the most recent five year accident experience at that crossing as contained in the FRA Railroad Accident/Incident data file.

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.

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

$$B = \frac{T_o}{T_o + T}(a) + \frac{T}{T_o + T}\left[\frac{N}{T}\right], \; T_o = \frac{1}{0.05 + a} \qquad [2]$$

$$A = \begin{cases} \text{K1 x B (for passive devices)} \\ \text{K2 x B (for flashing lights)} \\ \text{K3 x B (for gates)} \end{cases} \qquad [3]$$

The DOT formula is of the absolute type, since it estimates the number of accidents, as opposed to providing a "relative" index (often referred to as a hazard rating index). The formula combines two independent calculations of the number of accidents for a crossing to produce the final absolute accident prediction. The two independent calculations are obtained from the first two formulas described in the next paragraphs.

1. A "basic" formula provides an initial prediction of the accidents on the basis of the physical and operational characteristics of the crossing as described in the Inventory. This formula predicts crossing accidents through a calculation similar to that used in other common formulae, such as the Peabody-Dimmick and New Hampshire, and can be considered as a "hazard rating index."

The basic formula is as follows:

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

where

a = initial accident prediction index, (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,

MS = factor for maximum timetable speed,

MT = factor for number of main tracks,

HP = factor for highway paved (yes or no), and

HL = factor for number of highway lanes.

The basic formula was developed by applying nonlinear multiple regression techniques to crossing characteristics stored in the 1976 Inventory and Accident data files. Half of the file was used to determine the formula coefficients by regression and iteration, and the other half for testing the formula. The data sets were disjoint, of equal size, and comprised of a random sample of records from the inventory, including all records for which accident data existed. Each data set was categorized into two groups of accident and non-accident crossings. The result can be expressed as a series of factors which, when multiplied together, yield the initial predicted accidents per year at a crossing.

The basic formula consists of a number of multiplicative factors, with 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 an accident prediction, but (a) has 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 contained in the publications listed in Section 9.3. 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, only the passive set of equations should be used. The same applies for crossings with flashing lights and crossings with gates.

2. The predictive capacity of the basic formula is limited because certain important crossing characteristics, such as sight distance at the crossing, are not included in the DOT Crossing Inventory. Inclusion of actual accident history at a crossing is done in equation **[2]**, which 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 value of (B) is determined by combining the value (a) with the crossing's accident history, using equation **[2]** or a table by extrapolation as contained in other publications referenced in this Section.

The intermediate prediction (B) thus includes the observed accident history (over a five year period) at a crossing. It assumes that future accidents per year will be the same as the average historical accident rate. It is referred to as the accident history of the crossing, and is equal to the total observed accidents divided by the number of years over which the observations were made. (Note: The formula allows any number of years of accident history data to be used. However, a five year period is more commonly recognized and used.)

The DOT accident prediction formula is then expressed as

$$B = \frac{T_o}{T_o + T}(a) + \frac{T}{T_o + T}\left[\frac{N}{T}\right], \qquad \textbf{[2]}$$

where

B = intermediate accident prediction, accidents per year at the crossing,

T_o = formula for weighting factor $= \dfrac{1}{0.05 + a}$,

a = initial accident prediction index (accidents per year) from formula **[1]**, and

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

The DOT formula calculates a weighted average of the predicted accidents at a crossing from the basic formula "a" and accident history "N/T". The two formula weights, $\frac{T_o}{T_o + T}$ and $\frac{T}{T_o + T}$, add to the value of 1.

The intermediate prediction (B) is the value (a) from equation **[1]**, which provides an initial prediction on the basis of a crossing's characteristics (as described in the DOT Crossing Inventory), and the actual accident history at a crossing where $\frac{N}{T}$ 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. The most recent five years of accident history data should be used to insure good performance from the formula. Accident history information older than five years may be misleading because of changes in crossing characteristics.

3. To get the final predicted accidents (A), (B) is multiplied by one of three constants as indicated by equation **[3]**.

$$A = \begin{cases} K1 \times B \text{ (for passive devices)} \\ K2 \times B \text{ (for flashing lights)} \\ K3 \times B \text{ (for gates)} \end{cases} \qquad [3]$$

The particular constants, K1, K2, and K3, depend on whether the crossing has passive devices (e.g., crossbucks), flashing lights, or gates. These constants adjust the predictions to reflect more recent levels of accident experience. They are recalculated periodically and published annually in FRA's *Highway-Rail Crossing Accident/Incident and Inventory Bulletin.*

A flow diagram of the DOT accident and severity prediction formulas, showing the data bases employed, is shown in Figure 9-1. The abbreviations used for the Accident Prediction lists produced by FRA are contained in Appendix B.

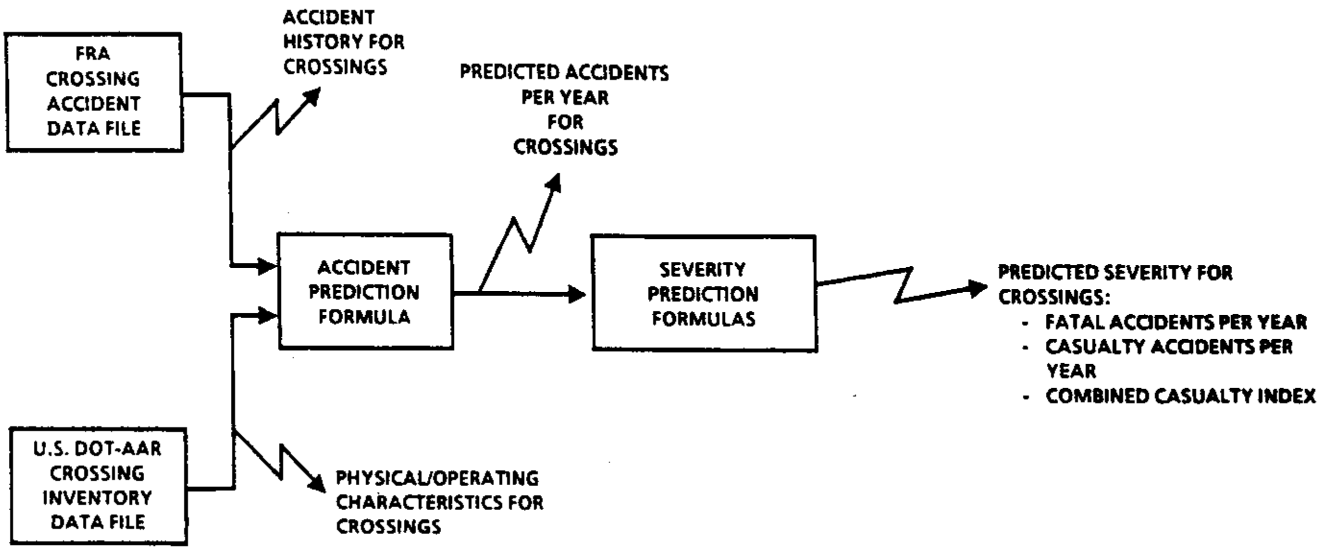

Figure 9-1. DOT Highway-Rail Crossing Accident and Severity Prediction Formulas

9.3 Resource Allocation Model

The availability of the U.S. DOT-AAR National Highway-Rail Crossing Inventory and Accident data permitted the development of a resource allocation model. Development of accident prediction formulas was a necessary intermediate step. The U.S. DOT Highway-Rail Crossing accident prediction formulas were created utilizing nonlinear, multiple regression techniques applied to the crossing characteristics in the National Inventory and the Accident databases compiled by FRA. The model calculates the expected annual accident rate at a crossing.

It is important to note that the U.S. DOT's accident prediction formulas produce an <u>absolute prediction</u> which is different from a hazard index (e.g., the New Hampshire formula). The hazard index only produces a relative index for each crossing based on available physical characteristic data and does not include any accident history information. A hazard index has value only in relatively comparing one crossing with another with very similar characteristics. The U.S. DOT accident prediction formulas provide an absolute prediction process which can compare all crossings and one that is needed for the resource allocation model.

The U.S. DOT resource allocation model determines which crossings should have motorist warning devices installed so as to achieve the maximum crossing safety benefit for a given level of funding. The net result is a list of the most cost-effective improvement decisions.

Possible grade crossing improvements include: (1) passive devices to flashing lights, (2) passive devices to gates, and (3) flashing lights to gates.

Inputs to the resource allocation model include the predicted accident rate of the crossing, costs and effectiveness of the different improvement options, and the budget level available. Cost data required are the installation costs for each of the possible upgrade options. Effectiveness is defined as the percentage by which accidents are reduced after installation of a warning device at a crossing.

The resource allocation model provides a ranked list based on benefit/cost ratios. Benefit is expressed as predicted accidents prevented per year and cost is the life-cycle cost of the equipment. The algorithm considers the benefit/cost ratios beginning with the largest ratio and continuing in decreasing order. The process continues until the monies spent (costs of recommended warning devices) equal or exceed the available budget. Thus, an optimal list of recommended improvements is obtained.

The primary function of the resource allocation procedure is to assist States and railroads in preparing Statewide grade crossing improvement programs. Because of the magnitude of the Inventory and Accident data bases, use of the model has required a mainframe computer. Data and computer printout list are available by directing a request to FRA.

Information on the formulas and procedures may be found in the *"Rail-Highway Crossing Resource Allocation Procedure, User's Guide, Third Edition,"* U.S. Department of Transportation, Federal Railroad Administration, August 1987, Transportation Systems Center, Cambridge, MA, 02142, Report Numbers DOT/FRA/OS-87/10 and DOT-TSC-FRA-87-1 (both for the same report). This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161.

Further information on the formulas and procedures is contained in *"Summary of the DOT Rail-Highway Crossing Resource Allocation Procedure - Revised,"* U.S. Department of Transportation, Federal Railroad Administration, June 1987, Transportation Systems Center, Cambridge, MA, 02142, Report Numbers DOT/FRA/OS-87/05 and DOT-TSC-FRA-86-2 (both for the same report). This summary contains the formulas which calculate a severity prediction, extended warning device effectiveness data, and inclusion of the stop sign option in the resource allocation model. This document also is available to the public through the National Technical Information Service, Springfield, Virginia, 22161.

The theory underlying the formulas is contained in P. Mengert, *"Rail-Highway Crossing Hazard Prediction Research Results,"* U.S. Department of Transportation, Transportation Systems Center, Washington, DC, March 1980, FRA-RRS-80-02, which is available as a reference only.

9.4 Data Provided to States and Railroads

The U.S. DOT accident prediction computer printouts list public highway-rail crossings ranked by predicted accidents per year. The printouts show the ordered ranking in a State, county, city, railroad or any combination thereof and include the accident history along with other crossing data. They also list the crossings in ascending order, by crossing number, and provide location information.

The U.S. DOT resource allocation procedure consists of three computer printouts listing public highway-rail crossings. One printout lists crossings according to the number of accidents predicted annually. The highest prediction is listed first. The second printout shows proposed crossing projects in a benefit-cost sequence determined by simultaneous consideration of accident predictions, alternative costs and benefits and budget levels. The proposed project with the highest benefit-cost ratio is listed first. A third printout indexes all the crossings considered in this process, by crossing number, accident prediction, and rank.

The Department of Transportation accident prediction formula combines two independent calculations: (1) a basic formula that predicts accidents based on the Inventory's physical and operating characteristics, and (2) the initial prediction combined with another prediction derived from the reported accident history at the crossing.

The values and data are derived from the Federal Railroad Administration's Inventory and Accident files and are subject to the processing contractor's keypunch errors and input data submission errors from both railroads and States. Efforts have been made to find and correct errors, but there remains a possibility that some errors still exist. For this reason, States and/or railroads should verify the data by conducting on-site inspections of those crossings whose prediction ranking indicates a relatively high value. Erroneous data may significantly alter accident prediction and resource allocation values. It must also be recognized that this is only one model and that other models may give different results. As with all models, there are certain characteristics that are not or cannot be included in arriving at a prediction value. These characteristics include the sight distance at the crossing, highway congestion, and the volume of hazardous materials traffic.

These data are produced by using accident prediction formulas developed to aid in planning highway-rail crossing safety programs. The resource allocation procedure uses these accident prediction formulas together with cost evaluation data to produce a ranking of those crossings that can achieve maximum improvement benefits given a specific level of funding. This model is designed to nominate crossings for improvements on a cost-effective basis and suggests the type of warning device to be installed. The cost-effective data used for producing the enclosed material appear at the beginning of the printout.

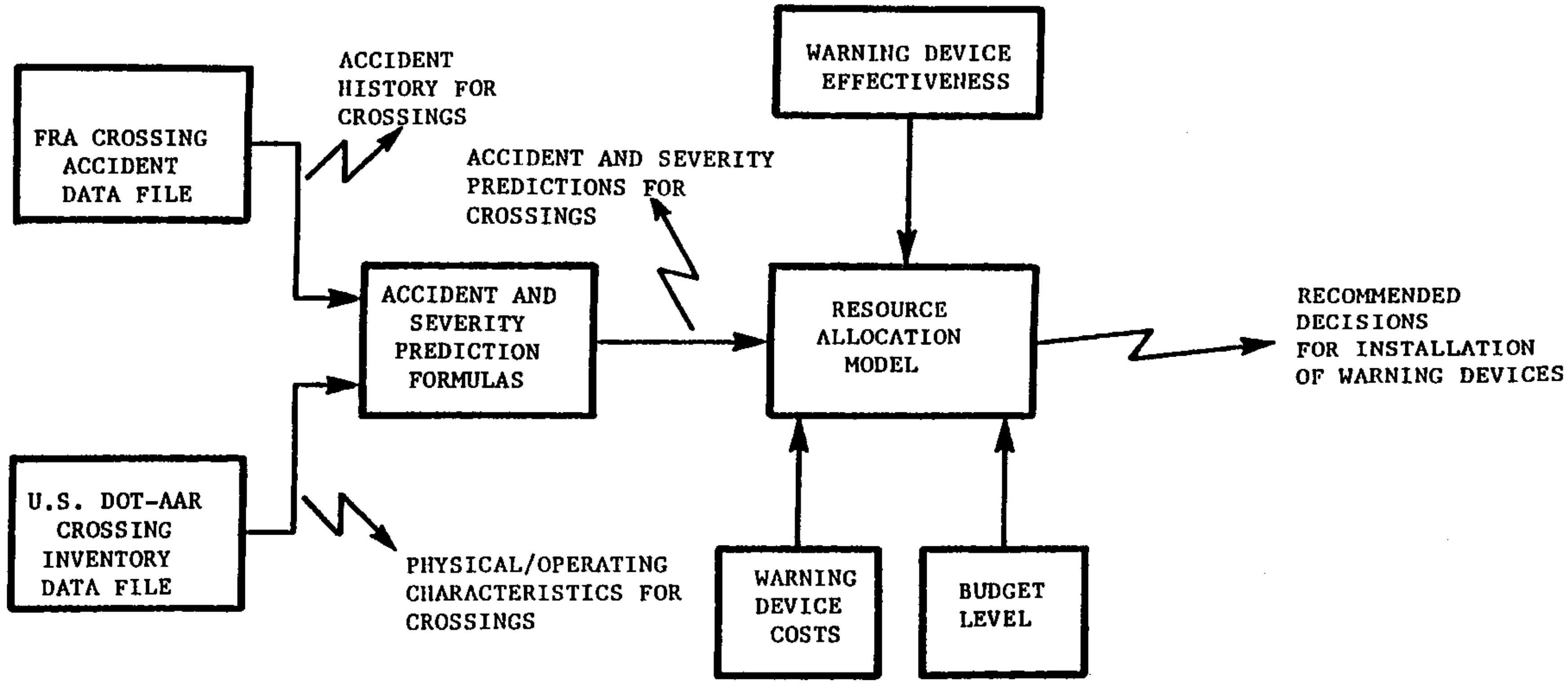

Figure 9-2. Highway-Rail Crossing Resource Allocation Procedure

When requesting a resource allocation printout, four data elements are required:

(1) The average cost of warning device upgrade from passive devices (crossbucks) to flashing lights.

(2) The average cost of warning device upgrade from passive devices (crossbucks) to gates (with flashing lights).

(3) The average cost of warning device upgrade from flashing lights to gates (with flashing lights).

(4) The total budget level of available funds, or a higher value for planning purposes.

States and/or railroads desiring to install the formula and models on their own computer should contact FRA. The current computer programs used by FRA can be provided on a customer supplied reel-to-reel magnetic tape for use on a mainframe computer. Because of the size of the supporting data bases, use of the model has required a mainframe computer. However, for smaller data bases, an individual State or railroad may avail themselves of programs developed by non-government sponsored researches that will operate on a personal computer (PC) or microcomputer.

9.5 Performance Compared to Other Models

In a report prepared for the 1986 annual meeting of the Transportation Research Board (TRB), researchers at the University of Virginia revealed that the U.S. DOT accident prediction formula is a better procedure for establishing priorities for grade crossing safety improvement projects than other models tested. A total of five formulas were evaluated using the State of Virginia Department of Highways and Transportation grade crossing inventory. In addition to the U.S. DOT formula, the other formulas were: Peabody-Dimmick; NCHRP No. 50; Coleman-Stewart; and the New Hampshire. According to the researchers, the DOT formula outperformed the other models in both the evaluative and comparative analyses.

The authors of the Virginia study caution the reader that although the U.S. DOT accident prediction formula outperformed the other four nationally recognized models, the following facts remain:

"The DOT accident prediction formula takes into account the most important variables that are statistically significant in predicting accidents at rail-highway crossings. However, it must be noted that there is no general consensus as to which of the site characteristics are the most important ones. As a result, the priority list that is produced by using this formula must serve as only one of the criteria for improving conditions at any crossing. This

information must be supplemented by regular site inspections and other qualitative issues that can not be feasibly incorporated into a mathematical formula."

To determine the availability of this report, contact:

Rail Transportation Division
Virginia Department of Highways
and Transportation
1221 East Broad Street
Richmond, Virginia 23219

To obtain a copy of the TRB paper presented at the 1986 annual meeting, contact:

Department of Civil Engineering
University of Virginia
Thornton Hall
Charlottesville, VA 22901

During development and review of the accident prediction formula, comparisons were made with other highway-rail 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, the DOT accident prediction formula will reflect the latest information.