Accident Severity Prediction Formula for Rail-Highway Crossings

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ABSTRACT

The development of formulas to predict the severity of accidents at public rail-highway crossings is described. The formulas make use of the previously developed DOT Accident Prediction Formula, the U.S. DOT-AAR National Rail-Highway Crossing Inventory, and the FRA accident files. When these new formulas are used in the DOT Resource Allocation Procedure, information will be available to assist in making better decisions about where to install motorist-warning devices to further increase crossing safety for a given level of funding. Established statistical techniques were used to develop two formulas: one that estimates the number of fatal accidents per year at a crossing and one that estimates the number of injury accidents per year at a crossing. It was found that the factors in the inventory that significantly influence fatal accident severity, given that an accident occurred, were maximum timetable train speed, the number of through trains per day, the number of switch trains per day, and urban or rural location. For injury accident severity, given that an accident occurred, the significant factors were maximum timetable train speed, the number of tracks, and urban or rural location. The performance of these severity formulas is discussed and calculated results are presented.

The DOT Rail-Highway Crossing Resource Allocation Procedure, developed at the U.S. Department of Transportation's Transportation Systems Center (TSC), employs an accident prediction formula. In an attempt to improve the effectiveness and usefulness of the resource allocation procedure, a study was undertaken to incorporate a quantitative measure of severity in the accident prediction formula. That study (1) is documented in this paper. Two severity formulas were developed using established statistical techniques; one formula estimates the number of fatal accidents per year at a crossing and the other estimates the number of injury accidents per year at a crossing. The resulting formulas are to be incorporated in the DOT Rail-Highway Crossing Resource Allocation Procedure (2,3).

BACKGROUND

The Highway Safety Acts of 1973 and 1976 and the Surface Transportation Assistance Acts of 1978 and 1982 provide federal funding authorizations to states specifically for safety improvement projects at public rail-highway crossings. Such safety improvements frequently involve the installation of active motorist-warning devices such as flashing lights or gates. To promote the effective use of federal funds for these safety projects, the U.S. Department of Transportation (DOT) has developed a procedure to assist states and railroads in planning rail-highway crossing safety programs. This procedure, the DOT Rail-Highway Crossing Resource Allocation Procedure (DOT procedure), determines crossing safety improvements that result in the greatest accident reduction benefits based on consideration of predicted accidents at crossings, the costs and effectiveness of safety improvement options, and budget limits.

Two analytic methods have been developed as part of the DOT procedure. Their development followed completion of a joint U.S. DOT-Association of American Railroads (AAR) National Rail-Highway Crossing Inventory (inventory), which numbered and collected inventory information for all public and private crossings in the United States (4). The first analytic method included in the DOT procedure is the DOT accident prediction formula, which computes the expected number of accidents at crossings based on information available in the inventory and crossing accident data files (5). The second analytic method is a resource allocation model designed to rank crossings that are candidates for improvement on a cost-effective basis and to recommend the type of warning device that is to be installed (6).

The current effort is motivated by the recognition that not all rail-highway crossing accidents are equally severe. In 1981 there were a total of 8,546 rail-highway crossing accidents (7). Of these accidents 5,761 caused no casualties, 2,224 caused injuries only, and 561 involved fatalities. Thus, 67 percent of the accidents involved no measurable casualty severity, and only 6.6 percent involved fatalities. This unequal distribution of severity among crossing accidents makes it important, but difficult, to identify those crossings that are likely to have high-severity accidents. A priority ranking of crossings by number of predicted accidents (as done by current DOT procedure) could be significantly different from such a ranking by predicted severity of accident. This difference might affect the use of improvement funds.

ACCIDENT SEVERITY FORMULA

The traditional approach to risk analysis (8) views safety risk as the product of two independent factors: (a) the frequency of accident occurrence, and (b) the severity or consequences of accident occurrence. The product of these two factors for a given hazardous situation provides the total safety risk for that situation. For example, a rail-highway crossing with a predicted accident frequency of 0.5 accidents per year and a predicted accident severity of 0.2 fatalities per accident poses a total safety risk of 0.1 fatalities per year. The division of safety risk into accident frequency and severity components is particularly appropriate for the current effort because one of the components, the DOT accident prediction formula, already exists. The proposed severity prediction formula would be used with the accident prediction formula to provide a prediction of total safety risk as follows:

$$R = A \times S \quad (1)$$

where

- R = risk of a crossing measured in expected casualties per year,
- A = predicted accident frequency from the current DOT accident prediction formula, and
- S = predicted accident casualties from the severity prediction model.

A major benefit of this approach is that the current DOT accident prediction formula will remain unchanged and can be used either with or without the severity formula. Procedures for use of the severity formula with the DOT accident prediction formula and the DOT Rail-Highway Crossing Resource Allocation Procedure will be described in an updated version of the Rail-Highway Crossing Resource Allocation Procedures User's Guide (3), due for completion during fiscal year 1984.

APPROACH

Under this effort two severity formulas were developed: one formula to predict fatality severity and another to predict injury severity. These formulas provide predictions on the basis of the crossing characteristics described in the inventory. The first task in developing the severity formulas involved the selection of specific measures of severity to be quantified by the formulas. The next task was to identify in the inventory crossing factors that showed a strong correlation with measures of severity for possible inclusion in the severity formulas. The severity formulas were then developed using a regression procedure, referred to as the logistic discriminant approach, which employs an iterative weighted regression technique that is a modification of a method described in Cox (9). The last task in development of the severity formulas was to evaluate their performance by comparing predicted versus actual accident severity.

SEVERITY PREDICTION FORMULA DEVELOPMENT

Selection of Severity Measures

The proposed use of the severity formulas dictates that severity be measured in terms of consequences, given that an accident occurred. The severity measures must therefore be expressed in terms of consequences per accident. The current effort concentrated on developing formulas for quantifying fatalities and injuries as measures of severity.

For the purposes of this study, a fatal accident is an accident in which at least one fatality occurred independent of injuries or property damage; an injury accident is an accident in which there were no fatalities and at least one injury occurred independent of property damage.

To assist in evaluating alternative measures of fatality and injury severity, histograms were developed as shown in Figures 1 and 2. These histograms relate average values of the measures, calculated from accident records, to accidents grouped by intervals of maximum train speed. This permits a review of how the measures vary as a function of a factor (maximum timetable train speed) previously shown to be correlated with accident severity (10). It should be noted that maximum timetable train speed is a crossing characteristic included in the inventory, and it is used here as a surrogate for actual train speed at the time of an accident.

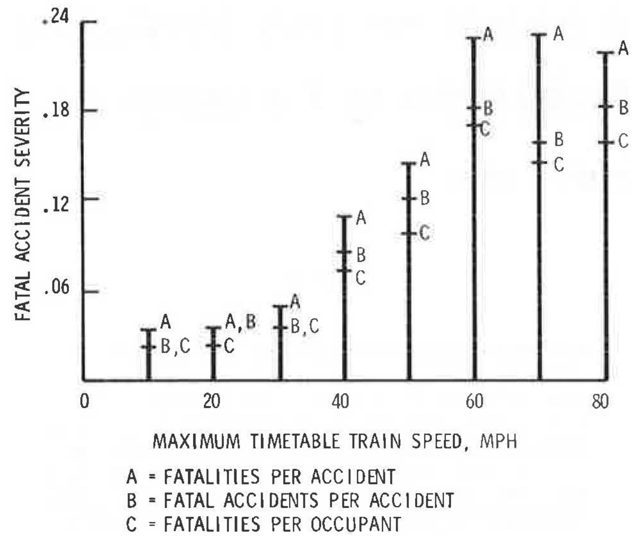

FIGURE 1 Comparison of fatality severity measures.

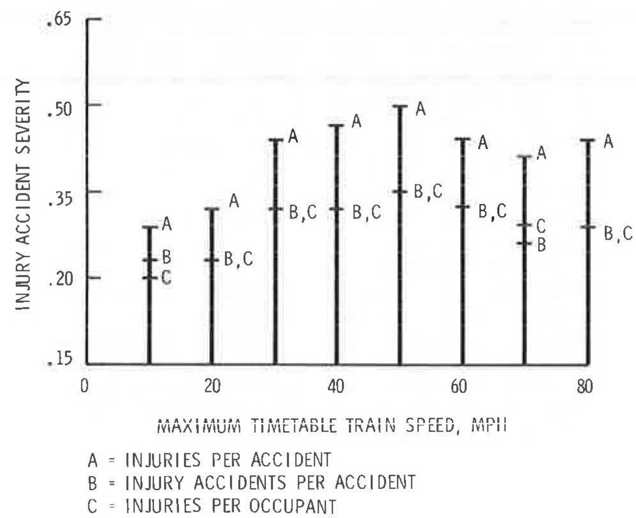

FIGURE 2 Comparison of injury severity measures.

The histograms in Figure 1 show that the three fatality measures considered vary with train speed in the same general manner. All three increase with train speed to about 60 mph beyond which they remain relatively constant. This is intuitive because, beyond some high value of severity, fatalities can no longer increase. As originally surmised, values for fatalities per accident are higher than values for fatal accidents per accident which, in turn, are higher than those for fatalities per occupant per accident. The shape of the histograms for the three measures is generally the same, however, suggesting that any of the measures could be used with similar results. Given the general compatibility of the measures, fatal accidents per accident was chosen as the measure of fatality severity because it avoids the complexities of dealing with vehicle occupants.

This measure can be restated, in statistical terms, as the probability of a fatal accident, given an accident.

The same reasoning led to the selection of injury accidents per accident as the measure of injury severity. This measure can be restated as the probability of an injury accident, given an accident. It is of interest to note from Figure 2 that the shape of the injury severity histograms increases and then decreases with increasing train speed. This is also intuitive because, beyond some severity threshold, casualties will increasingly be fatalities rather than injuries.

Selection of Severity Factors

Development of the severity formulas started with identification of factors that correlate with the severity measures and are thus potential predictors of severity. All crossing characteristic factors in the inventory were systematically reviewed to identify those correlated with the severity measures. To accomplish this, histograms similar to Figures 1 and 2 were developed relating average values of the measures calculated for accidents grouped by intervals of the factor in question. Results of this analysis showed that train speed was the strongest predictor of fatal accident severity of all the factors in the inventory. This is consistent with results obtained by Coleman and Stewart (10) in an earlier study of crossing accident data. Histograms were also constructed relating the severity measures to two factors. The following factors were identified as potentially useful in predicting fatality and injury severity:

- Maximum timetable train speed,
- Urban or rural crossing,
- Number of main tracks,
- Number of other tracks,
- Number of through trains, and
- Number of switch trains.

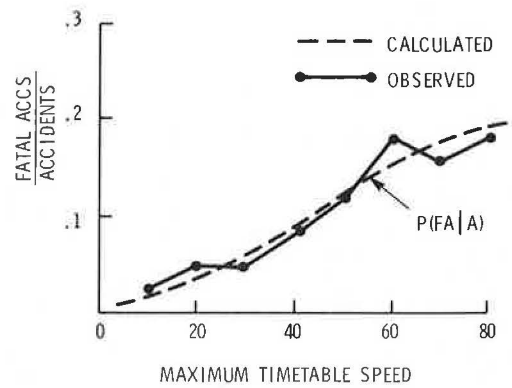

FIGURE 3 Typical plot of observed fatal accident frequency and calculated values of P(FA|A).

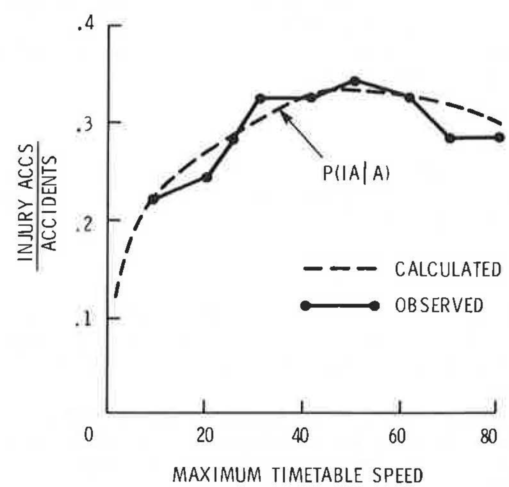

FIGURE 4 Typical plot of observed injury accident frequency and calculated values of P(IA|A).

Summary of Formula Development

The analytic objective of this phase of the study was to develop formulas that would predict the probability of a fatal accident given an accident, P(FA|A), and the probability of an injury accident given an accident, P(IA|A). From these two formulas the safety risk expressed in terms of expected number of fatal accidents, R_f, and injury accidents, R_i, per year at a crossing can be determined from

$$R_f = A \times P(FA|A) \tag{2}$$

$$R_i = A \times P(IA|A) \tag{3}$$

where A is the expected number of accidents per year at the crossing from the DOT accident prediction formula.

The analytic character of the fatal accident probability function, P(FA|A), relative to observed data is shown in Figure 3. This graph is a frequency plot of the observed ratio of fatal accidents to total accidents versus maximum timetable train speed. The function P(FA|A) is represented by the dashed line that is a best fit to the observed data points connected by the solid line. Of course, the severity formula is multivariate and, hence, the dashed line for P(FA|A) would be a multidimensional "surface."

The analytic character of P(IA|A) relative to observed data is shown in Figure 4. This graph is a frequency plot of the observed ratio of injury accidents to total accidents versus the same variable, maximum timetable train speed. In this case, the function P(IA|A) does not increase monotonically with severity. However, the particular regression procedure used to develop the severity formulas involved fitting a monotonic function to the observed data. The required formula for predicting injury accident probability could, therefore, not be obtained directly from the regression analysis. This problem was overcome by limiting the accident data to nonfatal accidents. A formula was then developed, from the regression analyses, to predict the probability of an injury accident given that a nonfatal accident occurred, P(IA|NFA). The formula for P(IA|NFA) is, as required, a monotonically increasing function of severity. Having obtained the formula for P(IA|NFA), the desired formula for P(IA|A) was then obtained from the following relationship:

$$P(IA|A) = P(IA|NFA) \times P(NFA|A) \tag{4}$$

where P(NFA|A) is the probability of a nonfatal accident, given an accident, that is,

$$P(NFA|A) = 1 - P(FA|A) \tag{5}$$

where P(FA|A) is the fatal accident probability formula obtained earlier. Hence,

$$P(IA|A) = P(IA|NFA) \times [1 - P(FA|A)] \quad (6)$$

In performing the regression analyses, the observed data for the dependent variable were assigned only two values. In the case of the fatal accident formula these values were +1 for a fatal accident and -1 for a nonfatal accident. For the injury accident formula the values assigned were +1 for an injury accident and -1 for a noninjury accident. The data used for the analyses were for the years 1978-1980. The regression analyses resulted in nonlinear formulas for the dependent variable f, from the fatal accident data, and i, from the injury accident data.

The resulting regression formulas typically produced values between +1 and -1 for the independent variables f and i. Extreme values of the independent variables f and i can, in theory, be from +00 to -00. The desired values for f and i, however, are between 0 and 1 as required by the probability functions P(FA|A) and P(IA|A). The formulas for f and i therefore had to be transformed into probability functions. To accomplish this the following transformation was made to f to obtain the desired fatal accident probability formula:

$$P(FA|A) = 1/(1 + e^{-2f}) \quad (7)$$

For the injury accident formula, the probability of an injury accident given a nonfatal accident, P(IA|NFA), was obtained first:

$$P(IA|NFA) = 1/(1 + e^{-2i}) \quad (8)$$

The probability of an injury accident given an accident, P(IA|A), was then obtained by substituting Equations 7 and 8 into Equation 6 as described previously.

This discussion has provided an overview of the strategy involved in obtaining the formulas required for predicting fatal accident and injury accident probabilities. A more detailed discussion of the regression analysis is presented elsewhere (1).

Resulting Severity Prediction Formulas

The resulting formulas for predicting the probabilities of fatal accidents and injury accidents can be expressed in terms of several factors that are combined by simple mathematical operations. Each factor in the formulas represents a crossing characteristic described in the inventory. The probability of a fatal accident given an accident, P(FA|A), is expressed as

$$P(FA|A) = 1/(1 + CF \times MS \times TT \times TS \times UR) \quad (9)$$

where

CF = formula constant = 695,
MS = factor for maximum timetable train speed,
TT = factor for through trains per day,
TS = factor for switch trains per day, and
UR = factor for urban or rural crossing.

The equations for calculating crossing characteristic factors for the fatal accident probability formula are

$$CF = 695$$
$$MS = ms^{-1.074}$$
$$TT = (tt + 1)^{-0.1025}$$
$$TS = (ts + 1)^{0.1025}$$
$$UR = e^{0.188ur}$$

where

ms = maximum timetable train speed (mph);
ts = number of switch trains per day;
tt = number of through trains per day; and
ur = 1 for urban crossing, 0 for rural crossing.

The probability of an injury accident given an accident, P(IA|A), is expressed as

$$P(IA|A) = [1 - P(FA|A)]/(1 + CI \times MS \times TK \times UR) \quad (10)$$

where

P(FA|A) = probability of a fatal accident, given an accident, obtained from Equation 9,
CI = formula constant = 4.280,
MS = factor for maximum timetable train speed,
TK = factor for number of tracks, and
UR = factor for urban or rural crossing.

The equations for calculating crossing characteristic factors for the injury accident probability formula are

$$CI = 4.280$$
$$MS = ms^{-0.2334}$$
$$TK = e^{0.1176tk}$$
$$UR = e^{0.1844ur}$$

where

ms = maximum timetable train speed (mph);
ur = 1 for urban crossing, 0 for rural crossing; and
tk = total number of tracks at crossing.

To simplify use of the formulas, the values of the crossing characteristic factors have been tabulated for typical values of crossing characteristics. These values are given in Tables 1 and 2 for the fatal accident and injury accident probability formulas, respectively.

Use of Severity Prediction Formula

A sample application of the fatal and injury accident severity formula for a typical crossing is provided to demonstrate their use. Characteristics of the sample crossing are listed in Table 3.

To determine the probability of a fatal accident given an accident at the sample crossing, Equation 9 is used. Values for the factors in the fatal accident severity formula (Equation 9) can be computed from the equations given previously or looked up in Table 1. Table 1 gives the following factor values for the crossing characteristics specified:

CF = 695.0
MS = 0.019
TT = 0.782
TS = 1.202
UR = 1.000

Substituting the factor values into the fatal accident probability formula yields

$$\begin{aligned} P(FA|A) &= 1/(1 + CF \times MS \times TT \times TS \times UR) \\ &= 1/(1 + 695.0 \times 0.019 \times 0.782 \times 1.202 \times 1.000) \\ &= .075 \end{aligned}$$

To determine the probability of an injury acci-

TABLE 1 Factor Values for Fatal Accident Probability Formula

Formula Constant (CF)	Maximum Timetable Train Speed (mph)	MS	No. of Through Trains/Day	TT	No. of Switch Trains/Day	TS	Urban or Rural Crossing[a]	UR
695.0	1	1.000	0	1.000	0	1.000	0	1.000
	5	0.178	1	0.931	1	1.074		
	10	0.084	2	0.894	2	1.119	1	1.207
	15	0.055	3	0.868	3	1.152		
	20	0.040	4	0.848	4	1.179		
	25	0.032	5	0.832	5	1.202		
	30	0.026	6	0.819	6	1.221		
	40	0.019	7	0.808	7	1.238		
	50	0.015	9	0.790	9	1.266		
	60	0.012	10	0.782	10	1.279		
	70	0.010	20	0.732	20	1.366		
	80	0.009	30	0.703	30	1.422		
	90	0.008	40	0.683	40	1.464		
	100	0.007	50	0.668	50	1.497		

[a]0 = rural, 1 = urban.

TABLE 2 Factor Values for Injury Accident Probability Formula

Formula Constant (CI)	Maximum Timetable Train Speed (mph)	MS	Total Number of Tracks	TK	Urban or Rural Crossing[a]	UR
4.280	1	1.000	0	1.000	0	1.000
	5	0.687	1	1.125	1	1.202
	10	0.584	2	1.265		
	15	0.531	3	1.423		
	20	0.497	5	1.800		
	25	0.472	6	2.025		
	30	0.452	7	2.278		
	40	0.423	8	2.562		
	50	0.401	9	2.882		
	60	0.385	10	3.241		
	70	0.371	15	5.836		
	80	0.360	20	10.507		
	90	0.350				
	100	0.341				

[a]0 = rural, 1 = urban.

TABLE 3 Characteristics of Sample Crossing

Characteristic	Value
Maximum timetable train speed (mph)	40
Through trains per day	10
Switch trains per day	5
Total number of tracks (main plus other)	2
Urban or rural location	Rural

dent given an accident, at the same sample crossing, Equation 10 is used. Values for the factors in Equation 10 can be obtained from the equations given previously or from Table 2. Table 2 gives the following factor values for the characteristics of the sample crossing:

$$P(FA|A) = .075 \text{ (from fatal accident severity formula)}$$
$$CI = 4.280$$
$$MS = 0.423$$
$$TK = 1.265$$
$$UR = 1.000$$

Substituting the factor values into the injury accident probability formula yields

$$\begin{aligned} P(IA|A) &= [1 - P(FA|A)]/(1 + CI \times MS \times TK \times UR) \\ &= (1 - .075)/(1 + 4.280 \times 0.423 \times 1.265 \times 1.000) \\ &= 0.281 \end{aligned}$$

SEVERITY FORMULA PERFORMANCE

To illustrate characteristics of the fatal and injury severity formulas, the two functions P(FA|A) and P(IA|A) are plotted as a function of maximum timetable train speed and one other severity factor in Figures 5 and 6. The probability of a fatal accident given an accident P(FA|A) (Figure 5) increases as a nearly linear function of timetable train speed. Changes in the number of through trains do not have a major influence on fatal accident severity. The probability of an injury accident given an accident P(IA|A) (Figure 6) increases as a nonlinear function of timetable train speed. Injury accident severity generally increases rapidly with timetable train speed and then remains relatively constant beyond 40 mph. The function actually decreases at high speeds under certain conditions as previously predicted from observation of actual accident data (see Figure 4). The number of tracks at the crossing has a significant influence on the function (injury accident severity decreases with the number of tracks).

The performance of the severity formulas was evaluated using two methods: (a) comparing predicted versus actual severity for sample sets of accidents and (b) comparing the ability of the formulas to rank accidents by severity with a random ranking. Results of the first evaluation are summarized in Table 4. Using 1978, 1979, and 1980 data, the severity formulas were used to predict the number of

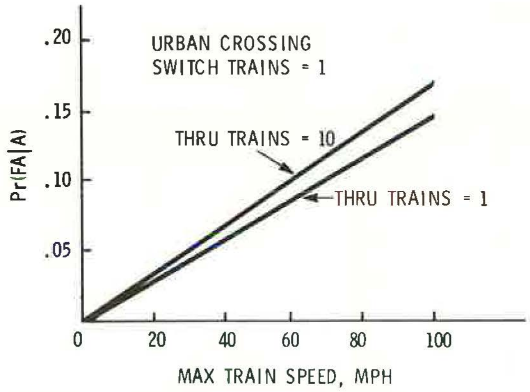

FIGURE 5 Probability of fatal accident, given an accident, versus maximum timetable train speed.

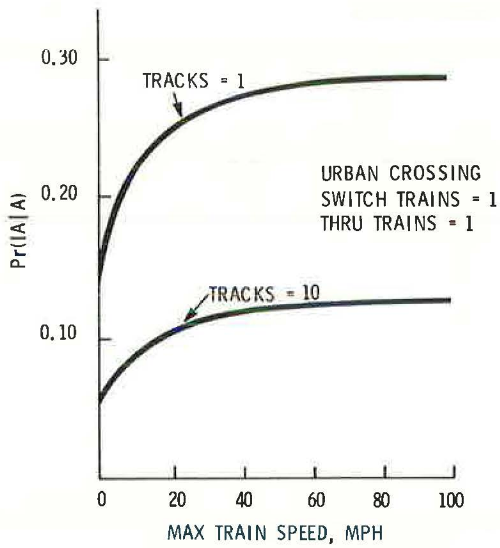

FIGURE 6 Probability of injury accident, given an accident, versus maximum timetable train speed.

TABLE 4 Predicted Versus Actual Accident Severity

No. of Ranked Accidents	No. of Predicted Fatal Accidents	No. of Actual Fatal Accidents	No. of Predicted Injury Accidents	No. of Actual Injury Accidents
100	18.2	13	31.3	42
500	79.3	76	154.2	171
1,000	142.6	145	305.9	348
7,934	511.9	539	2,018.5	2,192

fatal and injury accidents for sets of accidents that occurred in 1981. The predictions were then compared with actual accident records for the same sets of accidents. The sets of accidents considered were selected from the top of a list of accidents ranked by predicted severity. According to Table 4 the severity prediction formulas compare well with observed data. For example, the first row shows that, for the top 100 accidents in 1981, the formulas predicted 18.2 fatal accidents versus 13 actual and 31.3 injury accidents versus 42 actual. It should be noted that predicted severity values represent expected long-term annual rates and should be used with caution when estimating severity at individual crossings for a short time.

Results of the second evaluation of the severity formulas are based on the premise that, for accidents properly ranked by predicted severity, those at the top of the list (the most severe) should have a higher than average number of actual fatal and injury accidents. On the other hand, accidents at the top of a randomly ranked list should have only an average number of actual fatal and injury accidents. The ratio of actual accident severity for a set of accidents ranked by predicted severity to actual accident severity for the same size set of accidents ranked by random selection is a measure of the formula's ability to identify more severe accidents. This measure is referred to as the power factor for the prediction formula.

The power factors for the fatal and injury formulas for sets of accidents, ranked by predicted severity, are given in Table 5. The table indicates, for example, that for the top 100 ranked accidents the power factors for the fatal and injury formulas are 1.91 and 1.52, respectively. This means that the top 100 accidents ranked by the formulas have 1.91 and 1.52 times the number of fatal and injury accidents, respectively, as a randomly selected group of 100 accidents. Similar comparisons are made for the top 500 and 1,000 accidents. The results all show that the fatal and injury severity formulas are quite effective in predicting accident situations that tend to be more severe than the average.

TABLE 5 Ranking Performance of Severity Formulas

No. of Ranked Accidents	Fatal Severity Formula Power Factors[a]	Injury Severity Formula Power Factors[a]
100	1.91	1.52
500	2.24	1.24
1,000	2.13	1.26

[a] Actual severity for ranked group of accidents/actual severity for randomly selected group of accidents.

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Stability and Other Considerations in Simulation Analysis of Signal Control

FENG-BOR LIN

ABSTRACT

Lack of understanding of the nature of simulation and the characteristics of a system to be simulated can result in misuse of simulation models and simulation results. To promote better applications of simulation models to the evaluation of signal controls, three problems related to the generation and interpretation of simulation data are discussed in this paper. These problems include the stability of simulation results, the use of seed numbers for generating probabilistic events, and the aggregation of input data. Using simple examples of signal control, several fallacies in the application of signal simulation models are illustrated. Suggestions for avoiding these fallacious applications are presented.

Simulation models are increasingly used to aid in the design and evaluation of signal control systems. Some of these models, such as UTCS-1 (1) and NETSIM (2), are intended for general application in the evaluation of traffic control alternatives. These models require microscopic simulation of traffic flow characteristics to approximate the real world.

Experience with existing microscopic simulation models has produced a wealth of information on the potential and limitations of applying such models (3). Current concerns appear to focus on model enhancement, user needs and constraints, resource requirements for model application, and promotion and implementation of application by the traffic engineering community. The problem of experimental design for simulation analysis has also drawn some attention.

With increased use of simulation models for evaluation purposes, the risk of misuse and misinterpretation of simulation results can be expected to increase. A reason for this is that simulation models require substantial user interactions. An evaluation model is essentially a tool for data collection. Consequently, simulation results should be treated as a sample of observations. Estimates obtained from such a sample should be subjected to statistical tests for interpretation. It follows that experimental design should be an important part of simulation analysis. At issue is how, within the capability of a model, a user can apply the model efficiently to obtain statistically valid estimates.

The experimental design for simulation analysis is a profound subject. It requires a comprehensive understanding of the characteristics of a system to be simulated and the nature of simulation. At the present time, such an understanding is nonexistent. This is due in part to the large number of different systems a model has to accommodate. High costs and the reliability issue associated with the use of a model are also contributing factors. Nevertheless, there are several aspects of simulation application