Reliability and Risk Assessment in the Prediction of Hazards at Rail-Highway Grade Crossings

ARDESHIR FAGHRI AND MICHAEL J. DEMETSKY

The principles of reliability and risk assessment were applied in a model for the evaluation of rail-highway grade crossings and the prioritization of improvements. The performance of this newly developed model was evaluated and compared with the performance of five other nationally recognized models—the DOT, Peabody-Dimmick, NCHRP 50, Coleman-Stewart, and New Hampshire—by using a data base maintained by the Virginia Department of Transportation. The results indicated that because of the probabilistic nature of the model, its performance was exceptional when compared with that of the other models. The developed model is seen as a valuable prediction tool, but more important, it demonstrates the potential for applications of reliability and risk assessment in transportation.

Industrial and government planners, managers, engineers, and researchers have long recognized the importance of risk and uncertainty considerations in engineering tasks. These considerations, however, have not been central to policy formulation until recently. This trend toward consideration of risk and uncertainty has been accompanied by a rapid proliferation of literature on the subject of risk, indicating that both the professional and general public are becoming aware of the need to consider uncertainty in engineering decisions.

A careful examination of many basic engineering problems shows the various roles of risk analysis at decision points. In general, risk and uncertainty analysis includes identifying, quantifying, and evaluating risk, understanding the perception of risk, and determining the level of risk that is acceptable within a particular social and technical context.

The focus of this paper is the problem of measuring hazardous indices for rail-highway crossings. This problem was selected because uncertainty is not explicitly considered in the derivation of methods that are currently being used in the United States. The analysis in this paper deals with the problem of identifying the risk. After identification, the risk is reflected as a quantifiable metric that is used as one consideration in a multiattribute design process that allocates improvement funds to selected crossing sites.

Various empirical formulas for calculating hazard indices for rail-highway grade crossings have been developed by various organizations and researchers. One type, the relative formula, provides a measure of the relative hazards or the accident expectations at various types of railway crossings. These indices may be used to rank a large number of crossings in order of priority for improvements. The crossing with the highest hazard index is regarded as potentially the most dangerous and hence the most in need of attention. Another type of formula is called an absolute formula because it forecasts the number of accidents that is likely to occur at a crossing or a number of crossings over a certain time period and the number of accidents that may be prevented by making improvements at these crossings.

In a recent study conducted through the Virginia Transportation Research Council (*1*), Faghri and Demetsky evaluated five nationally recognized models for predicting rail-highway crossing hazards: the Department of Transportation (DOT), Peabody-Dimmick (P-D), NCHRP 50, Coleman-Stewart (C-S), and New Hampshire (N.H.). The general formats of these models are as follows:

NCHRP 50 Method

$$EA/\text{year} = A_1 X\ B_1 X \text{ trains/day}$$

New Hampshire Formula

$$\text{Hazard Index} = V\ T\ P_f$$

DOT Accident Prediction Formula

$$A = \frac{T_0}{T_0 + T}(a) + \frac{T}{T_0 + T}\,\frac{N}{T}$$

where

$$a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL$$

Coleman-Stewart Model

$$\log \bar{A} = C_0 + C_1 \log \bar{V} + C_2 \log \bar{T} + C_3 (\log \bar{T})^2$$

Peabody-Dimmick Formula

$$I = 1.28\,\frac{H^{0.170} \times T^{0.151}}{P^{0.171}} + K$$

where

Virginia Transportation Research Council, Department of Transportation, P.O. Box 3817 University Station, Charlottesville, Va. 22903.

EA = expected number of accidents;
A_1, B_1 = empirical adjustment factors;
V = average 24-hour traffic volume;
T = average 24-hour train volume;
P_f = protection factor;
A = final accident prediction, accidents per year at the crossing;
N = number of observed accidents;
T = number of years;
T_0 = formula weighing factor;
a = initial accident prediction, accidents per year at the crossing;
K = constant for initialization of factor values at 1.00;
EI = factor for exposure index based on product of highway and train traffic;
MT = factor for number of main tracks;
DT = factor for number of through trains per day during daylight;
HP = factor for highway paved;
MS = factor for maximum timetable speed;
HT = factor for highway type;
HL = factor for number of highway lanes;
$\bar{A}$ = average number of accidents per crossing year;
$\bar{V}$ = weighed average daily traffic volume for the N crossings;
$\bar{T}$ = weighed average train volume for the N crossings;
C_0, C_1, C_2, C_3 = empirical factors;
H = average number of vehicles in 24 hours;
T = number of trains per day;
P = protection type coefficient; and
K = additional adjusting parameter.

The DOT, Peabody-Dimmick, NCHRP 50, and Coleman-Stewart are absolute formulas. The New Hampshire model is a relative formula.

The results of this comparative study indicated that the DOT model was more accurate than the rest of the group in predicting rail-highway crossing hazards; thus it was recommended for use in Virginia. During the evaluation process, however, several problematic common features were observed among the five models. These included the following:

- The models were developed by using nationwide data.
- The parameters were determined through linear regression techniques (except the DOT model, which was developed by using nonlinear regression analysis).
- None of the absolute models are expected to predict the exact number of accidents that will occur at a crossing. At best, they can predict only the mean number of expected accidents at a crossing during an extended time period. However, the expected value is a better indicator of the number of accidents that will occur at a location than is a mere review of that location's history (2).

Given that the problem deals with a random variable, the occurrence of accidents at a crossing, it is odd that probabilistic approaches have not been developed. The foregoing observations motivated an investigation into the feasibility of approaching the problem from a probabilistic viewpoint. Accordingly, the mathematic principles of reliability and risk assessment were used to establish a hazard index for a crossing on the basis of the probability that an accident would occur at the crossing. Before the problem is formulated, however, a brief summary is presented of the concepts and fundamentals of reliability and risk assessment that apply.

FUNDAMENTAL CONCEPTS OF RELIABILITY AND RISK ASSESSMENT

Risk analysis, which is a subset of safety analysis, requires consideration of the probability of an accident's occurrence and its consequences (3). Reliability and risk analysis have had a wide variety of applications in nuclear engineering (3), chemical engineering (4), and civil engineering (5).

In this work, the probability per unit time that an undesirable event may occur is estimated by using the fundamentals of reliability theory and is expressed as the expected frequency with which the event might be initiated (3). To formulate the probability concepts of failure analysis, two types of systems are considered: those that operate on demand and those that operate continuously. Demand failures occur in a system during its intermittent, possibly repetitive, operation: either the system operates at the nth demand (event D_n) or it does not operate (event $\bar{D}_n$). The probability $P(W_{n-1})$ that the system works for each of $n - 1$ operations is the intersection of the probabilities of success for each operation:

$$P(W_{n-1}) = P(D_1 D_2 \ldots D_{n-1}) \tag{1}$$

The fact that the system works for $n - 1$ operations does not mean that it will operate at the nth demand. That is, $P(D_n | W_{n-1})$ is the conditional probability that the system will operate at the nth demand, given that the system works for $n - 1$ demands. $P(\bar{D}_n | W_{n-1})$ is the corresponding conditional probability of failure. The probability that a system will not operate on the nth demand when it has worked for all previous demands is

$$P(\bar{D}_n W_{n-1}) = P(\bar{D}_n | W_{n-1}) P(W_{n-1}) \tag{2}$$

Equation 2 may also be written as

$$\begin{aligned} P(D_1 D_2 \ldots D_{n-1} \bar{D}_n) = {} & P(\bar{D}_n | D_1 D_2 \ldots D_{n-1}) P \\ & \times (D_{n-1} | D_1 D_2 \ldots D_{n-2}) \ldots P \\ & \times (D_2 | D_1) P(D_1) \end{aligned} \tag{3}$$

Ideally, for demand-type failures there should be available a complete tabulation of all the probabilities in Equation 3 for every intermittently operating component in a system. Because of limitations in the experimental data available, it is usually necessary to assume that the demand events are identical and independent. Any failure is then assumed to be random so that

$P(\bar{D}_n|W_{n-1}) = P(\bar{D})$ and $P(D_n|W_{n-1}) = P(D)$. In such a case,

$$P(D_1 D_2 \ldots D_{n-1}) = [P(D)]^{n-1} = [1 - P(\bar{D})]^{n-1} \quad (4)$$

and

$$P(D_1 D_2 \ldots D_{n-1} \; \bar{D}_n) = P(D_1 D_2 \ldots D_{n-1}) \, P(\bar{D}_n) = P(\bar{D}) \, [1 - P(\bar{D})]^{n-1} \quad (5)$$

In this case, only the demand failure probability $P(\bar{D})$ needs to be tabulated.

For systems that are in continuous operation and that do not undergo repair, the analog to Equation 2 is given as

$$f(t) \, dt = \lambda(t) \, dt \, [1 - F(t)] \quad (6)$$

where

$f(t) \, dt$ = probability of failure in dt about t;
$\lambda(t) \, dt$ = probability of failure in dt about t, given that it survived to time t; and
$1 - F(t)$ = probability that the device did not fail prior to time t.

Another way of saying the same thing is

$$f(t) = \lambda(t) \, [1 - F(t)] \quad (7)$$

where $f(t)$ is the failure probability density, that is, the probability of failure in dt about t per unit time. The term $\lambda(t)$ is the conditional failure rate and is often called the hazard rate; the units of $\lambda(t)$ are inverse time.

Reliability, $R(t)$, is defined as the probability that a specified fault event has not occurred in a system for a given period of time and under specified operating conditions. In other words, reliability is the probability that a system performs a specified function or mission under given conditions for a prescribed time. Reliability is the complementary probability of $F(t)$, that is,

$$R(t) = 1 - F(t) \quad (8)$$

In other words, $F(t)$ is the unreliability, the probability that the device or system will fail at some time between 0 and t, and $R(t)$ is the probability that it will not fail during that time period.

A summary of equations relating $\lambda(t)$, $R(t)$, $F(t)$, and $f(t)$ is presented in Table 1. Derivations of these formulas may be obtained elsewhere (*3*).

To formulate the failures of components mathematically, several probability distributions that describe such failures are used. For systems whose operations are intermittent, discrete probability distributions are used, and systems whose operations are continuous can be described by continuous probability distributions. Some of the most common probability distributions that are applied in reliability engineering problems are presented in Table 2.

To summarize,

- Two conditional failure probabilities are used in reliability: the failure/demand and the failure/unit time (or hazard rate).
- The hazard rate $\lambda(t)$ contains all the information needed to study failures of a system. If $\lambda(t)$ is not known with certainty, statistical estimation procedures must be used to estimate the value of λ (*3*).

The fundamental relationships defined in Equations 1–8 and the selection of an appropriate probability distribution now provide the means for applications of reliability and risk assessment in rail-highway hazards prediction.

APPLICATION

The ideal hazard prediction technique for rail-highway grade crossings is an equation that accurately predicts the frequency of accident occurrence by taking into account all variables that have some influence on the event. From a practical point of view, such an equation is too large and the data requirements too extensive to be of any value. Also, accidents are influenced by such factors as driver skill and perception, certain environmental conditions, and other factors that are at many times impossible or too costly to accurately quantify in any consistent way. Finally, accidents occur from essentially random causes; consequently, any predictive equation is bound to explain less than 100 percent of accident behavior, even in the very long run.

Accordingly, such an equation should not be expected to predict the exact number of accidents that will occur at a given time period. At best, it can predict the expected number of

TABLE 1 SUMMARY OF RELIABILITY EQUATIONS (*3*)

Word Description	Symbol	=	First Relationship	=	Second Relationship	=	Third Relationship
Hazard rate	$\lambda(t)$		$-(1/R) \, dR/dt$		$f(t)/[1 - F(t)]$		$f(t)/R(t)$
Reliability	$R(t)$		$\int_t^\infty f(\tau) \, d\tau$		$1 - F(t)$		$\exp\left[-\int_0^t \lambda(\tau) \, d\tau\right]$
Cumulative failure probability	$F(t)$		$\int_0^t f(\tau) \, d\tau$		$1 - R(t)$		$1 - \exp\left[-\int_0^t \lambda(\tau) \, d\tau\right]$
Failure probability density	$f(t)$		$dF(t)/dt$		$-dR(t)/dt$		$\lambda(t)R(t)$

TABLE 2 PROBABILITY DISTRIBUTIONS USED IN RELIABILITY ANALYSIS

Name	Function
Discrete Distributions	
Binomial	$P(r) = (n!)\ [r!(n - r)!]^{-1}\ [P(D)]^r\ [P(D)]^{n-r}$ where n is the number of demands or trials that an experiment consists of and r is a random variable, defined to be the number of demands for which the system fails.
Poisson	$P(r) = (\exp -\mu\ \mu^r)\ (r!)^{-1}$ where μ is the most probable number of occurrences of an event.
Continuous Distributions	
Erlangian	$f(t) = [\lambda(\lambda t)^{r-1} \exp -\lambda t]\ [(r - 1)!]^{-1} \quad \lambda > 0, r \geq 1$ where λ is the hazard rate.
Exponential	$f(t) = \lambda \exp - \lambda t$
Gamma	$f(t) = [\lambda(\lambda t)^{r-1} \exp -\lambda t]\ \Gamma(r)]^{-1} \quad \lambda > 0, r > 0$ where $\Gamma(r)$ is the gamma function.
Lognormal	$f(t) = (\sqrt{2\pi}\alpha t)^{-1} \exp \{-[\ln (t/\beta)]^2\ (2\alpha^2)^{-1}\} \quad \alpha, \beta > 0$ where α is the shape parameter (dimensionless) and β is the scale parameter or "characteristic life" (in units of time).
Weibull	$f(t) = \alpha/\beta\ [(t - \tau)/\beta]^{\alpha-1} \exp\{-[(t - \tau)/\beta]^{\alpha}\} \quad \alpha > 0, \beta > 0, 0 \leq \tau \leq t \leq \infty$ where τ the time delay parameter.

accidents at a crossing during a given time period. Any change that occurs in the variables of the equation alters the mean number of expected accidents. Thus the forecasted expected value is considered by statisticians to be a better indicator of the number of accidents that will occur at a location than that location's history.

The probability of an accident at a rail-highway crossing has been formulated as follows (2):

$$\lambda = P = R(K + S) \tag{9}$$

where

$\lambda = P$ = probability of the event of an accident,
K = probability of a vehicle arriving at a grade crossing occupied by a train,
S = the probability of a train arriving at a grade crossing occupied by a vehicle, and
R = the risk that a driver will be unaware of his surroundings and hence will not (or perhaps will be unable to) take the evasive action necessary to avoid a pending collision.

$R = 1$ implies total risk (unswerving drivers who completely ignore onrushing trains or are completely unaware of an obstacle in their path), and $R = 0$ implies perfect information and complete awareness, hence no risk.

"Risk" defined in the foregoing way includes both cases in which a train occupies the crossing and cases in which a train is approaching the crossing:

$$P = rK + RS \tag{10}$$

in which r and R are the corresponding risks for the two situations. Furthermore, P would also be expected to be a function of warning devices. This would change Equation 10 to

$$P = C(rK + RS) \tag{11}$$

in which C is a coefficient that depends on the type of protection at the crossing.

Early accident statistics indicate that accidents that could be predicted by the function CrK account for about 35 percent of the accidents involving trains. However, further analysis indicates that unless the crossing is used by extremely slow-moving trains at night, the value of r drops so low when a train is occupying the crossing prior to the motorists' final opportunity to stop that it is almost negligible (2). For mathematical expediency, this allows the return to an assumption of a common formula for all cases:

$$P = CR'S' \tag{12}$$

where R' is the risk of operation perception and S' is the probability of a vehicle arriving at a grade crossing occupied by another vehicle.

This approach was necessary because the Virginia data base contained data for both types of accidents (i.e., the accidents with trains occupying the crossing and accidents with vehicles occupying the crossing) and does not differentiate between them. Also, this modified formula provides a level of mathematics suitable for developing a usable model.

Now, because S' is the probability of a train arriving in a given second of time and a vehicle arriving in a given 2 to 3 sec,

$$S' = ab \tag{13}$$

where a is the probability of a train arriving in a given second and b is the probability of a vehicle arriving in a given 2 to 3 sec. Although the logic of a 2- to 3-sec arrival interval seems to be good, the statistics do not entirely support it (2). For example 2.5 times as many accidents occur in the 1-sec interval (moving train hits a moving car) as occur in the 2- to 3-sec interval (moving train appears on the crossing after the driver has gone beyond his final opportunity to stop). During those 2 to 3 sec the driver still has alternatives of evasive action, even though he cannot stop. He can run off the road or he can hit an object other than the train. He can also accelerate and possibly cross the tracks before the train arrives. For the purposes of the accident model, a highway risk time of 1 sec is used.

The flow of traffic on a facility is a function of the time of the day, which makes it desirable to estimate hourly traffic flow rates. However, there is a high degree of randomness within any hour. If it is given that V_h is the volume of traffic in the hth hour but randomness is assumed within that hour, the probability that no vehicle crosses a predetermined point on a roadway in a randomly chosen second of time is exp $-V_h/T_h$ (assuming Poisson arrivals), where T_h is the number of seconds in an hour. Therefore the probability of at least one random arrival in a chosen second is $1 - \exp -V_h/T_h$. Because of the low volume of trains, the approximation of Z_t/T_t (in which Z_t is the number of trains in the time period) is valid for almost any distribution that may be used. The information available for this study was the number of trains per day and the average daily traffic. Thus

$$b = 1 - (\exp -V/24 \times 3{,}600) \tag{14}$$

and

$$a = Z/24 \times 3{,}600 \tag{15}$$

DISCUSSION OF VARIABLES

Protection Type (C)

Previous research in the form of before and after studies has developed relative hazard relationships for the various protection types. If crossbuck protection is set equal to one, the relative hazard is as follows:

Protection	*Hazard*
Crossbucks	1.00
STOP signs	0.65
Wigwags	0.34
Flashing lights	0.30
Gates	0.17

Risk Factor (R')

R' was defined as the risk that a driver will be unaware of his surroundings when a train is approaching and therefore will not take the evasive action necessary to avoid collision. R' can also be expected to be a function of the physical features at the crossing. Features such as angle of crossing, highway speed, train speed, sight distance, visibility, number of lanes, and others can alter the risk. $R' = 1$ implies total risk, that is, unswerving drivers who completely ignore on-rushing trains or are completely oblivious to an obstacle in their path. $R' = 0$ implies perfect information and complete awareness, hence no risk. All models in the literature use regression analysis techniques to find the correlation between the number of accidents and site variables. In this study, the risk factor for each crossing was determined by using all the variables that were used in the DOT model, which were then normalized to be used as probabilities in the final formulation. These variables are factor for exposure index based on product of highway and train traffic, factor for number of main tracks, factor for number of through trains per day during daylight, factor for highway type, and factor for number of highway lanes. The variables from the DOT model were used because, as will be shown later, this model had the highest predictive power. However, if there are other relevant factors (such as school bus traffic and sight distance) in an agency's data base, they may also be included in R'. The more relevant variables are included in the value of R', the more accurate the final results will be.

Final Formulation

Once all the variables have been defined, the probability of occurrence of an accident per second per crossing can be stated as

$$P = CR'ab \tag{16}$$

This probability per unit time (P) can be looked on as the hazard rate (defined earlier) for each crossing. If each crossing is considered as a separate system and random failures are assumed for each system [i.e., those failures for which the hazard rate $\lambda(t)$ is a constant], the Poisson discrete distribution can be used to derive the final form of this equation. The probability of exactly r failures occurring in time t is given by

$$P(r; t) = \exp -\lambda t\,(\lambda t)^r/r! \tag{17}$$

and the cumulative probability of X or fewer failures is

$$P(X < x; t) = \sum_{r=0}^{x} \exp -\lambda t\,(\lambda t)^r/r! \tag{18}$$

Equation 18 permits calculation of the failure probability density $f(t)$ for the rth failure in dt about t. What is required, of course, is for the system to have undergone $(r - 1)$ prior failures so that it is ready to fail for the rth time with a conditional probability λ [i.e., $P(r - 1|r) = \lambda$, because λ is constant]. Thus the Erlangian distribution (time-dependent form of the Poisson discrete distribution) follows, as

$$f(t) = P(r - 1, t) = \lambda(\lambda t)^{r-1} \exp -\lambda t/(r - 1)! \qquad \lambda > 0,\ r \geq 1 \tag{19}$$

The Erlangian distribution is valid for an integer number of failures r. The most important special case is for $r = 1$, in which case the exponential distribution is obtained as

$$f(t) = \lambda \exp -\lambda t \quad (20)$$

The cumulative failure probability for the exponential distribution is

$$F(t) = 1 - \exp -\lambda t \quad (21)$$

and the reliability is

$$R(t) = \exp -\lambda t \quad (22)$$

Substituting the value of λ in Equation 22 for each crossing gives

$$R(t) = \exp -(CR'ab)\, t \quad (23)$$

or

$$R(t) = \exp [CR'(1 - \exp -V/24 \times 3{,}600) \times (Z/24 \times 3{,}600)]t \quad (24)$$

By using Equation 24, the reliability of each crossing can be determined over a certain period of time.

This model was applied to the 1,536 rural public grade crossings that define the data base maintained by the state of Virginia, and the results were saved on a microcomputer hard disk for comparison with the other models. The methodology for comparing the models is discussed in the following section.

METHODOLOGY

The technique used for the comparison of representative models in this study was the power factor (PF) test. This test, which compares models for their hazard prediction capability, was first described by Mengert (6) and is defined as follows. The 10 percent power factor is the percentage of accidents that occur at the 10 percent most hazardous crossings (as determined by the given hazard index) divided by 10 percent. The same sort of definition holds for the 5 percent power factor, and so on. Thus, if PF (5 percent) = 3.0, then 5 percent of the crossings account for 15 percent (3 × 5 percent = 15 percent) of the accidents (when the 5 percent considered is the 5 percent most hazardous, according to the hazard index in question).

The PF can be seen as a primary measure of the usefulness of a hazard index for relative rankings of crossings. As an example, suppose that 10 percent of a certain group of crossings is to be selected for improvement, and assume that the most hazardous crossings are to be selected for this purpose. Then, if a given hazard index is used, the 10 percent most hazardous crossings will be selected according to that hazard index. The number of accidents that may be expected at these selected crossings in any period of time is proportional to the PF for the given hazard index. The greater the proportion of the total accidents that would occur at the crossings selected as the most hazardous, the more effective the hazard index, as evidenced by the PF. In fact, for some purposes, the payoff (or benefits) will be proportional to the number (or proportion) of accidents that would occur at the selected crossings because these accidents may be partially or totally prevented. Consequently, when the hazard index is to be used for selecting the 10 percent most hazardous crossings, the 10 percent PF seems to be the most direct measure of its effectiveness. The same would hold for the 20 percent power factor if 20 percent of the crossings were to be selected, and so forth.

RESULTS

To evaluate the performance of the new reliability-based model, the 1 percent, 2 percent, 3 percent, 6 percent, 10 percent, 20 percent, and 40 percent power factors of all the crossings in the data base were determined for each of the models. The results of the power factor test are shown in Tables 3

TABLE 3 POWER FACTORS OF EACH MODEL

Crossings (%)	Incremental Accidents	Cumulative Accidents	Accidents (%)	Power Factor
DOT Model				
1	5	5	3.10	3.10
2	6	11	6.83	3.42
3	3	14	8.69	2.90
6	11	25	15.52	2.58
10	11	36	22.36	2.24
20	30	66	40.99	2.05
40	42	108	67.08	1.68
NCHRP 50 Model				
1	4	4	2.48	2.48
2	6	10	6.21	3.10
3	3	13	8.07	2.69
6	14	27	16.77	2.79
10	11	38	23.60	2.36
20	27	65	40.37	2.01
40	33	98	60.86	1.52
New Hampshire Model				
1	5	5	3.10	3.10
2	5	10	6.21	3.10
3	0	10	6.21	2.07
6	9	19	11.80	1.96
10	20	39	24.22	2.42
20	25	64	39.75	1.98
40	33	97	60.25	1.51
Coleman-Stewart Model				
1	2	2	1.24	1.24
2	5	7	4.34	2.17
3	3	10	6.21	2.07
6	10	20	12.42	2.07
10	12	32	19.87	1.98
20	31	63	39.13	1.96
40	44	107	66.45	1.66
Peabody-Dimmick Model				
1	4	4	2.48	2.48
2	3	7	4.34	2.17
3	3	10	6.21	2.07
6	10	20	12.42	2.07
10	15	35	21.74	2.17
20	30	65	40.37	2.02
40	37	102	63.35	1.58
Reliability Model				
1	3	3	1.86	1.86
2	10	13	8.07	4.04
3	5	18	11.18	3.72
6	8	26	16.14	2.69
10	13	39	24.22	2.42
20	27	66	40.99	2.05
40	40	106	65.83	1.64

TABLE 4 RANKING OF THE MODELS IN THE POWER FACTOR TEST

Crossings (%)	Rank[a] 1	2	3	4	5	6
1	DOT	N.H.	NCHRP 50	P-D	Reliability	C-S
2	Reliability	DOT	N.H.	NCHRP 50	P-D	C-S
3	Reliability	DOT	NCHRP 50	N.H.	P-D	C-S
6	Reliability	NCHRP	DOT	P-D	C-S	N.H.
10	Reliability	N.H.	NCHRP 50	DOT	P-D	C-S
20	Reliability	DOT	P-D	NCHRP 50	N.H.	C-S
40	DOT	C-S	Reliability	P-D	NCHRP 50	N.H.

[a]Rank 1 has the highest power factor, Rank 5 the lowest.

and 4. Table 3 presents the power factors of each model separately for the previously mentioned percentages of hazards, and Table 4 presents the results of using the power factors to rank the models according to their hazard prediction capability.

The two tables indicate the stability and the exceptional performance of the reliability model. The probability distribution that was selected in this study to describe the reliability of crossings turned out to be a more realistic hazard predictor for the crossings than other models because of the random nature of the accidents that take place at the crossings.

CONCLUSION

Through application of the probabilistic concepts of reliability and risk assessment, a reliability-based model was developed for determining the reliability of rail-highway grade crossings in the state of Virginia. This model can be used as a prediction tool for evaluating and prioritizing rail-highway grade crossings for any period of time. The main improvement of the model over other available techniques is its probabilistic nature. The results of the comparison of this model and five other nationally recognized models show the stability and superior performance of this model as a relative hazard predictor.

The potential applications of reliability and risk assessment in a variety of transportation-related problems are evident from this paper. Through careful formulation, many dangerous and hazardous situations in transportation and traffic can be described by using this theory. Model sensitivity to the issue of whether a train occupies a grade crossing or a vehicle occupies a grade crossing can only be clearly resolved when future data bases differentiate this condition for observed accidents. The current solution to the question of whether a train or a vehicle occupies a grade crossing was expedited by the fact that the data base used did not differentiate between the two types of situations. This necessitated the use of a practical mathematical formulation. A more complex model that will differentiate between the vehicles that might occupy the crossing should be addressed in further research, and the trade-offs between accuracy and computational efficiency should be evaluated.

REFERENCES

1. A. Faghri and M. J. Demetsky. A Comparison of Formulae for Predicting Rail-Highway Crossing Hazards. Presented at the 65th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 1986.
2. *NCHRP Report 50: Factors Influencing Safety at Highway-Rail Grade Crossings.* HRB, National Research Council, Washington, D.C., 1968.
3. N. J. McCormick. *Reliability and Risk Analysis: Methods and Nuclear Power Applications.* Academic Press, Orlando, Fla., 1981.
4. E. J. Henley and H. Kumamoto. *Reliability Engineering and Risk Assessment.* Prentice-Hall, Englewood Cliffs, N.J., 1981.
5. H. S. Ang and W. H. Tang. *Probability Concepts in Engineering Planning and Design, Vol. 2, Decision, Risk, and Reliability.* John Wiley, New York, 1984.
6. P. Mengert. *Rail-Highway Crossing Prediction Research Results.* Transportation Systems Center, Cambridge, Mass., 1980.

Publication of this paper sponsored by Committee on Railroad-Highway Grade Crossings.