Abridgment

A Comparison of Formulae for Predicting Rail-Highway Crossing Hazards

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The need for improvement at a rail-highway crossing typically is based on the expected accident rate (EAR) in conjunction with other criteria carrying lesser weight. In recent years new models for assessing the need for improvements have been developed, and in the research reported here, five such models selected from a list established from a literature review and a user survey were evaluated. The selected models—the U.S. Department of Transportation (DOT), Peabody-Dimmick, *NCHRP Report 50*, Coleman-Stewart, and New Hampshire—were evaluated using a data base maintained by the Virginia Department of Highways and Transportation. In addition, the performance of the methods for predicting the EAR were compared by using the chi-square test and the power factor. The results indicated that the DOT formula outperformed the other four methods in both the evaluative and comparative analyses, and thus was recommended for use. The priority list produced by this formula is only one criterion used in determining the need to improve conditions at any crossing. This information must be supplemented by regular site inspections and other qualitative issues that cannot be feasibly incorporated into a mathematical formula.

The need for improvement at a rail-highway crossing typically is based on the expected accident rate (EAR) as states use this rate with other criteria to rank crossings. The model used in Virginia to estimate the EAR is documented in *NCHRP Report 50* and is a modified version of the New Hampshire model *(1, 2)*.

Virginia maintains a grade crossing inventory based on the format used by the Federal Highway Administration (FHWA), Federal Railroad Administration (FRA), and the Association of American Railroads (AAR). Part of the information is maintained in a computerized data base, and the remainder is maintained in written form *(1)*. This data base supports the presently used prediction method, but lacks data that some important alternative models require.

In recent years, new methods, such as the U.S. Department of Transportation (DOT) Accident Prediction Formula *(3)* and the Coleman-Stewart model *(4)*, have been developed. With the availability of these methods, the Rail and Public Transportation Division of the Virginia Department of Highways and Transportation requested that several of the most promising methods be evaluated for its use in conjunction with both state and U.S. data bases (DOT, AAR national rail-highway crossing inventory, and FRA accident files). In response a study was conducted to (a) establish a list of nationally recognized models; (b) evaluate representative models for their ability to use available data to show hazard potential at crossings; and (c) recommend whether the currently used method, a modification of it, or a different method should be used by the Rail and Public Transportation Division to predict the accident potential at a crossing.

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REVIEW OF AVAILABLE MODELS

Information on 13 nationally recognized models was collected and reviewed *(1)*. These models included the following:

Coleman-Stewart
Peabody-Dimmick
Mississippi
New Hampshire
Ohio
Wisconsin
Contra Costa County
Oregon
North Dakota Rating System
Idaho
Utah
City of Detroit
DOT

The information obtained for seven of these models—the Coleman-Stewart, Peabody-Dimmick, New Hampshire, Oregon, Utah, city of Detroit, and DOT—provided full documentation on their development, testing, verification, and application. In addition to the information collected on these 13 models, data were obtained through a survey questionnaire sent to the departments of transportation in 49 states and the District of Columbia to determine the formulae and methods they use to predict accidents at public rail-highway crossings.

The empirical formulae for calculating hazard indices that have been developed by various organizations and researchers can be categorized into two basic groups. In one group are relative formulae that provide a measure of the relative hazards or the accident expectations at various types of railway crossings. These may be used to rank a large number of crossings in order of priority for improvement, the crossing with the highest hazard index being regarded as potentially the most dangerous and hence the most in need of attention. The second group consists of absolute formulae that forecast the number of accidents 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.

Based on the information obtained and reviewed on the 13 aforementioned models and the results of the survey questionnaire to the states, 5 formulae were selected for testing and evaluation. The DOT, Peabody-Dimmick *(5)*, *NCHRP Report 50*, and Coleman-Stewart represent the absolute formulae. The Coleman-Stewart model, which is relatively new, was included in the evaluation because little is known about its performance. The New Hampshire represented relative formulae.

PRELIMINARY COMPARISONS

The five representative models, though of different forms, share some common features in their basic formats including

1. The use of nationwide data for developing the models.
2. Employment of linear regression techniques for determining the parameters. (Except the DOT model, which was developed by using nonlinear regression analysis.)
3. The expectation that the absolute models cannot 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 should be a better indication of the number of accidents that will occur at a location than even that location's history *(2)*.

DATA BASE

The Rail and Public Transportation Division maintains a grade crossing inventory program that was developed by the FHWA, FRA, and the AAR. Part of the information used for predictive purposes is maintained in a computer data base, and the remainder is maintained in written form.

The computer data base is sufficient for computing the New Hampshire, Peabody-Dimmick, and *NCHRP Report 50* models, but must be supplemented to compute the DOT and Coleman-Stewart models. The supplemental data items include the number of through trains per day during daylight hours, maximum timetable speed for each crossing, and highway type. Data on the number of school buses per day per crossing and the sight distance for each crossing were also included to permit further analysis.

For this study, the data base was recorded on an NBI (384k) microcomputer. Three computer programs were written to (a) compute the 5-year accident rate for each crossing according to the four absolute models and the hazard index for the New Hampshire model, (b) perform the chi-square statistical testing for the models, and (c) compute the power factors of the models. The computed numbers of accidents, as well as the hazard index for all the crossings determined by each of the models, were saved on the data diskette.

EVALUATION

Methodology

The two methods described next were used to evaluate the representative models.

1. A statistical chi-square formula of the form

$$\sum_{i=1}^{1,536} \frac{(AO_i - AC_i)^2}{AC_i}$$

was used to determine the relative goodness of fit of the four absolute formulae. In this formula, AO is the number of observed accidents, and AC is the number of computed accidents for each of the 1,536 crossings. The computed number of accidents according to each of the four representative absolute formulae (DOT, *NCHRP Report 50*, Coleman-Stewart, Peabody-Dimmick) were determined and tested by means of the preceding formula.

2. The primary tool for comparison of the representative relative formula (the New Hampshire model) and the four absolute formulae used in this study is the power factor 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 *(6)*. The same type of definition holds for the 5 percent power factor, and so forth. Thus, if $PF(5\%) = 3.0$, then 5 percent of the crossings account for 15 percent ($3 \times 5\% = 15\%$) of the accidents (when the 5 percent referred to is the 5 percent most hazardous according to the hazard index in question).

RESULTS

The chi-square tests on the four absolute models indicated that the number of accidents computed by the basic DOT formula had the closest fit to the actual number of accidents at all of the crossings. The summation of chi squares for all of the crossings by the four absolute models is given in the following table.

Model	*Chi Squares*
Peabody-Dimmick	2175.609
NCHRP Report 50	3810.222
Coleman-Stewart	961.166
DOT	833.096

The performance of all five representative models in the second test (the power factor) is summarized in Table 1.

The data in Table 1 indicate the stability of the basic DOT formula as compared with the other four. Research results have also indicated that once the accident history is incorporated into the basic DOT formula, that is, the main DOT formula is used, the DOT power factors for different percentiles of hazard will be significantly better than those of any other model *(6)*.

Testing the Significance of Other Variables

In order to study the significance and possible inclusion of other important variables in the final hazard prediction formula, data were obtained on 9 crossings that had restricted sight distances and 913 crossings that had school bus traffic.

The nine crossings that had inadequate sight distances were statistically insignificant because the 5-year accident data did not indicate the occurrence of an accident on any of these

TABLE 1 RANKING OF THE REPRESENTATIVE MODELS IN THE POWER FACTOR TEST

Percentage of Crossings	Rank 1	2	3	4	5
1	DOT	New Hampshire	*NCHRP Report 50*	Peabody-Dimmick	Coleman-Stewart
2	DOT	New Hampshire	*NCHRP Report 50*	Peabody-Dimmick	Coleman-Stewart
3	DOT	*NCHRP Report 50*	New Hampshire	Peabody-Dimmick	Coleman-Stewart
6	*NCHRP Report 50*	DOT	Peabody-Dimmick	Coleman-Stewart	New Hampshire
10	New Hampshire	*NCHRP Report 50*	DOT	Peabody-Dimmick	Coleman-Stewart
20	DOT	Peabody-Dimmick	*NCHRP Report 50*	New Hampshire	Coleman-Stewart
40	DOT	Coleman-Stewart	Peabody-Dimmick	*NCHRP Report 50*	New Hampshire

NOTE: No. 1 has the highest power factor, No. 5 has the lowest.

TABLE 2 SCHOOL BUS DATA

No. of Accidents	Frequency: Total No. Crossings	Percent	No. Crossings With School Bus	Percent	Average Percent of School Bus Total Traffic	Range (%)
0	1,392/1,536	90.60	816/1,392	58.6	–	–
1	130/1,536	8.40	91/130	70.0	1.54	0.10–7.14
2	10/1,536	0.65	5/10	50.0	0.74	0.46 0.96
3	4/1,536	0.26	1/4	25.0	1.94	1.94

crossings. A summary of the statistics regarding the school bus traffic on the 913 crossings is given in Table 2.

As can be seen from Table 2, of all the crossings that experienced one accident during the last 5 years, 70 percent had an average of 1.54 percent daily school bus traffic. Fifty percent of all crossings that experienced two accidents had an average of 0.74 percent daily school bus traffic, and 25 percent of the crossings with three accidents had 1.94 percent daily school bus traffic.

It can thus be concluded that the two variables—sight distance and number of school buses—are statistically insignificant, and that their inclusion in the final hazard prediction formula will not alter the results.

CONCLUSIONS

In this study, the DOT accident prediction formula outperformed the other four nationally recognized accident prediction formulae. The DOT formula is fully documented in the *Rail-Highway Resource Allocation Procedure User's Guide*. Also described in the guide is a resource allocation model that, together with the accident prediction formula, provides an automated and systematic means of making a cost-effective allocation of funds among individual crossings and available improvement options. The FRA will run the DOT model for states, if requested, on receiving an updated version of the states' inventory file.

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. 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 cannot be feasibly incorporated into a mathematical formula.

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DISCUSSION

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The authors report on a study that was designed to evaluate several rail-highway grade crossing accident prediction and hazard index models with respect to their potential applicability in the state of Virginia. One aspect of the paper that merits discussion and comment is the evaluation of the significance of sight distance as a hazard-influencing variable.

Although the authors report that 9 selected grade crossings having restricted sight distance (out of a total of 1,536 crossings available for study) did not experience any vehicle-train accidents over a 5-year period, this is not a sufficient basis to conclude that sight distance is a statistically insignificant variable which, if incorporated in an accident prediction model, would not alter the results. Prior research has shown otherwise *(1)*. Unfortunately, sight distance data are expensive to collect and therefore are not often available to model developers.

It should also be noted that the influence of sight distance on safety, and thus accident rates, will vary with the nature of other prevailing conditions at the crossing. For example, given that grade crossings equipped with only passive warning devices experience on an average of about one accident every 20 years, then a 5-year accident history (as used by the authors) may be misleading. The crossing that is truly average will not experience an accident in 19 out of every 20 years. Clearly a 5-year sample period could not be expected to yield the actual average rate of 0.05 accidents per year. Rather, a rate of either 0.0 (no accidents in 5 years), or 0.2 (one accident in 5 years) would be observed; neither would be a good estimate of the mean.

The contribution of sight distance to hazards at those high-exposure crossings equipped with automatic warning devices is related to track configuration (number and alignment), as well as the design of the track circuit. The presence of multiple tracks where one train can obscure a second train creates a sight distance problem for which a common countermeasure is the addition of gates. A set of tracks that approach the crossing from a horizontal curve may not afford adequate sight distance to a motorist (especially a trucker) who has stopped because of activated flashing light signals. If the track circuit design speed is significantly greater than the train approach speed, the sight distance problem will be worsened because of diminished credibility caused by an unnecessarily long warning time (during much of which the train may not be visible).

Based on the foregoing observations, there is little basis to support the authors' contention that sight distance is a statistically insignificant hazard-influencing variable and, if included in a hazard prediction model, would not be likely to alter the results of an application of the model. It is hoped that this discussion will stimulate future research into this important aspect of rail-highway grade crossing safety.

REFERENCE

1. W. D. Berg and J. C. Oppenlander. Accident Analysis at Railroad-Highway Grade Crossings in Urban Areas. *Accident Analysis and Prevention*, Vol. 1, 1969, pp. 129–141.

AUTHORS' CLOSURE

The study reported in this paper was performed in response to a request by the Rail and Public Transportation division of the Virginia Department of Transportation. The scope of the work was confined to evaluation of available methods (developed by others) to evaluate hazard potential at rail-highway crossings. The investigation was further limited to use of data currently available from the state of Virginia and the U.S. Department of Transportation (DOT). The emphasis was therefore on practical applications of the methodology.

The models tested were selected as a result of a literature review and a national survey of users. The most widely used approaches did not include sight distance as an explanatory variable. As a result of discussions with the client who recognized the potential effects of sight distance as well as the number of school buses using a crossing, it was decided to investigate the significance of these two data items on accident potential.

Berg's concern that the study dismissed the significance of sight distance as a hazard-influencing variable is unrealistic in view of the scope and constraints on the study. This view is based on the following facts. First, the conclusions stated that the priority list produced by using the formula must serve as only one criterion for improving conditions at any crossing. In the final sentence of the paper, it is explained that this information must be supplemented by regular site inspections and other qualitative issues that cannot be feasibly incorporated into a mathematical formula. It is implicit that sight distance falls into this latter category. In the study, the data were interpreted to indicate that the large majority of crossings had adequate sight distance and that crossings with inadequate sight distance (9 of 1,536) were not represented in the sample. The suggestion of site observations in conjunction with formula ratings provides the opportunity for officials to detect inadequate sight distance and overrule the initial prioritization. In this sense, sight distance is given priority over the other variables.

It is possible that many of the variables used in the models tested have statistically insignificant coefficients; this is also true of the coefficients for sight distance in Berg's 1969 paper. He states in the discussion that prior research *(1)* has shown otherwise (i.e., the inclusion of a sight distance ratio altered the results). This is not shown in his paper; it only includes the sight distance ratio as one of seven explanatory variables.

The real question is, Why did the models developed after 1969 not include sight distance? The literature did not reveal any correlation analysis between sight distance and accidents using a large data base that is common to the applications at hand. If the transportation community feels strongly about this issue, the DOT should sponsor a study to resolve this issue of sight distance once and for all.

REFERENCE

1. W. D. Berg and J. C. Oppenlander. Accident Analysis at Railroad-Highway Grade Crossings in Urban Areas. *Accident Analysis and Prevention*, Vol. 1, 1969, pp. 129–141.

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