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Abridgment

Roadside Hazard Model

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One category of traffic accidents that has received increased attention in recent years is the collision of a single vehicle with an object adjacent to the roadway. These single-vehicle, fixed-object (SVFO) accidents constitute approximately 17 percent of all reported accidents, and the probability of occupant injury in these accidents is significantly higher than is the probability for the complementary set of accidents. In an effort to develop cost-effective solutions to this problem, the Maryland Department of Transportation sponsored a study of these collisions on state-administered roads other than freeways. The objective of the study was to identify and quantify the parameters associated with SVFO accident severity and probability and to incorporate them into a hazard model. Previous reports (4, 5) have described the preliminary findings, and this abridgment presents the results of the concluding phase of the study.

INPUTS TO A ROADSIDE HAZARD MODEL

Field surveys conducted as part of the first phase of this study identified numerous objects adjacent to the roadway. A majority of these objects, including drainage facilities, traffic signal supports, and utility poles, were manmade. The number of these elements, coupled with the cost and logistical problems of their removal, relocation, or redesign, requires that attention be devoted to those elements that (a) result in injury to the occupants of striking vehicles and (b) are relatively more likely to be struck.

Severity

The degree to which a particular type of object results in injury to vehicle occupants can be quantified by its severity index (SI). From 1970 to 1975, reported SVFO accidents on Maryland and U.S. routes had an average SI of 0.44. The severity indexes determined from accident records are average values for all reported SVFO accidents. Caution must be exercised in using these averages primarily because of a significant number of unreported accidents.

All other factors being equal, accidents at higher speed will result in a larger frequency of injuries. Rural highways have more severe accidents although some SVFO accidents on 47- to 56-km/h suburban arterials, especially those that occur at night when traffic volumes are relatively low and involve drivers who are in "other than normal" condition, occur at high speeds. Accident records indicate that 44 percent of SVFO accidents involve drivers who are traveling at speeds too fast for conditions. A general model for determining the priority of roadside-hazard improvements must incorporate some speed-related parameter to highlight locations where SVFO accidents are likely to be more severe.

The most serious problem that is not reflected in accident records or accounted for by the SI is the variation in object design. For example, a variety of guardrail designs are used; W-beam designs are the most common, but single- and multiple-wire cable guardrails are also used. Various mounting heights are used in conjunction with blunt, flared, or buried terminals. Similar variations exist for the designs of other fixed objects and are of considerable importance because they affect the severity of SVFO accidents.

Probability of Impact

It is also essential for the hazard model to incorporate the likelihood of impact with a fixed object. Based on this research, the most important factors are traffic exposure, roadway geometrics, and placement of fixed objects.

The extent to which traffic is exposed to the object is partially reflected by the traffic volume on the route. However, volume by itself is not directly related to SVFO accident experience since multiple-vehicle accident experience increases at higher volumes whereas single-vehicle accidents decrease. Traffic volume is also related to roadway characteristics—notably road width and shoulders—that are associated with the frequency of roadside encroachments (3, 7). This research found that an unusually high percentage of SVFO accidents (62 percent) occur during conditions other than daylight. On some study sections, 80 percent of SVFO accidents occur during hours of darkness.

Studies that have concentrated on accidents and the geometrics of rural highways (1) have found that alignment and roadway width are the most significant factors. The field investigations in this study found that the adverse features of roadway alignment—notably steeper downgrades, sharp horizontal curvature, and the absence of shoulders—are the most critical factors.

Placement of objects involves three components that influence the probability of impact and warrant inclusion in the roadside hazard model: (a) the distance of the object from the edge of the traveled way, (b) the placement of the object inside versus outside a curve, and (c) the presence or absence of curbs or guardrail protecting the object.

MODEL DESCRIPTION

Results of previous studies (2) prompted the following conclusions with respect to the SVFO relative hazard model:

1. Recognition must be given to the probability and severity of impact;
2. It is essential to minimize the data items that must be collected for each object while maintaining the accuracy of the model; and
3. Because of problems with the reported frequency of SVFO accidents, verification of the model will be difficult.

The initial structure for the roadside hazard model is

$$H = K f_1(D) f_2(S) f_3(SI) f_4(V) f_5(G) \qquad (1)$$

where

H = relative hazard of a particular object,
K = a normalizing constant,
D = distance of the object from the road edge,
S = prevailing speed of traffic on the roadway,
SI = severity index associated with the type of object,
V = volume of traffic, and
G = geometric conditions.

Quantification of Parameters

In determining the values of the factors to be used in the model, the following considerations are of prime importance:

1. Each factor must be based on data that can be easily obtained from field studies and the existing record system.
2. For a given parameter, the factors must recognize in a logical manner the varying level of hazard associated with that parameter.
3. The quantification must recognize that individual parameters are not necessarily independent nor of equal importance.
4. The resultant hazard index can be normalized but should be proportional to the combined effect of the expected frequency and severity of accidents.

Distance

An object close to the roadway is more hazardous than a similar one that is farther removed. The relevant distance is measured from the right-hand edge of the travel lane to the object's nearest point. Since exact measurement for each object would be time-consuming and would not increase reliability in proportion to the effort involved, it is recommended that distance ranges be used. An analysis of distance-exceedance distributions provided the basis for quantifying the distance factor, as given below:

D (m)	$f_1(D)$
<1.5	1.00
1.5-3.0	0.76
3.0-9.0	0.33
>9.0	0.12

Speed

The factor of speed is important to the roadside hazard model because it affects the time an errant driver has to perceive and react and is related to the kinetic energy dissipated by a collision. Because of the limited data available, the posted speed limit, which is a reasonable representation of speeds on most state highways, was used in the model rather than the distribution of speeds of vehicles leaving the roadway. Since the speed factor is primarily intended to reflect severity and secondarily to account for probability of impact, the inclusion of these two considerations is achieved by using the parameter $(S + 16)^2$ where S is the posted speed limit. The rationale for this parameter is the reported higher accident experience at speeds 16 km/h faster than the posted speed limit. Using an assumed maximum speed of 80 km/h gives the following values of this parameter:

S (km/h)	$f_2(S)$	S (km/h)	$f_2(S)$
48	0.44	72	0.84
56	0.56	80	1.00
64	0.69	88	1.17

Severity Index

The SI for reported SVFO accidents serves as the best criterion for judging the seriousness of accidents that involve the various types of objects. It can be readily obtained from the accident-record system and can be periodically updated as new data become available. Using data for 20 000 SVFO accidents and the SI of 0.55 for light supports as the normalizing value gives the following calculated values of $f_3(SI)$:

SI	Type of Object	$f_3(SI)$
0.271	Construction barrier	0.49
0.280	Other fixed object	0.51
0.283	Sign support	0.52
0.309	Fence	0.56
0.353	Curb or wall	0.64
0.379	Building	0.69
0.399	Guardrail	0.73
0.463	Culvert or ditch	0.84
0.506	Embankment	0.92
0.513	Bridge	0.93
0.529	Other poles	0.96
0.533	Tree or shrubbery	0.97
0.550	Light support	1.00

Traffic Volume

Traffic volume is included in the roadside hazard model because it is related to the rate of encroachment (although the latter is exceedingly difficult to measure) (6). This research has found that 52 percent of all SVFO accidents (versus 20 percent of all other accidents) occur between 9:00 p.m. and 7:00 a.m. Although reliability is improved by incorporating nighttime traffic volumes, the simplest procedure would employ only type of roadway and estimated average daily traffic (ADT). The volume factors given below were determined from an analysis of SVFO accident rates and normalized to a base of 25 000 ADT:

Type of Roadway	Adjustment Factor
Multilane	0.040 x (ADT in 000s)
Wide rural	0.064 x (ADT in 000s)
Narrow rural	0.088 x (ADT in 000s)

Geometrics

The principal geometric conditions of the roadway related to SVFO accident experience are roadway alignment and the placement of the fixed object. Data from this study have been combined with findings reported by Wright (9) to assess the relative hazard of these various conditions. The following matrix gives $f_5(G)$ as a function of roadway grade and curvature and placement of the fixed object:

		Grade (%)		
Curvature	Placement	< -2	-2 to -5	> -5
0°-3°	Inside	0.108	0.135	0.215
	Tangent	0.133	0.167	0.265
	Outside	0.250	0.315	0.500
3°-6°	Inside	0.129	0.163	0.258
	Tangent	0.159	0.200	0.318
	Outside	0.300	0.378	0.600
> 6°	Inside	0.215	0.271	0.430
	Tangent	0.265	0.334	0.530
	Outside	0.500	0.630	1.000

Other Parameters

The most obvious factor not directly accounted for in the model is the distinction between spot and continuous objects. The study found that 42 percent of the SVFO accidents involved spot objects. In comparison with freeways, the distinction loses significance because some suburban roadway sections had more than 190 fixed objects/one-directional km, and rural sections had up to 60 objects/one-directional km. A second parameter not adequately addressed by the model is differences in the design of the fixed object. For example, the model does not indicate a reduction in hazard if wire guardrail is replaced by a more modern installation. A third element that is not considered at this stage in the model is the relative hazard of objects placed on the foreslope versus the backslope. The latter is intuitively a better condition, but this research was unable to quantify the difference. These shortcomings are all accommodated to some extent in other models designed for limited-access facilities (8).

USE OF THE MODEL

The hazard rating has three basic uses. Of primary interest is the fact that it can use field data to determine the relative hazard associated with the various fixed objects along the roadside, thus establishing a priority ranking for improvement. Second, the model permits a relative assessment of the various forms of remedial action, including the effects of severity or accident reduction. Third, the model can be applied to a variety of roadway design and operating features to develop a hazard hierarchy for fixed objects.

Field Data Collection

In the development of the model, major emphasis was placed on minimizing field data collection while maintaining reliability. The data needed include route characteristics (speed limit and traffic volumes), type and placement of objects, and geometric design features. The field data are recorded on a suitably designed form by a two-member survey crew who travel the roadway in a properly instrumented vehicle. Essential equipment includes an accurate odometer, a slope meter, and equipment for measuring lateral distance.

Despite efforts to simplify the data requirements of the model, a substantial amount of information will have to be collected, especially on roadway sections that have large numbers of fixed objects within 9 m of the roadway. On several of the study routes, there was less than 4.5 m of right-of-way adjacent to the pavement. This consideration, coupled with a hazard model analysis, led to the recommendation that initial data collection efforts be limited to objects that are within the existing highway right-of-way, or 4.5 m, whichever is less. A second limitation to facilitate data collection is the adoption of a policy for the correction of easily identifiable objects that use hazardous designs (e.g., deficient guardrail). A third possibility for expediting the inventory would be an automated field data collection system that would directly create a file for computer processing.

Application

The model can be applied on a theoretical basis to determine the effect of various forms of remedial action and to establish a ranking of relative hazard. The specific inputs in this analysis are the calculated hazard index reduction and considerations of practicality and economics. Although specific characteristics at a particular location may dictate otherwise, a general cost-effective structure for remedial action that is in general agreement with published guidelines for fixed-object correction was developed (5).

Interaction of Model Parameters

The application of the model provides a method for obtaining some insight into which combinations of fixed objects and other parameters warrant the most immediate attention. To use the model in this manner, a variety of roadway-volume classifications were considered. For each category of roadway volume, there are 8424 combinations of speed, object, distance, and geometric parameters. A computer program was used to calculate the hazard index for each of the combinations, to sort the hazard indexes in order of decreasing numerical value, and then provide an ordered listing of the parameters that gave rise to these indexes. Since the combinations were generated theoretically, some of the conditions that appear high on the ordered listing may not exist anywhere along the roadway system. An examination of the top 150 hazard indexes (1.8 percent of the total combinations) for wide rural roads with an ADT of 8000 identified the following characteristics:

1. Forty-five percent of the entries have speeds of 88 km/h and five entries have speeds of 56 km/h.
2. Each type of object appears in the list of the top 150 hazard indexes.
3. Seventy-eight percent of the entries are for grades of less than -5 percent; 80 percent involve curves in excess of 6° curvature.
4. Location on the outside of curves is dominant al-

though locations on the inside of curves and on tangent sections also appear.

5. No objects more than 3 m from the edge of the roadway appear in the list of the top 150 indexes, and most are within 1.5 m.

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Macroscopic Modeling of Two-Lane Rural Roadside Accidents

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A macroscopic study of off-road accident, road, and traffic flow characteristics on the rural two-lane state trunkline system was made to assist the Michigan Department of State Highways and Transportation (MDSHT) in developing priority programs for roadside hazard improvement. Statewide accident data for the period between 1971 and 1974 were analyzed, and, based on these data, a macroscopic modeling effort was undertaken for two-hundred and seventy 3.2-km (2-mile) sections of homogeneous two-lane road that had widely varying road and traffic conditions. Road data came primarily from analysis of MDSHT photolog files. Multiplicative models for different groups of average daily traffic were developed in which restriction on passing-sight distance, number and length of curves, and length of road with exposure to roadside obstacles within given distances from the road were found to be the main explanatory variables. These models, which were evolved dynamically with the aid of statistical computer programs, were tested for the validity of underlying assumptions and were shown to explain as much of the variance as would be expected assuming a Poisson process of accident frequency. The models were validated by using additional data for two cases of low average daily traffic, and satisfactory results were obtained. Several immediate uses for the models are presented.

Despite heavy urbanization, more than one-third of the total automotive accidents reported in Michigan happen on rural roads outside of incorporated areas (1). These accidents occur on facilities that range from low-flow, unimproved routes to multilane, intercity freeways. Even an agency such as the Michigan Department of State Highways and Transportation (MDSHT), which is responsible for the most important 12 900 km (8000 miles) of highway in the state—the portion that carries 38 percent of the rural traffic—has a range in rural facilities from 4.3-m (14-ft) wide two-lane routes to six-lane divided freeways.

This system suffers approximately 50 000 accidents and a total of 600 deaths/year (1). In recent years, much attention has been focused on these accidents in which damage or occupant injury results from the vehicle leaving the road by striking an obstacle or losing its stability and turning over.

Highway agencies have several countermeasures available that can reduce the toll from off-road accidents. Obstacles can be removed or moved farther from the road; they can be weakened so as to break away without damaging the vehicle extensively; and they can be protected by devices that absorb the energy of the vehicle or redirect it along a safer path. In addition, the ground form created by such features as ditches and slopes can be made more forgiving by reshaping and stabilizing it for improved vehicle stability under emergency conditions.

It is recognized that a program of creating a "forgiving road" on every kilometer of the Michigan rural highway system would require a tremendous investment in funds and time. Agencies with rural responsibilities must invest their limited funds and manpower resources in those roadside improvements that return safety benefits that justify these expenditures, and these investments must be made in a sequence that will maximize the time-scaled return to society.

Clearly, a key step in a roadside safety program is to be able to predict what will happen when a roadside improvement of a particular type is made. An organized way of developing the necessary understanding to make such a prediction is to create a model that is accurate enough to be used in the investment decision. Useful models must be able to predict the consequences of a wide range of improvement alternatives. Unfortunately, current understanding of the causes of accidents is inadequate, and only in recent years have sustained model-