Prediction of Head-On Accident Sites

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The roadway features of head-on sites versus control sites were compared vis-à-vis differences in head-on accident experience. The study used the discriminant analysis technique. The following features were found to be significant predictors of the head-on accident proneness of a 1-mi section: (a) the proportion of the section with pavement width of less than 24 ft, (b) the weighted pavement width, (c) the proportion of the section with shoulder width of less than 6 ft, (d) the proportion of the section with vertical alignment, (e) the average highway speed limit, (f) the number of major access points on both sides, and (g) the number of reverse curves with zero tangents.

Although head-on crashes are relatively rare, this class of vehicular accidents accounted for 14.6 percent of the highway fatalities on the roads of the United States for the period 1982 to 1984 *(1)*. Head-on collisions tend to be more frequent on urban than on rural highways. However, fatalities from such crashes occur more commonly on rural than on urban highways. For example, in 1984 the portion of head-on collisions was 27.3 percent on rural highways versus 72.7 percent on urban highways. However, the portion of the fatal head-on accidents on rural highways was 75.0 percent versus 25.0 percent for that on urban highways *(1)*. In other words, head-on collisions were about three times more likely to be fatal on rural than on urban highways.

This study focuses on head-on accidents as related to geometric and traffic control features with the objective of identifying those factors that predict head-on accident proneness of a particular site on the Georgia state route system. The study is limited to two-lane rural roads carrying average daily traffic (ADT) of at least 2,000 vehicles per day (vpd).

LITERATURE SEARCH

The few existing technical papers related to head-on accident occurrence fall in two categories: those that deal with the effect of a single roadway feature on head-on accidents and those that consider the effect of a combination of several features.

Pavement Width

Zegeer et al. *(2)* found that run-off-road and opposite-direction accidents were the primary accident types associated with narrow lanes. Accident rates (expressed in units of accidents per million vehicle-miles) of these two types of accidents combined tended to decrease as pavement width increased. But little reduction in accidents was gained by widening a 22-ft-wide road to a 24-ft pavement, and thus widening beyond 22 ft was not cost-effective.

Shoulder Width

Zegeer et al. *(2)* analyzed accident rates on two-lane rural roads for various ranges of shoulder widths as no shoulder, 1 to 3 ft, 4 to 6 ft, 7 to 9 ft, and 10 to 12 ft. The accidents were broken down by type. It was found that run-off-road and opposite-direction accident rates decreased as shoulder width increased up to 9 ft. There was a slight increase in rate for shoulders 10 to 12 ft wide. Rates for other than run-off-road and opposite-direction accidents tended to remain fairly constant or increased slightly as shoulder width increased. Shepherd and Lowe *(3)* found that sections with shoulder width of less than 2 m (6.6 ft) have a 15 percent higher accident rate than those with wider shoulders. However, shoulder width had no significant effect on the occurrence of head-on accidents. In another aspect of the effects of shoulders on highway operation, Jorol *(4)* noted that narrow shoulders resulted in drivers' positioning their vehicles closer to the centerline of the roadway. This action, in effect, can be taken as a cause for the occurrence of head-on accidents because it increases the chance of friction between opposing vehicles.

Pavement-Shoulder Combination

Several other researchers *(2, 5, 6)* agreed that roadways with shoulders are safer than those without shoulders. Zegeer et al. *(2)* found that for the same lane widths, total accident rates tend to decrease as shoulder width increases. When only run-off-road and opposite-direction accidents were used, more uniform decreases in accident rates were found with increases in shoulder width. They also concluded that greater reduction in accidents could be realized by lane widening than by shoulder widening.

Horizontal Alignment

Kurimoto *(7)* conducted a survey of 31,800 traffic accidents in Japan. He found that 15 percent of these accidents were head-on and that for this type of accident the accident rate increased as the horizontal radius decreased [at radii of less than 2,623 ft (800 m) and less than 2.2° curvature]. The trend in the association of head-on accident rate to curvature was noticeable for curves sharper than this radius, that is, those of 2.2° or more. Shepherd and Lowe *(3)*, in a study of 44 sections in England, found that head-on accidents per section increased as the

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degree of horizontal curvature increased, with a sharp increase beyond 3.5°.

Vertical Alignment

Steep grades affect the operation of the vehicle and the roadway capacity *(6)*. However, their direct effect on accident occurrence has been shown to be inconsistent *(9–12)*. Although of particular interest, the literature lacks information on the relationship of head-on accidents to grade steepness.

Combined Horizontal-Vertical Alignment

Often, changes in horizontal and vertical alignments are combined in a roadway section. Combinations of horizontal curves of radii of 820 ft (7°) or sharper with vertical gradients of 4 percent or steeper increase accident rates *(7)*. However, there is little in the literature on quantitative effects of combined alignments on head-on accident rates.

Roadside Elements

Traditionally, roadside features have been considered in association with run-off-road crashes, irrelevantly to this study. However, there is an indication *(13)* that lateral obstructions located closer than 6 ft from the edge of pavement reduce its effective traffic width, a fact that forces drivers to travel closer to the centerline *(4)*. This factor can be thought of as a cause for the occurrence of head-on accidents because it increases the chance of friction between opposing vehicles.

Other aspects of the roadside elements are access and intersections. Fifty-seven percent of two-vehicle accidents that occurred nationwide between 1982 and 1984 happened at intersections, and head-on accidents constituted 16 percent of the total intersection accidents *(1)*. In an FHWA report *(14)*, it was mentioned that head-on accidents were 35 percent of the total accidents that occurred while vehicles attempted to enter driveways.

Traffic Control Features

Traffic control features believed to have an effect on head-on accidents are delineations, speed limits, no-passing controls, and curve-warning signs.

Centerline-related head-on accidents were 13 percent of the total accidents in a study conducted by Agent and Deen *(15)*.

Various studies *(14–18)* have shown that the incidence of accidents does increase with speed limit. The majority of fatal head-on accidents occur on roads with a high posted speed limit *(19)*.

Although the no-passing control is intended to provide guidance for motorists for proper overtaking, improper overtaking was cited as a factor in 3.6 percent of the total rural accidents during 1984, and the fatal accidents involving passing constituted 3.3 percent of the total fatal accidents *(1)*. Studying accidents on rural highway systems in Kentucky, Agent and Deen *(15)* found that 25 percent of the head-on accidents studied were in no-passing zones.

Little explicit evidence has been shown of the relation of curve-warning signs to the occurrence of head-on accidents; however, as Leisch *(19)* noted, these signs reduced the accidents as a total of all types in Los Angeles County, California, in a study conducted in 1955.

General Relationships

Shepherd and Lowe *(3)* conducted a study to develop a set of models to relate the occurrence of nonjunction accidents on two-lane rural roads to traffic, geometric features, and other conditions. Of relevance to this study is the opposite-direction accident type. As found in this study, horizontal curvature, presence or absence of access points, developed or underdeveloped land use, and the flow of vehicles in a period of 5 years were significant in predicting the number of head-on accidents.

APPROACH AND METHODOLOGY

To fulfill the objective of this research, discriminant analysis was used to distinguish between two groups of sites, head-on crash sites and control sites, based on their geometric and traffic control features. In a general form with p discriminatory variables, the result of the discriminant analysis is a linear combination of these variables in a discriminant equation in the following form:

$$D = d_0 + d_1V_1 + d_2V_2 + \ldots + d_iV_i + \ldots + d_pV_p \qquad (1)$$

where

D = score of the discriminant function;
d_i = weighting coefficients, d_0 being a constant; and
V_i = values of the discriminating variables.

Once the discriminant equation with p variables provides satisfactory discrimination between the two groups of sites, its predictive ability can be used for assigning the cases with unknown group membership. The classification process is based on the score of the case under consideration relative to the midpoint between the scores corresponding to the means of each group. According to the theory of discriminant analysis, this procedure is valid only when the prior probabilities of the two groups are equal, that is, each equal to 0.50. The SPSS *(20)* discriminant program was the basic program used, with some use of the BMDP7M program *(21)* also.

The approach of the study required the identification of head-on accident sites, control sites, and the discriminatory variables.

Development of Head-On Sites

The database of this study was the 3-year (1979, 1980, and 1981) collection of head-on accident records on Georgia two-lane rural state routes with an ADT of at least 2,000 vpd. The length of the segment was chosen as 1 mi. Because of the correlation between accident frequency and section length, the length of the segment could be fixed, thus providing a common basis for comparison and eliminating variability associated with segment length. The 1-mi section length provided a length long enough to produce reasonably large frequencies of head-on crashes while avoiding inordinate variability in geometric features and traffic conditions.

A frequency of three head-on accidents during the 3-year period of analysis was selected to define the head-on sites. This choice followed from statistical justification that proved that this frequency was sufficient to make these sites distinct from the general population *(22)*. Thus, 62 sites that had at least three head-on collisions with the frequency distribution shown in Table 1 were selected.

Development of Control Sites

The concept of using the control sites stemmed from the desire to make an objective comparison between them and the head-on crash sites based on differences in geometric and traffic control features, while normalizing extraneous effects such as the pairwise effects of driver, vehicle, and environment. In order to have a common basis for comparison, the control sites were required to be 1-mi sections on rural two-lane highways with ADT of at least 2,000 vpd. Further, these control sites were required to be as close as possible to the head-on sites to normalize the effect of the irrelevant features. It was decided that a 1-mi separation would achieve this requirement. Finally, the control sites had to have fewer than three head-on accidents in the same period of analysis in order to differ from the head-on sites *(22)*.

Following these guidelines, 62 control sites were selected on either side of head-on accident sites. The head-on site was determined randomly by flip of a coin. For the resulting control sites, 14 sites had one accident, 2 had two accidents, and the rest (46 sites) had none. With this result, comparison between head-on and control sites seemed valid.

Selection of Variables

Several variables were selected as potential discriminants based on the following two criteria: evidence from the literature of the association between head-on accidents and the variables and logical reasoning as to whether the selected variables might be expected to influence the occurrence of head-on accidents. (The first criterion alone was insufficient to specify all the variables.)

There were also some controls on the selection of the variables. First, some variables such as pavement width varied within a section. So it was important to define the variables to reflect variation, for example, to define pavement width in terms of the percentage of pavement width of less than 24 ft or of weighted pavement width (defined as the summation of the products of width times length over which the width is uniform, divided by the total length, 1 mi).

Second, because of the use of discriminant analysis, it was logical that variables distinguished between head-on and control sites. Common features of the sites, such as edge marking, were not expected to have a discriminatory effect on state rural routes. (Virtually all of these routes have edge marking.)

Third, variables so selected had to be simple and easy to measure in the field if the prediction technique to be developed in this research was to be practical. For example, although site distance is logically important to safety, a restrictively defined sight distance was too complex to use. For example, Raff *(9)* defined a restrictive sight distance as 400 ft in mountainous and 600 ft in flat and rolling terrain, whereas Sparks *(23)* used 1,500 ft for passing sight distance. In addition, sight distance is difficult to measure in the field. Finally, because sight distance was correlated with alignment *(3, 24)*, its use in the analysis was considered to be redundant, and thus was avoided.

As a result of the selection process, 25 potential variables were analyzed.

MODEL

Through various fine-tuning processes, including refining for multicollinearity among variables, testing for power of discriminant ability, and testing of the between-group differences, the following model was found:

$$D = 5.7707 - 0.0074\,WLDL24 + 0.0727\,WPW - 0.0101\,SHL6 - 0.0151\,PERVER - 0.0903\,AHSL - 0.2047\,BACC - 0.2965\,REV \quad (2)$$

TABLE 1 DISTRIBUTION OF SITES ACCORDING TO THE FREQUENCY OF HEAD-ON ACCIDENTS PER SITE

H-O ACCIDENTS PER SITE	SITES		TOTAL H-O ACCIDENTS	
	No.	%	No.	%
3	35	56.5	105	49.9
4	16	25.8	64	27.4
5	6	9.7	30	12.8
6	2	3.2	12	5.1
7	1	1.6	7	3.0
8	2	3.2	16	6.8
TOTAL	62	100.0	234	100.0

where

D = discriminant score;
$WLDL24$ = percent width less than 24 ft in the section;
WPW = weighted pavement width (ft) (the summation of products of segment widths by their lengths divided by the total length);
$SHL6$ = percent shoulder width less than 6 ft;
$PERVER$ = proportion of the section other than level;
$AHSL$ = average highway speed limit (mph) (summation of products of speed limit times length it is posted for divided by length of section in both directions);
$BACC$ = number of major access points on both sides; and
RVE = number of reverse curves with zero tangents.

Of the 25 variables considered, only these 7 variables were found to be statistically significant. The insignificant variables were number of horizontal curves, percent horizontal curvature, sum of central angles of the horizontal curves in the section, number of grades greater than zero, percentage of grade greater than 3 percent, sustainedness of grade (sum of products of the grades times their lengths), percentage of distance where passing was not permitted in both directions, number of changes in pavement width greater than 1 ft, number of single obstructions within 6 ft to pavement in both directions, number of minor access points (residential and small-business driveways), minimum radius in the section, ratio of minimum to maximum radii in the section, number of crests, number of crests formed with grades summing to 5 percent or higher, percent combined vertical and horizontal alignments, percent combined alignments of at least 3° curves and at least 2 percent grade, and ratio of number of curve-warning signs in both directions to twice the number of curves.

Given the seven significant features of a specific 1-mi section, a discriminant score D can be computed from Equation 2. The section is assigned to the head-on group if the resulting score is less than zero; otherwise, it is assigned to the control group. Another feature depicted by the model is that considered in the following standardized form:

$$D_s = 0.292\ WILDL24 + 0.596\ WPW - 0.313\ SHL6 - 0.377PERVER - 0.647\ AHSL - 1.019\ BACC - 0.268\ REV$$

where D_s is the standardized score. From this equation, it is observed that an increase in each of the variables except WPW would tend to make the site closer to the group of head-on sites. This finding eventually is logical.

Although the group membership of a case is a straightforward result from Equation 2, there is a need to design a tool that would be used to assess the safety level of a particular site from the standpoint of head-on accident proneness.

Figures 1 and 2 show the distributions of the discriminant scores for the sites of the head-on and control groups, respectively, as computed from Equation 2. The classification performance of the model is that 19.4 percent of the head-on sites were classified as control sites and 21.0 percent of the control sites were classified as head-on sites. Figure 1 also shows the scores corresponding to the centroids of each group, the mid-point (at $D = 0.0$) between these two scores determining the basis on which group membership is predicted. Further, the location of a score of a case of known group membership relative to the score of the centroid of the corresponding group can convey some significance. For example, for a score of a case that was originally defined as belonging to the head-on group of sites, the higher the value of the score relative to the centroid of the group is, the less chance that the case actually belongs to the head-on group; and the less the score is, the better chance that the case belongs to the head-on group. This argument, therefore, can provide a measure as to what degree the case has emanated from a specific group, a procedure that

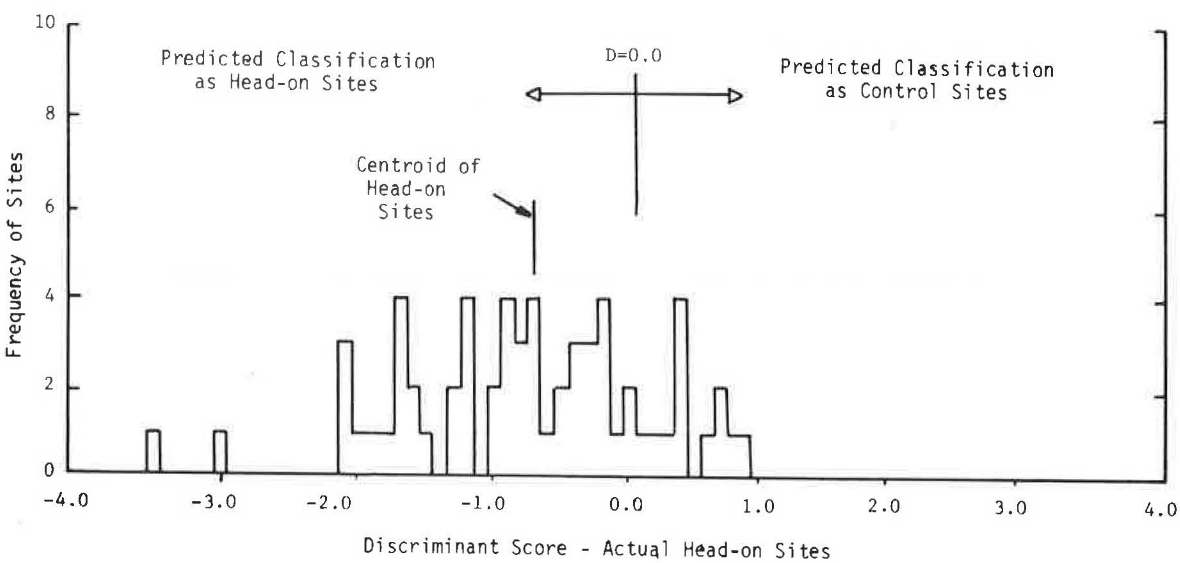

FIGURE 1 Distribution of discriminant scores for the head-on sites for the model.

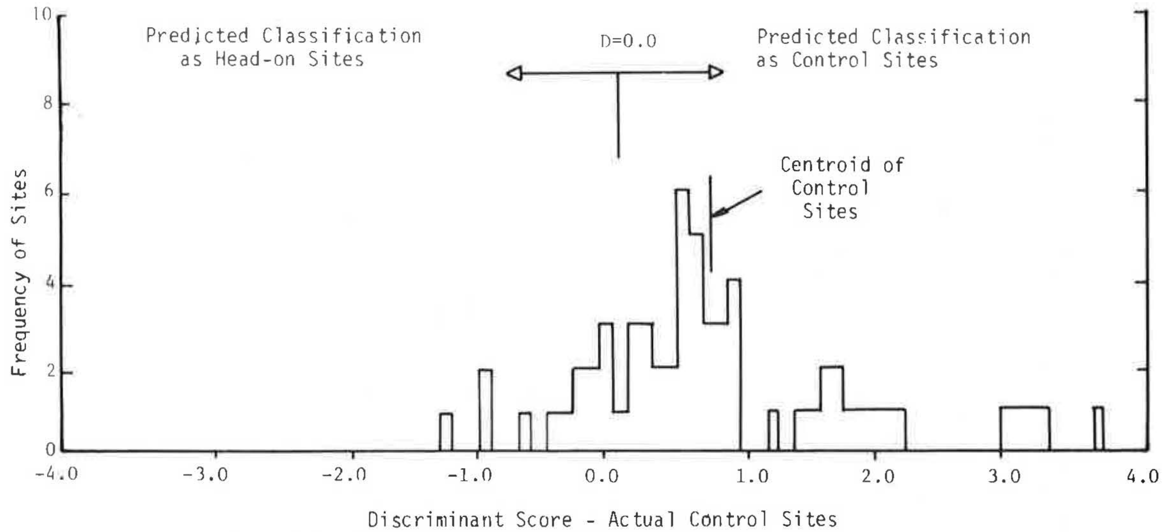

FIGURE 2 Distribution of discriminant scores for control sites for the model.

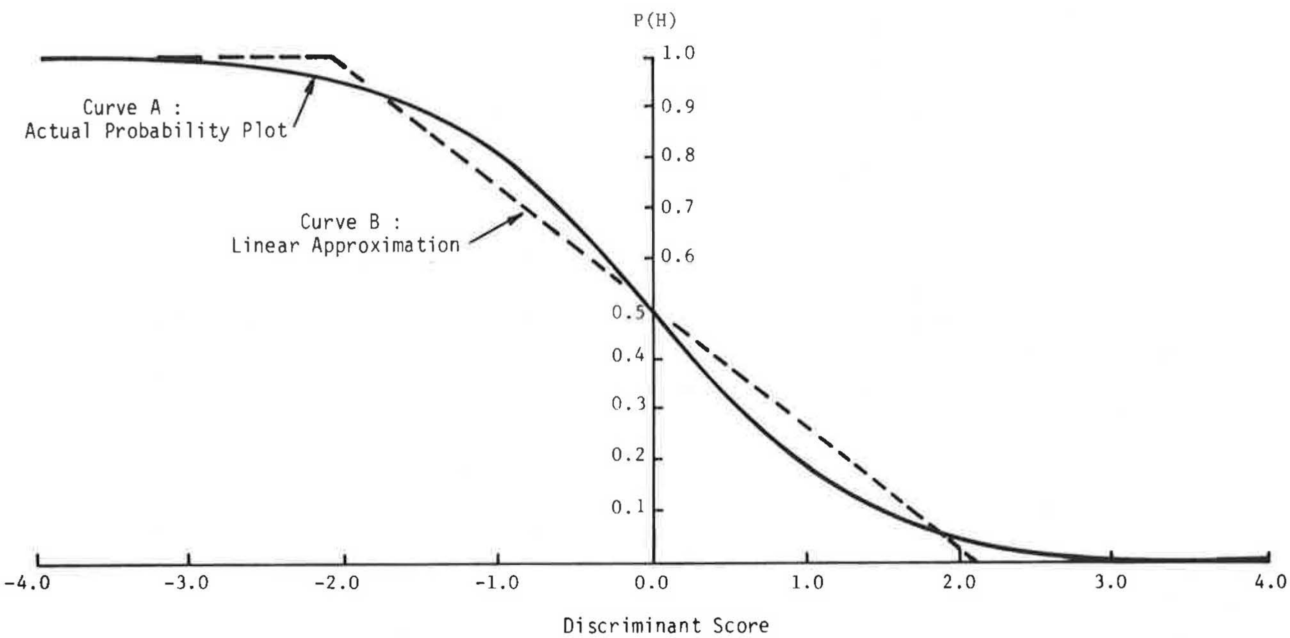

FIGURE 3 Probability of case membership to the head-on–accident-prone group versus its discriminant score for the sample data and its linear approximation.

incorporates information about the head-on group versus the control group by examination of the profile of the scores. In other words, based on the score of a given case, it is possible to associate a probability level of membership to a specific group even though the case was assumed to emanate from a known group a priori. The outcome of this argument is Figure 3, which shows the relation between the probability of a case membership to the head-on–accident-prone group *P(H)* and the discriminant scores.

Figure 3 shows two curves. Curve A is the actual probability score plot, and curve B is a linear simplification for curve A. This simplification of the plot, as can be seen in the figure, does not greatly depart from the actual plot. This simplified curve permits the establishment of the following relation between *P(H)*, the probability a site is head-on accident prone, and its discriminant score *D* as obtained from Equation 1:

$$\begin{aligned} P(H) &= 1 \quad \text{if } D < -2.1 \\ &= 0.5 - 0.25D \quad \text{if } -2.1 < D < 2.1 \\ &= 0 \quad \text{if } D > 2.1 \end{aligned} \qquad (4)$$

Therefore, given the following characteristics for the 1-mi section:

1. Percent width less than 24 ft,
2. Weighted pavement width (ft),
3. Percent shoulder width less than 6 ft,
4. Percent section is not level,
5. Average highway speed limit (mph),
6. Number of major access points, and
7. Number of reverse curves.

The specific score *D* is calculated from Equation 2, then *P(H)* is computed from Equation 4. This computation process is

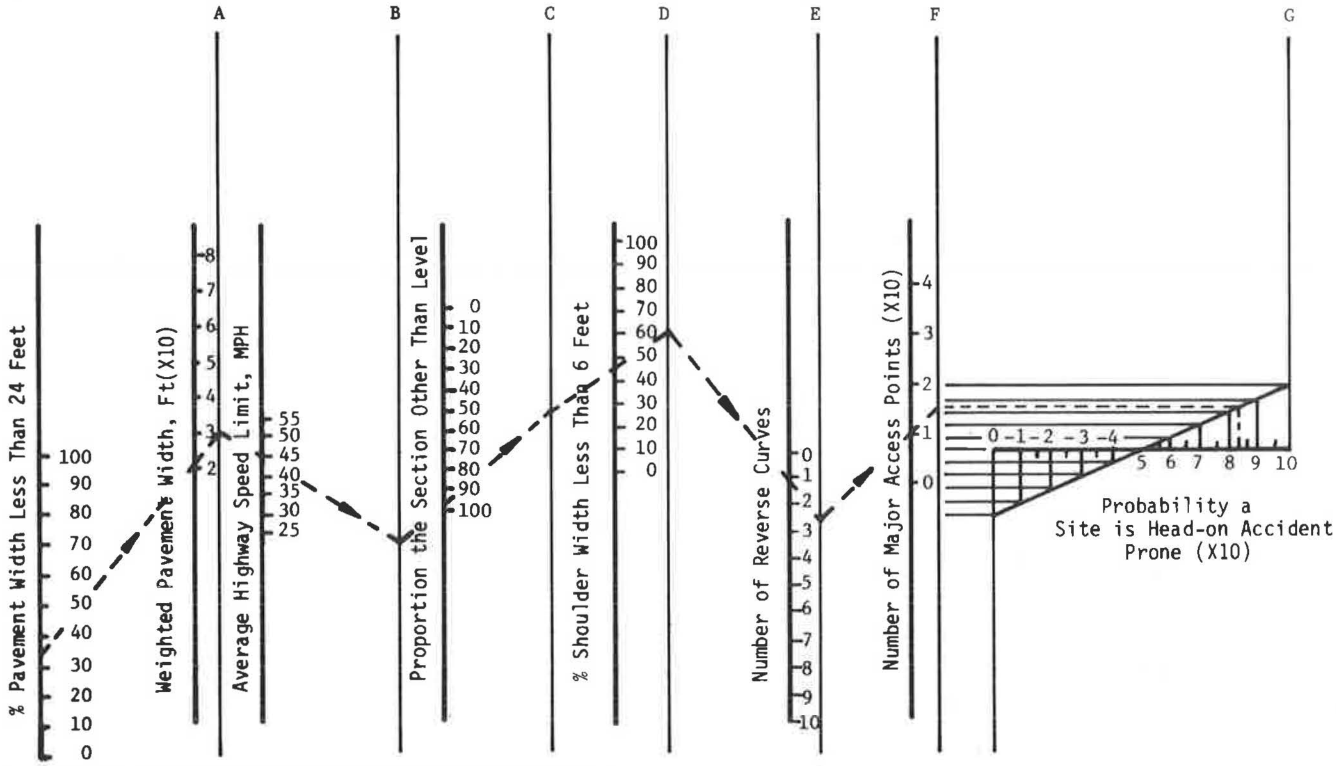

FIGURE 4 Probability nomograph of Equations 2 and 4.

facilitated through the use of a nomograph developed for the practical ranges of the site characteristics, as shown in Figure 4. This nomograph gives *P(H)* directly when the site characteristics are known as indicated by the dotted line in the figure.

Let us assume that the following characteristics were collected for a specific site:

Percent width less than 24 ft	=	35.0 percent
Weighted pavement width	=	23.0 ft
Percent section not level	=	96.0 percent
Average highway speed limit	=	45.0 mph
Percent shoulder width less than 6 ft	=	46.0 percent
Number of major access points	=	10
Number of reverse curves	=	1

Entering Figure 4 with these values, *P(H)* = 83 percent. In other words, the probability is that the given site is 83 percent head-on accident prone, that is, 83 percent likely to have three head-on accidents in a 3-year period. If improvement is to be done to the site, it would be beneficial to consider alterations to the corresponding factors, such as having less portion of the section with pavement width of less than 24 ft, that is, widening the section.

Other applications of the model include improvement priority rating of sites and weighing the relative improvement achieved by altering a single or several features at the roadway section.

CONCLUSIONS

Discriminant analysis was found to be a logical and convenient way that permits differentiation between two groups of 1-mi sections: head-on accident sections and control sections on rural two-lane roads with at least 2,000 vpd. The prediction of the proneness to a head-on site is related to the following variables:

1. Proportion of the section with pavement width of less than 24 ft,
2. Weighted pavement width,
3. Proportion of the section with shoulder width of less than 6 ft,
4. Proportion of the section that is not level,
5. Average highway speed limit of the section,
6. Frequency of major access points on both sides, and
7. Frequency of reverse curves with zero tangents.

In addition, this procedure allows for the quantification of head-on-accident proneness, that is, assigning a probability level for the potentiality for a 1-mi section to have three head-on accidents in a 3-year period based on these roadway features, which in turn allows the decision makers to establish priorities for improvement of head-on accident locations and to weigh the effectiveness of different alternatives proposed for a specific section based on their probability level after the proposed improvement.

RECOMMENDATIONS

During the course of the study the following recommendations have been suggested:

1. Enlarging the database to include various road categories, and thus conducting the discriminant analysis at various levels of traffic volume in order to assess its effect.
2. Because the 1-mi sections were considered from the viewpoint of head-on accident occurrence, the evaluation of the

overall safety level of the section would be more represented if the discriminant analysis were conducted for various types of accidents and similar evaluation considered for each type in the section.

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