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 modeling efforts been started and promising results obtained (2).

As a part of a sponsored research project for MDSHT, the investigators have explored and reported on the availability of models that are useful in predicting the frequency and severity of off-road accidents on short sections of road over fixed periods of time by using as inputs only knowledge of road and traffic conditions (3). Earlier efforts are found in the literature (4).

A brief summary of the findings of earlier investigations is that off-road accidents are particularly susceptible to occurrence on curves, at locations with restricted sight distance, on gradients, in the presence of structures, and where roadways and traffic flow vary.

The most extensive attempt to model this phenomenon was presented by Foody and Long (5). Their best regression models for predicting single-vehicle off-road accidents involved as many as 14 road and traffic variables and explained only 37 percent of the variance in the accident rate. They found that traffic flow, sight-distance restriction, road geometry transitions, and shoulder width were the most important of these variables. In an additional analysis, they concluded that shoulder width and surface stability were of primary importance in off-road accident experience. They concluded that the relative possible improvement resulting from removal of roadside obstacles was quite small, that the development of such a program would not yield adequate returns, and that attention should be focused on shoulders and the road surface itself. After careful study of the analysis of Foody and Long, it is believed that many possible contributing roadway and traffic elements were not taken into account simultaneously; the obvious existence of interactions among these elements casts serious doubts on the validity of the findings.

GLENNON MODEL

Glennon recently developed a detailed and widely known model that predicts the number and severity of accidents associated with each specific off-road obstacle (2). If the model were completely satisfactory (it is still being refined) and if a highway agency had full information on all roadside obstacles, preferably in an easily retrievable form, the Glennon model could be applied virtually automatically to the entire roadway system, sections that have particular problems could be identified, possibilities for improvement could be determined, and cost-effectiveness analyses could be made. We are not aware of any highway agencies that have data sources in this form and, accordingly, the work presented in this paper is intended to serve primarily as a filtering device by which those highway sections and types that have the greatest potential for off-road accidents can be identified. Then data for the application of the Glennon model can be developed and cost-effectiveness analyses of potential improvements made at the necessary level of detail.

It must be noted that the Glennon model in its most recently available published form does not specifically capture the observed higher frequency of off-road accidents on curves in comparison with tangents; does not respond to other alignment, intersection, or cross-section elements; and maintains that the frequency of accident occurrence is directly proportional to traffic flow, a finding not generally supported by authoritative empirical studies.

METHODOLOGY

The approach used in this research involved two stages of data acquisition. In the first stage, statewide accident data for all two-lane rural roads for the years 1971 to 1974 were obtained from MDSHT. From the accident summaries themselves, some information on the roadway was obtained (curvature, presence of an intersection, type of object struck). Average daily traffic (ADT) was acquired from another state data file. These data were classified appropriately, and statewide effects were determined.

The second stage involved using the same accident files for locating accidents and obtaining information on the roadway, roadside, and traffic from other sources such as studies of sufficiency rating, ADT files, and a detailed engineering study that used the MDSHT photolog system [a photographic record of the driver's view available at each 16.1 m (0.01 mile) along the main trunkline system] to study roadway sections of concern. The main modeling effort was guided by the analysis of first-stage data and used the second-stage data as inputs. A stratified sampling technique was used in determining a set of uniform 3.2-km (2.0-mile) roadway sections.

The modeling effort involved the careful selection of causal variables and alternatives of model structure. The interactive development and improvement of the models, including the estimation of parameters, were undertaken by using the University of Michigan OSIRIS and MIDAS systems (3). Models were subjected to standard tests that followed currently accepted techniques.

After the completion of the modeling effort, it was possible to validate two of the models by using easily available roadway data not used in the processes of modeling or parameter estimation (6). In evaluating the model's predictive performance, a Poisson assumption was postulated as an underlying structure of the accident count on homogeneous sections. At the same time, this assumption was applied to filter out the "outliers" that had extreme accident experience.

RESULTS

Statewide

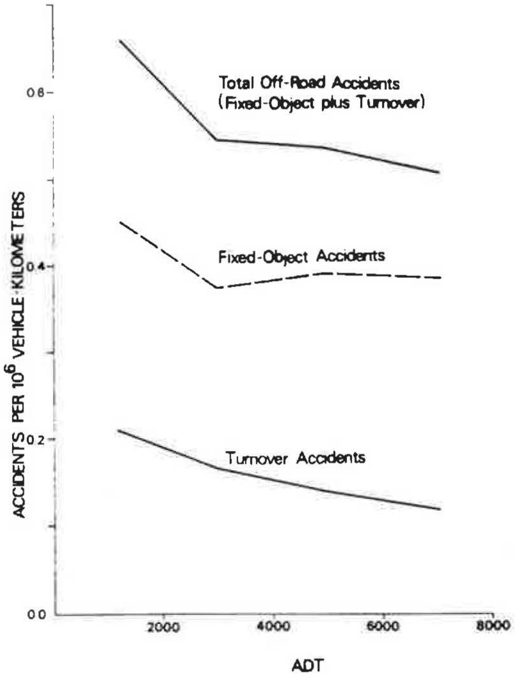
In the statewide data analysis, it was found that 75 percent of the off-road accidents on rural two-lane highways are of the fixed-object type and the remainder are turnover accidents. Approximately one-third of the fixed-object and three-fifths of the turnover accidents involve injuries or fatalities.

It was found that the off-road accident rate decreases with increasing ADT. Roadway alignment was found to have a dominant effect on the severity of these accidents, and there was a high rate of injury accidents on curves. Furthermore, in the comparison of fixed objects and turnover accidents, there was a higher occurrence of turnover accidents on curves.

It was found that the type of object struck is closely related to accident severity. However, this effect also interacts with roadway alignment in that the severity index (the fraction of all accidents that involve injuries or fatalities or both) is higher on curves for every type of object; this object-alignment interaction with severity is most noticeable for rigid objects with higher indexes of severity. It was also found that the severity of fixed-object accidents is less in intersection areas.

Some of the more significant results of the statewide analysis are shown in Figures 1 through 3 and are given in the table below. Figure 1 shows accident rates versus ADT. It can be seen that accident rates decrease as ADT increases, particularly for turnover accidents. The very high accident rate of the less-

Figure 1. Off-road accident rate and ADT: 1973.



than-2000-ADT class is particularly noticeable.

The table below compares the 1974 frequencies of fixed-object accidents along two-lane rural MDSHT trunklines with fixed-object accidents on all rural roadways in the state (which are generally lower type facilities):

Object	Strikings on MDSHT Trunkline Number	Strikings on MDSHT Trunkline Percent	Number of Strikings on All Rural Roadways	Trunkline Percentage of All Rural Roadways
Guardrail	575	15.2	3 148	18.3
Highway sign	448	11.9	2 622	17.1
Power pole	280	7.4	2 806	10.0
Culvert	82	2.2	423	19.4
Ditch	965	25.6	7 803	12.4
Bridge abutment or pier	27	0.7	300	9.0
Bridge railing	43	1.1	382	11.3
Tree	556	14.7	6 085	9.1
Highway or rail-road signal	15	0.4	102	14.7
Building	32	0.9	360	8.9
Mailbox	402	10.7	2 737	14.7
Fence	128	3.4	1 544	8.3
Island or curb	17	0.4	195	8.7
Concrete barrier	12	0.3	328	3.7
On-road object	90	2.4	1 250	7.2
Other off-road object	80	2.1	689	11.6
Overhead object	19	0.5	90	21.1
Unknown	3	0.1	149	2.0
Total	3774	100.0	31 013	12.2

Objects such as power poles and trees have a lower frequency of being struck along trunklines, which indicates the better clearance of these roadsides. The higher frequencies of striking of guardrails, highway signs, and traffic signals along the trunkline indicate the greater density of these objects along these routes.

The overall average severity index is 0.328. Figure 2 shows the effect of alignment on the index of accident severity as well as variation in the severity index for different types of objects struck. For all objects, accident severity on curves is greater than on tangents, and unyielding objects such as power poles, trees, bridge abutments, and culverts have much higher severity indexes on curves. The differential effect of roadway alignment on severity is compared in Figure 3 by proximity of an intersection. The non-intersection areas generally have accidents of greater severity than the intersection areas. Furthermore, the effect of alignment on severity is not as great in intersection areas. Clearly, the value of the severity index used in object hazard evaluation must respond to roadway alignment, especially for objects that show a high-severity difference.

Figure 2. Accident severity indexes of objects struck by alignment.

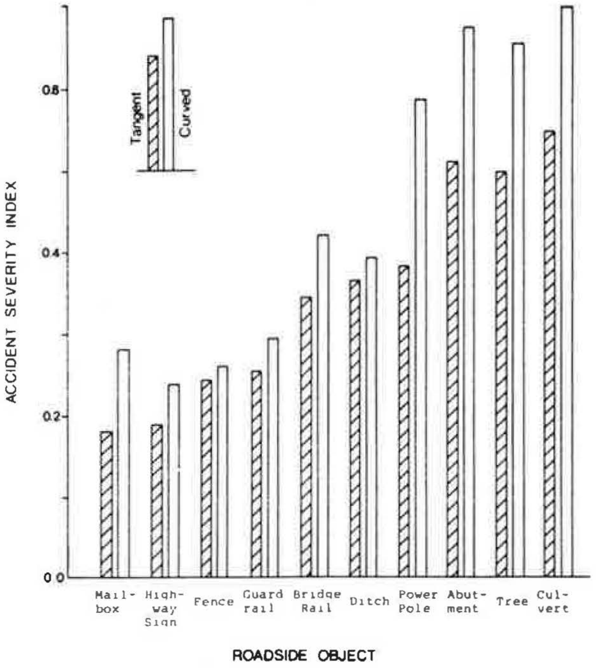
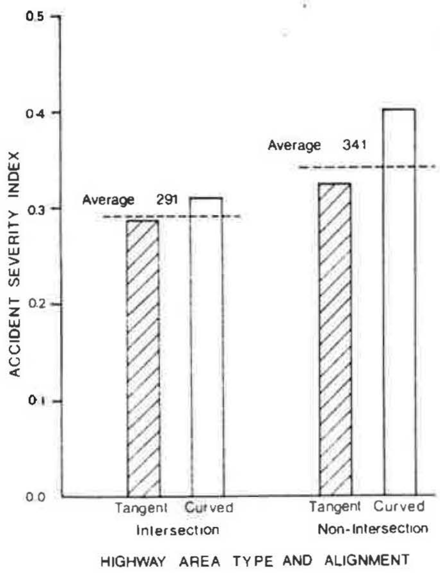


Figure 3. Accident severity index and alignment by intersection.



Accident Prediction Modeling

Since the input data for an operational model would be developed for a highway agency by using data from its own files, the models described in this section are based on MDSHT accident and highway files.

There is a tremendous variation in the frequency of off-road accidents on different sections of the Michigan trunkline system. Figure 4 shows this variation for the sample of two-hundred and seventy 3.2-km (2-mile) sections for the 4-year period between 1971 and 1974, which was used as a basis for the modeling effort. It can be seen that 10 sections recorded more than 20 off-road accidents in this period, one section had 34, and 26 sections had no reported off-road accidents.

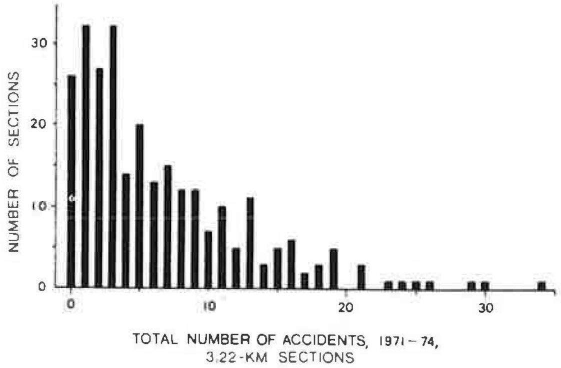
Models were developed separately for total off-road accident experience and for injury-fatality accident experience. Fixed-object accidents were modeled separately from turnover accidents because of their different characteristics. Because of an anticipated possible effect of the national 80-km/h (55-mph) speed limit (effective in March 1974 in Michigan), data for the period from 1971 to 1973 were initially modeled separately from the 1974 data. The results, however, showed that there was no important difference, and data for the entire 4-year period were then pooled and used in all subsequent modeling efforts.

It should be noted that this research concentrated on the occurrence of accidents and not on the accident rate. It is believed that the ultimate figure of merit is the number of accidents and that the use of rates can mask this effect. Since the models in this research are of a macroscopic nature, a decision was made to deal with a fixed length of highway (3), and only variables that summarize the relevant highway and traffic characteristics of such a section were used as inputs to the model.

The first task in the modeling effort involved the identification of relatively easily obtainable data on variables that were expected to be causal or strongly associated with the occurrence of off-road accidents. The table below gives the variables that were used in the analysis (1 m = 3.3 ft):

Variable	Abbreviation Used
Area	AREA
Pavement width	PAVE. W.
Shoulder width	SHOULD. W.
Percentage sight restriction	PSR
Rolling	*
Number of curves	NC
Percentage of segment length curved	PCL
ADT	ADT
Number of intersections on curves	NIC
Number of intersections on tangent	NIT
Total number of intersections	NITO
Shoulder treatment	*
Ditch condition	DITCH
Object stiffness	STIFF
Percentage exposure length to objects within 2 m	OB6
Percentage exposure length to objects within 3 m	OB10
Percentage exposure length to objects within 4 m	OB14
Percentage exposure length to objects within 6 m	OB20
Percentage exposure length to objects within 9 m	OB30

Figure 4. Distribution of total number of accidents on 270 roadway sections: 1971 to 1974.



Variables represented by an asterisk did not appear in the results. Traffic flow was represented by the 1971-1973 average of three ADT values (1974 data were not available).

Variables expected to be associated with alignment included the percentage of the section with passing-sight restrictions, a characterization of the terrain as rolling or level, a count of the number of curves in the section further broken down by the presence or absence of intersections on curves, and the total length of curved road in a section. Measures associated with the cross section and roadside included the width of pavement and shoulder, the type of stability provided by the shoulder treatment, the predominant distance to drainage ditches and a description of the cross-sectional abruptness of these ditches, the exposure distance to obstacles within a variety of distances of the edge of the roadway, and a characterization of the energy exchange characteristics of those obstacles located less than 4.2 m (14 ft) from the edge of the roadway. The photolog study provided much of the above information.

The next step involved drawing a probability sample of rural 3.2-km (2-mile) sections for study. The initial task was to identify the population of two-lane rural MDSHT trunklines in the state. An initial screening was made of the 1974 MDSHT sufficiency rating report. At later stages of the process, additional sections were eliminated, primarily because of the discovery of sections in urbanized villages classified as rural, sections that had been reconstructed to multilane standards, and those at the approaches to urbanized areas. A total of 1392 rural two-lane segments were identified. The strata formed for the final sampling consisted of three areal classifications for the state (the Upper Penninsula is much more rugged, rural, forested, and less densely populated than the highly urbanized southern sections), four ADT classification groups, four classifications of shoulder width, three classifications of pavement width, and the percentage restriction on passing sight distance and the general terrain classification of the section. If sections with all combinations of each stratum existed, there would be about 1400 possibilities.

Next, a review of individual sections was made to ensure that the length was 3.2 km (2 miles) or greater. Some shorter sections, frequently those with high ADTs near urbanized areas, were eliminated from the sample population. For each section, a random point of beginning was selected, and the succeeding 3.2 km were used.

It was then determined that the availability of time and funds limited the main data-acquisition effort (photolog analysis) to between 250 and 300 sections. This meant that an approximately 20 percent sampling rate of all sections could be used, which resulted in a slightly less than 10 percent sample of total rural MDSHT two-lane highway.

It was decided that stratified random sampling would be used since it is of crucial importance to obtain information on all existing combinations of possibly contributing causal elements. All strata that had two or fewer sections were selected for the final sample. For the other strata at least two sections were included in the sample. Combinations that involved extreme values of the strata were overrepresented. This sample particularly protects the results from extrapolation errors in the use of the resulting model at the possible sacrifice of accuracy in the most frequently occurring combinations.

At the conclusion of the sampling, a total of 270 sections had been identified and studied. Thus, the modeling efforts for this study are based on data from this 869.4 km (540 miles) of Michigan trunklines.

The next step was the use of the automatic interaction detection (AID) multivariate analysis technique, an extremely useful screening method developed at the University of Michigan (7). An effective method of presenting the results of an AID analysis is a branch diagram from which one can see the way explanatory variables interact as well as the importance of individual variables in the explanation of variation, an important early step in the construction of models. One of the AID diagrams used in the research is shown in Figure 5.

Although the average number of turnover accidents between 1971 and 1974 on the 270 sections was 1.91, it is obvious that traffic flow (ADT), the fraction of the road that is curved (PCL), the length of the route that has fixed objects relatively close to the pavement (OB14 and OB20), and the fraction of the road that has inadequate passing sight distance (PSR) affect this average immensely. Although sections that have an ADT less than 500 average only 0.28 accidents, those that have high ADTs, much curvature, and fixed objects within 6 m (20 ft) of the edge of the pavement along much of the route average 6.23 accidents. It should also be noted that this simple, unstructured model explains more than 42 percent of the variation in the entire data set.

The next step was to develop an appropriate model by using multiple regression techniques and the AID results. The AID process signaled the necessity of stratifying the models when clearly different variables were involved. The regression model structures explored included both linear and multiplicative forms. However, because the analysis indicated the superiority of the multiplicative models over the linear models, the linear models are not described here (3).

Total Accident Estimation Models

The AID branch diagram for total off-road accident experience is shown in Figure 6. This stratification accounts for 76 percent of the variation in only 18 ultimate classes of predictive variable combinations. The average number of accidents ranges from 1.08 for roads with low ADT and good passing sight distance to 26.0 for curved sections with many fixed objects within 6 m (20 ft) of the surface and ADTs greater than 7000 vehicles/d. The stratification is dominated by ADT, and a review of the variables for each of the ADT groups led to a decision to model separately each of the four ADT groups shown in Figure 6.

The final estimating equations for the four ADT classes are given below. The dependent variable y is always the number of accidents in a 3.2-km (2.0-mile) roadway segment for a 4-year period. PSR, PCL, and OB20 take values that range from 0 to 100.

For ADT < 750,

$$y = 0.024(\text{ADT})^{0.70}(\text{PSR} + 1)^{0.18} - 1 \qquad (1)$$

where t-statistics for the coefficients are 2.84, 2.98, and 3.03 respectively; $R^2 = 0.34$; and N = 50. For 750 ≤ ADT < 1500,

$$y = 2.54(\text{PSR} + 1)^{0.24} - 1 \qquad (2)$$

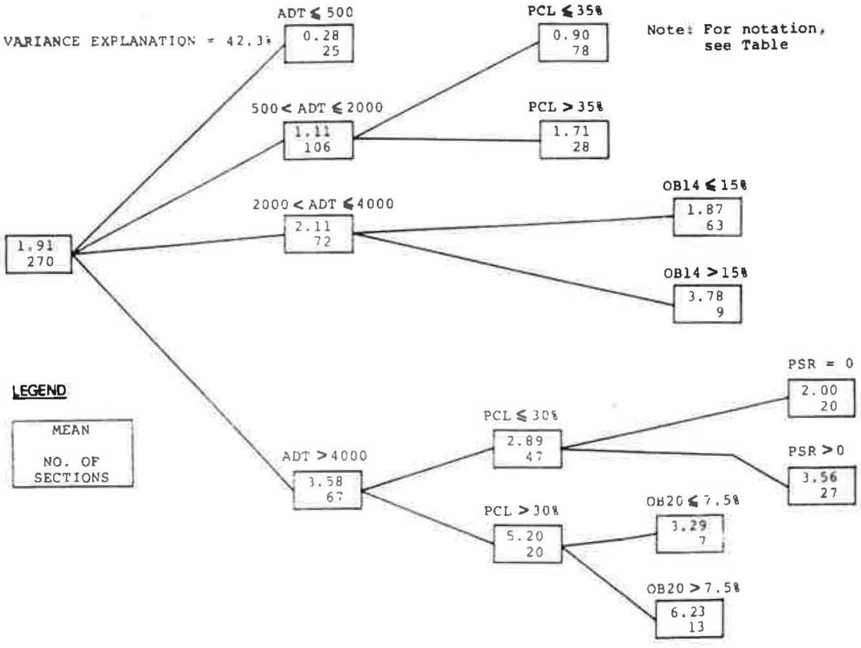
where t-statistics for the coefficients are 5.41 and 4.38 respectively, $R^2 = 0.26$, and N = 58. For 1500 ≤ ADT < 3500,

$$y = 0.016(\text{ADT})^{0.69}(\text{PCL} + 1)^{0.068}(\text{OB20} + 1)^{0.29} - 1 \qquad (3)$$

where t-statistics for the coefficients are 2.11, 2.68, 1.97, and 5.16 respectively; $R^2 = 0.32$; and N = 82. For ADT ≥ 3500,

$$y = 0.12(\text{ADT})^{0.46}(\text{NC} + 1)^{0.35}(\text{OB20} + 1)^{0.21} - 1 \qquad (4)$$

Figure 5. AID branch diagram: 1971 to 1974 turnover accidents.



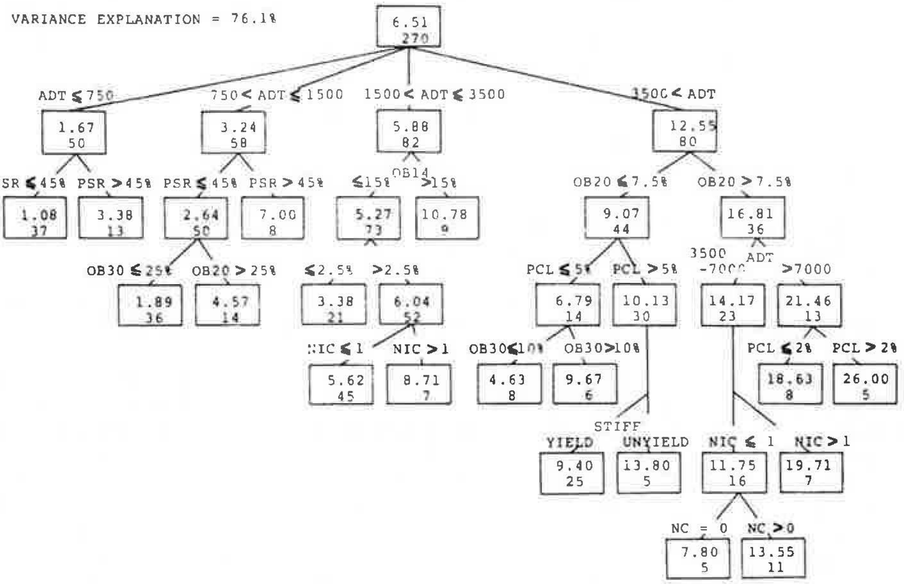


Figure 6. AID branch diagram: 1971 to 1974 total accidents.

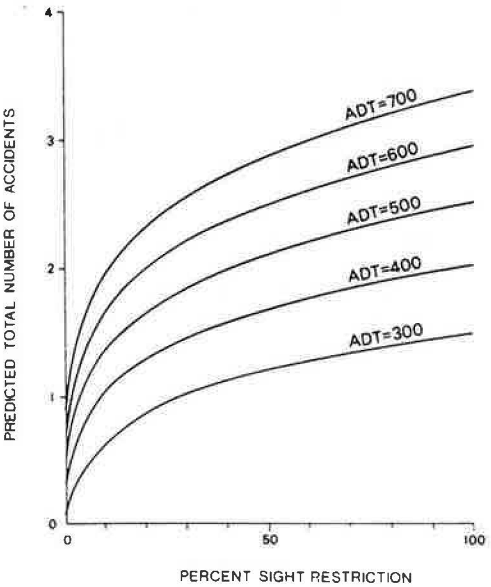


Figure 7. Model for prediction of total accidents: < 750 ADT.

where t-statistics for the coefficients are 1.91, 3.38, 4.81, and 4.66 respectively: $R^2 = 0.49$; and N = 80.

The variance explanation by these models may appear low. However, it should be noted that about 70 percent of the variance has already been explained by the ADT stratification. The entire variance explanation by these models exceeds 82 percent. It is seen that ADT, restriction on passing sight distance (PSR), length of route that has obstacles within 6 m (20 ft) (OB20), percentage of the road that is curved (PCL), and number of curves (NC) are the variables that appear in these models. As an example of the simplicity of the relations, Figure 7 shows a plot for sections that have an ADT of 750 vehicles or less. The lessening effect of increasing ADT, even at this low level, is clear, as is the importance of good alignment.

Estimation Model for Injury and Fatal Accidents

The AID branch diagram for injury and fatal accidents is shown in Figure 8. Note that the effect of ADT is not so dominant for injury accidents as for total accidents. Although curved alignment is important in the prediction of injury accidents, the variable for restriction on passing sight distance does not appear at all. It appears that the injury accident is more sensitive to horizontal alignment than the less severe accident and that vertical alignment, an important component of the passing sight restriction, is less important in injury accidents. This result is consistent with the statewide results described earlier.

One interaction that involves pavement width should be noted. The diagram shows that on high-ADT roadways that include much exposure to roadside objects and lengthy curved sections, the 6.0-m (20-ft) wide and 6.6-m (22-ft) wide surfaces have 1.5 times as many injury accidents as do 7.2-m (24-ft) wide pavements.

The injury-fatality model is given below. The model predicts y, the number of injury-fatality accidents in a 3.2-km (2-mile) roadway segment for a 4-year period:

$$y = 0.039(\mathrm{ADT})^{0.52}(\mathrm{PCL} + 1)^{0.096}(\mathrm{OB10} + 1)^{0.069}(\mathrm{STIFF}) - 1 \qquad (5)$$

where t-statistics for the coefficients are 11.94, 14.98, 4.70, 2.36, and 2.12 respectively; $R^2 = 0.49$; N = 270; and STIFF assumes a value of 1.36 if unyielding objects exist within 4.2 m (14 ft) of the edge of the pavement and 1.17 otherwise.

It is seen that injury-fatality accident prediction is approximately proportional to the square root of the ADT, higher roots of the fraction of the road that is curved, and the length of road that has objects closer than 3 m (10 ft). There is an approximately 17 percent effect for the energy exchange characteristics of the obstacles within 4.2 m of the road. The presence of objects within 3 m in this model suggests that the number of injury accidents is more affected by closer objects. This model can be viewed as a macroscopic version of the Glennon model in which a term is added to capture the effect of alignment.

Summary of Variables

A count of the frequency of explanatory variables was made based on the four primary AID analyses. It was found that ADT was always the most important variable and appeared more than twice as frequently as any other

Figure 8. AID branch diagram: 1971 to 1974 injury-fatality accidents.

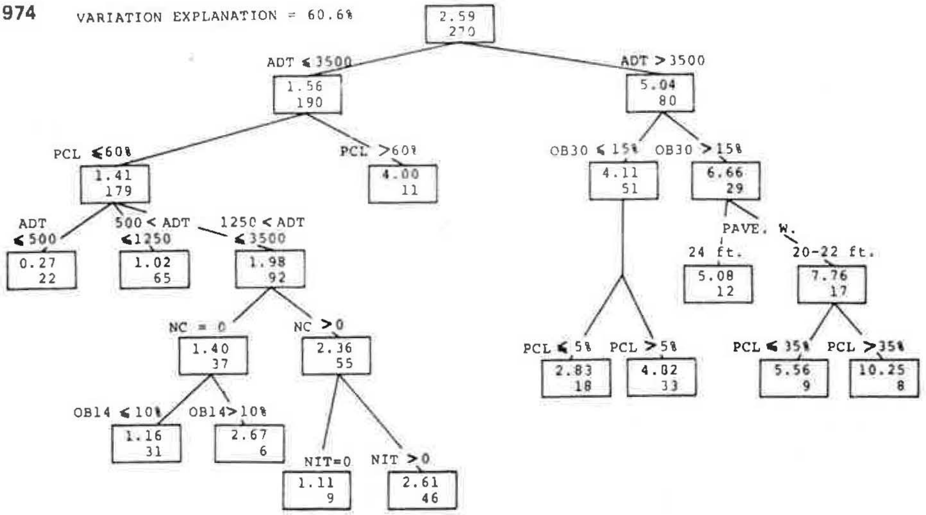
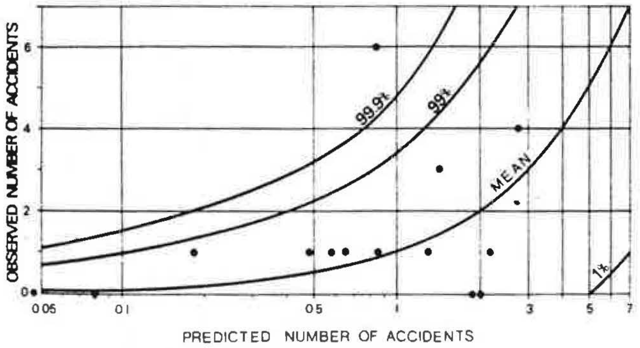
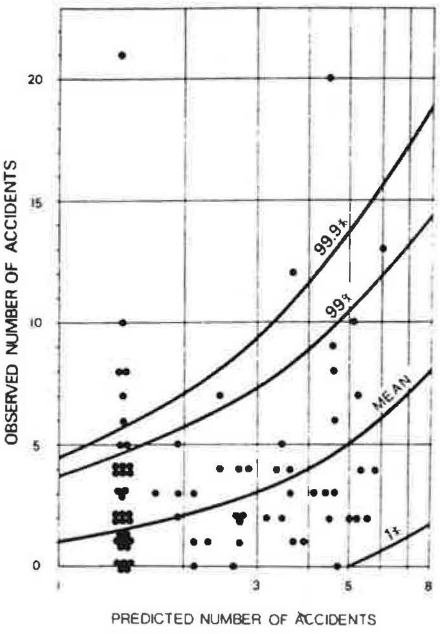


Figure 9. Validation check for sections that have <750 ADT.



explanatory variable. Other variables that appeared frequently were the length of road that had obstacles within 4.2 m (14 ft), 6.0 m (20 ft), and 9.0 m (30 ft) of the pavement edge and the fraction of the route that was curved and had inadequate passing sight distance. All other measures were of lesser importance, and variables that represented obstacles very close to the roadway [less than 2 m (6 ft)], shoulder treatment, rolling terrain, and number of intersections did not appear in any of the AID results.

Figure 10. Validation check for sections that have ADT from 750 to 1500.



VALIDATION OF THE MODEL

A partial validation study of the effectiveness of the models was developed. An extensive validation was not feasible within the time and fund constraints of the project. However, it was possible to use readily available data for ADT and restriction on passing sight distance to determine the effectiveness of the low-ADT total accident prediction models. The data required to compare 14 sections that had ADTs of less than 750 vehicles and 78 sections with ADTs of from 750 to 1500 vehicles that were not used in the model formulation and calibration were developed (5). The results of this analysis are shown in Figures 9 and 10 where actual accident experience is shown versus the predicted number of accidents.

Three Poisson probability bounds are drawn in these figures. These bounds imply that, if a highway section belongs to the population that the accident estimation model represents and if the Poisson law describes the distribution of the number of accidents, the observed number of accidents in the section should fall within these bounds with the probability associated with the bounds. Then, for those sections that lie outside the bounds, one may conclude that they have accident expectations that are different from those indicated by the model. It is reasonable to expect that some factors other than those that significantly affect the accident experiences of most of the sections included in the model are involved with these outliers. The generally good fit for most of the sections can easily be seen. However, a number of locations (10 to 20) are clearly out of control.

DISCUSSION AND APPLICATION

In the models developed in the research, the exponent of ADT is always less than 1, which confirms the diminishing effect of ADT on accident occurrence found by other observers. Clearly, obstacle-hazard evaluation models, such as Glennon's, should take this effect into account. Furthermore, the accident prediction models have supported and further quantified the importance of roadway alignment on off-road accident occurrences. This is another area in which Glennon's original model requires further development. As the statewide analysis indicated, the effects of alignment are twofold: those on accident occurrence and those on severity.

The importance of the roadway cross section was not supported by the models as it was in the Ohio results. Accordingly, we cannot support a belief in the importance of a shoulder stabilization program for Michigan highways as a means of counteracting the off-road accident or its severity.

These prediction models can be used as filtering devices in defining highway sections that have high accident rates and where more detailed microscopic studies should be made. The advantage of this filtering approach is clear from Figure 10. A simple ordering of sections according to accident frequency does not necessarily provide a set of sections that have higher accident rates than normally expected. Note that many sections that have high accident rates are within reasonable Poisson bounds. Particular attention should be given to an engineering analysis of the sections outside the 99.9 percent bound region as well as to all sections whose fundamental characteristics predict a high rate of off-road accidents. Another use of the models is the preliminary evaluation of programs for the removal of roadside objects or overall evaluation of systemwide accident improvement potentials.

CONCLUSIONS

This research has shown that a small number of carefully selected, straightforward causal variables can be combined in a multiplicative mathematical model to explain as much of the variability in rural, two-lane, off-road accident frequency as could be expected. The models are usable directly to identify locations that have the highest probability of frequent off-road accidents as well as to point out those locations where additional factors may be at work and engineering study is clearly needed.

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Discussion

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I would like to commend the authors for their work. Their report contributes to the state of the art in the area of roadside safety and raises other questions that need to be answered. Perhaps the most significant finding is that the severity of fixed-object accidents is higher on highway curves than on highway tangents for all objects. Given that encroachment rates are also higher on curves, this would suggest that the rate of off-road injury and fatal accidents on curves is an order of magnitude higher than the rate on tangents.

I am surprised that the authors either did not review or at least did not reference the Federal Highway Administration (FHWA) report in which I modified my model to account for roadside hazard for two-lane roads (8). Reference to that report indicates that, contrary to the authors' statement, the most recently available inputs to the subject model with regard to two-lane highways do account for a decreasing off-road accident rate with increasing ADT. The other item of interest in comparing the two researches is that the severity indexes found in the FHWA research tend to substantiate those found by the authors.

The second part of the paper attempts to develop methods (models) for identifying priority highway sections for roadside safety improvements. Although the authors made a commendable effort, they seem to have performed one more in a long line of unsuccessful multivariate analyses aimed at relating accident occurrence to roadway and traffic variables. The only variable that explained a substantial portion of the accident variance was traffic volume. But this conclusion is not a new one.

Although the modeling results may provide some general guidance in judging the relative roadside hazard of highway sections, the statistical practicality of these results must be viewed with some skepticism. For example, consider the validation plots shown in Figures 9 and 10. In Figure 9, the model for 750 ADT or less only predicts accident occurrence within ±50 percent for about one-third of the validation sites. Figure 10 has a slightly better result, but this model (for ADTs of from 750 to 1500) still only predicts accident occurrence within ±50 percent for about 43 percent of the validation sites. In addition, for many of the outliers the prediction equation is more than 100 percent in error. These results are not encouraging in terms of the reliability of predictions.

Perhaps the lack of model precision lies in the abstract nature of the selected variables. The percentage of passing sight restriction is a good example. Passing sight distance as defined can only be related to traffic operations in a general sense as demonstrated by the widely different treatments found in the 1965 blue book of the American Association of State Highway Officials (9) and the Manual on Uniform Traffic Control Devices (10). But the percentage of roadway that has restricted passing sight distance is one level of abstraction farther removed. For example, what is the effect on traffic operations of areas of acceptable passing sight distance that are not within legal passing zones? In a similar sense, using the percentage of roadway on curves without regard to the specific geometrics of those curves and their longitudinal relationship to each other presupposes an abstract effect on off-road accidents that may, in fact, be nonexistent.

In conclusion, I again commend the authors for their research on a very difficult problem. Their work has provoked some new thoughts for me and I hope for others as well.

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The need for models such as the ones presented by Cleveland and Kitamura is great. Highway agencies are experiencing financial austerities, so that each dollar spent must be justified. The 1973 Federal-Aid Highway Act established "new categories of earmarked funds for three roadway-related safety programs on Federal-aid highways other than the Interstate System: protection of railroad-highway grade crossings, improvements at high-hazard accident locations, and elimination of roadside obstacles." However, the 1976 Federal-Aid Highway Act combined the high-hazard location and roadside obstacle programs. The end result of combining these two programs has been the virtual elimination of the roadside obstacle program on a systemwide basis. A project under the roadside obstacle program cannot compete on a benefit-cost basis with the typical project under the high-hazard location program. Therefore, the highway agencies must decide on which high-hazard locations (including some rural roadside accidents) to include in a safety improvement program.

This is not as easy as it seems. The technology exists to solve many of these problems, but the data base on which to develop a priority system is weak at best, and the money to implement the improvements is scarce and in tough competition with other highway projects. The current roadside safety improvement program is more of a reactive (after the accidents occur) than an active approach. I am strongly in favor of the preventive maintenance approach or the active approach to reducing highway accidents and accident severity. This is where models such as those presented by Cleveland and Kitamura have an application. They can be used to indicate the accident potential of a section of rural highway before the accidents occur.

The models developed in the paper were based on reported off-road accidents. It is my opinion that a majority of the vehicles that leave the roadway are not involved in reported accidents. This could indicate, however, that these unreported departures occurred on forgiving roadsides and that the reported departures took place on highway sections that need roadside safety improvements. So the unreported accident situation may not be a significant problem in determining the accident potential of a highway section.

I like the fact that 3.2-km (2-mile) sections were used to develop the models. Using road sections instead of specific locations reduces the effects of improper reporting of accident location. The accident data base is the weak link in developing any model for highway accident potential.

In a 1977 report of the Federal Highway Administration (11), various design elements—such as degree of horizontal curve, type of curve transition, superelevation rate and runoff, sight distance, and grade—were to be evaluated to determine the influence of each on highway accidents. The main problems were the lack of independence between criteria and the lack of consideration for consistency in design elements. This latter point is difficult to include in any model, but it may be significant in determining the accident potential of a road section. For example, a 4° curve in the middle of a winding road may be a safe design element, but a 4° curve at the end of a 14.5-km (10-mile) tangent segment could be, and probably is, a hazardous location even though it is the only sight restriction in the 3.2-km (2-mile) section.

I feel that a strong point of the models developed in this paper is the fact that all the variables but one are very easy to obtain from plans or field inventories. Percentage sight restriction (PSR), percentage of curved length (PCL), number of curves per 1.6 km (1 mile), and an object stiffness factor (STIFF) are readily obtainable. However, the variables, which are based on the percentage length of exposure to objects within a certain distance of the roadway, would be a judgment value in many cases. There is no problem with measuring the length of guardrail, but how would values be determined for this variable if 50 isolated trees were located 6 m (20 ft) from the roadway on a 3.2-km (2-mile) section?

The main problem I have with modeling two-lane rural roadside accidents is the low frequency of accidents on any particular section. I do feel, however, that the approach taken by Cleveland and Kitamura is the first step in developing a roadside safety improvement program. The results of the models will indicate those road sections that could have an accident problem and that require a microscopic engineering analysis. If only highway agencies had the manpower and money to carry out this preventive approach to the roadside safety problems on non-access-controlled rural roads, these models, or models like them, would be worthwhile.

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Authors' Closure

We thank both Glennon and Mulinazzi for reading our paper and for their highly relevant and well-chosen comments.

We share Glennon's estimate of the importance of the finding that the severity of fixed-object accidents is much greater on highway curves than on tangents. If nothing followed from this research other than the direction of particular attention to objects located on curves, we would feel that our efforts have been more than worthwhile. It appears that the profession is now at a stage to use the Glennon modified microscopic model for a wide range of applications.

There was some concern with the variables that we used to capture the obviously important roadway alignment effect. In the model-building effort, attention was necessarily paid to variables that could be directly retrieved by our highway agency. In our opinion, the variables we selected meet this criterion for Michigan. Extensive efforts were made to select the best alignment variables from among those available (Table 2). Mulinazzi suggests the need for a quantitative measure that represents longitudinal changes in roadway alignment. Such a measure would also serve as a guideline for consistent roadway geometric design. We agree and would like to have developed such a measure.

The investigators would like to have had much more detailed information on roadway and traffic characteristics available in machine-retrievable form. Unfortunately, the state of practice and economics have not permitted the development of data systems in which obviously better variables are available. On the other hand, it is believed that the variables that we have used provide significant guidance with respect to the type of data file that would be valuable in future data systems.

Concern was also expressed about obtaining data on the length of exposure to objects at various distances from the edge of the road. In the study, these variables were developed by recording the dimensions and offset of the object from the roadway from the photolog screen and then converting them into equivalent exposure length at the edge of the roadway by using Glennon's relation (2). Although this process is time consuming, use of the photolog system eliminates expensive field trips, and developing this measure for the entire roadway system is, for Michigan, not a difficult task.

Concerning the predictive performance of the model, Glennon points out that our models predict the number of accidents on a section within a 50 percent error only one-third of the time. However, attention must be paid to the stochastic nature of accident occurrence, particularly on the low-ADT highways on which the validation studies were conducted. The percentage of predictions within a given percentage of error does not apply as an appropriate criterion to judge model performance. We suggest using an evaluation that involves the total number of accidents predicted on several sections versus those that actually occur and also paying attention to the extreme values. For the <750-ADT group, the total number of observed accidents in the 14 sections used in the validation study was 20 whereas the predicted total was 13.3—a 67 percent error. However, if we eliminate the (to us) obvious outlier, these figures become 14 observed versus 12.6 predicted, clearly a reasonable and unimportant difference. In similar fashion, an even better fit was found for the model for the higher ADT class.

Significant progress has been made during this decade in the identification of locations where off-road accidents are likely to occur as well as in the techniques of counteracting this serious highway safety problem. We are pleased to join our discussants in making some contribution to this effort.

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Two-Way Left-Turn Lanes: State-of-the-Art Overview and Implementation Guide

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The results of a research project to synthesize existing information on continuous two-way left-turn median lanes and to conduct before-and-after studies to evaluate the effectiveness of such lanes as an access control measure are presented. Recommendations were prepared for the traffic engineer concerned with the evaluation of a situation in which a two-way left-turn median lane is a potential solution to existing capacity and safety problems. The research approach included studies in three distinct areas: a nationwide expert opinion survey, a literature review, and before-and-after field studies. Both the literature review and the survey indicated that two-way left-turn median lanes work well in spite of a wide variety of methods of signing and marking. There is uniform agreement that these lanes have excellent safety records; specifically, head-on collisions in the lanes are extremely rare. The before-and-after studies demonstrated that the effectiveness of the lanes and public reaction depend on proper engineering. A step-by-step decision-making strategy has been developed for the implementation of two-way left-turn median lanes.

To increase efficiency, conserve energy, and reduce air pollution, it is national transportation policy to make maximum use of the available transportation capacity in the existing transportation network. There is a continuing emphasis on transportation system management (TSM) plans designed to solve short-range urban transportation problems. Typical examples of TSM actions are innovative traffic engineering measures that improve both capacity and safety and require a minimal investment of manpower, material, or capital.