Accident Effects of Sideslope and Other Roadside Features on Two-Lane Roads

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The purposes of this study were to (1) develop one or more methods for quantifying roadside hazard, (2) define factors that influence run-off-road accidents, and (3) estimate the accident benefits of various roadside improvements. Detailed traffic, accident, roadway, and roadside data were collected on 4,951 miles of two-lane rural roads in seven states. Roadside data included development and use of a pictorial seven-point roadside hazard scale, a measure of roadside recovery (clear zone) distance, field sideslope measurements, and detailed types of and lateral distances to roadside obstacles. Statistical testing was used along with log-linear modeling to determine the interactive effects of roadside and roadway features on accidents. Flatter sideslopes of 3:1 to 7:1 were found to be related to lower rates of single-vehicle accidents. However, only a 2 percent reduction in single-vehicle accidents was found for a 3:1 sideslope compared to a 2:1 sideslope. Reductions in related accidents due to general roadside improvements were found to range from 19 percent to 52 percent, depending on the amount of roadside improvement. Trees and utility poles are the roadside objects most often struck. Obstacles associated with the highest percent of severe accidents include culverts, trees, utility and light poles, bridges, rocks, and earth embankments.

Single-vehicle accidents represent a major safety problem and account for a majority of accidents on rural two-lane roadways with up to 2,000 vehicles per day (*1*, *2*). Many of these accidents occur on roadways with steep roadside slopes and numerous rigid, fixed objects (such as trees and utility poles) close to the roadway edge. Therefore, the need exists for cost-effective improvements to roadside features that will eliminate or reduce these unnecessary hazards.

Numerous types of roadside improvements can reduce the frequency and/or severity of run-off-road accidents. These include

- Flatten slopes where accident experience shows a need.
- Increase horizontal clearance (offset) to obstructions, including utility poles.
- Provide impact attenuators and breakaway devices.
- Extend culverts.
- Remove trees and other obstacles near the roadway edge.

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Although clearing roadsides of obstructions will provide more recovery area for run-off-road motorists, little information is available about the specific effects on accident frequency and severity of such improvements under various roadway conditions. Thus, highway officials may have difficulty justifying roadside improvements, even where there is a real need. The benefits of roadside improvements should, therefore, be determined so the cost-effectiveness of such improvements can be weighed against other types of improvements (for example, lane widening, shoulder widening, shoulder surfacing, and improved roadway delineation). To accomplish this, it is important to first quantify roadsides in terms of clear, concise definitions for highway safety purposes.

The purposes of this study were to (1) develop one or more methods for better quantifying roadside hazards, (2) define factors that influence the frequency and severity of run-off-road accidents, and (3) estimate the accident benefits of various improvements to the roadside environment. This study included the development of accident relationships and mathematical models based on numerous traffic, roadway, and roadside variables from 4,951 miles of two-lane rural roads in seven states. The study resulted in expected accident reductions resulting from sideslope flattening and various other roadside improvements. This paper was based on a research study performed jointly for the Federal Highway Administration and the Transportation Research Board. More details of the safety effects of roadside and roadway features may be found in that research report (*3*).

BACKGROUND

Roadside Features and Accident Frequency

Studies that have investigated fixed-object accidents by the type of object struck include studies by Newcomb and Negri (*4*), Rinde (*5*), Foody and Long (*6*), and Hall, Burton Coppage, and Dickinson (*7*). These studies indicate that utility poles are among the fixed objects most frequently involved in roadside accidents. Other frequently struck roadside objects include trees, sign posts, guardrails, ditch embankments, and bridge structures.

Other studies indicate that the number of fixed objects and their offset influences roadside accident frequency. For example, Zegeer and Parker found that utility pole accidents increased significantly with a decrease in pole offset or an increase in ADT or pole density (*8*). Mak and Mason also found that pole density and pole offset had an effect on the frequency of pole accidents (*9*). Jones and Baum found that the number of poles and pole spacing was highly related to the probability of a utility pole accident (*10*).

Hall et al. reported that most of the utility pole accidents they examined involved poles that were either within 11.5 feet of the roadway or on the outside of horizontal curves (*7*). Foody and Long reported that 37 percent of all single-vehicle, fixed-object accidents involved objects 6 to 12 feet from the roadway. Also, approximately 81 percent of the accidents involving roadside features occurred within 20 feet of the roadway (*6*).

Relationships have also been reported between the degree of sideslope and roadside accident frequency. Graham and Harwood examined the effect of clear recovery zones and different sideslopes and found that steeper sideslopes caused an increase in single-vehicle, run-off-road accidents for all ADT levels and roadway types (*11*). Weaver and Marquis simulated various roadside slope designs and discovered that vehicles leaving the roadway were less likely to roll if the slope was fairly flat (*12*). Perchonok, Ranney, Baum, Morrison and Eppick found that higher landfills and deeper ditches caused more vehicle rollovers (*13*). Roadway geometrics, such as horizontal curvature and grade, have been reported by Jones and Baum (*10*), Hall et al. (*7*), and Perchonok et al. (*13*) to affect the number of run-off-road and fixed-object accidents.

Roadside Features and Accident Severity

Jones and Baum found that the types of fixed objects associated with the most severe accidents include utility poles (49.7 percent injury) and trees (41.8 percent) (*10*). Rollover accidents resulted in 51.4 percent injury and 1.1 percent fatal accidents. Other accidents associated with high severity included accidents involving bridges, culverts, ditches, and embankments. Graf, Boos, and Wentworth found that 47 percent of utility pole accidents resulted in a fatality or injury and that ditch embankments and utility poles were also among the most hazardous obstacles in terms of accident severity (*14*).

Higher vehicle speeds have been found to be associated with greater accident severity. Mak and Mason investigated the relationship between the severity of pole accidents and vehicle impact speed (*9*). The authors reported that there is a 50 percent chance of injury in a pole accident at impact speeds as low as 6 mph. The severity of these injuries increased dramatically for impact speeds above 30 mph. On the other hand, Jones and Baum, using the speed limit to approximate impact speed of utility pole accidents, estimated that a 50 percent chance of injury exists in a utility pole accident when the impact speed is approximately 34 mph (*10*). The sizable discrepancy in results between these two studies could be partly due to difficulties in estimating impact speed and/or inappropriateness in using speed limit to approximate impact speeds.

Roadside Accident Prediction Models

Several models have been developed to predict the frequency and/or severity of single-vehicle or roadside accidents. Edwards et al. developed what is probably the most widely known model for determining hazardous roadside obstacles (*15*). This probabilistic hazard index model was developed to predict the annual number of fatal and nonfatal injury accidents associated with roadside objects on freeway sections. Glennon and Wilton modified the model to include other roadway types, including urban arterial streets, rural two-lane highways, and rural multi-lane highways (*16*). However, the model relies on accurate estimates of vehicle encroachments, which have been a topic of controversy in recent years.

Cleveland and Kitamura developed a group of multiplicative regression equations to predict the frequency of run-off-road accidents on rural two-lane highways in Michigan (*17*). Models were developed based on the following factors: (1) traffic volume, (2) percentage of road length with passing sight restrictions, (3) percentage of road length curved, (4) number of curves, and (5) percentage of road length with roadside objects within 20 feet. A severity model was also developed, and key factors included traffic volume, percentage of road length curved, percentage of road length having roadside objects within 10 feet, and object stiffness. Reported R^2 values for the models ranged from 0.26 to 0.49, but model validation revealed less than desired results due to data outliers.

Zegeer and Parker tested ten different models to predict annual utility pole accidents per mile (*8*). The models were based on 2,500 miles of highway in four states, involving 9,500 utility pole accidents. The multiplicative exponential model was selected as optimal because it not only had the highest R^2 value (0.63), but it also made intuitive sense. Model validation proved quite successful for an independent data set. A nomograph was developed that allows easy estimation of frequency of utility pole accidents based on known levels of traffic volume, the number of poles per mile, and the lateral offset of poles from the travel lane. The model, however, applies only to utility pole accidents and not to other roadside accident types, such as trees, rollover accidents, etc.

In summary, considerable research has been conducted on the frequency and severity of run-off-road accidents and related factors. However, review of the literature also indicated a definite need to better quantify roadside hazards and to develop a means to accurately predict run-off-road accidents for a variety of traffic, roadway, and roadside conditions. This study was initiated as a result of those needs.

PLANNING AND COLLECTION OF DATA

Analysis Issues

The data collection was guided by the need to address the following types of issues:

1. What methods or scales can be used to define and quantify roadside hazards?
2. What is the effect of various traffic, roadway, and roadside factors on run-off-road accidents?
3. What is the expected accident reduction that will result from improvements to the roadside?
4. What is the effect of sideslope on the rate of single-vehicle and rollover accidents?
5. What types of roadside obstacles are most often struck, and what accident severities are associated with each obstacle type?

The first issue above was addressed at a workshop of 13 safety professionals. Hundreds of roadside photographs were reviewed at the workshop, which led to the development of a "Roadside Hazard Scale" and "Roadside Recovery Distance" as measures of roadside condition. Issues 2 and 3 above were addressed after collection and analysis of detailed accident, traffic, and roadway data from 4,951 miles of two-lane rural roadways in seven U.S. states and the development of accident predictive models.

Issue 4 (effects of sideslopes) was investigated based on field-measured sideslopes on 1,776 miles of roadway in three states along with other accident, traffic, and roadway data. An accident predictive model was developed for sideslopes of 2:1 or steeper, 3:1, 4:1, 5:1, 6:1, and 7:1 or flatter. Issue 5 was addressed using the 4,951-mile database and other detailed accident severity information from three states to better define the types of obstacles associated with high accident frequencies and severities.

Selection of Data Variables

The data variables needed for this study included traffic and roadway variables (traffic volume, lane width, shoulder width, shoulder type, sideslope), roadside obstacle variables, accident variables, (for example, by type and severity), and other traffic and roadway features that have a proven or logical relationship with accidents. Variables were selected for use in this study based on a literature search of past research to determine which ones are important on two-lane roads in rural, suburban, or urban areas. The collection of every possible roadway, traffic, and accident variable would have been both unnecessary and impossible.

Traffic and Roadway Variables

For each of the selected roadway sections, the following traffic and roadway variables were collected:

- Section information (identification number, length, pavement type, terrain, ditch type, area type, type of development, speed limit)
- Traffic volume (ADT)
- Horizontal and vertical curvature of the section (expressed in terms of percent of section with various degrees of curvature or percent grade)
- Sideslope length and sideslope ratio (2:1 or steeper, 3:1, 4:1, 5:1, 6:1, or 7:1 or flatter, which is expressed as the ratio of the lateral distance to the vertical drop of the sideslope). For each section, sideslope measures were recorded up to four points per mile for each side of the road from field measurements and/or photolog techniques and expressed as minimum sideslope, maximum sideslope, average sideslope, 20 percent sideslope value, median sideslope value, and 80 percent sideslope value.
- Width of lanes and shoulders and shoulder type (paved, stabilized, gravel, earth, or grass)
- Number of bridges, intersections (by type of sign or signal control), overpasses, railroad crossings, driveways (by type—residential, commercial, recreational or industrial)
- Type of delineation and on-street parking

Roadside Obstacle Variables

Individual Obstacle Data Data were collected for specific types of roadside obstacles and also in terms of overall roadside hazard, as described later. For each roadway section, an inventory was taken of every point obstacle within 30 feet of the road, as measured from the edge line or the outside edge of the travel lane. The inventory involved classifying each point object into the appropriate category of distance from the travel lane: zero to 1 foot, 2 to 3 feet, 4 to 6 feet, 7 to 10 feet, 11 to 15 feet, 16 to 20 feet, 21 to 25 feet, and 26 to 30 feet. In addition to point objects, an inventory was also taken of 18 different types of continuous objects, such as guardrails and bridge rails for each roadway section in terms of their length and offset from the roadway (zero to 1 foot, 2 to 3 feet, etc.). The inventory of point and continuous objects in this manner allowed for matching the frequency, length, and placement of specific obstacle types for a section with the corresponding types of obstacles struck on each section. A detailed discussion of the results of the analyses by obstacle type is given in the full research report (*3*).

Roadside Hazard Ratings While a detailed inventory was conducted of roadside obstacles on each section, there was also a need to develop one or more measures of roadside hazard that would be representative of the overall roadside hazards for the section. However, very little such research has been performed to characterize roadside condition.

A roadside hazard scale was developed based on the literature review and the results of a workshop involving thirteen highway and roadside safety professionals. At the workshop, hundreds of photographs of roadside situations in both rural and urban areas from more than fifteen states were organized and shown to workshop participants. The participants rated situations in each photograph in terms of potential frequency and potential severity of accidents and also in terms of overall hazard, for a combined frequency and severity scale. A two-dimensional rating scale, involving a three by three matrix, with frequency on the horizontal axis and severity on the vertical axis, was tested at the workshop. In general, workshop participants considered the matrix confusing and difficult to use. Further, it was concluded that a two dimensional rating scale would make analysis of the rating difficult.

Three ordinal, seven-point scales were later tested individually by workshop participants. One scale was based on frequency and one on severity. The third, referred to as a hazard scale, considered both frequency and severity. The purpose of the tests was to determine whether the hazard scale or the separate frequency and severity scales provided the most consistent results. The workshop participants were asked to use the scales in the following way:

Hazard Rate each roadside according to accident damage likely for errant vehicles on a scale from one (low likelihood of off-road collision or overturn) to seven (high likelihood of an accident resulting in fatality or severe injury).

Frequency Rate each roadside according to the frequency with which errant vehicles are likely to become involved in off-roadway accidents (that is, collide with fixed objects or overturn) on a scale from one (low likelihood of involvement) to seven (high likelihood of involvement).

Severity Rate each roadside according to the likely severity of off-roadway accidents on a scale from one (low likelihood of fatality or severe injury) to seven (high likelihood of fatality or severe injury).

The thirteen participants were asked to rate 141 photographs of roadsides in rural areas and seventy-eight photographs of roadsides in urban areas (sixty-four without on-street parking, fourteen with on-street parking) based on the above instructions. The ratings were collected and descriptive statistics were examined to determine which scale(s) produced the most consistent ratings. The standard deviations, ranges of the ratings, and other data descriptors for each photograph were used to measure rating consistency.

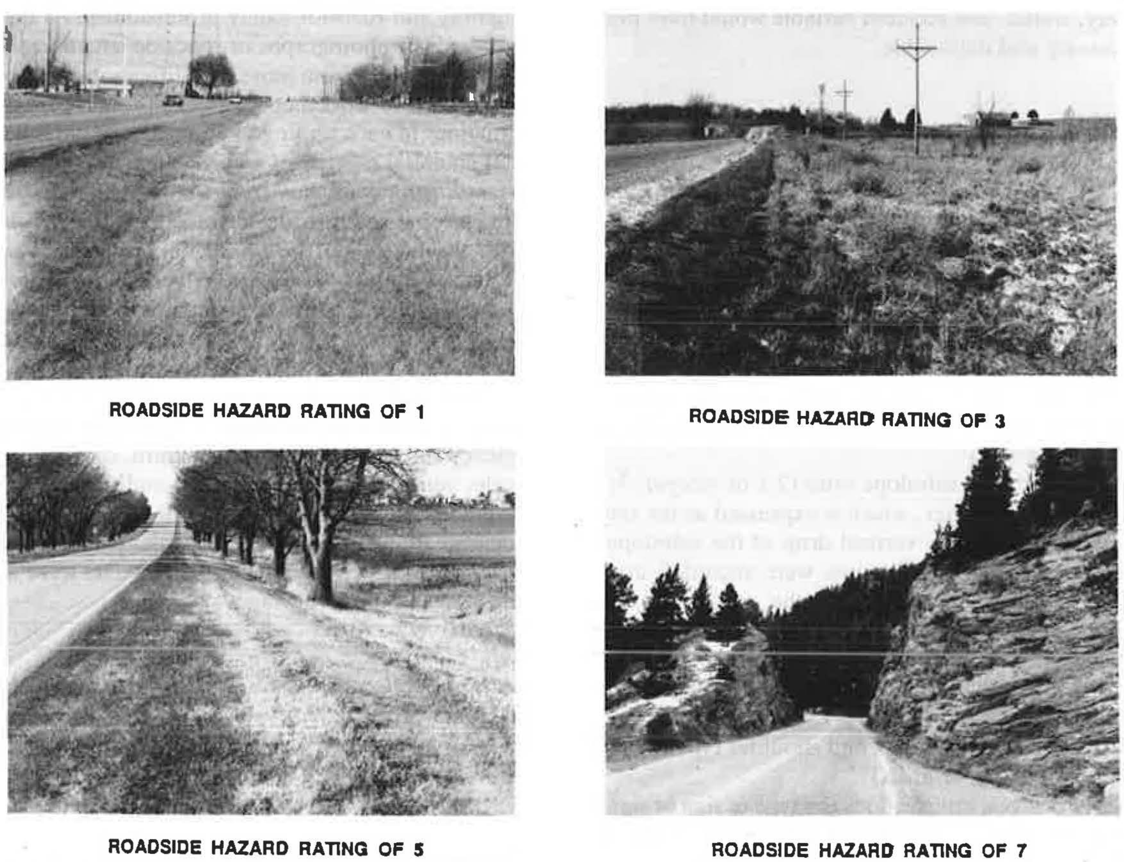
In summary, the hazard scale was the most desirable scale for rural areas, while the separate frequency and severity scales were slightly better suited for urban areas. For statistical analysis purposes (including model development) the hazard scale was favored over the other two scales, since it provided the capability for expressing the roadside condition in one independent variable, which could then be included in an accident model along with lane width, shoulder width, and other roadway features. Therefore, the seven-point hazard scale was selected for this study. Pictorial seven-point roadside hazard scales were developed separately for rural and urban areas. Sample photographs that were included in the final rural hazard rating scale are provided in Fig. 1. In general, steep sideslopes and/or large obstacles close to the roadway correspond to a hazard rating of seven, and clear, level roadsides represent a hazard rating of one.

For each highway section in this study, roadside hazard ratings were recorded each tenth of a mile on each side of the road, for a total of twenty measurements per mile. For each roadway section, the following roadside hazard rating variables were available for analysis:

1. Type of scale used for roadside rating; for example, did the roadside appear more like the rural scale or urban scale
2. Number of roadside ratings of each rating level (number of ratings of one, two, three, four, five, six, and seven)
3. Median (50th percentile), 20th percentile, and 80th percentile roadside ratings

Roadside Recovery Distance In addition to the subjective roadside hazard rating, a measure termed roadside recovery distance was also developed. This measure was defined as follows: The roadside recovery area is a basically flat, unobstructed, and smooth area adjacent to the outside edge of the travel lane (edgeline) within which there is reasonable opportunity for safe recovery of an out-of-control vehicle. The width of the roadside recovery area is the lateral distance from the edgeline to the nearest of the following:

- A hinge point where the slope first becomes steeper than 4:1



ROADSIDE HAZARD RATING OF 1

ROADSIDE HAZARD RATING OF 3

ROADSIDE HAZARD RATING OF 5

ROADSIDE HAZARD RATING OF 7

FIGURE 1 Sample photographs of roadside hazard scale.

- A longitudinal element such as a guardrail, bridge rail, or barrier curb
- An unyielding and therefore hazardous object
- The ditch line of a non-traversable side ditch (considering as an approximation that a ditch is traversable if both fore-slope and backslope are 4:1 or flatter)
- Other features such as a rough or irregular surface, loose rocks, or a watercourse that pose a threat to errant vehicles

In this study, the roadside recovery distance was measured from the edgeline (or outside edge of the lane), although it could have been measured from the shoulder edge. Measures of roadside recovery distance were taken from photolog film at 0.1-mile intervals (every 10th frame of film) for each section on both sides of the road, for a total of twenty measurements per mile. A series of calibrated grid overlays (with lines of lateral distances from the edge of the travel lane) was used on the photolog film to measure the clear recovery distance at the selected frames. Since an observer could view about 0.1 mile of the road in each frame and measurements were taken every 0.1 mile, the measurements of roadside recovery distance represented a nearly 100 percent coverage of road-side on both sides of the road.

For each section, the roadside recovery distance measurements were summarized and the following values were computed: minimum, average, maximum, and percentile values (for example, 20th, 50th, and 80th percentile). Separate variables were also computed which provide the percentage of the section with recovery area of ≤ 5 feet, ≤ 10 feet, ≤ 15 feet, ≤ 20 feet, ≤ 25 feet, ≤ 29 feet, and ≥ 30 feet.

Accident Variables

For each roadway section, the accident information collected included the number of years of accident data (5 years in most cases); total number of accidents on the section; number of accidents by severity category (property damage only, A-injury, B-injury, C-injury, and fatal); number of people injured (by injury level) or killed; number of accidents by light conditions and pavement conditions; number of accidents by type (fixed object, rollover, other run-off-road, head-on, opposite-direction sideswipe, same-direction sideswipe, rear end, backing or parking, pedestrian or bike or moped, angle or turning, train-related, animal-related, other or unknown); and number of accidents by type of fixed obstacle struck.

Site Selection

A sample of 4,951 miles of two-lane rural roads (1,944 roadway sections) was selected from the following seven states: Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia. Sites were selected using stratified random sampling (that is, sites were randomly selected from categories having specified values of lane width, shoulder width, shoulder type, and ADT) so the resulting data would cover the normal range of these important variables. Only two-lane rural and urban-suburban sites were selected, and section lengths ranged from 1 to 10 miles in rural areas and from 0.5 to 5 miles in urban areas. Sections were selected that were relatively homogeneous throughout the section with regard to basic geometric and operational features. For example, a section ended when moderate changes occurred in ADT, the lane width changed by one foot or more, the shoulder width changed by more than 3 or 4 feet, or a noticeable change occurred in the roadside condition.

Data Sources and Methods

The data sources for the accident analysis included field data collection, photologs, state agency records (maps, ADT listings, computerized roadway inventories), police accident records (either computer accident tapes or computer accident summaries), and the Highway Performance Monitoring System (HPMS) computer database. Most of the roadway information was extracted from photologs, including roadside data for individual obstacles, roadside hazard ratings, and measures of roadside recovery distance.

Detailed roadside data and roadway information were recorded from stated photologs. The photologs were 35mm photographs taken from a moving vehicle in equal distances of 100 frames per mile (52.8 feet between frames). Location information was given at the bottom of each frame of film and typically included route number, milepost, county, direction of travel, and date of filming. Teams of technicians viewed frames consecutively for preselected sections and recorded information directly onto data forms. The three data forms used with the photolog film included those for basic roadway data, cross-section data, and detailed roadside obstacle data. For data involving lane and shoulder widths and lateral placement of roadside obstacles, a calibrated grid was placed over the photolog viewing screens for each photolog frame. Data were keyed into a computer file, and extensive data checks and corrections were performed before the file was analyzed.

RESULTS

To identify the traffic and roadway factors most closely related to accident experience, numerous statistical procedures were used, including Chi-square analysis, analysis of variance and covariance, and stepwise regression. Single-vehicle (*AS*) accidents (includes fixed-object, run-off-road rollovers, and other run-off-road accidents) were considered to be of primary interest. Head-on, opposite-direction sideswipe, and same-direction sideswipe accidents were also found to be related to general roadway design. Thus, those three accident types plus the run-off-road accident types combined together were termed "related" (or *AO*) accidents for analysis purposes. Total accidents (*AT*) were also used in the modeling.

MODEL BUILDING

Statistical tests for association were used to determine the traffic and roadway variables most closely related to accidents on two-lane rural roads. Such important variables included ADT, lane width, width of paved and unpaved shoulder, roadside hazard rating, median recovery distance, sideslope steepness, terrain, horizontal curvature, number of driveways per mile, and number of intersections per mile.

The development of accident predictive models involved the use of these variables and variable interactions. The roadside recovery distance was redefined for use in the model to represent the measurement from the outside of the shoulder and not the edgeline as it was previously defined. The reason for the redefinition was that shoulder width was also included in the model and was, therefore, already accounted for. Many logical model forms were examined with the most important candidate data variables, as discussed in detail elsewhere (*3*).

The final recommended model using roadside hazard as the roadside variable was as follows:

$$AO/M/Y = 0.0019\ (\mathrm{ADT})^{0.8824}(0.8786)^{W}(0.9192)^{PA} \times (0.9316)^{UP}(1.2365)^{H}(0.8822)^{TER1}(1.3221)^{TER2}$$

where

$AO/M/Y$ = related accidents (single-vehicle, head-on, opposite-direction sideswipe, and same-direction sideswipe accidents) per-mile, per-year,
ADT = average daily traffic,
W = lane width,
PA = average paved shoulder width,
UP = average unpaved (gravel, stabilized, earth, or grass) shoulder width,
H = median roadside hazard rating,
$TER1$ = 1 if flat terrain, zero otherwise, and
$TER2$ = 1 if mountainous terrain, zero otherwise.

The R^2 value for this model was 0.456, which implies that 45.6 percent of the variation in *AO* accidents is explained by the traffic and roadway variables included in this model. The relative contribution of each variable to this explained variation was 70.2 percent by ADT, 8.6 percent by *W*, 1.7 percent by *PA*, 10.5 percent by *UP*, 7.2 percent by *H*, and 1.8 percent by *TER*. The coefficients were reasonable in terms of the relative importance of the variables, and the relationships were in basic agreement with much of the current literature. In fact, the average rates of total and single-vehicle accidents (by ADT and lane width categories) were found to agree closely with other prominent state and national research studies.

A similar model was also developed using average roadside recovery distance (*RECC*) in place of roadside hazard rating. This model for related (*AO*) accidents per mile per year is:

$$AO/M/Y = .0076\ (ADT)^{0.8545}\ (.8867)^{W}\ (.8927)^{PA}\ (.9098)^{UP} \times (0.9715)^{RECC}\ (.8182)^{TER1}\ (1.2770)^{TER2}$$

where

$RECC$ = the average roadside recovery distance as measured from the outside edge of the shoulder.

All other terms are as previously defined. The R^2 for this model was 0.461, and each term individually had a significant effect on related accidents. For this model, ADT accounted for 69.4 percent of the explained variation, 8.5 percent by *W*, 1.7 percent by *PA*, 10.4 percent by *UP*, 7.5 percent by *RECC*, and 2.5 percent by *TER*. Accident rate models (models using accidents per 100 million vehicle miles (mvm)) were also tested, but were found to be no better than the selected model forms in terms of R^2 and standard errors.

The first selected model described above was used to estimate accident reductions (accident reduction factors) expected due to roadway improvements such as lane widening, shoulder widening, and shoulder surfacing. Details of the effects of lane width, shoulder width, and shoulder type from this model are given elsewhere (*3*). The reductions in related (*AO*) accidents from roadside improvements were produced based on roadside hazard rating (from model 1) and roadside recovery distance (from model 2), as shown in tables 1 and 2, respectively.

Table 1 indicates that a reduction in roadside hazard rating of one (from seven to six, six to five, five to four, etc.) due to a roadside improvement would be expected to reduce the number of related (*AO*) accidents by 19 percent. Similarly,

TABLE 1 ACCIDENT REDUCTION FACTORS DUE TO REDUCING ROADSIDE HAZARD RATING

Reduction in Roadside Hazard Rating (Number of Levels)	Reduction in Related Accidents (%)
1	19
2	34
3	47
4	52
5	65

TABLE 2 ACCIDENT REDUCTION FACTORS DUE TO INCREASING ROADSIDE CLEAR RECOVERY DISTANCE

Amount of Increased Roadside Recovery Distance (feet)	Reduction in Related Accidents (%)
5	13
8	21
10	25
12	29
15	35
20	44

larger reductions in roadside hazard ratings will result in larger reductions. For example, a reduction in roadside hazard of five (such as from seven to two) would be expected to reduce related accidents by 65 percent. Such a roadside improvement would correspond to correcting an extremely dangerous roadside hazard to a nearly flat sideslope with few obstacles and would likely be inordinately expensive.

The roadside hazard scale is an ordinal scale, so an obstacle with a hazard rating of four is not necessarily twice as hazardous as an obstacle with a rating of two. Thus, it may be difficult to understand how a change in hazard rating of seven to five would yield a similar accident reduction (34 percent) as a change from three to one (both would reduce the hazard rating by two levels). This result is due to the nature of the accident model and the equivalent effect on accidents for each unit of increase in the roadside hazard scale. It should be mentioned, however, that the model will predict a higher number of accidents with a rating of seven than for a rating of three. Thus, a reduction in hazard rating from seven to five will indeed result in greater accident benefits than a reduction from three to one. It should also be mentioned that although the roadside hazard scale is subjective in nature, because it was developed by a panel based on roadside photographs, its association with accidents was found to be good, and it is also easy to apply.

Accident reduction factors were also computed for various increases in roadside recovery distance, as shown in table 2. An increase in recovery distance (measured from the outside edge of the shoulder) of 5 feet would reduce related (*AO*) accidents by 13 percent. Providing 20 feet of additional roadside recovery distance would reduce related accidents by 44 percent, according to the model.

One of the issues of importance in applying accident reduction factors in table 1 and 2 above is determining what action is needed to increase the recovery distance. Examples of such treatments may include tree removal, relocating utility poles, burying utility lines, flattening sideslopes and removing obstacles, providing traversable culverts, and others. Measures to reduce the hazard rating may include all of those cited above plus others such as installing a guardrail in front of a steep slope or rigid objects, or providing breakaway bases to light poles and/or signposts.

Roadside Conditions and Single-Vehicle Accidents

In addition to modeling accidents, more information was desired on actual rates of single-vehicle accidents for various roadside and roadway conditions. Single-vehicle accident rates were computed for various combinations of lane width, shoulder width, and average roadside recovery distance, as shown in table 3. Analysis of covariance procedures, with ADT as the covariate, were used to adjust the mean single-vehicle accident rates for differing values of ADT across the cells of the table. The adjusted mean accident rates decrease as lane width, shoulder width, and roadside recovery distance increase. Of particular note was the low rate of single-vehicle accidents for most cases of 17- to 30-foot roadside recovery distances.

Unadjusted single-vehicle accident rates for urban areas are given in table 4 for various lane width categories. Drastic reductions in single-vehicle accident rates may be observed for increases in average roadside recovery distances, particularly beyond 10 feet. These trends are consistent for all three lane width groups. Such summary tables agree with the results of the accident predictive models in terms of the beneficial effects of roadside improvements.

TABLE 3 MEAN ADJUSTED SINGLE-VEHICLE ACCIDENTS PER 100 MVM FOR LANE WIDTH, SHOULDER WIDTH, AND AVERAGE ROADSIDE RECOVERY DISTANCE USING RURAL SECTIONS

Lane Width, ft.	Shoulder Width, ft.	Average Roadside Recovery Distance, ft.		
		0-8	9-16	17-30
8 - 10	0 - 3	203 (130)	183 (47)	87 (20)
	4 - 5	140 (95)	119 (80)	70 (58)
	6 - 13	144 (19)	85 (104)	43 (67)
11 - 14	0 - 3	146 (100)	133 (95)	58 (92)
	4 - 5	122 (92)	77 (121)	46 (86)
	6 - 13	96 (50)	74 (301)	45 (244)

( ) = Number of sample sections given in parenthesis.

Note: Controlled for ADT.

TABLE 4 SINGLE-VEHICLE ACCIDENT RATE (ACC./100 MVM) BY LANE WIDTH AND AVERAGE ROADSIDE RECOVERY DISTANCE FOR URBAN SECTIONS IN SEVEN STATES

Lane Width (ft)	Average Roadside Recovery Distance (ft)			
	0 to 5	6 to 10	11 to 15	16 to 30
≤ 10	105(14)	76(11)	24(10)	23(5)
11	130(4)	100(15)	54(17)	37(7)
≥ 12	135(15)	97(15)	74(19)	56(11)

( ) = Numbers of sample sections are given in parenthesis.

Sideslope Effects

The next analysis was conducted to determine the effect of sideslope on the rate of single-vehicle and rollover accidents. The analysis of sideslope effects on accident experience was based solely on an analysis of 595 rural roadway sections (1,776.85 miles) in three states (Alabama, Michigan, and Washington) where field measurements of sideslope were taken. The rural sections were not used where only photolog estimates of sideslope were available, since an analysis found that sideslope estimates from photologs were of insufficient accuracy. Thus, even though a reduced sample of rural sections was used for this analysis, the greater accuracy of the field sideslope measurements was considered desirable and the sample size was more than adequate for the detailed analysis and accident modelling that was carried out.

The analysis of sideslope effects on accidents consisted of fitting loglinear regression models to two different dependent variables: single-vehicle accident rate (*AS*) and rollover accident rate (*AR*). The accident rates for *AS* and *AR* were in terms of accidents per 100 mvm. Single-vehicle accidents include three types: fixed object, rollover, and other runoff-road accidents (where each accident was counted only once).

For each of the 595 sample sections, the median (50th percentile) sideslope measurement was used as the most representative sideslope, even though sideslopes may vary considerably within a given section. Each section was then classified into one of the following six sideslope categories: 2:1 or steeper; 3:1; 4:1; 5:1; 6:1; or 7:1 or flatter.

A series of log-linear models were fit to the single-vehicle accident rates, starting with simple models containing only sideslope (*SS*) as an independent variable, then including other relevant variables, such as lane width (*W*), shoulder width (*SW*), roadside recovery distance (*RECC*), ADT, and roadside hazard rating (*H*). Sideslope was included in two different forms: as a continuous variable with values 1, 2, 3, etc. (indicating slopes of 1:1, 2:1, 3:1, etc.) and as a categorical variable with six categories (1:1 and 2:1), (3:1). (4:1), (5:1), (6:1), and (7:1 or flatter). In each model, sideslope was found to have a statistically significant effect, where segments with steeper sideslopes had higher rates of single-vehicle accidents than sections with flatter sideslopes. The best predictive models for single-vehicle accidents were found to contain the variables lane width, shoulder width, roadside recovery distance (as measured from the outside of the shoulder to the nearest roadside hazard), ADT, and sideslope. Roadside recovery distance was measured from the outside of the shoulder because the shoulder width is already accounted for in the model. An examination of the model forms with sideslope as a categorical variable showed that sideslopes of 3:1 or greater had significantly higher single-vehicle accident rates than those of 4:1 or flatter. Thus, the resulting model for the single-vehicle accident rate (*AS*) using two categories of sideslope was as follows:

$$AS = 793.58(1.191)^{SS}(0.845)^{W}(0.974)^{RECC} \times (0.99994)^{ADT}(0.908)^{SW}$$

$$R^2 = .18$$

where

AS = the rate of single-vehicle accidents (in accidents/100 MVM)
SS = median (50th percentile) sideslope measure, where SS = 1 if sideslope is 3:1 or steeper, or zero otherwise
ADT = average daily traffic (50 to 10,000)
W = lane width in feet (8 to 13)
SW = total shoulder width (paved plus unpaved) in feet (0 to 12)
$RECC$ = median (50th percentile) roadside recovery distance from the outside edge of the shoulder to the nearest roadside obstacle or hazard (0 to 30 feet)

In the model given above, each of the roadway variables was significant (including sideslope), in terms of affecting the rate of single-vehicle accidents. Since *SS* in this model takes on only values of zero or one, it follows that having a steep (such as 3:1 or steeper) slope is associated with a 19 percent higher rate of single-vehicle accidents than a flatter slope (such as 4:1 or flatter). This is because a factor of 1.191 (1.191^1 = 1.191) would be multiplied by the remaining terms for a steep sideslope, compared to a factor of 1.000 (1.191^0 = 1) for a sideslope of 4:1 or flatter.

While the results of this model are based on significant effects of sideslope on single-vehicle accident rate, there was a need to further refine the model for more sideslope categories. This would, for example, allow for determining the incremental effects of sideslopes of 2:1 or steeper, 3:1, 4:1, 5:1, 6:1, and 7:1 or flatter. The best sideslope model of this type was as follows:

$$AS = 731.16\,(0.839)^{W}\,(0.99995)^{ADT}\,(0.975)^{RECC}\,(0.909)^{SW} \times (1.373)^{SS1}\,(1.349)^{SS2}\,(1.238)^{SS3}\,(1.164)^{SS4}\,(1.091)^{SS5}$$

where

$SS1$ = 1 if sideslope = 2:1 or steeper, or zero otherwise,
$SS2$ = 1 if sideslope = 3:1, or zero otherwise,
$SS3$ = 1 if sideslope = 4:1, or zero otherwise,
$SS4$ = 1 if sideslope = 5:1, or zero otherwise,
$SS5$ = 1 if sideslope = 6:1, or zero otherwise.

For a sideslope of 7:1 or flatter, the last five terms of the equation would each become 1.0. For a sideslope of 2:1 or 1:1, the last four terms of the equation become 1.0 and the term $(1.373)^{SS1} = (1.373)^1 = 1.373$, so the remaining terms of the equation are multiplied by a factor of 1.373. Likewise, for a sideslope of 3:1, the corresponding factor would be 1.349, and so on.

This model indicates that the rate of single-vehicle accidents decreases steadily for sideslope categories of 3:1, 4:1, . . . to 7:1 or flatter, as illustrated in figure 2. Figure 2 shows a ratio of the single-vehicle accident rate for a given sideslope to the single-vehicle accident rate for a sideslope of 7:1 or flatter. These values are based on the coefficients from the predictive model and using the 7:1 or flatter category as the basis of comparison. A review of figure 2 shows, for example, that the single-vehicle accident rate is 1.24 times higher on roads with a 4:1 sideslope than on roads with a sideslope of 7:1 or flatter. Note that little difference is found for sideslopes of 3:1, compared to those of 2:1 or steeper. This indicates that flattening sideslopes from 2:1 or steeper to 3:1 would be of little, if any, value in reducing single-vehicle accidents.

Based on the model results for various sideslopes, table 5 was developed to show likely reductions in single-vehicle accidents due to various sideslope flattening projects. Table 5 indicates that flattening a sideslope of 2:1 on a two-lane rural highway would be expected to reduce single-vehicle accidents by two percent if flattened to 3:1, 10 percent if flattened to 4:1, and 27 percent if flattened to 7:1 or flatter. Similarly, flattening a 4:1 sideslope to 7:1 or flatter would be expected to yield a 19 percent reduction in single-vehicle accidents.

The R^2 value for the above model was 0.19, which indicates that only 19 percent of the variation in the single-vehicle accident rate is explained by the variables in the model. While this may appear to be less than desirable, it should be remembered that high R^2 values rarely result from predictive modeling of accident experience, due to random accident fluctuations, imperfect accident reporting systems, effects of driver and vehicle factors on accidents, and other reasons. Also, accident rates tend to fluctuate widely, particularly on low volume roads.

In spite of the R^2 value, the model was found to be desirable in terms of reasonableness of the coefficients, significance of the model (at the 0.0001 level), inclusion of important variables (each of which had a significant effect on single-vehicle accidents), logical relationships between accidents and other variables, and reasonable predictive ability compared with real-world data.

Figure 3 shows the single-vehicle accident rate expected for six categories of sideslope and for 9-foot to 12-foot lane widths based on the predictive model. All curves are for sections with an ADT of 1,000, a shoulder width of 4 feet, and a 10-

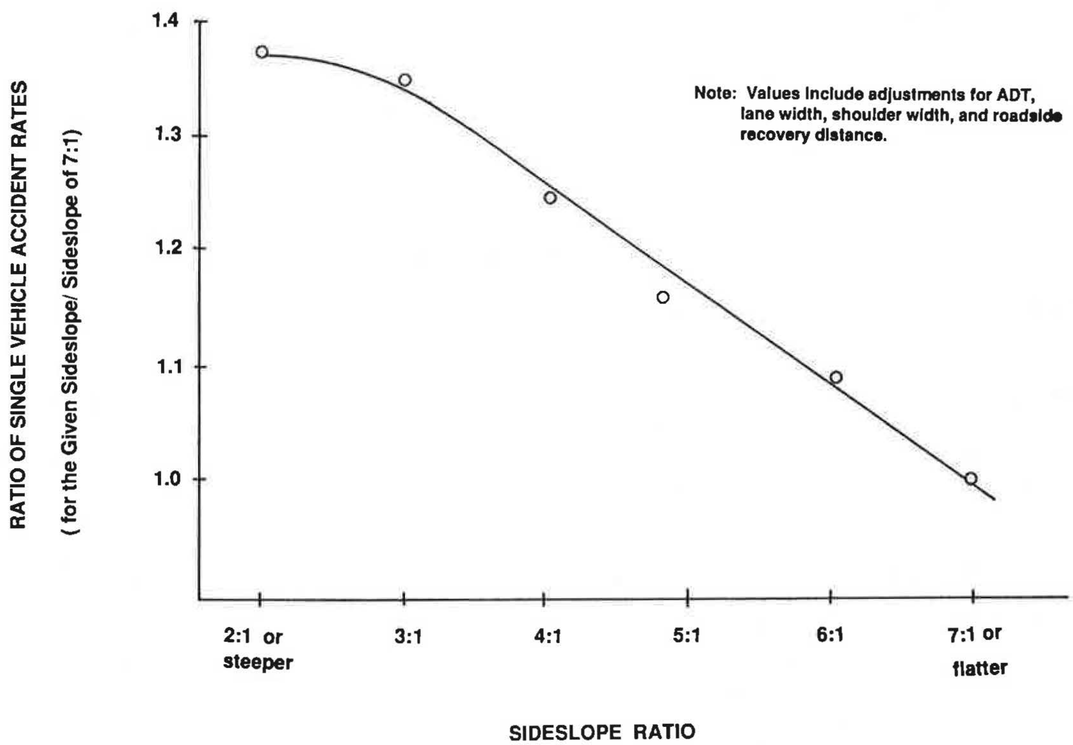


FIGURE 2 Plot of single-vehicle accident rate for a given sideslope versus single-vehicle accident rate for a sideslope of 7:1 or flatter.

TABLE 5 SUMMARY OF EXPECTED PERCENT REDUCTION IN SINGLE-VEHICLE ACCIDENTS DUE TO SIDESLOPE FLATTENING

Sideslope Ratio in Before Condition	Sideslope Ratio in After Condition				
	3:1	4:1	5:1	6:1	7:1 or Flatter
2:1	2	10	15	21	27
3:1	0	8	14	19	26
4:1	-	0	6	12	19
5:1	-	-	0	6	14
6:1	-	-	-	0	8

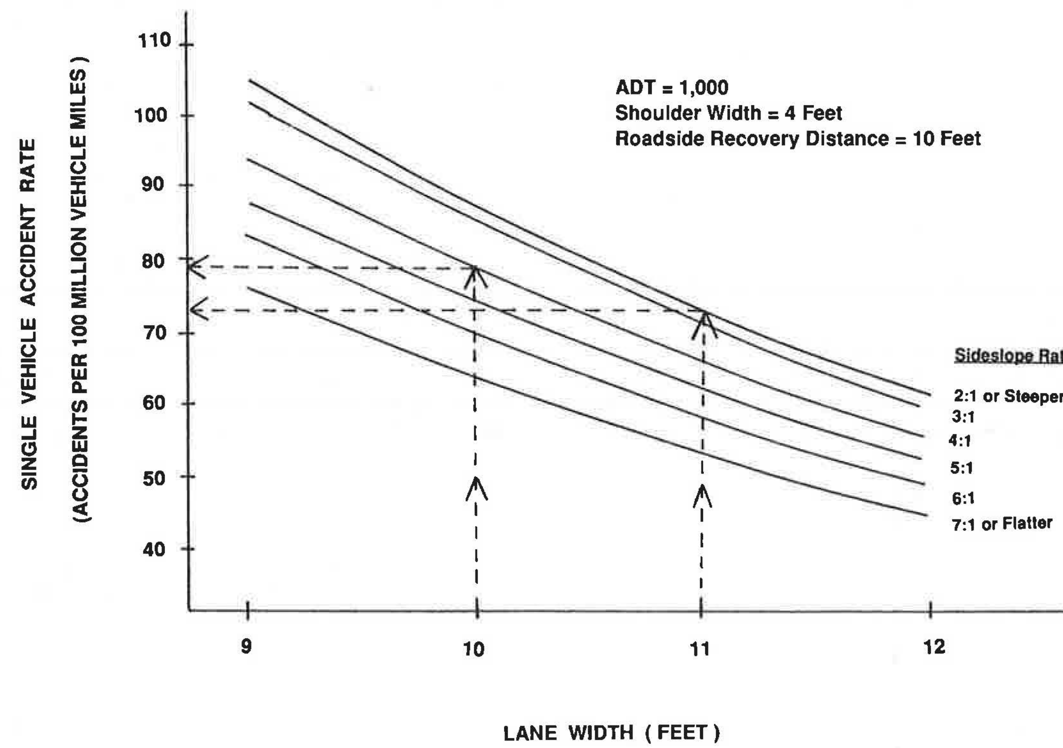


FIGURE 3 Illustration of single-vehicle accident rates for various lane widths and sideslopes.

foot roadside recovery distance beyond the shoulder edge. To illustrate the use of figure 3 for a lane width of 11 feet, sideslopes of 3:1, 4:1, and 6:1 would yield expected single-vehicle accident rates (accidents/100 mvm) of 72, 66, and 58, respectively.

The curves in figure 3 can also be used to determine trade-offs between the effects of lane width and sideslope. For example, for a roadway section with 1,000 ADT, 4-foot shoulders, 10-foot roadside recovery distance, 10-foot lane width, and a 4:1 sideslope, the expected single-vehicle accident rate is 79 (accidents/100 mvm). Widening this roadway to 11 feet would reduce the single-vehicle accident rate to 73, even if the resulting sideslopes were 2:1. Thus, in this example, one foot of lane widening at the expense of a steeper sideslope should not adversely affect the rate of single-vehicle accidents (although the overall accident severity may possibly be affected if, for example, more rollover accidents occur as a result of steepened sideslopes). While other types of comparisons can also be made using figure 3, the use of the predictive equation would allow for comparing the effects of sideslope changes on the single-vehicle accident rate versus lane and shoulder widening and roadside improvements.

Similar types of log-linear models were fitted using the rollover accident rate (AR) as the dependent variable. The best model for the rollover accident rate was

$$AR = 192.99\,(1.319)^{SS}(0.849)^{W}(0.983)^{RECC} \times (0.99984)^{ADT}(0.958)^{SW}$$

$$\bar{R}^2 = .25$$

where

AR = rollover accidents per 100 million vehicle miles
SS = 1 if sideslope is 4:1 or steeper, or zero otherwise;
all other terms are as previously defined.

This model has only two categories of sideslope, since no consistent trends were found in rollover rate for more defined sideslope groups. Note that in this model, a 4:1 sideslope was included with the steep (3:1 and 2:1 or steeper) group. This could indicate that sideslopes of 5:1 are more desirable than 4:1 slopes in preventing rollover accidents. Another explanation is that some vehicle types, such as mini-cars, are having a rollover accident problem on 4:1 sideslopes as well as on 3:1 and 2:1 slopes, which could partly account for the relatively high rollover accident rate for 4:1 sideslopes.

It should also be remembered that for each of the sample sections, the value of the sideslope used in the modeling was the 50th percentile (median value) of all of the field measurements for that section. A section labelled as having a 4:1 sideslope might actually consist of a range of sideslopes with 4:1 as the median value. Thus, in the database, each section labelled as 4:1 could have as much as 49 percent of the measurements steeper than 4:1 and the rest 4:1 or flatter. It is, therefore, quite possible that the 4:1 sideslope sections have rollover accident rates similar to the 3:1 and steeper category because these sections consist of a substantial portion of 3:1 and 2:1 sideslopes.

Rollover accidents represent only 23 percent of single-vehicle accidents (and only 8 percent of total accidents) in the database, so the relatively small samples of rollover accidents could have resulted in less reliable models than the models using single-vehicle accident rate. Also, the actual density of roadside fixed objects (such as trees) is generally greater on sections with steeper slopes than on sections with flat slopes. Thus, if a vehicle runs off the road onto the sideslope, it may hit an obstacle before having a chance to roll. Because of such considerations, it was believed that the rate of single-vehicle accidents was a better indication of sideslope effects than the rate of rollover accidents.

The single-vehicle accident model discussed earlier (and corresponding accident reductions) for various sideslopes provides perhaps the most reliable results currently available of sideslope effects on accidents. However, there remains considerable uncertainty relative to the precise rollover potential of various sideslopes (in conjunction with ditch types, height of fill, shoulder dropoff, etc.) for different vehicle characteristics.

Roadside Obstacle Types and Accidents

Another analysis involved determining the types of roadside obstacles that are most commonly struck on roads with various traffic volume conditions. The frequency of six types of fixed-object accidents for different ADT categories is summarized in table 6, based on data from six of the states in the current database. Utah accident data were not included because very few obstacle types were recorded in that state's accident file. Obstacle types other than trees, signs, utility poles, mailboxes, bridge ends, and guardrails were defined or recorded differently in different states, making tabulation of those types impossible.

Overall, the most frequently struck obstacles listed on table 6 were trees (14.8 percent) and utility poles (14.1 percent). This finding agrees with Jones and Baum (*10*) who cited these two obstacle types as among the most frequently struck fixed objects. Guardrail (9.6 percent), signs (6.5 percent), mailboxes (4.7 percent), and bridge ends (1.1 percent) were hit less frequently. The "other obstacle" category in table 6 includes all other obstacle types (including earth embankments) in addition to obstacles that were not specifically coded by the police officers.

For roads with ADTs of 4,000 or less, trees are the single most common type of obstacle struck. This may simply be the result of the fact that trees are generally the most common type of obstacle along low-volume rural roads. For roads with ADTs over 4,000, utility poles are the single most frequent type of fixed object struck, which is logical in view of the fact that higher volume roads are generally in the urban and suburban areas where utility poles are frequently placed near the roadway. Guardrail accidents accounted for less than seven

TABLE 6 FIXED-OBJECT ACCIDENTS BY ADT GROUP AND TYPE OF OBSTACLE STRUCK ON URBAN AND RURAL HIGHWAYS

ADT Group	Number of Accidents (Percent of accidents by ADT class)							
	Trees	Signs	Utility Poles	Mail Boxes	Bridge Ends	Guard Rail	Other Obstacles	Total FO Accs.
50-400	31(24.0)	6(4.7)	2(1.6)	2(1.6)	1(0.8)	5(3.9)	82(63.6)	129(100.0)
401-750	92(23.7)	20(5.2)	24(6.2)	10(2.6)	5(1.3)	20(5.2)	217(55.9)	388(100.0)
751-1,000	107(22.4)	9(1.9)	26(5.4)	6(1.3)	2(0.4)	33(6.9)	295(61.7)	478(100.0)
1,001-2,000	278(15.8)	95(5.4)	118(6.7)	46(2.6)	33(1.9)	192(10.9)	997(56.7)	1,759(100.0)
2,001-4,000	467(15.8)	200(6.8)	319(10.8)	144(4.9)	29(1.0)	319(10.8)	1,475(49.9)	2,953(100.0)
4,001-7,500	483(13.8)	235(6.7)	611(17.5)	198(5.7)	31(0.9)	323(9.3)	1,609(46.1)	3,490(100.0)
> 7,500	275(10.9)	198(7.9)	556(22.1)	145(5.8)	31(1.2)	239(9.5)	1,070(42.6)	2,514(100.0)
Total	1,733(14.8)	763(6.5)	1,656(14.1)	551(4.7)	132(1.1)	1,131(9.6)	5,745(49.1)	11,711(100.0)

Note: The data base includes 1,741 urban and rural sections in six states (excludes Utah).

percent of all fixed-object accidents on roads with ADTs of 1,000 or less, but they account for 9.3 to 10.9 percent of fixed-object hits for roads with ADTs of 1,001 or greater. The values in table 6 represent only the frequency of accidents and do not account for the placement or frequency (exposure) of these roadside objects.

It was impossible to determine the relative severity of accident types from the seven-state database, since data were aggregated by sections. However, accident data from the states of Michigan, Utah, and Washington were available for this analysis. These data include the rural two-lane roads, urban two-lane roads, and/or multi-lane roads. Nonetheless, the analysis afforded a reasonable look at the relative severity of different fixed-object (FO) accident types.

The severity of run-off-road fixed-object accidents relative to other common accident types was investigated, and the results are summarized in table 7. The percentage of FO accidents resulting in injury were 35, 36, and 44 for Michigan, Utah, and Washington, respectively. These percentages were lower than the percentages for rollover, head-on, and pedestrian/bicycle accidents; higher than the percentages for sideswipe opposite direction and sideswipe same direction; and about the same as the percentages for rear-end and angle accidents. The percentages of FO accidents resulting in a fatality were 0.8, 2.0, and 1.5 for Michigan, Utah, and Washington, respectively. These percentages again ranked FO accidents in the middle of the eight accident types shown in table 7. In terms of absolute numbers of injury accidents, however, FO accidents were the most frequent of the eight accident types in Michigan, the second most frequent in Washington, and the fourth most frequent in Utah. FO accidents were also the accident type most frequently associated with fatalities in Michigan and in Washington (fifth in Utah). In summary, FO accidents are both frequent and severe compared to other accident types.

The relative severity of the different types of fixed-object accidents is summarized by state in table 8. Fixed-object accidents which resulted in injuries generally ranged from 24 to 64 percent, depending on the type of object struck. Fatalities generally ranged from 0.2 to 6.1 percent. Among the objects associated with the highest percentage of injury and fatality were trees, culverts, bridges (bridge columns and bridge ends),

TABLE 7 SEVERITY OF COMMON ACCIDENT TYPES IN SEVERAL DATABASES

Accident Type	Accident Severity	Percent of accidents within type resulting in injury or fatality — State: Michigan	Utah	Washington
Run-off-road fixed object	Injury	35 (10137)	36 (827)	44 (15902)
	Fatal	0.8 (228)	2.0 (46)	1.5 (532)
Run-off-road rollover	Injury	55 (6587)	55 (1076)	56 (6488)
	Fatal	1.1 (73)	3.2 (63)	2.1 (245)
Head on	Injury	41 (1922)	50 (237)	60 (803)
	Fatal	2.7 (127)	11.9 (56)	20.4 (272)
Sideswipe Opposite dir.	Injury	21 (27)	30 (162)	41 (1118)
	Fatal	2.4 (3)	1.9 (10)	2.0 (54)
Sideswipe Same dir.	Injury	13 (42)	11 (87)	20 (2012)
	Fatal	1.6 (5)	0.2 (2)	0.2 (20)
Rear end	Injury	27 (2228)	33 (2320)	43 (21239)
	Fatal	0.3 (27)	0.2 (11)	0.2 (96)
Pedestrian or bicycle	Injury	86 (1769)	84 (654)	90 (2007)
	Fatal	7.0 (144)	7.8 (61)	9.8 (218)
Angle	Injury	46 (3145)	31 (2768)	37 (13272)
	Fatal	1.1 (78)	0.1 (55)	0.5 (174)

Note: The Michigan data base consisted of all reported accidents on rural roads in 1983. The Utah data base consisted of accidents reported from mid-1980 to mid-1985 on routes which had portions chosen as sections for the seven-state data base (and thus, included limited amounts of urban and multi-lane road accidents). The Washington data base consisted of all accidents reported in the State from 1980 through 1984.

( ) = The total numbers of accidents of the given type are in parenthesis.

TABLE 8 SEVERITY OF COMMON RUN-OFF-ROAD FIXED-OBJECT ACCIDENT TYPES IN SEVERAL DATA BASES

Accident Type	Accident Severity	Percent of total accidents resulting in injury or fatality — Data Base: Michigan	Utah	Washington
Utility/Light Pole	Injury Fatal	45 (3385) 0.8 (58)	39 (163) 1.2 (5)	47 (2282) 1.6 (75)
Guardrail	Injury Fatal	35 (1392) 0.7 (28)	42 (130) 4.2 (13)	41 (3403) 1.7 (144)
Sign	Injury Fatal	25 (1397) 0.4 (22)	24 (74) 1.3 (4)	40 (700) 1.4 (25)
Fence	Injury Fatal	28 (851) 0.2 (7)	35 (139) 1.0 (4)	40 (594) 1.7 (26)
Tree	Injury Fatal	47 (4419) 1.8 (171)		53 (984) 3.4 (64)
Culvert	Injury Fatal	49 (250) 3.3 (17)		64 (277) 2.1 (9)
Bridge Rail	Injury Fatal	41 (178) 0.7 (3)		41 (1060) 1.6 (42)
Bridge Column	Injury Fatal			54 (53) 6.1 (6)
Bridge End	Injury Fatal			53 (72) 5.2 (7)
Barrier Wall	Injury Fatal			41 (908) 0.5 (10)
Earth Embankment	Injury Fatal			53 (1793) 1.6 (55)
Rock	Injury Fatal			49 (891) 1.1 (21)
Mailbox	Injury Fatal			40 (132) 0.0 (0)
Fire Hydrant	Injury Fatal			30 (44) 0.7 (1)

Note: The Michigan data base consisted of all reported accidents on rural roads in 1983. The Utah data base consisted of accidents reported from mid-1980 to mid-1985 on routes which had portions chosen as sections for the seven-state data base (and thus, included limited amounts of urban and multi-lane road accidents). The Washington data base consisted of all accidents reported in the STate from 1980 through 1984.

( ) = The total numbers of accidents of the given type are in parenthesis.

rocks, utility poles, and earth embankments. Objects associated with the lowest percentages of injury and fatality were signs, mailboxes, fire hydrants, barrier walls, and fences. Trees, utility and light poles, guardrails, and earth embankments are the objects involved in the most FO injury and fatal accidents.

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the effects of various roadside features on accident experience. Detailed traffic, accident, roadway, and roadside data were collected on 4,951 miles of two-lane rural roads in seven states. Statistical analyses and log-linear modeling were used to determine the effects of various roadside and roadway features on single-vehicle and other related accident types. Roadside measures used in the analysis included a roadside hazard scale (a seven-point pictorial scale), the roadside recovery distance (clear zone distance), and field measurements of roadside side slope.

A reduction of one rating value on the seven-point roadside hazard scale (such as a five hazard rating to a four rating) due to a roadside improvement is estimated to result in a 19 percent reduction in related (*AO*) accidents. A 34 percent reduction in related accidents may be expected for a two-point reduction in hazard rating, a 47 percent reduction for a three-point decrease in roadside hazard rating, and a 52 percent accident reduction for a four-point decrease in hazard rating. Similar effects on accidents were found using a different predictive model when roadside recovery distance was increased. Reductions in related accidents were found to be 13 percent, 25 percent, 35 percent, and 44 percent, when the roadside recovery distance (as measured from the outside edge of shoulder to the nearest roadside obstacles or hazards) was increased on a section by an additional five feet, 10 feet, 15 feet, and 20 feet, respectively. These results were based on log-linear models that controlled for the effects of lane width, width of paved and unpaved shoulders, traffic volume, and terrain.

The effects of sideslope on accident experience were determined using a sample of 595 rural roadway sections (1,776 miles) in Alabama, Michigan, and Washington where field sideslope measurements were taken. Based on log-linear modeling that controlled for the effects of ADT, lane width, shoulder width, and roadside recovery distance, increased rates of single-vehicle accidents and rollover accidents were found for steeper sideslopes. The rate of single-vehicle accidents decreased steadily for sideslopes of 3:1 to 7:1 or flatter. However, only a slight reduction (2 percent) in single-vehicle accidents was found for a 3:1 sideslope compared to a sideslope of 2:1 or steeper. Expected reductions in single-vehicle accidents due to sideslope flattening ranged from 2 to 27 percent, depending on the sideslope in the before and after condition. For example, flattening sideslopes of 2:1 or steeper to 3:1, 4:1, 5:1, 6:1, or 7:1 or flatter would be expected to result in reductions in single-vehicle accidents of two percent, 10 percent, 15 percent, 21 percent, and 27 percent, respectively. Improvements to existing 3:1 sideslopes would reduce single-vehicle accidents by 8 percent, 19 percent, and 26 percent due to flattening them to 4:1, 6:1, and 7:1 or flatter, respectively.

Overall, trees and utility poles are the roadside fixed obstacles most often struck, while guardrails, signs, mailboxes, and bridge ends are less frequently struck. On roads with traffic volumes of 4,000 vehicles per day or less, trees are the obstacles most often struck, while utility poles are the obstacles most frequently struck on roadways with higher volumes. Roadside objects associated with the highest percentages of severe (injury plus fatal) accidents include culverts, trees, utility and light poles, bridges, rocks, and earth embankments, while signs, mailboxes, fire hydrants, barrier walls and fences were associated with lower percentages of severe accidents.

RECOMMENDATIONS

The results of this study clearly show the importance of roadside conditions on accidents for two-lane roads, and the safety effects of improving roadside conditions were quantified. It is recommended that highway agency officials use this information to determine where roadside improvements are justified. For example, on future 3R projects and highway reconstruction projects, the benefits of various roadside improvements should be determined using the information described in this paper. By estimating the costs for such roadside improvements such as sideslope flattening, removing trees, and relocating utility poles, the cost effectiveness may be determined.

Agencies could also consider the safety impacts of various roadside conditions when designing new highway segments, in order to minimize roadside hazards. Highway agencies should also be sensitive to highway sections where roadside improvements are feasible. In addition, when locations are identified which have an unusually high incidence of single-vehicle accidents, the accident reduction factors contained in this paper may be useful for computing expected accident benefits from roadside improvements and thus for weighing various project alternatives.

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