Safety Effects of Cross-Section Design for Two-Lane Roads

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The purpose of this study was to determine the effect on accidents of lane widening, shoulder widening, and shoulder surfacing. Detailed traffic, accident, roadway, and roadside data were collected on 4,951 miles of two-lane roadway in seven states. Statistical testing was used along with an accident prediction model to determine the expected accident reductions related to various geometric improvements. Accident types found to be most related to cross-section features included run-off-road, head-on, and sideswipe (same direction and opposite direction) accidents. The roadway variables found to be associated with a reduced incidence of these related accident types (and included in the predictive model) are wider lanes, wider shoulders (paved slightly safer than unpaved), better roadside condition, flatter terrain, and lower traffic volume. Lane widening was shown to reduce related accidents by 12 percent for 1 foot of widening (for example, 10-foot lanes to 11-foot lanes), 23 percent for 2 feet of widening, 32 percent for 3 feet of widening, and 40 percent for 4 feet of widening. The effects of shoulder widening on related accidents was determined for paved and unpaved shoulders. For shoulder widths between zero and 12 feet, the percent reduction in related accidents due to adding paved shoulders is 16 percent for 2 feet of widening, 29 percent for 4 feet of widening, and 40 percent for 6 feet of widening. Accident reductions due to adding unpaved shoulders were slightly less than for paved shoulders.

In the U.S. today, there are an estimated 3.1 million miles of rural two-lane highways, which represent 97 percent of the rural mileage and 80 percent of all highway miles. Approximately 80 percent of rural two-lane roads have an average daily traffic (ADT) of less than 400, while 38 percent have an ADT of less than 50. Rolling terrain accounts for 58.9 percent of rural two-lane roads, with 31.5 percent on flat terrain, and 9.6 percent in mountainous areas.

For the two-lane rural highway system, 32.5 percent has 10-foot lane widths, 40.5 percent has 11- to 14-foot lane widths, and 27 percent has lane widths of 9 feet or less. Only 16.2 percent of rural two-lane highways have shoulder widths of 7 feet or more, with 47.8 percent having shoulder widths of 3 to 6 feet, and 36.1 percent with shoulders of 2 feet or less. Only 12.4 percent of rural two-lane roads have paved shoulders (*1*).

In recent years, there has been increased concern by highway officials and the public regarding the deterioration of the U.S. highway network, particularly on two-lane rural roads. Efforts have continued by highway agencies to maintain the structural integrity of highways through various improvement programs such as 3R (resurfacing, restoration, and rehabilitation). Considerable controversy has resulted regarding the effects of such pavement maintenance activities on highway safety and the most appropriate designs for improved roadways.

Faced with upgrading the existing two-lane rural highway system, highway officials need accurate information on the relationships between accidents and various geometric and roadside designs. Previous research studies have reported widely differing results, and little is known about the combined effects of both geometric and roadside features on accident frequency and severity. Thus, there is a need to better quantify the effects on accidents of alternative geometric and roadside designs. In addition, there is a need to develop a method for estimating accident-related benefits that would result from various roadway improvements on two-lane rural roads.

The major objective of this study was to determine the effects of lane width, shoulder width, and shoulder type on accidents. Then, based on these effects, the safety benefits of 3R improvements should be quantified relative to improvements to lanes and shoulders. This paper was based on a research study performed jointly for the Federal Highway Administration and the Transportation Research Board (*2*) and uses data collected in Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia. More details of the safety effects of roadside features from that report are presented in a companion paper in this Record (*3*).

BACKGROUND

More than thirty articles and reports were critically reviewed relative to the safety effects of lane and shoulder width and shoulder type. Specific criteria were used to determine the major strengths and weaknesses of each source, including data sample size, adequate data detail, possible data errors, data biases, use of adequate control variables, proper analysis assumptions, accident types used (for example, run-off-road, head-on), appropriate analysis techniques, and proper interpretation of results. Basic principles outlined in the Federal Highway Administration's "Accident Research Manual" (*4*) and a User's Manual on "Highway Safety Evaluation" (*5*) were also considered in the critical review.

Initial review of the literature found major flaws in many

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of the accident studies, and only nine of them survived preliminary screening. Of these nine, a study by Rinde (*6*) dealt with shoulder widening, while studies by Dart and Mann (*7*), Shannon and Stanley (*8*), and Zegeer, Mayes, and Deen (*9*) involved analyses of both lane and shoulder widths. Studies by Heimbach, Hunter, and Chao (*10*), Turner et al. (*11*), and Rogness, et al. (*12*) involved an analysis of shoulder type, while studies by Foody and Long (*13*) and Jorgensen (*14*) analyzed lane width, shoulder width, and shoulder type.

The studies by Rinde (*6*) and Rogness, et al. (*12*) were before-and-after studies of completed shoulder widening projects in which the authors controlled for external factors. The remaining seven studies were comparative analyses that developed accident relationships with one or more geometric variables. Of these seven, three used regression analysis to develop predictive accident models.

To select the most reliable and complete information available, data and information from the nine studies were carefully analyzed. Data that covered a wide range of lane- and shoulder-width and shoulder-type combinations were desired. Also, data showing accident experience for the specific accident types most related to lane and shoulder deficiencies were considered most useful.

Although no satisfactory quantitative model was found within the published literature relating accident rate to various lane and shoulder conditions, prior research has established the general effects of these elements on highway accidents. Qualitatively, these effects can be summarized as follows:

- Lane and shoulder conditions directly affect run-off-road (ROR) and opposite direction (OD) accidents. Other accident types, such as rear-end and angle accidents, are not directly affected by these elements.
- Rates of ROR and OD accidents decrease with increasing lane width. However, the marginal effect of lane-width increments is diminished as either the base lane width or base shoulder width increases.
- Rates of ROR and OD accidents decrease with increasing shoulder width. However, the marginal effects of shoulder-width increments are diminished as either the base lane width or base shoulder width increases.
- For lane widths of 12 feet or less, each foot of lane widening has a greater effect on accident rates than an equivalent amount of shoulder widening.
- Non-stabilized shoulders, including loose gravel, crushed stone, raw earth, and turf, exhibit greater accident rates than stabilized (such as tar with gravel) or paved (such as bituminous or concrete) shoulders.

These qualitative relationships served as the basis for developing a quantitative accident model from previous literature, as given in detail in a publication by Zegeer and Deacon (*15*).

PLANNING AND COLLECTION OF DATA

Analysis Issues

Prior to deciding the types and amount of data to be collected, a clear understanding was needed of the specific analysis issue of concern. The key issue addressed in this study was determining the relationships between accidents and various combinations of lane width, shoulder width and shoulder surface types on two-lane roads. In addressing this analysis issue, there was a need to first determine what traffic, roadway, and roadside variables have a significant influence on accidents. Then, appropriate mathematical models could be developed to predict accident experience as a function of related traffic and roadway variables. Such models would enable estimation of the expected accident reduction for improvements on two-lane roads such as lane widening, shoulder widening, and shoulder surfacing for various traffic and roadway conditions. For this analysis, there was also a need to develop measures, ratings, or hazard scales that could be used to quantify roadside characteristics for purposes of data collection, analysis, and improvement considerations.

Study Design

As discussed previously, the key issue of this study is aimed at determining the effects of various combinations of lane width, shoulder width, and shoulder surface type on accident experience. Two basic analysis approaches were considered for addressing this issue:

1. A before-and-after study with control sites.
2. Modeling the relationships between accidents and various combinations of geometric and roadside conditions (to control for numerous factors that may affect the results).

While the before-and-after-with-control-site analysis may be used for determining countermeasure effectiveness in some cases, numerous problems prevented its use in this study. First, sites with each of the cross-sections of interest in this study would have to be found for numerous traffic and highway conditions in each of several states. Furthermore, projects would have to be found for which no other improvements were made. This would have been unlikely, since many widening projects, for example, are done in conjunction with pavement resurfacing along with such improvements as drainage, resurfacing, delineation, and/or bridge improvements. Also, control sites (in other words, sites similar to the project sites for which no improvements were made) are needed to minimize data biases. Since suitable control sites and project sites would have been difficult to find, the use of the before-and-after-with-control-site analysis was considered to be impractical for use in this study.

The use of mathematical accident predictive models does not utilize accident data before and after projects were implemented. Instead, they can be used to develop relationships between accidents and the traffic and roadway features of concern. This type of analysis does not rely on locating suitable project and control sites but is based instead on a large sample of randomly selected roadway sections. However, care must be exercised to collect and control for the variables that have important effects on accident experience in addition to the variables of interest. It should also be mentioned that nearly all of the major accident research studies on roadway geometrics use some form of accident modelling instead of before-and-after-with-control-site experimental designs. For this study, accident predictive models were used to determine the effects of various geometric and roadside improvements on accidents.

Selection of Data Variables

Accident experience on rural highways is a complex function of many factors including those associated with physical aspects of the roadway, as well as a multitude of other factors related to driver, vehicle, traffic, and environmental conditions. One 1978 study estimated that at least 50 roadway-related features could have an effect on accidents (*14*). However, in typical accident analyses, there are often relatively few important traffic and roadway variables that individually show significant relationships with accidents.

The selection of variables for use in this study was based on a literature search of past research to determine the ones that have been shown to be most 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 impractical.

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

- Section information (section identification, length, pavement type, terrain, ditch type, area type, type of development, speed limit)
- Average annual daily traffic (AADT)
- Speed limit
- Horizontal curvature (seven different data variables indicating percent of the section within curvature groups of >2.5 degrees, 2.5 degrees, >5.5 degrees, 7.0 degrees, >14.0 degrees, 19.0 degrees, and >28.0 degrees). Horizontal curve data were not available for some sections.
- Vertical grade (four different data variables indicating the percent of the section with percent grade of >2.5 percent, >2.5 percent, >4.5 percent, and >6.5 percent). Vertical grade data were not available for some sections.
- Sideslope ratio (two to one or steeper, three to one, four to one, five to one, six to one, or seven to one or flatter).
- Width of lanes and shoulders and shoulder type (such as 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 setting).
- Type of delineation and on-street parking.

Since the roadside condition is known to be an important factor related to accidents, a roadside hazard scale was developed based on the literature review and the results of a workshop involving thirteen highway and roadside safety professionals. The roadside hazard rating developed for this study was a subjective measure of the hazard associated with the roadside environment. The rating values indicated the accident likelihood and damage expected to be sustained by errant vehicles on a scale from one (low likelihood of an off-roadway collision or overturn) to seven (high likelihood of an accident resulting in a fatality or severe injury). The ratings were determined from a seven-point pictorial scale, as illustrated in figure 1 for rural highways. The data collectors chose the rating value (one through seven) that most closely matched the roadside hazard level for the roadway section in question. In many cases, the roadside hazard along a section varied considerably, so the roadside hazard rating should represent a "middle"

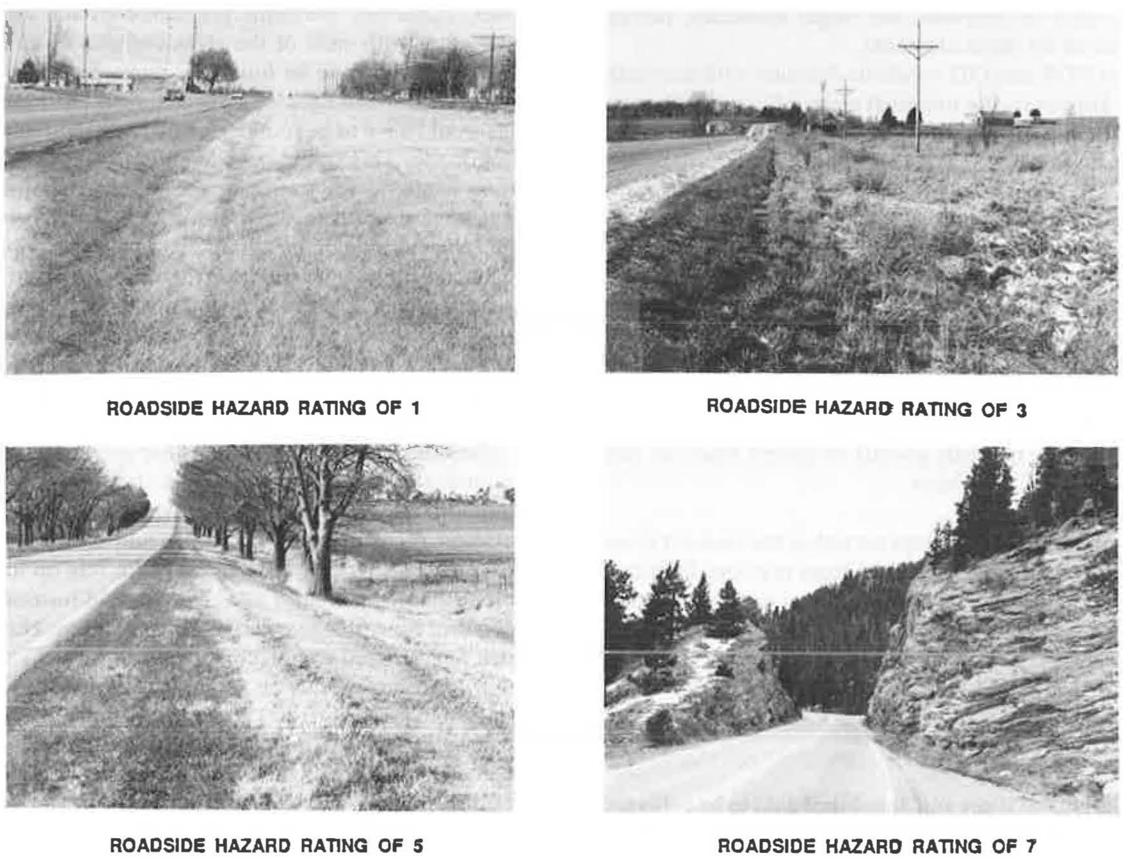

FIGURE 1 Examples of pictorial ratings from the roadside hazard rating scale.

value (for example, if ratings generally range from four to six along a section, a rating of five would best represent the roadside hazard rating of the section). In addition to the subjective roadside hazard rating, a measure termed "roadside recovery distance" was also developed and collected for each section along with detailed data on roadside obstacles by type and distance from the roadway. Details of these measures and the resulting analysis are given elsewhere (*2, 3*).

Accident Variables

For most of the selected roadway sections, accident data were collected from the state computer records for a 5-year period. For approximately 5 percent of the roadway sections, accident data for 2 to 3 years were used, to exclude time periods when roadway characteristics changed or when accident data were not readily available. Non-uniform variables and definitions among the seven states had to be considered in redefining the accident variables for the analysis. While dozens of accident variables could have been chosen, only those necessary for the analysis were selected.

For each roadway section, the accident information collected included 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) and killed; number of accidents by light condition and pavement condition; 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

To fulfill the study objectives, sites were desired in states that covered a variety of geographic characteristics, climatic conditions, roadway designs, terrain conditions, traffic conditions, and other factors. Also, states were desired that had reasonably low accident reporting thresholds (for example, $500 or less per accident) to minimize inconsistencies among states in reporting property damage accidents. States were also desired that had accurate computer accident data for five or more years with accident data items of interest (such as accident type, severity, accurate locational information, etc.). States must also have accurate and current traffic volume (ADT) data, roadway inventory information, and photolog film (for collecting roadside and other information). The seven states chosen for data collection were Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia.

A sample of 4,951 miles of two-lane roads was selected from the seven states, which was considered to be more than adequate for meaningful analysis and for accident modeling purposes. Only two-lane roadway 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 regarding basic geometric and operational features. For example, a section ended when ADT changed moderately, lane width changed by 1 foot or more, shoulder width changed by more than 3 or 4 feet, or a noticeable change occurred in the roadside condition.

Selecting from these categories also produced a variety of roadside conditions for analysis. Samples were selected only on state numbered or U.S. numbered routes, since accident data was found to be more accurate and complete on those systems than on local road systems.

Data Collection

Data Sources

The data sources for the accident analysis included field data collection, photologs, state agency records (such as 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. Much of the roadside information was extracted from photologs including roadside data for individual obstacles, roadside hazard ratings, and measures of roadside recovery distance.

State records were used as a primary source for ADT data and vertical and horizontal curvature data for many of the sections (for example, non-HPMS sections). The HPMS database was used for initial site selection and also as a secondary source for ADT data and horizontal and vertical curvature data for much of the rural sample. Police accident records were the sources of all accident data in the seven states.

For many of the most important data elements, two or three sources were used for verification. For example, independent field measurements and photolog measurements were taken of sideslopes, lane width, shoulder widths and types, and cross-section design for much of the sample. For many data variables, the photolog measurements were the primary data source, but verification was carried out using state inventory data and/or HPMS data. Inconsistencies in measurements of key data variables were resolved and corrected.

Data Collection Techniques

Homogeneous roadway sections were identified from the HPMS data tape and from computerized state roadway inventories. Samples of approximately 500 to 1,000 miles were desired from each state. Sections were selected independently of accident data to avoid any accident bias of the database. Therefore, some zero-accident sections resulted. Stratified random sampling was used to select an adequate sample of sections within certain needed categories of ADT, lane width, and shoulder width and type. This was necessary since a database of nearly all 11- and 12-foot lanes, for example, would not allow for determining the effects of various lane widths (for example, 9 to 12 feet) on accidents.

Detailed roadside data and roadway information were recorded from state 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 file frame 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. Three data forms used with photolog film included those of 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. This process allowed for coding of roadside recovery distance for each 0.1 mile for each roadway section (both sides of the road).

Creation of the Database

Close data quality control was practiced throughout the data collection process. All data were double-keyed into a computer file. A series of programs was written, which read data for each section and checked—

- Each data variable against allowable lower and upper limits;
- The logic of accident totals (for example, total accidents had to equal PDO + injury + fatal);
- The computed accident rates by accident type; and
- The match of lane width, shoulder width, speed limit, area type, and other variables to ensure agreement for all data sources (HPMS, photolog, state records, and field measurements).

Data "outliers" were printed and corrected or deleted as necessary. The final data file contained 325 data variables for each roadway section. With 1,944 records (roadway sections) and 868 characters per record, the database consisted of 1.69 million data characters.

RESULTS OF DATA ANALYSIS

Database Characteristics

The database contained data for 4,785.14 miles of rural roadway (1,801 sections) and 166.14 miles of urban streets (143 sections), for a total of 4,951.28 miles (1,944 total sections). The average section length was 2.66 miles in rural areas and 1.16 miles in urban areas, or 2.55 miles overall. Data were collected on approximately 1,033 miles of roadway from Alabama, 699 miles from Michigan, 547 miles from Montana, 746 miles from North Carolina, 525 miles from Utah, 737 miles from Washington, and 665 miles from West Virginia.

Data were collected entirely on two-lane roads but covered a wide range of traffic and geometric conditions. Shoulder widths ranged from zero to 12 feet and lane widths varied from 8 to 14 feet. In terms of traffic volume, approximately half of the mileage (2,392 miles) had an ADT between 1,000 and 4,000, while only 387.7 miles (7.8 percent) had an ADT above 7,500, and 938.4 miles (19 percent) had ADTs of 750 or less.

It is clear that this data sample has higher traffic volume levels than those of the nationwide two-lane rural highway system. This was expected, since our sample was purposely taken on state-maintained (in other words, U.S. and state numbered routes), whose accident data accuracy was thought to be much better than that on local roads. However, as discussed below, this sampling procedure resulted in a data sample with accident rates very close to national samples as reported by Smith (*1*). Also, the effect of higher ADTs was accounted for in all of the accident predictive models, along with the other roadway variables of concern, such as lane width, shoulder width and type, and roadside condition. It should also be mentioned that the ideal data sample for this type of modelling analysis was not one that was truly representative of national distributions by ADT only, but instead covered the full range of traffic and roadway conditions in the United States, to the extent practical.

Of the 4,785 miles of rural highway, 4,119 miles (or 86 percent) had speed limits of 55 mph; 544.5 miles (11.4 percent) had speed limits of between 40 and 50 mph; and 121.6 miles (2.5 percent) were in built-up rural areas with speed limits of 25 to 35 mph. The predominance of 55 mph speed limits for sections in the rural databases prevented an in-depth analysis of the effects of speed limits on accident experience. Data were included from 1,946.7 miles in flat terrain, 2,134.0 miles in rolling terrain, and 870.5 miles in mountainous areas. The database also included sections with wide ranges of roadside conditions, sideslopes, curvature, and other factors.

General Accident Characteristics

There were 62,676 total reported accidents on sections in the database including 38,857 property-damage-only accidents (62.0 percent), 22,944 injury accidents (36.6 percent), and 875 fatal accidents (1.4 percent). A review of the accident data by type revealed that the most frequently reported accidents were angle and turning (23.5 percent), followed by rear end (19.8 percent), run-off-road fixed object (19.3 percent), animal (8.3 percent) and rollover (6.8 percent). The average accident rate was found to be 266.35 accidents per 100 million vehicle miles (mvm), or 3.69 accidents per mile of roadway per year.

Of the 1,944 sample sections in the database, 1,468 were from rural areas and the remaining 476 were from urbanized areas (areas with populations of 5,000 or more). Of those 476 sections, 143 were classified as having an urban appearance (designated as urban sections) by the data collectors and 333 appeared rural to the data collectors (designated as U/R sections). For purposes of the predictive model, only the "pure" rural sections were used (in other words, U/R and urban sections were excluded). Detailed analyses of urban sections and roadside characteristics are given elsewhere (*2*).

A summary of various accident statistics is given for the 1,801 rural sections and 143 urban sections in table 1. The average rate of total accidents was 603.18 per 100 mvm for urban sections, and 239.61 per 100 mvm for rural sections. There were 13.51 accidents per mile per year in urban areas, compared to 2.91 in rural areas. In both cases, the urban rate was greater than the rural rate. Higher traffic volumes, more frequent intersections, and denser roadside development are a few of the possible factors that may cause higher accident rates in urban areas than rural areas.

In terms of accident severity, injury accidents constituted 37.5 percent (20,008 of 53,358) of total accidents in rural areas, compared to 31.5 percent (2,936 of 9,318) in urban areas. Fatal accidents accounted for 1.57 percent of the accidents in rural areas and 0.41 percent in urban areas. Accident

TABLE 1 SUMMARY OF ACCIDENT STATISTICS FOR RURAL AND URBAN ROADWAY SECTIONS

Variable Name	No. of Accidents		Accs/100 MVM		Accs/Mi/Yr	
	Rural	Urban	Rural	Urban	Rural	Urban
Total Accs.	53,358	9,318	239.61	603.18	2.91	13.51
PDO Accs.	32,513	6,344	146.41	432.85	1.81	9.46
Injury Accs.	20,008	2,936	88.75	168.31	1.06	3.99
Fatal Accs.	837	38	4.45	2.02	0.04	0.05
People Injured	32,756*	4,565*	141.74*	262.53*	1.74*	6.62*
People Killed	1,016*	52*	5.26*	3.97*	0.05*	0.07*
Daylight Accs.	31,108	6,294	135.94	430.61	1.75	9.39
Dawn or Dusk Accs.	2,535	353	11.31	19.83	0.13	0.47
Dk. with Lights	1,863	907	6.78	62.49	0.12	1.34
Dk. w/o Lights	17,764	1,732	84.97	86.06	0.90	2.20
Unkn. Light Cond.	88	32	0.61	4.18	0.01	0.10
Dry Accs.	35,783	6,174	162.79	408.12	1.96	9.10
Wet Accs.	11,294	2,193	47.02	146.96	0.64	3.27
Snow/Ice Accs.	5,802	855	27.17	40.52	0.29	0.97
Unkn. Pvt. Accs.	479	96	2.63	7.58	0.03	0.16
ROR - Fixed Object	10,937	1,154	54.71	60.54	0.54	1.44
ROR - Rollover	4,122	123	25.91	6.72	0.18	0.14
ROR - Other	2,621	219	15.36	12.28	0.15	0.29
Head-On	1,858	255	8.01	13.41	0.10	0.32
Sideswipe - Opp. Dir.	2,628	369	12.55	19.89	0.15	0.50
Sideswipe - Same Dir.	1,925	363	8.74	29.82	0.12	0.59
Rear End	9,593	2,827	30.12	162.95	0.58	3.89
Parking	922	233	4.51	20.16	0.06	0.39
Ped./Bike/Moped	516	139	2.12	7.23	0.03	0.18
Angle & Turning	11,415	3,315	41.39	244.44	0.68	5.25
Train	43	4	0.32	0.18	0.002	0.004
Animal	5,068	144	26.80	7.34	0.22	0.19
Other or Unknown	1,710	173	9.08	18.22	0.10	0.33

*These variables represent the number of people injured or killed, and not the number of accidents.

rates were higher in rural areas than in urban areas for rollover, train, and animal accidents. Urban rates were higher for the remaining accident types, and particularly for angle and turning, parking, rear-end, and same-direction sideswipe accidents.

A detailed review of the distribution of the variables in the database was made to examine the quality of the data. The minimum, maximum, mean, and standard deviation were computed for selected variables. Lane widths ranged from 8 to 14 feet and shoulder widths varied from zero to 12 feet (11 feet for earth shoulders). There were an average of 2.35 intersections per mile (maximum of 11 on one section), 0.20 bridges per mile, and 0.21 other structures (such as overpasses) per mile. There were 13.77 driveways per mile on the average (total of both sides of the road) with a maximum of 81 per mile on one section. The number of total accidents per mile per year ranged from zero on some low-volume sections to 71.14 on one particularly high-volume section. There were an average of 0.94 single vehicle accidents per mile per year with a range from zero to 11.38. Extensive data checking was conducted, particularly to confirm the accuracy of the extremes. A comparison was made of accident rates between the seven-state database and previous accident studies. The FHWA study by Smith et al. of rural roads throughout the United States included accident rates and the percent of injury and fatal accidents for rural roads in many states by ADT group as shown in table 2 (*1*). Corresponding rates from the seven-state database revealed close similarities. For example, rates of total accidents (per 100 mvm) were similar for each ADT group, except for ADTs greater than 10,000, where the rate of 244 from the seven-state database was lower than the rate of 300 from the Smith study. This may be due to the low sample size (only 80 sections) in that ADT group in the seven-state database. Percentages of injury and fatal accidents also compared quite favorably for each ADT group.

Another comparison was made with the results of the 1979 Kentucky study on lane and shoulder widths by Zegeer, as shown in table 3 (*9*). Accident rates are given for total and single-vehicle accidents for lane widths of 7 to 13 feet. Total and single-vehicle accident rates were similar between the studies for the 10-, 11-, and 12-foot lane widths. For less than 10-foot lanes, the rates were slightly lower for the seven-state database for both total accidents and single-vehicle accidents. The differences are probably the result of wider shoulders in the seven-state database compared to the Kentucky sites for sections with 9-foot lanes. For 13-foot lane widths, the Kentucky database had a lower rate of single-vehicle accidents and a higher rate of total accidents than the seven-state database. This may be the result of smaller sample sizes or other site differences.

TABLE 2 COMPARISON OF RURAL ACCIDENT EXPERIENCE BY ADT GROUP FOR RURAL SEVEN-STATE DATABASE AND SMITH STUDY

Accident Measure	ADT Group					
	1-400	401-1,000	1,100-2,000	2,501-5,000	5,001-10,000	>10,000
Avg. Total Acc. Rate (Acc/100 MVM)	288(300)*	246(250)	228(230)	225(220)	257(250)	244(300)
Percent Fatal Accs.	2.4(2.5)	3.1(3.0)	1.9(3.0)	1.8(2.5)	1.2(2.0)	0.9(2.0)
Percent Injury Accs.	38.9(36)	39.3(37)	38.8(37)	35.8(36)	37.7(35)	39.4(35)
Percent PDO Accs.	58.7(61.5)	57.6(60)	59.2(60)	62.4(61.5)	61.1(63)	59.8(63)

*Values in parenthesis are from Smith study.

While the accident rates agree closely between the seven-state database and other studies, differences did exist in average accident frequencies. For example, an average of 2.91 total accidents per mile per year was found on rural roads in the seven-state database, compared to approximately one accident per mile per year reported for rural Kentucky roads (*9*). This difference was the result of considerably higher traffic volumes on the seven-state sample compared to the Kentucky data. Thus, in the model-building process, ADT was used as a control variable and the effects of the other important variables were determined as accurately as possible.

Determination of Important Variables

The next series of analyses was intended to provide input into the selection of variables for use in the model-building process. The final selection of variables for inclusion in the model was based on (1) which variables were logically related to accidents (lane width, shoulder width, shoulder type, and roadside conditions), (2) the Chi-square analysis, (3) stepwise linear regression, and (4) analysis of variance and covariance.

Accident Variables

A series of Chi-square analyses were conducted to determine the specific accident types that were most highly correlated with lane width, shoulder width, shoulder type (paved, gravel, or earth) sideslope, and roadside rating. The significance levels were 0.05 or less (95 percent confidence or higher) for many of the tests, due primarily to large sample sizes but not necessarily to strong correlations. Thus, the

TABLE 3 COMPARISON OF ACCIDENT RATES BETWEEN KENTUCKY STUDY AND RURAL SEVEN-STATE DATABASE

Lane Width (feet)	Rate of Single Vehicle Accidents (Acc/100 MVM)		Rate of Total Accidents (Acc/100 MVM)	
	Kentucky Study	Seven-State Study	Kentucky Study	Seven-State Study
7	196 (396)	-	416 (396)	-
8	185 (2,808)	174 (28)	366 (2,808)	369 (28)
9	155 (8,249)	130 (711)	303 (8,249)	283 (711)
10	127 (2,537)	130 (907)	287 (2,537)	300 (907)
11	74 (788)	75 (1,438)	206 (788)	218 (1,438)
12	63 (610)	76 (1,406)	197 (610)	211 (1,406)
13	51 (38)	95 (294)	217 (38)	174 (294)

Numbers in parentheses represent mileage of samples in each cell.

contingency coefficient (which takes sample sizes into consideration) was used as the primary measure of association between the geometric elements of concern and the specific accident types. A matrix of contingency coefficients was produced during the series of Chi-square tests for various accident types and roadway features. Contingency coefficients of 0.220 were found to differentiate the upper third of the contingency coefficients in this analysis. The accident types that consistently appeared to be highly correlated with the roadway features of concern were single vehicle (fixed object, rollover, and other run-off-road accidents), head-on, and sideswipe (opposite-direction and same-direction) accidents. Single-vehicle, total, and some types of multi-vehicle accidents were found to be strongly associated with one or more of the roadway variables. On the other hand, animal, parking, angle and turning, and other or unknown accidents were not highly correlated with the roadway variables of concern. Insufficient samples of pedestrian and train accidents were available for these analyses.

Based on the results discussed above and a review of accident rates and trends for various accident types, the accident types thus considered to be most appropriate and logical for use in a predictive model were—

- Single-vehicle (fixed-object, rollover, and other run-off-road) accidents and
- Related multi-vehicle (head-on, opposite-direction sideswipe, and same-direction sideswipe) plus single-vehicle accidents.

Total accidents were found to be a reasonably strong measure of the overall effects of traffic roadway variables.

Traffic and Roadway Variables

The most important traffic and roadway variables for use in an accident predictive model were determined. Since many of the geometric variables in the database were interrelated or were derivations of the same variable, only one form of each variable was considered for use in the predictive model. Relationships were determined between accidents and individual traffic and roadway variables, as given in the full report (*2*). Accident relationships with individual variables were somewhat misleading, due to strong interactions between some roadway variables in terms of their combined effect on accidents. For example, narrow lanes and high roadside hazards were associated with higher accident experience than wide lanes or safe roadsides. However, roads with narrow lanes were found to often have a high roadside hazard rating as well. Also, roads with wide lanes are more likely to have reasonably safe roadsides than roads with narrow lanes. Thus, a review of the simple relationship between lane width and accidents gives a distorted picture, since roadside condition and other factors are also interacting to affect accidents unless they are controlled for in the analysis.

Chi-square analysis, stepwise linear regression, and analysis of variance and covariance were also conducted to infer accident relationships. The following traffic and roadway variables were found to be most highly related to accident experience and thus were used as candidate independent variables for modeling purposes:

- Average daily traffic (ADT)
- Lane width (*W*) in feet
- Average paved shoulder width (*PA*) in feet
- Average unpaved (gravel/stabilized/earth/grass) shoulder width (*UP*), in feet
- Median roadside (or hazard) rating (*H*)
- Median sideslope rating (*SS*)
- Terrain (*TER*)
- Percent of sections with >2.5 degree curves (*CURV*)
- Percent of sections with >2.5 percent grade (*GRAD*)
- Number of driveways per mile (*NDRI*)
- Number of intersections per mile (*NINT*)
- Certain derived variables (for example, $W + PA$)
- Selected interactions

DEVELOPMENT AND TESTING OF PREDICTIVE MODEL

Guided both by the previous literature (*15*) and an examination of the relationships of the important independent variables with various accident types, models were fit to the following (*15*):

- Single-vehicle accidents (*AS*) including fixed object, run-off-road rollover, and other run-off-road.
- Single vehicle plus opposite direction head-on, opposite direction sideswipe, and same direction sideswipe (*AO*).
- Total accidents (*AT*).

Of the 32,417 accidents on the 1,362 rural sections, 13,105 or 40.4 percent were *AS* (single vehicle) while 17,155 or 52.9 percent were related (*AO*) accidents.

Again guided by past work (*15*), several general model forms were investigated, including

$$A/M/Y = C_0(\mathrm{ADT})^{C_1}(C_2)^{W}(C_3)^{PA}(C_4)^{UP}(C_5)^{H} \quad \text{(Model 1)}$$

$$= C_0(C_1)^{\mathrm{ADT}}(C_2)^{W}(C_3)^{PA}(C_4)^{UP}(C_5)^{H} \quad \text{(Model 2)}$$

$$= C_0 + C_1\mathrm{ADT} + C_2W + C_3PA + C_4UP + C_5H \quad \text{(Model 3)}$$

$$= C_0(\mathrm{ADT})^{C_1}(W)^{C_2}(PA)^{C_3}(UP)^{C_4}(H)^{C_5} \quad \text{(Model 4)}$$

where:

$$A/M/Y = \text{accidents per-mile-per-year} = \frac{A}{L \times T}$$

with:

A = number of accidents on highway section

L = section length (miles)

T = number of years of accident data

C_0, C_1, C_2, C_3, C_4, and C_5 are constants, and ADT, W, PA, *UP*, and *H* are as given previously. Model forms consist of the basic model equation without numerical coefficients (in other words, only C_i), whereas the equations will include numerical coefficients. The above models were tested using *AS*, *AO*, and *AT* accidents per mile per year. In addition to models with only main effects, several models with interaction terms were also evaluated. These interaction terms included (lane width × paved shoulder width) and [(lane width + paved shoulder width) × unpaved shoulder width]. In no case did the interaction terms noticeably improve upon the main effects models, and most often the interaction term coefficients were insignificant. Thus, the final models contain only main effects variables.

In all cases tested, Models 1 and 2 fit the data better than Models 3 or 4, and, also, coefficients of Models 1 and 2 were more reasonable. Although Model 2 seemed to fit the data slightly better than Model 1 on the basis of the R^2 values (which indicate the proportion of the total variation explained by the model), in some cases the relative effects of *W*, *PA*, and *UP* were not as reasonable. For example, for single-vehicle accidents using Model 2, the effects of *PA* and *UP* (paved and unpaved shoulders) are more important than *W* (lane width). This finding, in addition to the fact that the R^2 values were not much different between Models 1 and 2, led to the selection of Model 1 as the recommended model form.

All models utilized ADT as an independent variable because it was highly correlated with accidents per mile per year. ADT is a measure of exposure that has been shown in the literature to have a relatively high correlation with accident frequency in most situations. Basic cross-section elements lane width (*W*), paved shoulder width (*PA*), and unpaved shoulder width (*UP*) were also included in every model, and their individual effects were significant. Other primary variables examined were median roadside rating (*H*), median sideslope rating (*SS*), and other measures of roadside condition. In addition, certain likely confounding variables were studied including terrain (*TER*), percent of section with ≥2.5 degree curves (*CURV*), percent of section with ≥2.5 percent grades (*GRAD*), number of driveways per mile (*NDRI*), and number of intersections per mile (*NINT*).

It should be noted that a variety of models were examined that used alternative definitions of the cross-section variables (for example, one model using ADT, *W*, (*W* + *PA*), (*W* + *PA* + *UP*), and (*W* + *PA* + *RECC*) and another using W^2). In no case did models with these various alternatives fit the data as well as the original model form or provide coefficients as intuitively acceptable as those derived for models with simpler variables.

Final Models

A series of models was produced that best fit various accident types (*AS*, *AO*, and *AT*), using lane width, width of paved shoulder, width of unpaved shoulder, ADT, and roadside hazard rating. Values of R^2 ranged between 0.39 and 0.46. In examining the effects of other potentially confounding variables, models incorporating terrain were found to be useful in further enhancing the models.

Thus, although several models were found to be acceptable, the final selected model is as follows:

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

where TER1 = 1 if flat, 0 otherwise; *TER*2 = 1 if mountainous, 0 otherwise and ADT, *W*, *UP*, *PA*, and *H* are as given previously. The R^2 value for this model was 0.456, or 45.6 percent of the variation in accidents was explained by the traffic and roadway variables. The relative contribution of each variable to this explained variation was 70.2 percent by ADT, 8.6 percent by *W* (lane width), 1.7 percent by *PA* (paved shoulder width), 10.5 percent by *UP* (unpaved shoulder width), 7.2 percent by *H* (roadside hazard rating), and 1.8 percent by *TER* (terrain).

This model was selected because (1) it included the accident types found to be most related to cross-sectional features (head-on, sideswipe, and single-vehicle accidents), (2) the coefficients appear to be reasonable and consistent with the literature, (3) it had a relatively high R^2 value, and (4) terrain effects (flat, rolling, or hilly) are incorporated into the model. Models using accident rates (such as Accidents/100 mvm or single-vehicle accidents per 100 mvm) were calibrated in parallel to those for accidents per mile, per year. In general, the R^2 values were considerably lower for models using Accidents/100 mvm. Details of these and other models are given elsewhere (*2*).

Model validation was performed on single-vehicle accidents using 75 percent of the data, which were randomly selected. The average deviation between the observed and predicted accidents per mile, per year was 0.36. Since the average single-vehicle accident rate for all 1,362 rural sections was 0.73 accidents per mile, per year, the average deviation was just slightly less than half the average rate. Considerable efforts were also made to examine other confounding variables and multicollinearity between two or more independent variables, as discussed elsewhere (*2*). In short, the final model given above was considered the best available for expressing relationships between accidents and related traffic and roadway features.

To illustrate the use of the predictive model, consider a two-lane rural roadway section 3.4 miles long on a rolling terrain, 2,500 ADT, lane width (*W*) of 10 feet, paved and gravel shoulders (*PA* and *UP*) of zero feet, and a roadside hazard rating (*H*) of five. An estimate of the number of related (*AO*) accidents per mile, per year would then be

$$\begin{aligned} AO &= .0019\,(\text{ADT})^{.8824}\,(.8786)^{W}\,(.9192)^{PA}\,(.9316)^{UP} \times (1.2365)^{H}\,(.8822)^{TER1}\,(1.3221)^{TER2} \\ &= .0019\,(2{,}500)^{.8824}\,(.8786)^{10}\,(.9192)^{0}\,(.9316)^{0} \times (1.2365)^{5}\,(.8822)^{0}\,(1.3221)^{0} \\ &= 1.5 \text{ related accidents per mile, per year.} \end{aligned}$$

For a 3.4-mile section, the expected accidents would be (1.5 related accidents per mile, per year) × 3.4 miles = 5.1 related accidents per year.

Accident Predictive Nomograph

A nomograph was developed, which represents the relationships between selected accidents and the six variables of con-

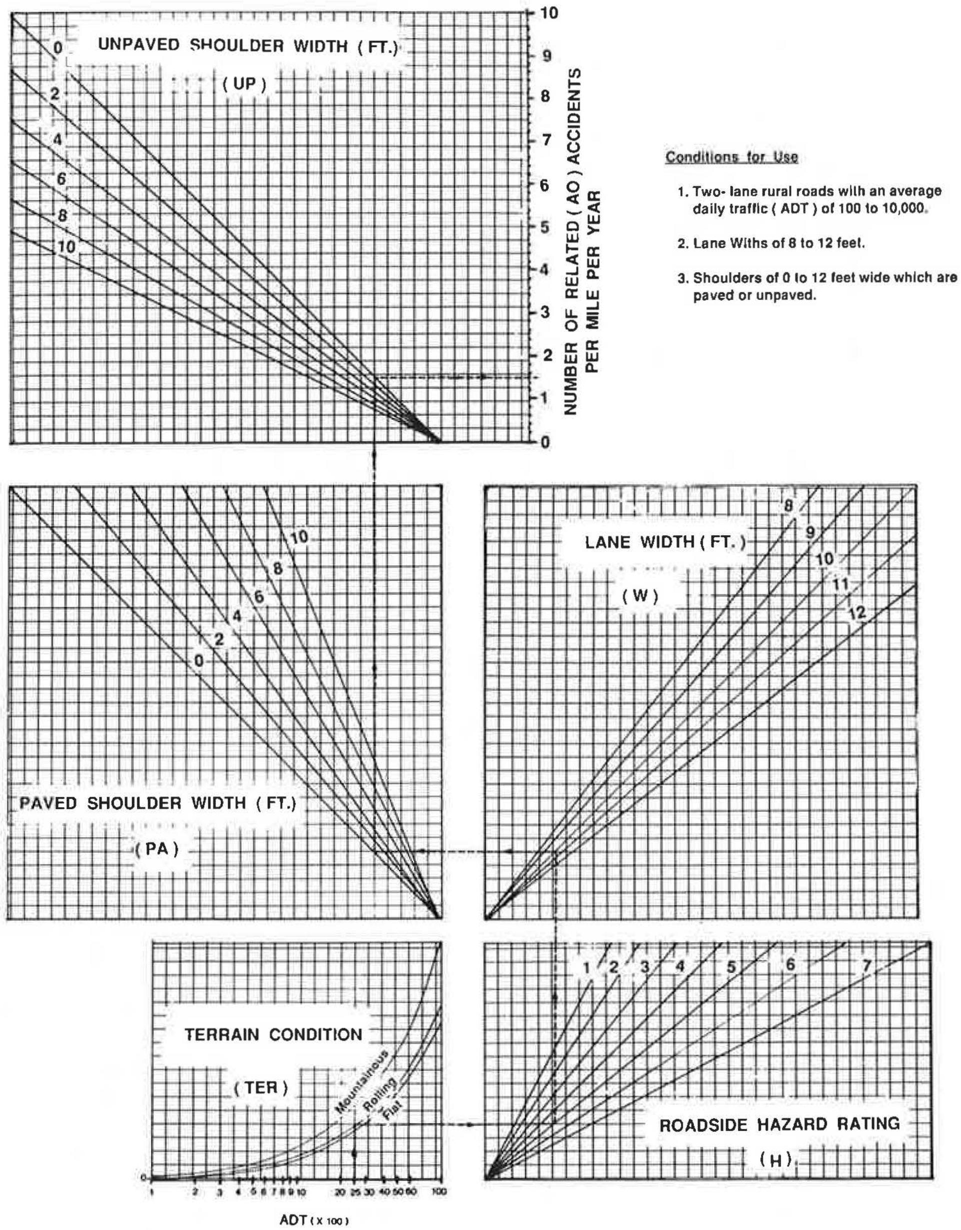

FIGURE 2 Accident prediction nomograph.

cern as illustrated in figure 2. Thus, by knowing the lane width, ADT, terrain, roadside hazard rating, and width of paved and unpaved shoulder, the expected number of related (*AO*) accidents may be determined for a two-lane highway section.

For example, assume the sample section given previously. Enter the nomograph with an ADT of 2,500 and proceed up to the terrain curve (rolling, in this case). From that point, draw a horizontal line to the roadside hazard rating line (5). Draw a line up to the lane width (10 feet) line; and then proceed horizontally to the line of the paved shoulder width (zero feet). Next, draw a line up to the unpaved shoulder width line (zero feet) and then over to the accident scale. Read the value of the predicted number of related (*AO*) accidents per mile per year, which is 1.5 in this case (as found using the accident predictive model. Multiplying the section length (3.4 miles) by the number of related accidents per mile per year (1.5) yields 5.1 related accidents per year as calculated in the previous section.

In order to determine the percentage of accident reduction that would result from lane or shoulder widening projects, accident reduction (AR) factors were developed using the model. Values for the factors were determined by computing the predicted difference in related accidents between the before and after conditions (from the model) and dividing that value by the predicted accidents in the before condition. Accident reduction factors for lane widening only are shown in table 4. Table 4 reveals that as the amount of lane widening increases, the percent reduction in related accidents also increases. For example, widening a road with 10-foot lanes to 12-foot lanes (in other words, 2 feet of widening per lane) would be expected to result in a 23 percent reduction in related accidents, all other factors being equal. Accident reduction factors for shoulder widening are shown in table 5. This table reveals

TABLE 4 PERCENT ACCIDENT REDUCTION OF RELATED ACCIDENT TYPES FOR LANE WIDENING ONLY

Amount of Lane Widening (ft.)	Percent Reduction in Related Accident Types
1	12
2	23
3	32
4	40

TABLE 5 PERCENT ACCIDENT REDUCTION OF RELATED ACCIDENT TYPES FOR SHOULDER WIDENING ONLY

Amount of Shoulder Widening (ft.) per Side	Percent Reduction in Related Accident Types	
	Paved	Unpaved
2	16	13
4	29	25
6	40	35
8	49	43

that wider shoulders are associated with a reduction in related (AO) accidents. Widening paved shoulders by 4 feet, for example, will be expected to reduce related accidents by 29 percent.

AR factors for various combinations of lane and shoulder widening and paving are shown in table 6. For example, assume a roadway with a 9-foot lane width and a 2-foot gravel shoulder (before condition) is being considered for widening to 11-foot lanes with 4-foot paved shoulders. The expected percent reduction in related accidents can be obtained from table 6, by finding the amount of lane widening (2 feet in this example) and the existing shoulder condition at the left of the table (2-foot unpaved). Looking to the right, find the cell that corresponds to a 4-foot paved shoulder. In this example, a 37 percent reduction in related accidents would be expected to result from the proposed improvements. To determine the number of related accidents per mile, per year that would be avoided by lane and/or shoulder improvements, multiply the AR factor by the number of related accidents per mile, per year from the nomograph or predictive model.

To illustrate the use of these tables, assume an existing 3-mile section of rolling terrain with an ADT of 1,000, a 10-foot lane width, no shoulder, and a roadside hazard rating of five. This would correspond to 0.68 related accidents per mile, per year × three miles = 2.04 related accidents per year in the untreated condition. Widening to 12-foot lanes and 6-foot gravel (unpaved) shoulders would result in a 50 percent reduction in related accidents, according to table 6. This translates to (0.50 × 2.04) = 1.02, or approximately two related accidents reduced per year on the 2-mile section.

Based on the AR factors developed from the model, the same percentage of accidents will be reduced for a specific amount of lane or shoulder widening, regardless of the lane width or shoulder width in the before condition. For example, adding a 4-foot paved shoulder to a 10-foot lane with no shoulder would result in the same accident reduction percentage as adding 4 feet of shoulder to a 12-foot lane with an existing 6-foot paved shoulder. However, the actual number of related accidents eliminated per mile, per year will be greater for adding the 4-foot paved shoulder to the 10-foot lane, since the model would also predict a greater number of accidents for the section with the 10-foot lane. Greater overall benefits would result, then, from adding the 4-foot shoulder to the 10-foot lane.

It is also important to mention that the predictive model and nomograph only apply to two-lane, rural roadways with lane widths of 8 to 12 feet, shoulder widths of zero to 12 feet (paved or unpaved) and traffic volumes of 100 to 10,000. One must not assume that these accident reductions apply, for example, to lane widths of ≤7 feet or ≥13 feet.

AR factors were also developed to determine the percentage of related (AO) accidents that would be reduced due to sideslope flattening and lowering the roadside hazard ratings, and details of such effects of roadside improvements are discussed elsewhere (*2, 3*).

SUMMARY AND CONCLUSIONS

This study was intended to quantify the benefits expected from lane widening, shoulder widening, shoulder surfacing, and general roadside improvements. Detailed accident, traffic,

TABLE 6 ACCIDENT REDUCTION FACTORS FOR RELATED ACCIDENT TYPES FOR VARIOUS COMBINATIONS OF LANE AND SHOULDER WIDENING

Amount of Lane Widening (ft)	Existing Shoulder Condition (Before Period)		Percent Related Accidents Reduced — Shoulder Condition in After Period							
			2 ft. Shoulder		4 ft. Shoulder		6 ft. Shoulder		8 ft. Shoulder	
	Shoulder Width	Surface Type	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
3	0	N/A	43	41	52	49	59	56	65	62
	2	Paved	32	--	43	--	52	--	59	--
	2	Unpaved	34	32	44	41	53	49	60	56
	4	Paved	--	--	32	--	43	--	52	--
	4	Unpaved	--	--	36	32	46	41	54	49
	6	Paved	--	--	--	--	32	--	43	--
	6	Unpaved	--	--	--	--	37	32	47	41
	8	Paved	--	--	--	--	--	--	32	--
	8	Unpaved	--	--	--	--	--	--	39	32
2	0	N/A	35	33	45	42	53	50	61	56
	2	Paved	23	--	35	--	45	--	53	--
	2	Unpaved	25	23	37	33	46	42	55	50
	4	Paved	--	--	23	--	35	--	45	--
	4	Unpaved	--	--	27	23	38	33	48	42
	6	Paved	--	--	--	--	23	--	35	--
	6	Unpaved	--	--	--	--	29	23	40	33
	8	Paved	--	--	--	--	--	--	23	--
	8	Unpaved	--	--	--	--	--	--	31	23
1	0	N/A	26	24	37	34	47	43	55	50
	2	Paved	12	--	26	--	37	--	47	--
	2	Unpaved	14	12	28	24	39	34	48	43
	4	Paved	--	--	12	--	26	--	37	--
	4	Unpaved	--	--	17	12	30	24	41	34
	6	Paved	--	--	--	--	12	--	26	--
	6	Unpaved	--	--	--	--	19	12	31	24
	8	Paved	--	--	--	--	--	--	12	--
	8	Unpaved	--	--	--	--	--	--	21	12

-- These cells are left blank, since they would correspond to projects which would decrease shoulder width and/or change paved shoulders to unpaved shoulders.

roadway, and roadside data from 4,951 miles of two-lane roads in seven states were collected and analyzed. An accident predictive model and detailed statistical procedures were used to determine expected accident reductions related to various geometric improvements. The following are the key study results:

1. The types of accidents found to be most related to cross-section features (lane width, shoulder width, shoulder type, and roadside characteristics) include
   — Single-vehicle (fixed-object, rollover, or run-off-road other)
   — Related multi-vehicle (head-on, opposite-direction sideswipe, or same-direction sideswipe)
   — The combination of the accident types listed above were termed related accidents (or *AO* accidents)

2. The traffic and roadway variables found to be associated with a reduced rate of single-vehicle accidents were wider lanes, wider shoulders, greater recovery distance, lower roadside hazard rating, and flatter terrain. This effect and the accident reductions discussed below are based on the detailed analyses and accident predictive model developed for two-lane rural roads having ADTs between 50 and 10,000; lane widths of 8 to 12 feet, and shoulder widths of zero to 12 feet (paved or unpaved).

3. The effects of lane width on related accidents were quantified. The first foot of lane widening (2 feet of pavement widening) corresponds to a 12 percent reduction in related (*AO*) accidents, 2 feet of widening (widening lanes from 9 to 11 feet, for example) results in a 23 percent reduction, 3 feet results in a 32 percent reduction, and 4 feet of widening results in a 40 percent reduction. These reductions apply only for lane widths between 8 and 12 feet.

4. The effects of shoulder widening on related (*AO*) accidents was determined for paved and unpaved shoulders. For shoulder widths between zero and 12 feet, the percent reduction in related accidents due to adding paved shoulders is 16 percent for 2 feet of widening (each side of the road), 29 percent for 4 feet of widening, and 40 percent for 6 feet of widening. Adding unpaved shoulders would result in 13 percent, 25 percent, and 35 percent reductions in related accidents for 2, 4, and 6 feet of widening, respectively. Thus, paved shoulders are slightly more effective than unpaved shoulders in reducing accidents.

RECOMMENDATIONS

This study provides a set of accident reduction factors to enable computation of estimated accident benefits for a variety of cross-sectional improvements. It is recommended that consideration be made for such improvements on all roadway sections being considered for 3R-type projects. In fact, an informational guide, *Two-Lane Road Cross-Section Design*, has been developed that enables estimation of the safety benefits of various roadway and roadside improvements on specific sections of two-lane roads (*16*). The guide also includes a project-cost model, which is based on cost information from numerous U.S. states.

As discussed earlier, many of the rural, two-lane roads in the United States are restrictive and substandard in terms of lanes, shoulders, roadsides, and other roadway features. Unfortunately, budgetary and practical constraints prevent widening and other needed roadway improvements on all substandard highways at once. One rational approach is to establish priorities for cross-sectional improvements based on where the needs are the greatest. The use of the accident reduction factors given in this paper along with the step-by-step procedures in the informational guide provide a way of computing expected benefits and costs of improvements. This rational decision-making process can help identify the types of projects that are most desirable and cost-effective in various roadway situations.

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