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

Publication No. FHWA/RD-87/008

October 1987

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

This report presents the results of two research studies, one sponsored by the Federal Highway Administration (FHWA) and the other by the Transportation Research Board (TRB). The FHWA study was conducted under NCP Program Area A5 - Design, and the TRB study was conducted as part of the study on "Design Practices for Resurfacing, Restoration, and Rehabilitation (3R) Projects." The FHWA study dealt with the cross-section elements of lane width, shoulder width and type, and sideslope, while the TRB study dealt with the condition of the roadside and roadside obstacles such as trees. To assist the reader, the results of these two studies were combined into a single report.

A model was developed which relates accidents to traffic volumes (ADT), lane width, shoulder width (both paved and unpaved), a measure of the condition of the roadside, and type of terrain (flat, rolling, and hilly). Using the model, accident reduction factors were developed for lane widening, shoulder widening, and improving the roadside.

Sufficient copies of Report No. FHWA/RD-87/008 are being distributed to provide a minimum of one copy to each region office, division office and State highway agency. Direct distribution is being made to the division offices. Additional copies for the public are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Stanley Byington

Stanley R. Byington, Director
Office of Safety and Traffic
Operations R&D
Federal Highway Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-87/008	PB88 156682/AS	

4. Title and Subtitle	5. Report Date
SAFETY EFFECTS OF CROSS-SECTION DESIGN FOR TWO-LANE ROADS - VOLUME I - FINAL REPORT	October 1987
	6. Performing Organization Code
	8. Performing Organization Report No.

7. Author(s) Zegeer, C.V., Hummer J., Reinfurt, D., Herf, L., and Hunter, W.

9. Performing Organization Name and Address

Goodell-Grivas, Inc.
17320 W. Eight Mile Road
Southfield, MI 48075

10. Work Unit No. (TRAIS) NCP3A5a0062

11. Contract or Grant No. DTFH61-83-C-00117

13. Type of Report and Period Covered: Final Report, September 1983 - December 1986

12. Sponsoring Agency Name and Address

Safety Design Division	Transportation Research Board
Federal Highway Admin.	National Research Council
6300 Georgetown Pike	2101 Constitution Ave., N.W.
McLean, VA 22101-2296	Washington, D.C. 20418

14. Sponsoring Agency Code T-0678

15. Supplementary Notes

FHWA Contract Manager: Justin True (HSR-20)
TRB Contract Manager: Robert Skinner
Subcontractor: University of North Carolina, Highway Safety Research Center

16. Abstract

This study was intended to quantify the benefits and costs resulting from lane widening, shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvements. Detailed traffic, accident, and roadway data were collected on 4,951 miles of two-lane roads in seven States. An accident predictive model and statistical tests were used to determine expected accident reductions related to various geometric improvements. Factors found to be most related to reduced accidents were wider lanes and shoulders, improved roadside conditions, and flatter sideslopes. Paved shoulders were found to have a marginal safety benefit compared to unpaved shoulders.

Detailed accident analyses were also conducted for roadside features. Factors associated with increased fixed object accidents include higher traffic volumes, greater numbers of roadside objects, and closer distance of roadside objects to the road. Roadside objects associated with high accident severities include culverts, trees, utility and light poles, bridges, rocks, and earth embankments. Construction cost data from several States were used to develop a cost model for numerous types of roadway and roadside projects.

This volume contains the final report and four appendixes. The final report contains detailed information on data collection and data analysis and conclusions and recommendations. The appendixes contain detailed information on the literature review, photographs used for the rural and urban roadside hazard scales, and economic analysis inputs.

This volume is the first of a two volume final report. The other volume is:

FHWA No.	Vol. No.	Title
RD-87/009	II	Safety Effects of Cross-Section Design for Two-Lane Roads - Vol. II - Appendixes (Vol. II contains Appendixes E - J. The titles of these appendixes are listed on page iv of Volume I.)

17. Key Words	18. Distribution Statement
Sideslope, Roadside Features, Lane Width, Shoulder Width, Accident Prediction Model, Accident Reduction Factors	No restrictions. This document is available to the public through the National Technical Information Service Center, Springfeild, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	210	PC $35.95 A08 $6.95

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

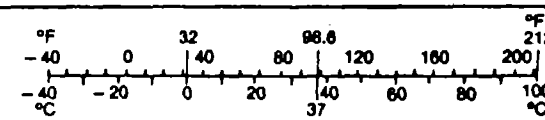
* SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

Table of Contents

VOLUME I - FINAL REPORT

Table of Contents (Continued)

List of Figures

VOLUME I - FINAL REPORT

List of Figures (Continued)

VOLUME I - FINAL REPORT

VOLUME II - APPENDIXES

List of Tables

VOLUME I - FINAL REPORT

List of Tables (Continued)

List of Tables (Continued)

List of Tables (Continued)

List of Tables

. VOLUME II - APPENDIXES

List of Tables (continued)

List of Tables (continued)

EXECUTIVE SUMMARY

The purpose of this study was to determine the effects of lane width, shoulder width, shoulder type, sideslope, and roadside condition on accidents for two-lane roads in the U.S. Also, the expected accident reduction benefits and construction costs were quantified for lane and shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvement projects.

The study first included a review and critique of past accident research related to lane width, shoulder width and type, and roadside condition. Based on data and accident relationships from previous research studies, an accident predictive model was developed which represented the best available information prior to 1986, and was considered to be a useful first approximation of the effects of lanes and shoulders on accident rates. Overall trends from the literature were also summarized regarding the effects of roadside features on accident frequency and severity.

The development of accident relationships with geometric and roadway features involved the collection and analysis of detailed accident, traffic, roadway and roadside data from 1,944 roadway sections, covering 4,951 miles of two-lane roads in seven States (Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia). Innovative variables were developed to characterize the roadside environment for each roadway section, including (1) roadside recovery distance (i.e., distances from the edgeline to the closest fixed objects or steep slopes), (2) roadside hazard rating (i.e., a rating of roadside hazard from 1 to 7 from a pictorial scale, where a 1 is the safest, and a 7 presents the most danger to a run-off-road vehicle), and (3) actual counts of 20 specific types of point and continuous roadside objects and the lateral distances from the road of each type.

Accident data were coded by type (e.g., run-off-road, head-on, sideswipe, rear end), severity, weather conditions, type of obstacle struck, and other variables. Detailed sideslope data were also included for analysis based on field measurements in three States for 1,776 miles of rural two-lane roads. Detailed information was also collected on driveways, traffic volume, terrain, curvature, and numerous other roadway features. Data sources included State computer accident files, State roadway inventory files, photolog film of the selected sections, and the HPMS data base. A total of 325 data variables were coded into a computer file for each of the 1,944 roadway sections. Extensive data checking and quality control measures were used to maximize data reliability.

A comprehensive analysis was conducted of the data base to quantify accident relationships with traffic, roadway, and roadside features. Statistical tests included the Chi-square analysis, analysis of variance and covariance, and development of log-linear and other predictive models. Expected accident reductions were determined due to various types of accident countermeasures. Construction cost data from several States were used to develop a cost model for such projects.

The following are the key study results:

1. The types of accidents found to be most related to cross-section features (i.e., lane width, shoulder width, shoulder type, and sideslope) and roadside characteristics included:

   - Single-vehicle (i.e., fixed-object, rollover, plus other types of run-off-road accidents)

   - Related multivehicle (i.e., head-on, plus sideswipe opposite direction, plus sideswipe same direction).

   The combination of these 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, flatter terrain, and flatter sideslopes.

3. The effects of lane width on related accidents were quantified. The first foot of lane widening (i.e., two feet of pavement widening) corresponds to a 12 percent reduction in related (AO) accidents; two feet of widening (e.g., widening lanes from 9 to 11 feet) results in a 23 percent reduction, three feet results in a 32 percent reduction, and four feet of widening would result 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 0 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. Adding unpaved shoulders would result in 13 percent, 25 percent, and 35 percent reduction 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.

5. The effects of general roadside improvements on related accidents were also determined. Using the seven-point roadside hazard scale, a reduction of one rating value (e.g., a 5 hazard rating to a 4 rating) due to a roadside improvement will result in a 19 percent reduction in related (AO) accidents. Other reductions include a 34 percent reduction for a two-point reduction in hazard rating, 47 percent reduction for a three-point decrease in roadside hazard, and a 52 percent accident reduction due to a four-point decrease in hazard rating. Similar accident effects were found due to increasing roadside recovery distance using a different predictive model. Reductions in related accidents were found to be 13 percent, 25 percent, 35 percent, and 44 percent, due to increasing the roadside recovery distance (as measured from the outside edge of shoulder to the nearest roadside obstacles or hazards) on a section by an additional 5 feet, 10 feet, 15 feet, and 20 feet, respectively.

6. The effects of sideslope on accident experience was 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 which 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 decreases steadily for sideslopes of 3:1 to 7:1 or flatter. However, only a slight reduction 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 2 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. A more detailed analysis was also conducted on the effects of specific roadside features on accident experience.

7. For each type of roadside obstacle tested (i.e., utility poles, mailboxes, culverts, signs, guardrail, fences, and trees), the specific types of fixed-object accidents-per-mile-per-year increased for (1) increasing ADT, (2) closer obstacle distance from the road, and (3) increasing numbers of obstacles per mile. Average accidents were computed for various categories of fixed object by these factors but this information was not sufficient for determining the effectiveness of tree removal, utility pole relocation, and other specific roadside treatments.

8. The rate of guardrail accidents increases with an increase in the percent of the section covered by guardrail for all terrains. However, no significant difference was found in the overall rate of single-vehicle or rollover accidents or in accident severity due to the presence of guardrail. This finding could be due to the fact that numerous roadway factors interact with guardrail presence in terms of affecting single-vehicle and rollover accidents. A data base containing details on each guardrail section compared to similar sections without guardrail would allow for more accurately quantifying accident effects of guardrail.

9. Roadside objects associated with the highest percent of severe (injury plus fatal) accidents include culverts, trees, utility and light poles, bridges, rocks, and earth embankments. Those with lower percent of severe accidents include signs, mailboxes, fire hydrants, and fences.

10. Overall, trees and utility poles are the roadside fixed obstacles most often struck, while guardrail, signs, mailboxes, and bridge ends are less frequently struck. On roads with ADT's of 4,000 or less, trees are the most often struck obstacle, while utility poles are the most frequently struck obstacle on roadways above 4,000 ADT.

CHAPTER 1 - INTRODUCTION

Background

In the U.S. today, there are an estimated 3.1 million miles of rural two-lane highways, which represents 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. The most common lane width for the two-lane rural highway system is 10 feet (32.5 percent), with 40.5 percent of the mileage having 11 to 14 foot lane widths and 27 percent with lane widths of 9 feet or less. Only 16.2 percent of such 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]

The accident rate on two-lane rural highways is higher than on all other kinds of rural highways, except four-lane undivided roads. Two-lane rural highways also have a higher percentage of head-on collisions and single-vehicle accidents than any other type of rural highway. However, overall accident severity for rural two-lane highways is about the same as for other types of rural roads.[1]

This accident experience for rural two-lane roads is particularly noteworthy in light of the high mileage of travel. Of the estimated 4 billion daily vehicle miles of travel on all U.S. highways in 1980, 2.2 billion (55 percent) was on urban streets and 1.8 billion (45 percent) was on rural highways. Of the 1.8 billion daily vehicle miles of rural travel, 1.19 billion daily vehicle miles, or 66 percent, was on two-lane rural roads. Thus, even though rural roads typically have much lower traffic volumes than urban streets, the total travel mileage on rural two-lane roads is a substantial portion of the nation's travel.[1]

In recent years, there has been increased concern by highway officials and the public regarding the deterioration of the U.S. highway net-work, 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 found 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 accident effects of alternative geometric and roadside designs. Also, there is a need to develop a method for estimating accident reduction benefits and project costs which would result from various roadway improvements on two-lane rural roads.

Study Objectives and Scope

The major objectives of this study were to:

1. Develop a method of quantifying roadside hazards.

2. Determine the effects of lane width, shoulder width, shoulder type, sideslope, and roadside condition on accidents.

3. Determine the expected benefits and costs of 3R improvements related to lanes, shoulders, and the roadside environment.

This study is concerned with cross-section and roadside design of two-lane roads in the U.S. Although primary emphasis of the study was on rural two-lane roadways, urban two-lane streets were also included in the study. The study did not address problems related specifically to individual intersections or bridges on two-lane roads.

The study included a review and critique of past accident research related to lane width, shoulder width and type, and roadside condition. The development of accident relationships involved the collection and analysis of detailed accident, traffic, roadway, and roadside data from 4,951 miles of two-lane roads in seven U.S. States. An accident predictive model and detailed statistical tests were used to determine expected accident reductions related to various geometric improvements. Construction cost data from several States were used to develop a cost model for such projects.

CHAPTER 2 - REVIEW OF LITERATURE

A review and critique of literature was conducted of previous accident research related to lane width, shoulder width, shoulder type, and roadside condition. Details of this review are presented in appendix A, and a brief summary is given below.

Effects of Lanes and Shoulders

More than 30 articles and reports were reviewed relative to effects of lane and shoulder width and shoulder type. Criteria used to determine the major strengths and weaknesses of each source are listed in table 1. Basic principles outlined in the Federal Highway Administration's (FHWA) "Accident Research Manual" (1980) and the User's Manual on "Highway Safety Evaluation" (1981) were also considered in the critical review.[2,3]

Initial review of the 30 articles found numerous major flaws in many of the accident studies, and only nine of them survived preliminary screening. Of these nine, the study by Rinde (1977) dealt with shoulder widening, while studies by Dart and Mann (1970), Shannon and Stanley (1976), and Zegeer, Mayes and Deen (1979) involved analyses of both lane and shoulder widths (see references 4,5,6,7). Studies by Heimbach, Hunter, and Chao (1974), Turner et al. (1981), and Rogness, et al. (1982) involved only shoulder type, while studies by Foody and Long (1974) and Jorgensen (1978) analyzed lane width, shoulder width, and shoulder type (see references 8,9,10,11,12).

The studies by Rinde (1977) and Rogness, et al. (1982) were before/after studies of completed shoulder widening projects in which the authors controlled for external factors.[4,10] The remaining seven studies were comparative analyses, which 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 were desired which covered a wide range of lane- and shoulder-width and shoulder-type combinations. Also, data showing accident experience for the

Table 1. Criteria for critically reviewing literature.

Criteria Related to Data Reliability

1. Is the study data reasonably current or is it outdated?

2. Did the author collect a sufficient sample for establishing reliable results?

3. Was adequate detail maintained in the collection of important data variables?

4. Did the author adequately control for possible data errors?

5. What data biases exist in terms of State, geographic region, section lengths, roadway class, etc.? (It should also include the zero-accident sections).

Criteria Related to Data Analysis and Results

6. Were adequate control variables used?

7. What accident types (rear end, run-off-road, etc.) and units (frequencies, rates, etc.) were used in the analysis? Were they properly handled?

8. What assumptions were made in conducting the analysis and were they valid?

9. Were appropriate analysis techniques and statistical tests applied?

10. Did the author correctly interpret the analysis results?

specific accident types most related to lane and shoulder deficiencies was considered most useful.

Although no satisfactory quantitative model was found within the published literature relating accident rate to 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 is 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.

- Nonstabilized shoulders, including loose gravel, crushed stone, raw earth, and turf, exhibit larger accident rates than stabilized (i.e., tar with gravel) or paved (i.e., bituminous or concrete) shoulders.

These qualitative relationships served as the basis for developing a quantitative accident model from previous literature (see appendix A). Data for calibration of the model was extracted from the 1979 Kentucky study (by Zegeer, Mayes, and Deen) and the 1974 Ohio Study (by Foody and Long).[7,11] Adjustments were made to the model in an attempt to remove unwanted effects of other confounding variables -- such as curvature, ADT, roadside condition, etc. -- and to assure appropriate consideration of shoulder width effects for roadways having wider lanes. This log linear model included terms of lane width, width of total shoulder, and width of stabilized shoulder and model-coefficients, which could be used to compute the rate of related (i.e., ROR and OD) accidents. Many assumptions were necessary in developing this model, including reliance on available data bases from two states. However, the model was based on the best information available prior to 1986, and was considered to be a useful first approximation of the effects of lanes and shoulders on accident rates. This previous model was the starting point for modelling in the current study. Details of that model are given in appendix A.[13]

Effects of Roadside Features

In general, considerable research has been conducted in the past on the effects of roadside characteristics and the factors associated with the frequency and severity of run-off-road accidents. Studies of safety effects of utility poles and/or other types of poles were conducted by Zegeer and Parker (1983), Mak and Mason (1980), Jones and Baum (1980) and Graf et al. (1976) (see references 14,15,16,17). Effects of more general types of roadside objects were studied by Foody and Long (1974), Newcomb and Negri (1971), Rinde (1979), Hall et al. (1976), and Perchonok, et al. (1978) (see references 11,18,19,20,21).

Studies dealing with other aspects of roadside safety include a 1982 analysis by Graham and Harwood on the effects of clear recovery zones and a 1976 study by Weaver and Marquis on the safety of various roadside slope designs.[22,23] Attempts to model accident frequency and/or severity of single-vehicle accidents were reported in articles by Edwards, et al. (1968), Glennon and Wilton (1974), Cleveland and Kitamura (1978), Zegeer and Parker (1983), and Deacon (see references 24,25,26,14,27). While some of the models may be useful for certain applications, none of them provides a means to accurately predict run-off-road accidents for a variety of traffic, roadway, and roadside conditions.

Based on an investigation of past research on roadside features and safety, some overall conclusions may be reached as follows:

- The frequency of run-off-road accidents generally increases with higher traffic volumes, obstacles closer to the roadway (particularly within about 10 feet), greater numbers of rigid obstacles, steeper sideslopes (particularly 3:1 or steeper), and poor roadway geometrics (i.e., on sharp horizontal curves and/or on narrow roadways).

- The factors related to increased severity of run-off-road and fixed object accidents include high vehicle speeds, rigid fixed objects, (i.e., trees, utility poles, bridges, culverts, and embankments in particular), and steep sideslopes (which are associated with greater numbers of rollover accidents).

- Types of roadside obstacles most often struck include trees, utility poles, and earth embankments, due to their relatively high frequency of occurrence and closeness to the roadway. Others struck with relative frequency include guardrail, sign posts, and bridge structures.

Relevance of Past Research to Current Study

The literature review revealed that although considerable research has been conducted in the past on the effects of roadway and roadside design on accident experience, much of the research presents conflicting or inconsistent results. Also, no study to date provides a means to accurately predict accident experience for a variety of traffic, geometric, and roadside conditions. In fact, there is a need for concise definitions or measures to better describe roadside conditions for highway safety purposes. The data collection and analysis discussed in the following chapters was structured to address these and other issues related to accident effects of geometric and roadside designs on two-lane roads.

CHAPTER 3 - 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 issues. The key issue addressed in this study was:

> Determining the relationships between accidents and various combinations of lane width, shoulder width, shoulder surface types, sideslopes, and roadside condition on two-lane roads.

In addressing this overall analysis issue (i.e., macrolevel analysis), there was a need to first determine what traffic and roadway variables have a significant influence on accidents. Then, appropriate mathematical models could be developed which could be used to predict accident experience as a function of related traffic and roadway variables. Such models would allow for estimating the expected accident reduction for improvements on two-lane roads such as lane widening, shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvements for various traffic and roadway conditions. For this macro level of accident analysis, there is a need to develop measures, ratings, or hazard scales which could be used to quantify roadside characteristics for purposes of data collection, analysis, and improvement considerations.

A more detailed level of analysis (i.e., a microlevel analysis) was also planned, which would focus on the effects of specific roadside characteristics on accident frequency and severity. This detailed roadside analysis was structured to determine the accident frequencies and severities associated with trees, guardrails, culverts, signs, fences, utility poles, and other types of roadside objects. Analysis issues also involved the accident effects of sideslopes, in conjunction with various geometric conditions and roadside obstacles.

In addition to accident issues, there was also a need to quantify construction costs associated with various geometric and roadside improvements. Thus, this study also involved compiling project cost information from several State highway agencies. This included the development of a procedure for computing costs and benefits for various roadside and cross-section improvements under a variety of traffic, accident, and roadway conditions. The data collection procedures discussed below were developed with these ideas in mind.

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, shoulder surface type, sideslope and roadside condition on accident experience. Two basic analysis approaches were considered for addressing this issue:

1. A before and after study with control sites.
2. A comparative analysis (i.e., comparative parallel study), of accident relationships with various combinations of geometric and roadside conditions.

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 of all, sites with each of the cross-sections of interest in this study along with each roadside improvement 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 installed. This would have been unlikely, since many widening projects, for example, are done in conjunction with such improvements as drainage, resurfacing, delineation, and/or bridge improvements. Also, the use of control sites (i.e., site similar to the project sites for which no improvements were made) are needed to minimize data bias. In short, suitable control sites are usually difficult to find.

The comparative analysis does not utilize accident data before and after projects are implemented. Instead, it can be used to develop relationships between accidents and the traffic and roadway features of concern. This study design does not rely on locating suitable project and control sites, but instead is based on large randomly selected roadway sections. In comparative studies, however, care must be exercised to collect and control for the variables which 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 utilized comparative analyses instead of before and after with control sites. For this study, the comparative analysis was used for determining the effects of various geometric and roadside improvements on accidents.

Selection of Data Variables

The data variables needed for this study included traffic and roadway variables (lane width, shoulder width, shoulder type, sideslope,) roadside obstacle variables, accident variables, (e.g. by type and severity) and other traffic and roadway features which have a proven or logical relationship with accidents.

Traffic and Roadway Variables

Accident experience on rural highways is a complex function of many factors including not only those associated with physical aspects of the roadway, but also a multitude of others 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.[12] However, in typical accident analyses, there are often relatively few of the more important traffic and roadway variables which 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 are important on two-lane roads in rural, suburban, or urban areas. The collection of every possible roadway, traffic, and accident variables would have been both unnecessary and impractical.

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

1. Section identification number (where the four digits denote the state number, data source, sequencing number, and subsection numbers).
2. Area type (urban or rural).
3. Type of development (rural, rural dense, urban CBD, etc).
4. Terrain (flat, rolling, or mountainous).
5. Section length (in miles and hundredths of a mile).
6. Average annual daily traffic (AADT).

7. Speed limit.

8. Horizontal curvature (i.e., 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 was not available for some sections.

9. 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 was not available for all sections.

10. Sideslope ratio (i.e., 2 to 1 or steeper, 3 to 1, 4 or 5 to 1, 6 or 7 to 1, and 8 to 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 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.

11. Lane width.

12. Average paved shoulder width.

13. Average gravel shoulder width.

14. Average earth or grass shoulder width.

15. Ditch type (vee, flat bottom, rounded, rounded with flat bottom, no backslope, or no ditch).

16. Length of slope.

17. Pavement type (concrete, bituminous, or a combination of both).

18. Delineation (centerline and edgeline striping, centerline striping only, no centerline or edgeline, or edgeline striping only).

19. Parking (not permitted, permitted with restrictions, or allowed any time).

20. Parking side of street (not allowed, permitted one side, permitted both sides).

21. Number of signalized intersections.

22. Number of stop sign intersections.

23. Number of other or no control intersections.

24. Number of bridges.

25. Number of overpasses.

26. Number of structures.

27. Number of railroad crossings.

28. Number of residential driveways.

29. Number of commercial, recreational, and industrial driveways.

30. Number of total driveways.

31. Cross-section design of the section, where each section is classified as one of the following: (1) Single smooth paved surface for lanes and shoulders (separated by edgeline), (2) Paved shoulders separated from lanes by a visible joint, (3) Shoulder partly paved and partly gravel, (4) Gravel or stabilized gravel shoulder, (5) Grass or dirt shoulder, (6) No shoulder, (7) Curb adjacent to travel lanes.

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 edgeline or the outside edge of the travel lane. Of the 38 specific types of point obstacles inventoried, the first nine listed in table 2 were designated for analysis purposes. The others were grouped into a category of other point objects.

The inventory involved classifying each point object into the appropriate category of distance from the travel lane: 0 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 for each roadway section in terms of their longitudinal length and offset from the roadway (0 to 1 feet, 2 to 3 feet, etc.) The first nine types of continuous objects in table 2 were designated for analysis and the others were grouped into other continuous objects.

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.

Table 2. Listing of roadside obstacle types.

PRIMARY OBJECTS

Point Objects	Continuous Objects
1. Trees (4-inch diameter or larger)	1. Continuous Trees (>8 in 150 feet)
2. Sign and Delineator Posts	2. Guardrail (Steel Beam or Cable)
3. Utility Poles and Luminaires	3. Bridge Rail
4. Multiple/Massive Mailboxes/ Newsboxes	4. Rock Cuts/Wall
5. Culvert Headwalls	5. Concrete Wall/Barrier
6. Bridge Columns	6. Fences/Gates
7. Bridges and Bridge Ends	7. Earth Embankment
8. Fire Hydrants	8. Railroad Tracks/Curbs
9. RR Crossbuck/Signal Pole	9. Large Ditch

OTHER OBJECTS

(Grouped Together for Analysis)

Point Objects	Continuous Objects
10. Woodpile	10. Waterfront
11. Rocks/Boulder	11. Tombstones
12. Electrical Box	12. Brick Wall
13. Tombstone	13. Junk
14. Buildings	14. Building
15. Gas Pumps/Service Island	15. Electric Tower
16. Wood Post	16. Parking Lot/Parked Cars
17. Lawn Ornaments	17. Tunnel
18. Gate Posts/Pillar	18. Cement Stairs
19. Dumpster	
20. Barbeque (Brick)	
21. Cement Steps	
22. Guide Wire	
23. Gas Tanks	
24. Junk	
25. Fence	
26. Pipe	
27. Brick Sign	
28. Electric Tower	
29. Cattle Guard	
30. Phone Booth	
31. Concrete Wall Perpendicular to Road	
32. Flag Pole	
33. Concrete Gate	
34. Water Tower	
35. Billboard	
36. Gate	
37. Tree Stump	
38. Playground (equipment)	

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 which would be representative of the overall roadside hazard for the section. However, very little 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 13 highway and roadside safety professionals. At the workshop, hundreds of photographs of roadside situations in both rural and urban areas (from more than 15 States) were organized and shown to workshop participants. These participants rated situations in each photograph in terms of the potential frequency and the potential severity of accidents and also in terms of overall hazard (or a combined scale). A two-dimensional rating scale, involving a 3 x 3 matrix with frequency on the horizontal axis and severity on the vertical axis, was then tested at the workshop. In general, workshop participants considered the use of the matrix difficult and confusing. It was also found out that a two-dimensional rating scale would make analysis difficult.

Three ordinal, 7-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 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 the accident damage likely to be sustained by errant vehicles on a scale from one (low likelihood of off-roadway collision or overturn) to seven (high likelihood of accidents 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 13 observers were asked to rate 141 rural photographs and 78 urban photographs (64 without on-street parking, 14 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 and ranges of the ratings for each photograph were used to measure the rating consistency.

In summary, the hazard scale was the most desirable scale for rural areas, while the separate frequency and severity scales were best-suited for urban areas. For statistical analysis purposes (including model development), the hazard scale was highly desirable, compared to the other two scales. 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. The photographs that were included in the final urban and rural hazard rating scales are provided in appendix B of Volume I. Note the large obstacles close to the roadway for a hazard rating of 7 and the clear, level roadside for a hazard rating of 1. A more detailed description of the testing between rating scales is provided in appendix E of Volume II.

For data collection purposes for each section in this study, roadside hazard ratings were recorded each tenth of a mile on each side of the road or a total of 20 measurements per mile. For each roadway section, the following roadside hazard rating variables were coded:

1. Type of scale used for roadside rating (i.e., did the roadside appear more like the rural scale or urban scale).
2. Number of roadside ratings of each rating level (i.e., number of ratings of 1, 2, 3, 4, 5, 6, and 7).
3. Median (50 percentile) roadside rating.
4. 20 percentile roadside rating.
5. 80 percentile roadside rating.

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 flat unobstructed, and smooth area adjacent to the outside edge of the travel lane (i.e., 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;
> - A longitudinal element such as a guardrail, bridge rail, or barrier curb;
> - An unyielding and hazardous object;
> - The ditch line of a non-traversable side ditch (considering as an approximation that a ditch is traversable if both foreslope and backslope are 4:1 or flatter) or;
> - 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 the photolog film at 0.1 mile intervals (i.e., every tenth frame of film) for each section on both sides of the road, or a total of 20 measurements per mile. A series of calibrated grid overlays (with lines of lateral distances from the edge of the travel lane) were used on the photolog film to measure the clear recovery distance at the selected frames. Since an observer could view about 0.1 mile down the road in each frame and measurements were taken every 0.1 mile, the measurements of roadside recovery distance represented a nearly 100 percent sampling of roadside 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 (e.g., 20, 50 and 80 percentile). Separate variables were also computed which provide the percent of the section with recovery area of ≤ 5 feet, ≤ 10 feet, ≤ 15 feet, ≤ 20 feet, ≤ 25 feet, and ≥ 30 feet.

Accident Variables

For most of the selected roadway sections, accident data were collected for a five year period from the State's computer records. For approximately five percent of the roadway sections, accident data for two to three years were used, to exclude time periods where roadway characteristics changed or where accident data were not readily available. Nonuniform variables and definitions between the seven States had to be considered in re-defining 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 following accident information was selected:

1. Number of years of accident data (five years in most cases).
2. Total number of accidents on the section.
3. Number of accidents by severity category (property damage only, injury, or fatal).
4. Number of people injured.
5. Number of people killed.
6. Number of accidents by injury category (A-type, B-type, and C-type injury accidents).
7. Number of people injured by injury category (A-type, B-type, and C-type injuries).
8. Number of accidents by light conditions (daylight, dawn or dusk, dark with lights, dark without lights, and unknown light condition).
9. Number of accidents by pavement condition (dry, wet, icy, or unknown).
10. 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).

11. Number of accidents involving fixed objects by object type (trees, signs, utility or light poles, mailboxes, culverts, bridge columns, bridge ends, fire hydrants, railroad signals, guardrails, bridge rails, rocks, barriers or walls, fences, earth embankments, other fixed object accidents).

Site Selection Plan

To fulfill the study objectives, a comprehensive data base had to be developed and analyzed. Thus, a careful plan was needed to select the most appropriate State highway agencies and suitable data collection sites. The following explains the site selection procedure.

Selection of State Highway Systems for Data Collection

State highway systems which best satisfied the following criteria were chosen:

- Criterion 1 - State highway agencies should have a willingness to cooperate in the study by providing available accident data, photolog film, and roadway information, since such data are needed for the analysis.

- Criterion 2 - A variety of geographic regions, terrain, climate conditions, and roadway design practices must be available within the selected State highway systems. Although a data base cannot totally represent all situations in the U.S., the selection of seven States with different conditions was thought to lead to results that would be more generally applicable to a wide range of highway situations.

- Criterion 3 - The selected State highway agencies must all have reasonably low accident reporting thresholds (i.e., $500 or less per accident). This would allow the data to be consistent, and also help to avoid using States with a low portion of property-damage-only (PDO) accidents. If this criteria is not met, biased information could result.

- Criterion 4 - State highway agencies must have adequate and reasonably consistent coding of specific accident types and injury levels. Since the study will analyze specific accident types (i.e., run-off-road, fixed-object, etc.) and injury levels (i.e, fatal, and A, B, and C-type injuries), such information must be reliable to insure reasonable consistency in developing a seven-State data base.

- Criterion 5 - Five years of computer accident data must be readily available by the State highway agencies for specific sites. This will help to insure adequate accident sample sizes.

- Criterion 6 - State highway agencies must have accurate and reliable locational information which has been converted to a milepoint base and coded appropriately on a computerized system. This is essential to allow for reasonable accuracy in matching accident experience on each section with corresponding traffic and geometric conditions.

- Criterion 7 - State highway agencies must be able to produce a computer tape or printouts of accidents for each of the selected roadway sections for analysis purposes (to minimize costly manual data handling and processing).

- Criterion 8 - A reliable computerized roadway inventory must be maintained by the State highway agencies containing key physical and cross-sectional roadway features for their rural, two-lane roads and urban-suburban streets. Such inventories are important for data checking purposes.

- Criterion 9 - State highway agencies must have accurate, current traffic volume (ADT) data for a large sample (i.e., several hundred miles) of rural and urban two-lane roads, since ADT information is a necessary variable for computing accident rates.

- Criterion 10 - Photolog film must be available for collecting roadside and other information accurately and efficiently.

To apply these criteria for selecting State highway agencies, available information was compiled from the literature and other sources and discussions were held with TRB and FHWA representatives in this regard.

After applying the 10 criteria, the following seven State highway agencies were selected for study purposes.

- Alabama
- Michigan
- Montana
- North Carolina
- Utah
- Washington
- West Virginia

Highway systems in these States provided a wide distribution of geographic characteristics, climate conditions, roadway designs, terrain conditions, traffic conditions, and other factors.

Selection of Test Sites

Approximately 5,000 miles of two-lane roads were selected to meet sample size requirements. Sites were selected using stratified random sampling based on the following criteria:

- Only two-lane rural and urban-suburban sites were selected.

- Stratified random sampling techniques were used to insure an adequate range of roadway sections within different classes of lane width, shoulder width, ADT, etc.

- Section lengths ranged from approximately one to ten miles for rural sections to insure a stable data set for modelling purposes. Due to more frequent roadway changes in urban streets, shorter sections of 0.5 miles to 5 miles were selected.

- Selected sections were chosen which were relatively homogeneous throughout the section regarding basic geometric and operational features. For example, a section should end when moderate changes occurred in ADT, lane width changed by one foot or more, shoulder width changed by more than three or four feet, or a noticeable change occurred in roadside condition.

The Highway Performance Monitoring System (HPMS) data base was used as the initial source for site selection purposes in the seven States for the following reasons:

- The sections are randomly selected, as desired.

- Many of the sections are one mile or greater and homogeneous in terms of basic cross-sectional elements.

- Several of the needed data items are available on the HPMS file (i.e., horizontal and vertical curvature data).

Stratified random sampling was used to select sites to fill the following categories of cross-sectional elements:

- Lane width: 8 and 9 feet
10 feet
11 feet
$\geq$12 feet

- Shoulder width: 0 to 4 feet
5 to 8 feet
$\geq$9 feet

- Shoulder surface type: paved
stabilized or gravel
earth or dirt

Selecting from these categories was also expected to produce a variety of roadside conditions for analysis. Samples were selected only on State numbered or US numbered routes, since accident data was found to be more accurate and complete on those systems (i.e., investigated by State police) than on local road systems. Adequate samples were found of 10, 11, and 12-foot lanes and with gravel or paved shoulders. Considerable effort was expended to locate sufficient samples of 8 and 9-foot lane widths and sections with earth shoulders on the State and US routes in the seven States. State inventory files were used to supplement the HPMS site selection process to fulfill certain data combinations.

Data Collection Methods

The data collection methods are discussed below in terms of the (1) coordination with the seven State agencies, (2) sampling requirements, (3) data sources and uses, and (4) creation of the data base.

Coordinations with Agencies

States were initially contacted by FHWA representatives, and then visits were made by the project team members to:

- Meet with State personnel and discuss the project purpose.
- Get a first-hand view of the various data files and photologs.
- Select candidate sites.
- Obtain basic file formats and discuss needed accident, traffic, and roadway files.
- Obtain project cost data, if available.
- Make field visits to several candidate sites for a first-hand look at local geometric designs and to drive the roads to get a driver's perspective.

In each State, computerized roadway inventories were obtained for use in final site selection. Also, calibrated grid overlays had to be developed for photolog viewing machines in each State for use in extracting lateral placement data for roadside obstacles. After all data collection procedures were finalized, cooperation was provided by the States in allowing data collection teams to use their photolog films.

Sampling Requirements

The primary focus of this study was on rural two-lane roads, so a sufficient sample was needed of two-lane rural highways for model-building purposes. Also, a limited sample of urban and suburban two-lane streets was desired, primarily for roadside analysis purposes. The overall data sample was desired which covered not only a variety of geographic conditions, but also included a sufficient range of lane width (i.e., ≤9 feet, 10 feet, 11 feet, and ≥12 feet), shoulder width (i.e., 01, 2-6, 7-9, and 10-12 feet), shoulder type (paved, gravel or stabilized; and earth or dirt), ADT (50-400, 401-750, 751-1,000, 1,001-2,000, 2,001-4,000, 4,001-7,500, and >7,500), terrain conditions (flat, rolling, and mountainous), and area type (rural and urban). A variety of roadside conditions was also expected to result from such sampling (e.g., clear roadsides, roadsides cluttered with trees and other obstacles, steep slopes, guardrail along roadside, utility poles next to roadway, sidewalks and front yards in residential areas). It should be noted that due to real-world considerations, many combinations of geometric and traffic features do not normally exist (e.g., roads having 8-foot lane widths with 12-foot paved shoulders).

Estimates of minimum sample sizes were made based on the following factors:

- Sample sizes considered necessary for sufficient reliability for accident modeling purposes.
- Sampling requirements based on expected accident differences and normal confidence levels for statistical testing.
- Data collection costs.

A sampling of 4,000 to 5,000 miles was considered to be more than adequate for both meaningful analysis and for accident modeling purposes. Based on these considerations and project cost considerations, a final sample of 4,950 miles of data were collected.

Data Sources

The data sources for the accident analysis included field data collection, photologs, State agency records (i.e., maps, ADT listings computerized roadway inventories), police accident records (either computer accident tapes or computer accident summaries), and the HPMS (Highway Performance Monitoring System) computer data base. As summarized in table 3, most of the roadway information was extracted from photologs. This included roadside data for individual obstacles, roadside hazard ratings, and measures of roadside recovery distance.

Analysis Group, Inc., under a separate contract with FHWA, collected field data on sideslope and cross-sectional elements (i.e., lane width, shoulder widths and types, ditch information) for sample sections in Alabama, Washington, and Michigan. This field data collection process included approximately 2,400 miles of rural roadway. State records were used as a primary source for ADT data and vertical and horizontal curvature data for many of the sections (i.e., non-HPMS sections). The HPMS data base 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 source of all accident data in the seven States, and project cost data were obtained directly from nine States from recent cost tables and documents.

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 approximately half of the rural sample. For many data variables, the photolog measurements were the primary data source, but checking was made with state inventory data and/or HPMS data. Inconsistencies of measurements of key data variables were resolved.

Data Collection Methods

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 data base. Therefore, some zero-accident sections resulted. Stratified random sampling was used to select sections within certain needed categories of

Table 3. Data sources.

Data Variables	Data Sources: Field Data Collection	Photologs	State Agency Records	Police Accident Records	HPMS Data File
Area Type		P			S
Type of Development		P			S
Terrain		P			S
Section Length		P			
ADT			P		P
Speed Limit		P			S
Horizontal Curvature			P		P
Vertical Curvature			P		P
Sideslope	P	P			
Lane Width	P	P	S		S
Paved Shoulder Width	P	P	S		S
Gravel Shoulder Width	P	P	S		S
Earth or Dirt Shoulder Width	P	P			
Ditch Type	P				
Length of Slope	P	S			
Pavement Type		P			
Delineation		P			
Parking Allowed		P			
Parking Side of Street		P			
No. Signalized Intersections		P			
No. Stop Sign Intersections		P			
No. of Other Intersections		P			
No. of Bridges		P			
No. of Overpasses		P			
No. of Structures		P			
No. of Railroad Crossings		P			
No. of Residential Driveways		P			
No. Com./Res./Ind. Driveways		P			
No. Total Driveways		P			
Cross-Section Design	S	P			
Specific Obstacle Data		P			
Roadside Hazard Rating		P			
Roadside Recovery Distance		P			
Accident Data				P	

P = Primary data source

S = Secondary data source

ADT, lane width, and shoulder width and type. This was necessary since a data base of nearly all 11 and 12-foot lanes, for example, would not allow for determining effects of varying lane width (i.e., 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). Locational 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. Three data forms used with photolog film included those for basic roadway data (Form A), cross-section data (Form B), and detailed roadside obstacle data (Form C), as shown in figures 1, 2 and 3.

For data involving lane and shoulder widths and lateral placement of roadside obstacles, a calibrated grid was placed over the photolog viewing screens (see figure 4) for each photolog frame. This process allowed for coding each roadside obstacle by type (tree, sign, utility pole, etc.) and lateral distance category (0 to 1 foot, 2 to 3 feet, etc.) on Form C. For continuous obstacles, such as guardrails, the number of photolog frames was recorded for each obstacle type by offset categories. Since each photolog frame corresponded to 52.8 feet, the total length of continuous obstacles along each section was later computed.

Sideslope and related field data were collected and coded by Analysis Group, Inc. under a separate contract with FHWA. This data collection process was conducted in three States and involved two-person field crews who were given maps showing preselected sections. Each team travelled to assigned sections and collected measurements of roadside slopes, lane width, shoulder widths, ditch information, length of slope, and cross-section type. Also, information was collected on total roadway width, and width between joints and edgelines. A slope angle instrument was developed to measure the angle of slope to the nearest degree. The field data were coded and keyed, and a computer tape was provided for merging with the other data variables.

Form A - ROADWAY INFORMATION FORM

GGID 4002 State North Carolina County Anson Route ____

Coder JMM/JMB Date Coded 10-3-85 Beginning MP 23.8 Ending MP 26.25

Film Beginning MP 23.86 Film Ending MP 26.31 Section Length 2.45

Film ID Reel 147 Control Section # ——

Verify (Check)

2-lane ✓
2-way ✓
No Median ✓
Paved ✓

Pavement Type (Circle One)

1 Concrete
(2) Bituminous
3 Combination of both

Terrain (Circle One)

1 Flat
(2) Rolling
3 Mountainous

Type of Development (Circle One)

(1) Rural
2 Rural Dense
3 Urban CBD
4 Urban Fringe
5 Urban OBD
6 Urban Residential

Delineation (Circle One)

(1) Centerline and edgeline striping
2 Centerline striping only
3 No Centerline or edgeline striping
4 Edgeline striping only

Parking (Urban or Dense Rural) (Circle One)

(1) Not Permitted
2 Permitted with restriction (peak periods) weekdays, etc.)
3 Allowed any time

Parking-Side of Street (Circle One)

(1) Not allowed
2 Permitted one side
3 Permitted both sides

Number of Intersections

Signal 0
Stop Sign 0
Other or no control ////

Total 4

Number of Structures

Number of Bridges 0
Number of Overpasses 0
Total 0

Number of RR Crossings 0

Number of Driveways

Direction North
Residential ~~||||~~ ~~||||~~ |||| (14)
Commercial/Recreational Industrial ||| (3)

Direction South
Residential ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ || (22)
Commercial/Recreational Industrial |||| (4)

Total 43

Speed Limit 55

Notes ____

Figure 1. Roadway information data collection form (Form A).

GGID 4002 State North Carolina County Anson Route ______ Check One ___ Urban ___ Suburban ✓ Rural

Coder JMM/JMB Date Coded 10-3-85 Beginning MP 23.8 Ending MP 26.25 Page 1 of 2

Film ID ______ Film Beginning MP 23.86 Film Ending MP 25.76 Section Length 2.00

Data Point	MP	Roadside Rating (1-7)	Total Paved Width	Lane Width #1 (centerline to joint)	Lane Width #2 (centerline to edgeline)	Shoulder Width S1	Shoulder Width S2	Shoulder Width S3	Shoulder Type T1	Shoulder Type T2	Shoulder Type T3	Cross-Section Design	Sideslope Config.	Sideslope Length	Sideslope Slope	Recovery Area Distance
1	23.86	4	24	12	12	5	0	0	5	0	0	5	1	1	4	5
2	23.96	4											2	1	8	5
3	24.06	4											1	1	8	10
4	24.16	4											2	1	3	5
5	24.26	4											2	1	8	6
6	24.36	4											2	1	3	5
7	24.46	4											2	1	8	6
8	24.56	3											2	1	9	15
9	24.66	2											2	1	9	30
10	24.76	3											2	1	3	20
11	24.86	4											2	1	7	10
12	24.96	3											1	2	5	20
13	25.06	4											2	1	3	10
14	25.16	4											2	1	3	10
15	25.26	3											2	1	9	20
16	25.36	4											1	1	9	10
17	25.46	5											1	1	5	5
18	25.56	2											2	1	8	30
19	25.66	4											2	1	8	10
20	25.76	4											2	1	8	10

Cross Section Design

1 Single smooth paved surface
2 Paved shoulders (joint)
3 Shoulder partly paved and partly gravel or stabilized.
4 Gravel or stabilized shoulder
5 Grass or dirt shoulder
6 No Shoulder
7 Curb

Shoulder Type

1 Bituminous
2 Concrete
3 Stabilized
4 Gravel
5 Grass
6 Dirt
7 Curb
8 Other

Sideslope

Configuration

0 None
1 Gradual downslope
2 Moderate downslope
3 Hill
4 Steep downslope

Length

1 0-10
2 11-30
3 > 30

Figure 2. Subjective roadside rating, lane width, shoulder width and shoulder type data collection form (Form B).

GGID 4002 State North Carolina County Anson Route ______

Coder JMM | DG Date Coded 10-3-85 Beginning MP 23.8 Ending MP 26.25 Page 1 of 3

Film Beginning MP 23.86 Film Ending MP 24.86

TYPE OF OBSTACLE	DISTANCE FROM ROADWAY EDGE (FEET)							
POINT OBJECTS	0-1	2-3	4-6	7-10	11-15	16-20	21-25	26-30
Trees >4-inch diameter					|| (2)	卌 || (7)		|||| (4)
Signs (small posts)			卌|| (7)	|| (2)	卌 (5)			
Signs (large posts)								
Utility Poles (Electrical or telephone lines)				||| (3)	卌 | (6)	||| (3)		|||| (4)
Luminaire Supports (light poles)								
Multiple/Massive Mailboxes/Newsboxes (Post >4-inch diameter)			|| (2)	||| (3)				
Culvert Headwalls				| (1)				
Bridge Columns								
Bridge Abutments								
Fire Hydrant				| (1)	| (1)			
RR Crossbuck/Signal/Switch Box								
Other (Specify) Guide wire				| (1)		| (1)		
Other (Specify) Building							| (1)	
Other (Specify) Wooden post					| (1)			
Other (Specify)								

CONTINUOUS OBJECTS

	0-1	2-3	4-6	7-10	11-15	16-20	21-25	26-30
Continuous Trees (>8 in 150 feet)				3, (3)	3,2,1 (6)		3 (2)	1,2,3,6 (12)
Steel-Beam Guardrail								
Cable Guardrail								
Bridge Rail								
Rock Cuts								
Concrete Barrier Wall								
Fences					4,5 (9)			
Other (Specify)								
Other (Specify)								
Other (Specify)								

Figure 3. Roadside obstacle data collection form (Form C).

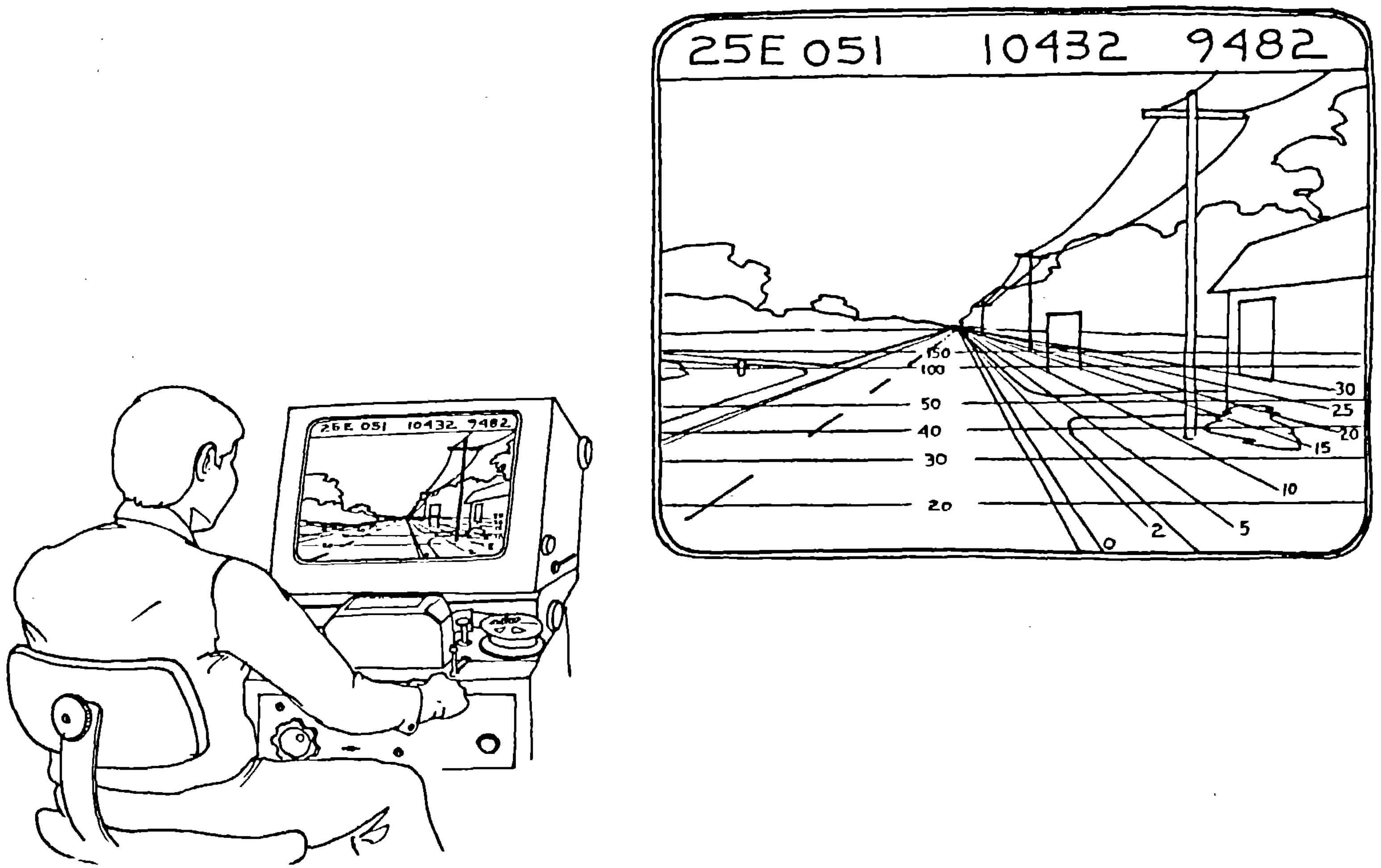


Figure 4. Photolog screen and grid overlay.

For sections in the other four States where field sideslope data were not collected, an alternative procedure was used. Color photographs were taken of a range of sideslopes (i.e., 1:1, 2:1, 3:1, 4:1, 6:1, 8:1, etc.) on two-lane sections in several States. A pictorial chart was developed which showed 10 categories of sideslopes and/or roadside situations as follows:

Code	Situation
1	Guardrail: no sideslope
2	Level slope or slight upgrade
3	Driveable sideslope
4	Non-driveable sideslope
5	Mixed Slopes
6	2:1 sideslope or steeper
7	3:1 sideslope
8	4:1 sideslope
9	6:1 sideslope
10	8:1 sideslope

After considerable training, photolog personnel recorded one of these codes at each 0.1 mile (every tenth photolog frame) in each direction. Such subjective photolog sideslope data were collected for all rural sections in five states and portions of Washington. For approximately 300 sections in Alabama and Washington, both fixed sideslope measures and photolog sideslope codes were taken for comparison purposes. (As discussed later, there was reasonable agreement in the two measures.)

Creation of the Data Base

Close data quality control was practiced throughout the data collection process. All data was double-keyed into a computer file for analysis purposes. A series of software check programs were written which read data for each section and checked the following items:

- Each data variable against allowable lower and upper limits;
- The logic of accident totals (i.e., 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 insure agreement for all data sources (HPMS, photolog, State records, and field measurements).

All data "outliers" were printed and corrected either manually (by reviewing the raw coded data) or by computer program (to eliminate any pattern of data inconsistency).

Data were processed from six different files:

<u>File</u>

1 - Curve and ADT data
2 - Field sideslope and cross-section data
3 - Form A: Basic Roadway photolog data
4 - Form B: Cross-Section photolog data
5 - Form C: Detailed roadside obstacle photolog data
6 - Accident data from seven States.

Extensive data checks were performed on the Master File prior to producing the Condensed Master File. This final file contained 325 data variables corresponding to 868 characters for each roadway section, or record. With 1,944 records (roadway sections) and 868 characters per record, the data base consisted of 1.69 million data characters.

CHAPTER 4 - RESULTS OF DATA ANALYSIS

The data analysis was structured to address the analysis issues listed in chapter 3. This involved the development of an accident predictive model and the use of various statistical tests. The analysis topics discussed in this chapter include:

- Data Base Characteristics
- General Accident Characteristics
- Determination of Important Variables
- Selection of Traffic and Roadway Variables
- Accident Relationships with Key Variables

Data Base Characteristics

The data base contained data on 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 and 2.55 miles overall. Data were collected on approximately 1,033 miles 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 0 to 12 feet and lane widths varied from 8 to 14 feet, as summarized in table 4. 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 ADT's of 750 or less (table 5).

A summary of the number of sections and mileage (in parenthesis) of the data base by area type and speed limit is presented in table 6. 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

Table 4. Descriptive statistics for the total data base -- lane width and shoulder width.

Number of Sections, With Total Mileage in Parentheses							
Shoulder Width (ft)	Lane Width (ft)						Total
	8	9	10	11	12	13-14	
0 - 1	0 -	20 (50.8)	45 (125.9)	38 (108.9)	87 (241.6)	42 (126.5)	232 (653.8)
2 - 3	6 (8.7)	58 (151.3)	89 (206.5)	72 (191.4)	73 (171.2)	23 (56.0)	321 (794.7)
4 - 5	3 (10.2)	127 (347.8)	117 (279.2)	172 (394.4)	122 (272.3)	26 (72.6)	567 (1,376.7)
6 - 7	0 -	40 (80.0)	57 (143.1)	80 (219.9)	68 (171.6)	17 (37.8)	262 (652.2)
8 - 9	0 -	18 (47.8)	36 (100.2)	113 (298.2)	99 (248.7)	8 (24.8)	274 (719.8)
10 - 13	0 -	15 (43.0)	29 (72.6)	92 (244.7)	152 (347.5)	0 -	288 (707.8)
Total	9 (28.5)	278 (722.2)	373 (936.7)	567 (1,483.3)	601 (1,462.9)	116 (317.6)	1,944 (4,951.3)

Table 5. Descriptive statistics for the total data base -- ADT and lane width.

Number of Sections, With Total Mileage in Parentheses							
	Lane Width (ft)						
ADT	8	9	10	11	12	13-14	Total
1-250	1 (5.0)	6 (19.8)	10 (28.6)	12 (36.5)	16 (45.2)	7 (21.1)	52 (156.2)
251-400	1 (3.6)	22 (71.9)	13 (35.3)	14 (42.8)	20 (67.7)	15 (54.2)	85 (275.6)
401-750	2 (5.0)	47 (154.1)	36 (118.0)	24 (93.4)	32 (109.0)	10 (27.0)	151 (506.6)
751-1,000	0 -	40 (121.5)	26 (70.2)	23 (78.0)	30 (95.7)	5 (14.7)	124 (380.2)
1,001-2,000	4 (11.9)	69 (188.4)	78 (225.7)	106 (310.0)	99 (282.4)	21 (66.7)	377 (1,085.2)
2,001-4,000	1 (3.0)	59 (112.3)	99 (245.2)	116 (450.5)	182 (428.4)	23 (67.3)	530 (1,306.7)
4,001-7,500	0 -	28 (45.3)	64 (130.0)	151 (337.2)	133 (290.7)	27 (49.9)	403 (853.1)
7,501 and higher	0 -	7 (9.0)	47 (83.4)	71 (134.7)	89 (143.8)	8 (16.8)	222 (387.7)
Total	9 (28.5)	278 (722.2)	373 (936.7)	567 (1,483.3)	601 (1,462.9)	116 (317.6)	1,944 (4,951.3)

Table 6. Descriptive statistics for the total data base -- area type and speed limit.

Number of Sections, With Total Mileage in Parentheses								
	Speed Limit (mph)							
Area Type	25	30	35	40	45	50	55	Total
Rural	8 (13.77)	9 (16.15)	52 (91.68)	42 (73.60)	131 (242.73)	94 (228.15)	1,465 (4,119.06)	1,801 (4,785.14)
Urban	10 (10.90)	12 (14.00)	53 (52.19)	13 (15.14)	29 (32.79)	8 (13.91)	18 (27.21)	143 (166.14)
Total	18 (24.67)	21 (30.15)	105 (143.87)	55 (88.74)	160 (275.52)	102 (242.06)	1,483 (4,146.27)	1,944 (4,951.28)

with speed limits of 25 to 35 mph. The predominance of 55 mph speed limits for sections in the rural data base prevented an in-depth analysis of the effects of speed limit on accident experience. Of the 166.14 miles of urban roads, 52.19 miles (31.4 percent) had a speed limit of 35 mph, with 89.05 miles (53.6 percent) above 35 mph and 24.9 miles (15.0 percent) below 35 mph. 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, as summarized in table 7. The data base also included sections with wide ranges of speed limits (25 to 55), roadside conditions, sideslopes, curvature, and other factors. Detailed descriptions of the data base for numerous factors are given in appendix F.

General Accident Characteristics

There were 62,676 total reported accidents on sections in the data base including 38,857 property damage only accidents (62.0 percent), 22,944 injury accidents (36.6 percent), and 875 fatal accidents (1.4 percent), as shown in table 8. A review of the accident data by type revealed that the most frequently reported accidents were angle and turning (23.5 percent), 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 (100 MVM), or 3.69 accidents per mile per year.

Of the 1,944 sample sections in the data base, 1,468 were from rural areas, and the remaining 476 were from urbanized areas (i.e., 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). Total single-vehicle accident rates were computed for the three types of roadways, as shown in table 9 for different lane widths. The total accident rate in rural areas was 219 per 100 MVM, compared to 330 for the U/R sections, and 603 for the urban sections. The single-vehicle accident rate for the U/R sections was similar to urban sections for lane widths of 10 feet or less. However, for lane widths of 11 feet or more, the rate of single-vehicle accidents was relatively similar for rural sections, U/R sections, and urban sections.

Table 7. Descriptive statistics for the total data base -- State and terrain.

Number of Sections, with Total Mileage in Parentheses				
	Terrain			
State	Flat	Rolling	Mountainous	Total
Ala.	134 (239.2)	294 (760.1)	9 (33.6)	437 (1,032.9)
Mich.	242 (583.7)	40 (115.4)	0 -	282 (699.1)
Mont.	76 (220.4)	56 (211.4)	36 (114.8)	168 (546.6)
N.C.	124 (350.0)	112 (277.7)	39 (117.9)	275 (745.6)
Utah	96 (238.9)	78 (212.9)	29 (73.1)	203 (524.9)
Wash.	92 (282.9)	110 (348.8)	29 (105.1)	231 (736.8)
W.V.	16 (31.7)	115 (207.7)	217 (426.0)	348 (665.4)
Total	780 (1,946.8)	805 (2,134.0)	359 (870.5)	1,944 (4,951.3)

Table 8. Summary of accident statistics for the total data base.

Variable Name	No. of Accs.	Acc/100 MVM	Acc/Mi/Yr	% of Total Accs.
Total Accs.	62,676	266.35	3.69	100.0
PDO Accs.	38,857	167.48	2.37	62.0
Injury Accs.	22,944	94.60	1.28	36.6
Fatal Accs.	875	4.28	0.04	1.4
People Injured*	37,321*	150.63*	2.07*	N/A
People Killed*	1,068*	5.16*	0.05*	N/A
Daylight Accs.	37,402	157.62	2.31	59.7
Dawn or Dusk Accs.	2,888	11.94	0.16	4.6
Dk. with Lights	2,770	10.88	0.21	4.4
Dk. w/o Lights	19,496	85.05	1.00	31.1
Unkn. Light Cond.	120	0.87	0.01	0.2
Dry Accs.	41,957	180.84	2.48	66.9
Wet Accs.	13,487	54.37	0.83	21.5
Snow/Ice Accs.	6,657	28.15	0.34	10.6
Unkn. Pvt. Accs.	575	2.99	0.04	0.9
ROR - Fixed Object	12,091	55.14	0.60	19.3
ROR - Rollover	4,245	24.50	0.18	6.8
ROR - Other	2,840	15.14	0.16	4.5
Head-On	2,113	8.40	0.12	3.4
Sideswipe - Opp. Dir.	2,997	13.09	0.18	4.8
Sideswipe - Same Dir.	2,288	10.29	0.16	3.7
Rear End	12,420	39.89	0.83	19.8
Parking	1,155	5.66	0.08	1.8
Ped./Bike/Moped	655	2.50	0.04	1.0
Angle & Turning	14,730	56.32	1.02	23.5
Train	47	0.31	0.002	0.1
Animal	5,212	25.37	0.22	8.3
Other or Unknown	1,883	9.75	0.11	3.0

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

N/A = Not Applicable.

Table 9. Unadjusted accident rates by area type and lane width.

			Sections in Urbanized Areas					
	Rural Sections		Rural Appearance		Urban Appearance		Totals	
Lane Width (feet)	Total Acc/100 MVM	SV Acc/100 MVM	Total Acc/100 MVM	SV Acc/100 MVM	Total Acc/100 MVM	SV Acc/100 MVM	Total Acc/100 MVM	SV Acc/100 MVM
8 & 9	278(235)	144(235)	330(39)	57(39)	638(13)	62(13)	302(287)	129(287)
10	282(276)	141(276)	367(70)	87(70)	405(27)	69(27)	307(373)	126(373)
11	191(422)	78(422)	331(102)	65(102)	647(43)	74(43)	251(567)	75(567)
$\geq$ 12	182(535)	81(535)	308(122)	73(122)	654(60)	92(60)	243(717)	80(717)
Totals	219(1,468)	102(1,468)	330(333)	72(333)	603(143)	80(143)	266(1,944)	95(1,944)

For purposes of the predictive model, only the "pure" rural sections were used (i.e., U/R and urban sections were excluded). For analyses in which urban and rural sections were analyzed separately, the U/R sections were included with the rural sections, since the appearance and total accident rates of the U/R sections were more similar to the rural sections than the urban sections. In such cases, the 1,468 "pure" rural sections were grouped with the 333 U/R sections to result in the 1,801 so-called rural sections. The remaining 143 urban sections were analyzed as a separate group.

A summary of accident statistics is given for the 1,801 rural sections and 143 urban sections in table 10. 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 only a few of the possible factors which may cause higher accident rates in urban areas than rural areas.

In terms of accident severity, injury accidents comprised 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. Rates were higher in rural areas than in urban areas for rollover, run-off-road (nonfixed object), train, and animal accidents. Urban rates were higher for the remaining accident types, and particularly for angle, turning, rear end, and same direction sideswipe accidents.

A detailed review of the distribution of the variables in the data base was made to examine the quality of the data. The minimum, maximum, mean, and standard deviation were computed for selected variables, as summarized in table 11. Lane widths ranged from 8 to 14 feet and shoulder widths varied from zero to 12 feet (11 feet for earth shoulders). There was an average of 2.35 intersections per mile (maximum of 11 on one section), 0.20 bridges per mile, and 0.21 structures per mile. There were

Table 10. 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.

Table 11. Summary of statistics for selected variables.

No.	Variable	No. of Cases	Maximum Value	Minimum Value	Mean	Standard Deviation
1.	Percent of Section ≥ 2.5 Deg. Curve	1,157	100	0	17.56	21.15
2.	Percent of Section ≥ 2.5 Percent Grade	942	100	0	18.60	22.98
3.	Lane Width	1,944	14	8	10.94	1.17
4.	Avg. Paved Shoulder Width	1,944	12	0	1.54	2.74
5.	Avg. Gravel Shoulder Width	1,944	12	0	2.08	3.00
6.	Avg. Earth or Grass Shoulder Width	1,944	11	0	1.72	2.99
7.	Intersections per Mile	1,944	21	0	2.35	2.57
8.	Bridges per Mile	1,944	4	0	0.20	0.40
9.	Structures per Mile	1,944	4	0	0.21	0.43
10.	Driveways per Mile	1,944	81	0	13.77	13.60
11.	Median Roadside Rating	1,944	7	1	3.95	0.87
12.	Avg. Recovery Area Distance	1,944	30	1	13.17	6.12
13.	Median Recovery Area Distance	1,944	30	0	13.14	7.06
14.	Percent with Recovery Area Dist. ≤ 5 Feet	1,944	100	0	19.66	25.99
15.	Percent with Recovery Area Dist. ≤ 10 Feet	1,944	100	0	50.55	33.61
16.	Percent with Recovery Area Dist. ≤ 15 Feet	1,944	100	0	69.31	29.51
17.	Total Accidents-per-Mile-per-Year	1,944	71.14	0	3.69	6.04
18.	SV Accidents-per-Mile-per-Year	1,944	11.38	0	0.94	1.15
19.	SV + HO + SS Accidents-per-Mile-per-Year	1,944	19.02	0	1.39	1.86

SV = Single-vehicle (fixed object + rollover + other run-off-road)
HO = Head-on
SS = Sideswipe (opposite direction + same direction)

13.77 driveways per mile on the average (less than 7 on each side 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 a high volume section. There was 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 validity of the extremes.

A comparison was made of accident rates between the seven-State data base and previous accident studies. The FHWA study by Smith included accident rates and the percent of injury and fatal accidents for rural roads in many states by ADT group as shown in table 12.[1] Corresponding rates from the seven-State data base revealed close similarities. For example, rates of total accidents (per hundred million vehicle miles) were similar for each ADT group, except for ADT's greater than 10,000, where the rate of 244 from the seven-State data base 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 data base. Percentages of injury and fatal accidents also compared quite closely between the studies 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 13.[7] 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 data base for both total accidents and single-vehicle accidents. The differences are probably the result of wider shoulders for the sections with 9-foot lanes in the seven-State data base. For 13-foot lane widths, the Kentucky data base had a lower rate of single-vehicle accidents and a higher rate of total accidents than the seven-State data base. This may be the result of smaller sample sizes or other site differences. Overall, the seven-State data base agrees closely with data bases from the two other studies.

Table 12. Comparison of rural accident experience by ADT group for rural seven-State data base and Smith study.

Accident Measure	ADT Group						
	1-400	401-1,000	1,001-2,000	2,001-5,000	5,001-10,000	>10,000	Overall
Avg. Total Acc. Rate (Acc/100 MVM)	288(300)*	246(250)	228(230)	225(220)	257(250)	244(300)	240
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)	1.6
Percent Injury Accs.	38.9(36)	39.3(37)	38.8(37)	35.8(36)	37.7(35)	39.4(35)	37.5
Percent PDO Accs.	58.7(61.5)	57.6(60)	59.2(60)	62.4(61.5)	61.1(63)	59.8(63)	60.9
Number of Sections	137	275	370	654	285	80	1,801

*Values in parenthesis are from Smith Study.[1]

Table 13. Comparison of accident rates between Kentucky study and rural seven-State data base.*

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 parenthesis represent mileage of samples in each cell.

Determination of Important Variables

The development of the best possible accident predictive model required first determining the types of accidents which were most related to roadside or roadway elements of concern. For example, widening a narrow roadway would probably reduce head-on and single vehicle accidents with little or no effect on pedestrian, animal, and right-angle accidents. Roadside obstacle removal may reduce certain types of single vehicle fixed object accidents but not rear end accidents. Thus, there was a need to determine those types of accidents that have the strongest relationships to cross-section and roadside variables.

Because of the study design and objectives, the model was expected to include at least the following traffic and roadway variables: (1) traffic volume (ADT), (2) lane width, (3) shoulder width, (4) shoulder type, and (5) one or more measures of roadside condition (i.e., sideslope, recovery distance, roadside hazard rating). It was also expected that other important roadway variables would be included in the model. Thus, prior to the model building, these traffic and roadway variables of importance also had to be identified.

The analyses in this section were intended to provide input into the selection of variables for use in the model building process (i.e., macro analysis). Thus, the preliminary analyses in this section are not intended to result in the final accident relationships, since the accident model was expected to provide the more complete picture of the relationships between accidents and combinations of traffic and roadway variables. The final selection of variables for inclusion in the model was based on (1) which variables were logically related to accidents (e.g., lane width, shoulder width, shoulder type, and roadside conditions), (2) the Chi-square analysis, (3) step-wise 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 which were most highly correlated with lane width, shoulder width, shoulder type (e.g., paved, gravel, or earth) sideslope, roadside rating, and roadside recovery area (i.e., distance from edgeline to roadside obstacle). The significance levels were 0.05 or less for many of the tests, due primarily to large sample sizes and not necessarily to strong correlations. Thus, the contingency coefficient was used as the primary measure of association between the geometric elements of concern and the specific accident types. A matrix of contingency coefficients produced during the series of Chi-square tests is given in table 14 for various accident types and roadway features, where values of 0.220 or greater are circled. The value of 0.220 was selected since it differentiated the the upper third of the contingency coefficients in this particular case (although a 0.220 value does not necessarily apply to differentiate the upper third of contingency coefficients in general).

The individual accident types which consistently appeared to be highly correlated with the roadway features of concern were fixed object, run-off-road other, head-on, and sideswipe - opposite direction. Rollover accidents were highly correlated with shoulder width (coefficient of 0.263). A coefficient of 0.226 was found between rear end accidents and median recovery distance, although this relationship is not easily supported. Single-vehicle, total, and selected multivehicle accidents were found to be strongly associated with one or more of the roadway variables. Insufficient samples of pedestrian and train accidents were available for these analyses. Animal, parking, "angle and turning," and "other or unknown" accidents were not highly correlated with the roadway variables.

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

- Single-vehicle (i.e., fixed-object plus rollover plus run-off-road other).
- Related multivehicle (i.e., head-on plus sideswipe opposite direction plus sideswipe same direction) plus single-vehicle accidents.
- Total (as a measure of the overall effects of traffic roadway variables).

Table 14. Chi-square results for selected variables and each accident types for seven-State urban and rural data base (1,944 sections).

		Contingency Coefficients					
No.	Accident Type	Lane Width	Total Shoulder Width	Shoulder Type	Median Sideslope Code	Median Roadside Rating	Median Recovery Distance
1.	Total	0.184	0.220	0.244	0.181	0.235	0.298
2.	Fixed-Object	0.245	0.225	0.115	0.164	0.316	0.335
3.	ROR Rollover	0.179	0.263	0.126	0.195	0.163	0.188
4.	ROR Other	0.179	0.278	0.294	0.096	0.289	0.292
5.	Head-On	0.185	0.192	0.281	0.103	0.191	0.204
6.	Sideswipe - Opp. Dir.	0.224	0.292	0.301	0.073	0.280	0.288
7.	Sideswipe - Same Dir.	0.191	0.218	0.277	0.118	0.205	0.204
8.	Rear End	0.174	0.212	0.192	0.203	0.127	0.226
9.	Parking	0.085	0.097	0.124	0.076	0.158	0.219
10.	Ped./Bike/Moped	*	*	*	*	*	*
11.	Angle and Turning	0.165	0.210	0.177	0.154	0.148	0.133
12.	Train	*	*	*	*	*	*
13.	Animal	0.145	0.201	0.173	0.097	0.141	0.186
14.	Other or Unknown	0.148	0.151	0.158	0.050	0.123	0.137
15.	Single Vehicle (No. 2+3+4 above)	0.236	0.313	0.137	0.177	0.345	0.363
16.	Selected Multi-Vehicle (No. 5+6 above)	0.251	0.304	0.296	0.095	0.277	0.268

* = Insufficient data available of a given accident type.

Note: Numbers which are circled represent contingency coefficients of equal to or greater than 0.220.

Traffic and Roadway Variables

The most important variables for use in an accident predictive model were selected using a two-step process. First, since many of the geometric variables in the data base were interrelated or were derivations of the same variable, only one form of each variable was considered for use in the predictive model. For example, 13 different expressions were given in the condensed master file for the recovery distance, (distance from the edgeline to the nearest obstacle or hazard) including the maximum, minimum, average, median, 20th percentile, and 80th percentile values. The percent of the section with recovery distances ≤5 feet, ≤10 feet, ≤15 feet, ≤20 feet, ≤25 feet, ≤29 feet, and ≥30 feet were also recorded. Thus, the most appropriate and meaningful form of each variable was determined based on a review of the accident data, a knowledge of the variables, and the results from the literature.

The selection of some model forms was also based on data availability. For example, the candidate measures of horizontal curvature were as follows:

1. Percent with < 2.5 degree curve.
2. Percent with ≥ 2.5 degree curve.
3. Percent with ≥ 5.5 degree curve.
4. Percent with ≥ 7.0 degree curve.
5. Percent with ≥ 14.0 degree curve.
6. Percent with ≥ 19.5 degree curve.
7. Percent with ≥ 28.0 degree curve.

Few sections in the data base had curves of 14.0 degrees or greater. Thus, the use of variables 5, 6, or 7 above would have been inappropriate in the predictive model, since nearly all of the sample sections would have zeros for those variables. The percent with ≥ 2.5 degree curve was selected as the most useful expression of horizontal curvature based on a preliminary review of the data distributions.

For the model building process, the only roadside measures considered were those that represented overall roadside conditions. Detailed data on trees, guardrail, or other fixed-objects were used for the roadside analysis and not for the modelling.

Step-wise linear regression was used to select the most important traffic and roadway variables for inclusion in the model. For example, using the rate of single vehicle accidents as the dependent variable, this analysis selected the following six variables in order of importance:

1. Shoulder width
2. Median roadside hazard rating
3. Lane width
4. Median sideslope ratio
5. Percent of section with $\geq$ 2.5 degree curve
6. Median recovery area distance

ADT was not included as a candidate independent variable at this stage, since it was included in the dependent variable (single vehicle accident rate). It was later added into the model.

A series of Chi-square tests were also conducted to confirm the most important variables in terms of five different accident measures. Contingency coefficients are given in table 15 for various traffic and roadway variables for measures of single-vehicle accidents, related multivehicle accidents and for overall accident severity, where coefficients of 0.25 or greater are circled (corresponding to the top one-third of the contingency coefficients). Variables identified as important from the Chi-square analysis included ADT, terrain, lane width, type of development, shoulder width (paved and gravel), length of slope, roadside recovery distance, median roadside hazard rating, number of driveways per mile, and horizontal curvature. This process of variable screening was helpful as an input into the model building process.

Accident Relationships with Key Variables

Several specific issues were addressed to gain insights into the model-building process and the use of variables within the model. These issues are discussed below in terms of the rate (i.e., accidents per 100 MVM) of single-vehicle accidents where single-vehicle accidents were considered to include the number of (1) fixed object accidents, (2) rollover accidents and (3) other run-off-road accidents. The analysis of covariance was used to compute the adjusted mean rate of single-vehicle accidents

Table 15. Chi-square results for selected variables for the seven-State rural data base.

Variable		Contingency Coefficient				
No.	Name	SV Acc/ 100 MVM	SV Acc/ Mi/Yr	MV/Acc/ 100 MVM	MV Acc/ Mi/Yr	Injury Ratio*
3	Type of Development (R/U)	0.048	0.321	0.178	0.307	0.157
4	Terrain	0.274	0.208	0.342	0.222	0.226
6	ADT	0.304	0.488	0.421	0.472	0.237
7	Speed Limit	0.038	0.228	0.082	0.198	0.067
9	Horizontal Curve ≥ 2.5°	0.380	0.206	0.357	0.221	0.247
16	Vertical Curve ≥ 2.5°	0.156	0.066	0.208	0.139	0.096
21	Average Sideslope Ratio	0.228	0.226	0.130	0.148	0.370
29	Median Sideslope Ratio	0.230	0.224	0.099	0.136	0.372
33	Lane Width	0.251	0.138	0.264	0.128	0.118
34	Paved Shoulder Width	0.203	0.087	0.251	0.115	0.121
35	Gravel Shoulder Width	0.263	0.240	0.332	0.300	0.236
36	Earth Shoulder Width	0.153	0.152	0.191	0.123	0.083
34+35+36	Total Shoulder Width	0.322	0.187	0.315	0.216	0.207
37	Ditch Type	0.194	0.172	0.110	0.126	0.278
39	Slope Length	0.258	0.162	0.108	0.149	0.253
41	Pavement Type	0.080	0.094	0.255	0.173	0.097
42	Delineation	0.097	0.174	0.162	0.169	0.119
48/5	Intersections/Mile	0.130	0.275	0.188	0.263	0.192
49/5	Bridges/Mile	0.062	0.067	0.031	0.057	0.027
51/5	Structures/Mile	0.060	0.058	0.028	0.032	0.025
57/5	Driveways/Mile	0.175	0.379	0.278	0.382	0.203
67	Median Roadside Rating	0.348	0.263	0.279	0.199	0.244
71	Sideslope Configuration	0.187	0.159	0.210	0.153	0.173
72	Median Sideslope Length	0.183	0.244	0.164	0.168	0.195
73	Sideslope Code 1-10	0.238	0.246	0.166	0.200	0.174
86	Average Rec. Distance	0.377	0.368	0.378	0.380	0.289
87	Median Rec. Distance	0.256	0.246	0.233	0.261	0.265
90	Percent Rec. Area ≤ 5'	0.384	0.246	0.272	0.153	0.251
91	Percent Rec. Area ≤ 10'	0.342	0.334	0.228	0.205	0.262
92	Percent Rec. Area ≤ 15'	0.343	0.391	0.255	0.256	0.231
Z6	Best Available Sideslope	0.193	0.270	0.142	0.210	0.174

*Injury ratio is the sum of injury + fatal accidents divided by the total accidents on the section for a section.

for various categories of lane width, shoulder width, shoulder type, ADT, average roadside recovery distance, median roadside hazard rating, terrain, and sideslope ratio.

Each analysis involved controlling for the "continuous" traffic and roadway variables. For example, in the analysis of lane width, the mean single-vehicle accident rate was adjusted, (by the SPSS computer program) based on controlling for shoulder width, ADT, average roadside recovery distance, and sideslope ratio. Each analysis was conducted on the 1,801 rural highway sections. Note that this type of analysis was intended only to show general accident trends for individual variables, and does not include consideration of interactions among numerous variables. The results of the following analyses were used along with other analyses and considerations for selection of data variables for the accident modelling. Detailed tabular results for this and other issues are given in appendix G.

Lane Width

The analysis of covariance was used to compute the adjusted mean rate of single-vehicle accidents for various lane width categories. Lane width appears to have a relatively small and steady effect on the single-vehicle accident rate in flat and rolling areas. An increase from 8 and 9 foot lane widths results in a rate decrease from approximately 100 single-vehicle accidents/100 MVM to approximately 80 for rolling sections and from 100 to 70 for flat sections. In mountainous terrain, however, the direct effects of lane width are not clear (probably overshadowed by other variables).

Shoulder Width

A similar analysis of rates of single-vehicle accidents (adjusted for lane width, ADT, average recovery distance and sideslope ratio) revealed that wider shoulders were associated with generally lower rates of single-vehicle accidents for all three terrain conditions. The accident rate in flat and rolling areas was noticeably higher for shoulder widths of zero or one-foot than for the two or three feet category but leveled off for shoulder widths greater than three feet. In mountainous terrain, four or five-foot shoulders had a far lower mean rate than narrower shoulders, but the rate increased slightly for shoulders wider than six feet.

Shoulder Type

The analysis of covariance was also used to compute the adjusted mean rate of single-vehicle accidents (accidents per 100 MVM) for rural sections, as shown below in table 16. Mean rates were adjusted for ADT, lane width, and average roadside recovery distance.

Table 16. Rates (i.e., single-vehicle accidents per 100 MVM) by shoulder types for rural sections.

Shoulder Width (ft.)	Paved Shoulder	Gravel Shoulder	Earth Shoulder
1 to 3	119 (139)	126 (172)	117 (36)
4 to 5	80 (93)	96 (180)	85 (224)
6 to 13	77 (179)	78 (245)	77 (216)

( ) = Number of sample sections.

Note: Rates were adjusted for ADT, average roadside recovery distance, and lane width.

For shoulder widths from 1 to 3 feet, the rate of single-vehicle accidents for gravel shoulders (126) was higher than that for paved (119) or earth (117) shoulders. For shoulder widths of 4 to 5 feet, the rate was lowest for paved shoulders (80), followed by earth (85) and gravel (96) shoulders. For shoulder widths of 6 to 13 feet, rates remained constant for the three shoulder types. Efforts to analyze the data by more detailed groups (i.e., for each terrain type, by lane width category, etc.) resulted in low samples in some cells.

This analysis did not show any strong relationship between single-vehicle accident rates and the type of shoulder. More insight on the effects of shoulder type was gained from the model discussed in the next chapter. In fact, the model did show a slight benefit (i.e., generally less than 10 percent reduction in accidents due to paved shoulders) when other variable interactions are included. The grouping of gravel and earth shoulders into an unpaved shoulder category was made for modelling purposes due to the subjectivity required by the data collectors who viewed photologs and had to decide in many cases whether the shoulder had enough rocks or scattered gravel to be considered as earth or gravel. The presence of a paved shoulder was usually an obvious distinction from an unpaved shoulder.

Traffic Volume (ADT)

In all three terrain categories, higher ADT's were associated with lower single-vehicle accident rates. It should be noted that the decline in the single-vehicle accident rate with increasing ADT does not necessarily mean that the total accident rate would decline. The 1979 Kentucky study found a similar steady decrease in the rate of the single-vehicle accidents as ADT increased, but the rate of multivehicle accidents was nearly constant across the ADT categories.[7]

Recovery Distance and Roadside Hazard Rating

Prior to determining accident relationships with these roadside measures, an analysis was conducted to determine the relationship between roadside hazard rating and roadside recovery distance. A summary is given in table 17 of the 1,801 rural sections by median roadside hazard rating and average roadside recovery distance.

Table 17. Correlation between roadside hazard rating and roadside recovery distance in rural data base.

Number of Samples

Median Roadside Hazard Rating	Average Roadside Recovery Distance (ft)				
	0 to 5	6 to 10	11 to 15	16 to 20	> 20
1 and 2	0	0	2	8	38
3	0	15	99	168	194
4	29	224	318	207	41
5	105	244	57	7	0
6 and 7	36	9	0	0	0

No. of Observations = 1,801
Chi-Square = 1,389
Degrees of Freedom = 16

Significance = 0.00
Contingency Coefficient = 0.66
Kendall's Tau B = -0.646

A high correlation was found between the two variables, with a significance level of 0.00, a contingency coefficient of 0.66, and a Kendall tau value of -0.646. Note the near-diagonal trend to the table which suggests that in general, recovery distances are equivalent to roadside hazard ratings in the following way:

Average Roadside Recovery Distance	Corresponding Range of Roadside Hazard Rating	Most Likely Rating
0 to 5	4 to 7	5
6 to 10	3 to 7	4 or 5
11 to 15	1 to 5	4
16 to 20	1 to 5	3 or 4
$\geq$ 20	1 to 4	3

There is also a logical correlation between these two roadside measures, since a roadside with large objects near the road would have a low average recovery distance and a high roadside hazard rating. During the model building process, models were tested with either roadside hazard rating or average recovery distance.

Next, analyses were conducted to determine the effect of roadside recovery distance and roadside hazard rating on the single-vehicle accident rate. The adjusted single-vehicle accident rate was generally lower for sections with greater roadside recovery distances. The mean rate for rolling terrain sections with average recovery distances greater than 16 feet was about one-third the rate for sections with average recovery distances of less than 9 feet. The trend for mountainous terrain is unreliable since there were only six sections with mountainous terrain and average recovery distance greater than 16 feet.

The results of one-way analysis of covariance tests on roadside hazard ratings (appendix G) look much like the results for recovery distances. This is not surprising, since the roadside hazard ratings were shown to be highly correlated with average recovery distances. For flat and rolling sections, the single-vehicle accident rate was consistently lower for less severe hazard ratings. For mountainous terrain, small sample sizes for lower hazard ratings and the influence of other variables (i.e., amount of vertical and horizontal curvature) appear to confound the issue.

Terrain

In terms of terrain effects on the single-vehicle accident rate, sections in mountainous terrain consistently had higher mean rates than sections with flat or rolling terrain. Sections with rolling terrain had consistently higher rates than sections with flat terrain, though the differences between rolling and flat terrain were usually not as great as the differences between mountainous and rolling sections.

Sideslope Ratio

Sideslopes for 595 sections (1,776 miles) in Alabama, Michigan, and Washington were measured in the field by Analysis Group, Inc., under a different contract for FHWA. For the remaining 1,206 sections in the rural data base, however, the only sources of data on sideslopes were the estimates made by the viewers of the photolog film. A check was made to verify the accuracy of these photolog sideslope estimates by comparing the median sideslope ratio computed from photolog estimates to the median computed from field measurements for sections with both measured and estimated values. Table 18 details this comparison for the sample of 261 sections from Alabama and Washington with both photolog estimates and field measurements. The contingency coefficient computed for table 18 was 0.363, indicating a low degree of correlation. Thus, the estimates of the sideslope ratio from photolog film appear to be of unacceptable accuracy. For further analyses, only sections where the sideslope ratios were measured in the field were used. The analysis of the sideslope ratio were quite detailed and are included in chapter 6.

Table 18. Comparison of median sideslope ratio computed from field measurements to median computed from photolog estimates for sections with both.

Median Sideslope ratio computed from photolog estimates	Number of Sections				
	Median sideslope ratio computed from field measurements				
	2:1 or steeper	3:1	4:1 or 5:1	6:1 or 7:1	8:1 or flatter
2:1 or steeper	2	1	1	0	0
3:1	4	5	3	1	1
4:1 or 5:1	11	19	42	19	6
6:1 or 7:1	4	19	54	45	19
8:1 or flatter	0	1	2	2	0

Contingency Coefficient = 0.363

CHAPTER 5 - MODEL DEVELOPMENT AND VALIDATION

Selection of Model Forms

The models were developed using 1,362 rural sections (approximately 4,000 miles). Initially models were fit to:

- Accidents per 100 million vehicle miles.
- Accidents-per-mile-per-year.
- Ratio of injury plus fatal accidents to total accidents.
- Injury plus fatal accidents-per-mile-per-year.

Table 19 lists the candidate independent variables for modelling. After investigating the distribution of the rural data, examining relationships between candidate independent and dependent variables, and initial modeling, all subsequent models used accidents-per-mile-per-year as the dependent variable.

Table 19. Candidate independent variables for modelling.

Average daily traffic (ADT)
Lane width (W) in feet
Average paved shoulder width (PA) in feet
Average gravel/stabilized/earth/grass shoulder width (UP) in feet
Median roadside (or hazard) rating (H)
Median recovery distance (measured from the edge of the shoulder) (RECC) in feet
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 (e.g., W + PA)
Selected interactions

It should be noted that the roadside recovery distance used in the model is measured from the outside of the shoulder and not the edgeline as it was defined previously. The reason for this is that shoulder width is also included in the model and is, therefore, already accounted for. Guided both by the previous literature (e.g., Zegeer and Deacon, 1985) and an examination of the relationships of the important independent variables with various accident types, models were fit to the following:[13]

- 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 sections, 13,105 or 40.4 percent were AS while 17,155 or 52.9 percent were AO.

Again guided by past work, several general model forms were investigated, including:

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

$$A/M/Y = C_0(C_1)^{ADT}(C_2)^{W}(C_3)^{PA}(C_4)^{UP}(C_5)^{H} \qquad \text{(Model 2)}$$

$$A/M/Y = C_0 + C_1ADT + C_2W + C_3PA + C_4UP + C_5H \qquad \text{(Model 3)}$$

$$A/M/Y = C_0(ADT)^{C_1}(W)^{C_2}(PA)^{C_3}(UP)^{C_4}(H)^{C_5} \qquad \text{(Model 4)}$$

where:

A/M/Y = accidents per-mile-per-year

$$= \frac{A}{L \times T}$$

with:

L = section length (feet)

T = number of years of accident data

ADT = average daily traffic

W = lane width (feet)

PA = average paved shoulder width (feet)

UP = average gravel/stabilized/earth/grass shoulder width (feet)

H = median roadside (or hazard) rating

Model forms consist of the basic model equation without numerical coefficients, whereas the equations will include numerical coefficients.

The above models were tested using AS, AO and AT 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 x paved shoulder width) and [(lane width + paved shoulder width) x unpaved shoulder width]. In no case did the interaction terms noticeably improve 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, Models 1 and 2 appeared to fit the data better than Models 3 or 4 and also coefficients of Models 1 and 2 were 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 about the mean explained by the model), in some cases the relative effects of W, PA, and UP conflicted with findings in the literature. 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, plus 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. Basic cross-section elements W, PA, and UP were also included in every model. Other primary variables examined were median recovery distance from the edge of the shoulder (RECC), median roadside rating (H) and median sideslope rating (SS). In addition, certain likely confounding variables were studied including terrain (TER), percent of section with $\geq$ 2.5 degree curves (CURV), percent of section with $\geq$ 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 utilized alternative definitions of the cross-section variables [e.g., one model using ADT, W, (W+PA), (W+PA+UP), and (W+PA+UP+RECC) and another using W^2]. In no case did models with these various alternatives fit the data as well as the original or provide coefficients which were as intuitively acceptable as those derived for models with simpler variables.

Final Models

Models with the hazard rating were slightly preferred to models incorporating recovery distance in that they were more consistent with the findings from prior research;[13] there was a more logical relationship among the variables in these models as judged by the relative magnitudes of the coefficients; the coefficients were more consistently significant; and they generally had higher R^2's. Since some users might not be able to utilize the hazard rating, both models (with corresponding R^2 values) are presented below. Models with hazard rating include:

$$AS/M/Y = 0.0018(ADT)^{0.7903}(0.8919)^{W}(0.9262)^{PA}(0.9256)^{UP}(1.3386)^{H}$$

with $R^2 = 0.393$ Equation (1)

$$AO/M/Y = 0.0017(ADT)^{0.8854}(0.8646)^{W}(0.9101)^{PA}(0.9233)^{UP}(1.3378)^{H}$$

with $R^2 = 0.449$ Equation (2)

$$AT/M/Y = 0.0015(ADT)^{0.9711}(0.8897)^{W}(0.9403)^{PA}(0.9602)^{UP}(1.2000)^{H}$$

with $R^2 = 0.459$ Equation (3)

Models with recovery distance include:

$$AS/M/Y = 0.0122(ADT)^{0.7447}(0.9034)^{W}(0.8878)^{PA}(0.8947)^{UP}(0.9588)^{RECC}$$

with $R^2 = 0.408$ Equation (4)

$$AO/M/Y = 0.0054(ADT)^{0.9822}(0.8378)^{W}(0.8672)^{PA}(0.8848)^{UP}(0.9629)^{RECC}$$

with $R^2 = 0.363$ Equation (5)

$$AT/M/Y = 0.0050(ADT)^{0.9425}(0.8970)^{W}(0.9157)^{PA}(0.9400)^{UP}(0.9739)^{RECC}$$

with $R^2 = 0.465$ Equation (6)

Note that the coefficients are consistently carried out to four decimal places in order to facilitate comparisons both across models and with previous work in this area.[13] Also, it should be noted that each of the coefficients is significantly different from zero ($\alpha = 0.05$) meaning that each of the corresponding factors (e.g., lane width) is important in explaining the variation in the outcome variable (i.e., accidents-per-mile-per-year).

In examining the effects of certain potentially confounding variables, models incorporating terrain appeared useful and are presented here for users with available terrain information. The general form of the model is:

$$A/M/Y = C_0(ADT)^{C_1}(C_2)^{W}(C_3)^{PA}(C_4)^{UP}(C_5)^{H}(C_6)^{TER1}(C_7)^{TER2} \quad \text{(Model 5)}$$

Where:

$$TER1 = \begin{matrix} 1 \text{ if flat} \\ 0 \text{ otherwise} \end{matrix}$$

$$TER2 = \begin{matrix} 1 \text{ if mountainous} \\ 0 \text{ otherwise} \end{matrix}$$

Coefficients (C's) for models using H or RECC with the corresponding R^2 values are provided in tables 20 and 21, respectively.

Table 20. Coefficients of models for accidents-per-mile-per-year (A/M/Y) using roadside hazard rating (H) and terrain (TER).

Coefficient	Variable	AS	AO	AT
C_0	Constant	0.0019	0.0019	0.0016
C_1	ADT	0.7841	0.8824	0.9638
C_2	W	0.9039	0.8786	0.8978
C_3	PA	0.9281	0.9192	0.9451
C_4	UP	0.9286	0.9316	0.9657
C_5	H	1.2899	1.2365	1.1701
C_6	TER1	0.9645	0.8822	1.0111
C_7	TER2	1.1723	1.3221	1.1800
	R2	0.396	0.456	0.458

Table 21. Coefficients of models for accidents-per-mile-per-year (A/M/Y) using average recovery distance (RECC) and terrain (TER).

Coefficient	Variable	AS	AO	AT
C_0	Constant	0.0104	0.0076	0.0044
C_1	ADT	0.7444	0.8545	0.9394
C_2	W	0.9185	0.8867	0.9067
C_3	PA	0.8933	0.8927	0.9231
C_4	UP	0.9008	0.9098	0.9477
C_5	RECC	0.9618	0.9715	0.9763
C_6	TER1	0.8849	0.8182	0.9587
C_7	TER2	1.0953	1.2270	1.1316
	R^2	0.412	0.461	0.463

The final recommended model is given by the following:

$$AO/M/Y = 0.0019\ (ADT)^{0.8824}\ (0.8786)^{W}(0.9192)^{PA}(0.9316)^{UP} \times (1.2365)^{H} \times (0.8822)^{TER1}(1.3221)^{TER2} \qquad \text{Equation (7)}$$

This model was selected because (1) it includes head-on and sideswipe accidents as well as single-vehicle accidents (all of which logically should be affected by roadway geometric features); (2) the coefficients and the R^2 value appear to be reasonable and consistent with the literature; and (3) terrain effects (flat, rolling or hilly) are incorporated into the model.

Models using accident rates (e.g., A/100 MVM or single-vehicle accidents per hundred million vehicle miles) were calibrated in parallel to those for accidents-per-mile-per-year. In general, the R^2 values were considerably lower for models using A/100 MVM. Coefficients for Model 1 using accident rates and H are given in table 22. Coefficients for Model 1 using accident rates and RECC are shown in table 23.

Table 22. Coefficients of models for accidents per 100 million vehicle-miles (A/100 MVM) using average roadside hazard rating (H).

Coefficient	Variable	AS	AO	AT
C_0	Constant	505.67	482.08	419.05
C_1	ADT	-0.2127	-0.1146	-0.0308
C_2	W	0.8970	0.8647	0.8923
C_3	PA	0.9235	0.9101	0.9411
C_4	UP	0.9242	0.9233	0.9615
C_5	H	1.3387	1.3378	1.2034
	R^2	0.242	0.232	0.095

Table 23. Coefficients of models for accidents per 100 million vehicle-miles (A/100 MVM) using average recovery distance (RECC).

Coefficient	Variable	AS	AO	AT
C_0	Constant	3534.62	3281.97	1441.30
C_1	ADT	-0.2602	-0.1521	-0.0613
C_2	W	0.9080	0.8666	0.8996
C_3	PA	0.8847	0.8741	0.9157
C_4	UP	0.8932	0.8933	0.9408
C_5	RECC	0.9585	0.9642	0.9733
	R^2	0.261	0.235	0.104

Model Validation

To validate the model, 75 percent of the data was randomly selected to calibrate a model for AS/M/Y incorporating H. The following equation resulted:

$$AS/M/Y = 0.0024(ADT)^{0.7904}(0.8843)^{W}(0.9140)^{PA}(0.9248)^{UP}(1.3013)^{H}$$

with $R^2 = 0.382$ Equation (8)

Note the similarity in the coefficients between equations (1) and (8). Equation (8) was then used with the remaining 25 percent of the data to create predicted rates $(AS/M/Y)_P$ which were compared with the observed rates $(AS/M/Y)_O$ for this smaller file.

Examination of the observed and predicted rates for each of the 342 sections in the 25 percent sample found reasonable agreement in most cases, with the largest (absolute and percentagewise) deviations occurring for sections with very low or very high single vehicle accident rates. The average deviation between the observed (O) and predicted (P) rates is given by the following:

$$\frac{1}{342} \sum_{1}^{342} \left| (AS/M/Y)_O - (AS/M/Y)_P \right| = 0.3607 \qquad \text{Equation (9)}$$

Since the average single vehicle accident rate for all 1,362 sections was 0.73 accidents per mile per year, the average deviation was just slightly less than half the average rate.

Residuals were also examined by plotting $(AS/M/Y)_O$ versus $(AS/M/Y)_P$. Deviations of the observed values from the predicted values reflect the goodness of fit of the model. Again, generally the greatest deviations percentagewise occur at the extremes. Overall, it is felt that, for the type and quantity of data, the resulting model is reasonably good.

Other Issues

It was mentioned previously that the effects of certain potentially confounding variables were examined. Confounding variables are those independent variables other than those of primary interest (e.g., lane width, paved shoulder width) whose effects on mileage accident rates are mixed up (i.e., confounded) with the effects of the main variables. In this case, obvious potentially confounding variables include terrain (TER), curvature (CURV), number of driveways per mile (NDRI), number of intersections per mile (NINT), etc. Data limitations have precluded examining models incorporating a number of confounding variables. However, an attempt was made to examine the most likely candidate confounding variables.

First, terrain was included in models for AS, AO and AT and the results were presented in tables 20 and 21. Comparison of the results shown in table 20 with equations (1), (2), and (3) show very little change in the coefficient estimates with the possible exception of H, while comparison of the results in table 21 with equations (4), (5), and (6) reveal relatively minor differences between the coefficient estimates. The potential importance of the remaining candidates is reflected in the correlation matrix provided in table 24. A correlation coefficient with a high absolute value means the two variables under study are closely related, and a correlation of 1 or -1 means a perfect linear relationship.

Table 24. Correlation matrix for confounding variable candidates.

	GRAD	NDRI	NINT	LAS/M/Y	LAO/M/Y	LAT/M/Y
CURV	0.373	0.064	-0.057	0.195	0.223	0.079
GRAD		-0.055	-0.035	0.005	0.017	-0.043
NDRI			0.425	0.358	0.403	0.421
NINT				0.182	0.215	0.291
LAS/M/Y					0.971	0.892
LAO/M/Y						0.927

where:

LAS/M/Y = ln [AS/(LxT)]

LAO/M/Y = ln [AO/(LxT)]

LAT/M/Y = ln [AT/(LxT)]

Possible problems involving multicollinearity between two or more independent variables were investigated. Multicollinearity occurs when independent variables are highly correlated making it difficult to separate the effects of these variables in the analysis. For example, paved shoulder width and unpaved shoulder width would be expected to be highly negatively correlated; i.e., wide paved shoulders would be expected to be accompanied by narrow unpaved shoulders resulting in a fairly constant total shoulder width . If so, it could be difficult to isolate the independent effects of paved shoulder width and of unpaved shoulder widths on accidents-per-mile-per-year due to this problem of multicollinearity.

To examine possible multicollinearity problems in the data, correlation coeffficents were divided for all pairs of candidate independent variables as shown in table 25.

Table 25. Correlation matrix for independent variables.

	PA	UP	RECC	H	ADT	CURV	GRAD	NDRI	NINT
W	0.367	-0.264	0.224	-0.280	0.166	-0.360	-0.083	-0.296	-0.092
PA		-0.513	-0.070	-0.153	0.184	-0.193	-0.094	-0.210	-0.095
UP			-0.128	-0.126	0.130	-0.121	-0.107	0.263	0.309
RECC				-0.618	-0.217	-0.336	-0.065	-0.208	-0.050
H					-0.040	0.494	0.192	0.071	-0.084
ADT						-0.162	-0.121	0.349	0.267
CURV							0.373	0.064	-0.057
GRAD								-0.055	-0.035
NDRI									0.425

It is seen, for example, that PA and UP are highly correlated (Pearson r = -0.513). To try to factor out the effect of PA, a model was fit on the 886 sections for which PA was 0. First Model 1 with PA = 0 was calibrated to produce a coefficient C_4 for UP. Then, a model was fit to provide the remaining (adjusted) coefficients for the full model.

Table 26 presents the coefficients derived in this two-stage fashion compared with those derived previously. There is little difference between the estimates, suggesting that the reasonably strong relationship between PA and UP may not be very important in formulating the model. The only variables showing a higher correlation are H and RECC and these are not utilized together in any of the models. Thus it would appear that multicollinearity may not be very important in this particular application.

Table 26. Comparison of coefficients between models developed with a two-stage process where PA = 0 and equations (1), (2), and (3).

Coefficient	Variable	AS/M/Y		AO/M/Y		AT/M/Y	
		2-stage	Eqn. (1)	2-stage	Eqn. (2)	2-stage	Eqn.(3)
C_0	Constant	0.0018	0.0018	0.0018	0.0017	0.0016	0.0015
C_1	ADT	0.7944	0.7903	0.8986	0.8854	0.9823	0.9711
C_2	W	0.8960	0.8919	0.8629	0.8646	0.8890	0.8897
C_3	PA	0.9240	0.9262	0.9074	0.9101	0.9373	0.9403
C_4	UP	0.9170	0.9256	0.9106	0.9233	0.9494	0.9602
C_5	H	1.3302	1.3386	1.3226	1.3378	1.1899	1.2000

Accident Reduction Factors

Several models were generated to predict single-vehicle accidents-per-mile-per-year (AS), single-vehicle plus opposite direction head-on and sideswipe along with same direction sideswipe (AO) and total accidents (AT). All of the final models have similar R^2 values and reasonable coefficients. The model that was used in the development of accident reduction factors and predicted accidents is as follows from Model 5 and table 20:

$$AO/M/Y = 0.0019(ADT)^{0.8824}(0.8786)^{W}(0.9192)^{PA}(0.9316)^{UP}$$

$$\times\ (1.2365)^{H}(0.8822)^{TER1}(1.3221)^{TER2}$$

$R^2 = 0.456$ Equation (7)

This model was chosen because: (1) it includes head-on and sideswipe accidents as well as single-vehicle accidents, (2) the coefficients and the R^2 value appear to be reasonable, and (3) a variable for inclusion of terrain effects is included.

To illustrate the accident prediction model, AO accidents-per-mile-per-year were calculated for several lane width, shoulder width, hazard rating, and ADT combinations, as shown in table 27. Values shown in the table range from 0.08 AO/M/Y (for 12 foot lanes with 3 foot shoulders with a hazard rating of 1, and an ADT of 400) to 3.53 AO/M/Y (for 10-foot lane width, no shoulder, hazard rating of 7, and ADT of 4,000). Logically, the number of related accidents-per-mile-per-year increases as lane and shoulder widths decrease and as ADT's and roadside hazard ratings increase.

The combined effects of lane width and paved shoulder width on related (AO) accidents are illustrated in figure 5 for ADT's of 1,000 and a roadside hazard rating of 5 on a rolling terrain. Note that widening a road with 9-foot lanes and no shoulder to 11-foot lanes with a 4-foot paved shoulder should reduce the related (AO) accidents nearly in half (i.e., from 0.77 to 0.40 per-mile-per-year). Another illustration of the predictive model is shown in figure 6 for an ADT of 4,000, and other conditions similar to the previous figure. In this case, a roadway with an 11-foot lane width and a 4-foot paved shoulder would yield an expected value of approximately 1.4 related accidents-per-mile-per-year. This com-

Table 27. Predicted number of related accident types using the model for rolling terrain.

Lane Width (ft.)	Shoulder Width (ft.)	Expected Related Accidents (AO/M/Y)															
		ADT = 400 Hazard Rating				ADT = 1,000 Hazard Rating				ADT = 2,000 Hazard Rating				ADT = 4,000 Hazard Rating			
		1	3	5	7	1	3	5	7	1	3	5	7	1	3	5	7
8	0	0.17	0.26	0.39	0.60	0.38	0.58	0.88	1.35	0.70	1.06	1.63	2.48	*	*	*	*
	3	0.13	0.20	0.31	0.47	0.29	0.45	0.68	1.05	0.54	0.83	1.26	1.93	*	*	*	*
	6	0.10	0.16	0.24	0.36	0.23	0.35	0.53	0.81	0.42	0.64	0.98	1.50	0.77	1.18	1.81	2.76
10	0	0.13	0.20	0.30	0.46	0.29	0.45	0.68	1.04	0.54	0.82	1.25	1.92	0.99	1.51	2.31	3.53
	3	0.10	0.15	0.24	0.36	0.23	0.35	0.53	0.81	0.42	0.64	0.97	1.49	0.77	1.18	1.80	2.74
	6	0.08	0.12	0.18	0.28	0.18	0.27	0.41	0.63	0.32	0.50	0.76	1.16	0.60	0.91	1.40	2.13
12	0	0.10	0.15	0.23	0.36	0.23	0.34	0.53	0.80	0.42	0.63	0.97	1.48	0.77	1.17	1.79	2.73
	3	0.08	0.12	0.18	0.28	0.17	0.27	0.41	0.62	0.32	0.49	0.75	1.15	0.59	0.91	1.39	2.12
	6	*	*	*	*	0.14	0.21	0.32	0.48	0.25	0.38	0.58	0.89	0.46	0.71	1.08	1.65
	9	*	*	*	*	0.11	0.16	0.25	0.38	0.19	0.30	0.45	0.69	0.36	0.55	0.84	1.28

* Combinations of these traffic and geometric conditions are highly uncommon and fall outside the range of the data base.

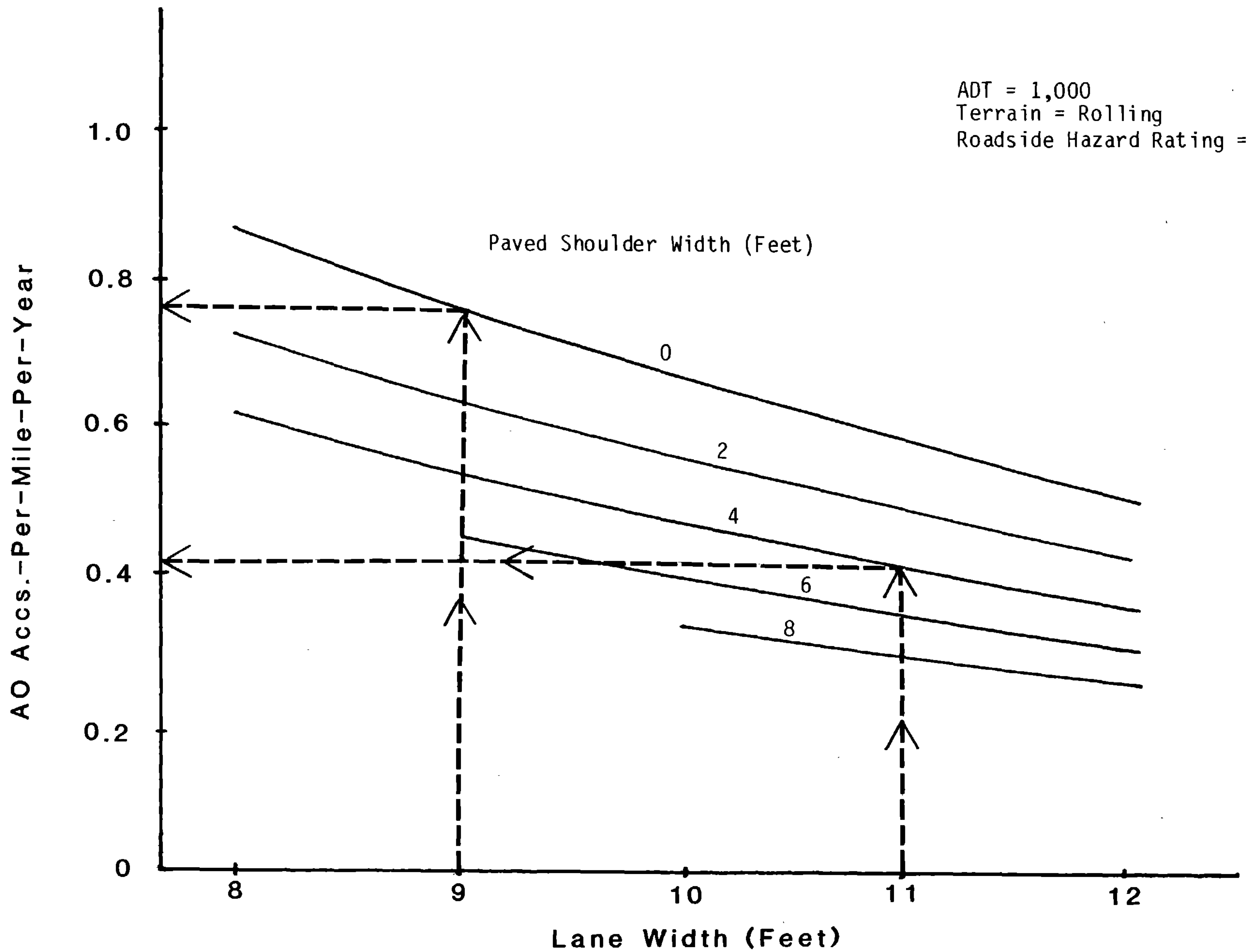


Figure 5. Plot of AO accidents-per-mile-per-year versus lane width using the selected model for ADT = 1,000, rolling terrain, and roadside hazard rating of 5.

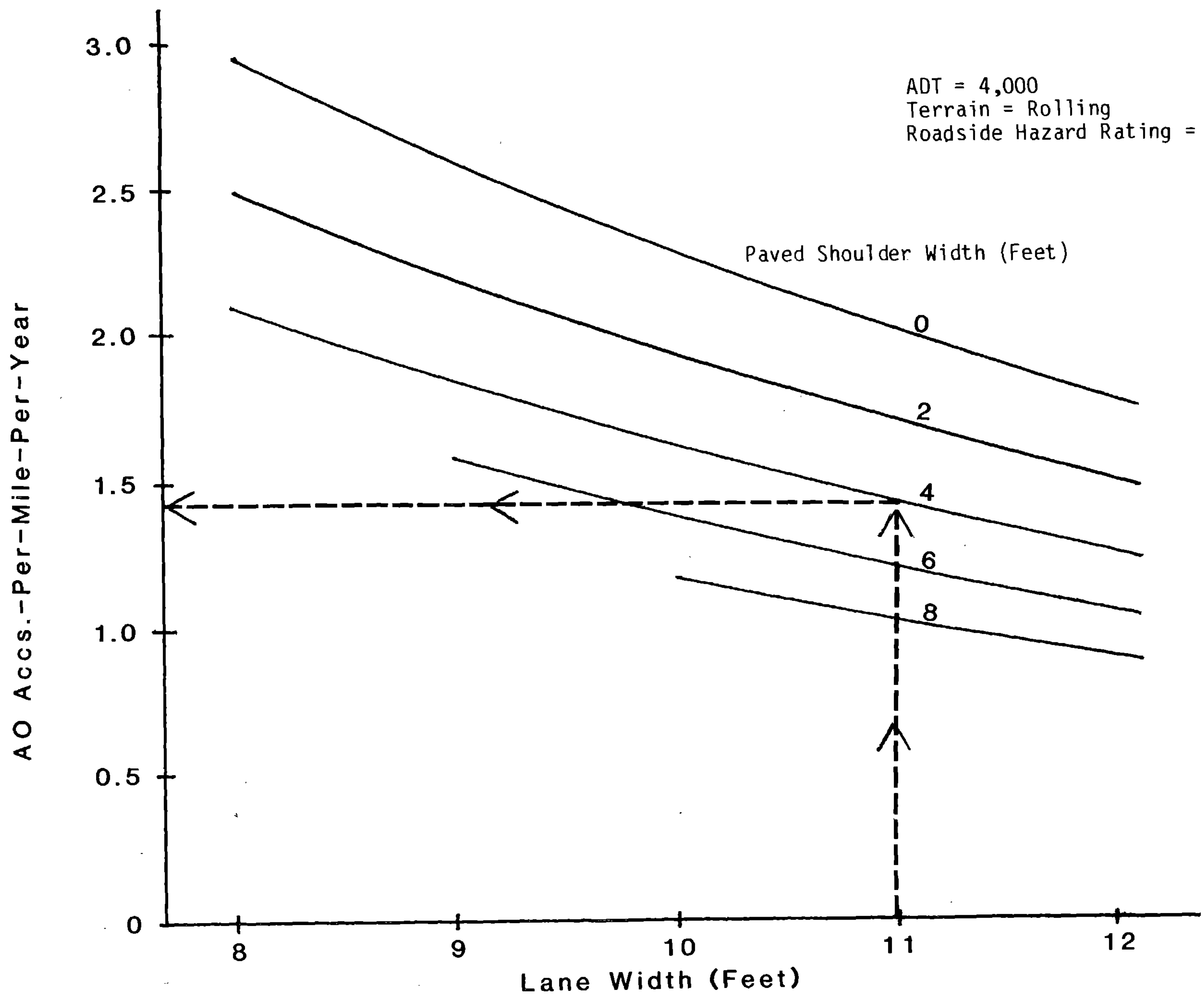


Figure 6. Plot of AO accidents-per-mile-per-year versus lane width using the selected model for ADT = 4,000, rolling terrain, and roadside hazard rating of 5.

pares with the value of 0.4 related accidents-per-mile-per-year shown in figure 5 for a similar section having an ADT of 1,000. Another graphical illustration of the predictive model is given in figure 7 for ADT's of 400 to 8,000 and for three types of terrain: flat, rolling, and mountainous (having roadside hazard ratings of 2, 4, and 6, respectively). This figure shows the expected difference in related accidents for these three conditions, assuming lane width of 11 feet, and unpaved shoulder widths of 4 feet in each case. These are only three of the many possible graphs which could be developed to illustrate the interactions of traffic roadway variables on related accidents based on the selected predictive model.

In order to determine the percent of related accidents that would be reduced due to lane or shoulder widening projects, accident reduction (AR) factors were developed using the model. These values of AR factors were determined by computing the 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 28. Table 28 reveals that as the amount of lane widening increases, the percent reduction in related accidents also increases. Accident reduction factors for shoulder widening and surfacing are shown in table 29. This table reveals that wider shoulders are associated with a reduction in related (AO) accidents. Paving a shoulder results in a slightly higher AR factor.

AR factors for various combinations of lane and shoulder widening are shown in table 30. AR factors in this table range from 4 percent (paving an existing shoulder and no lane widening) to 78 percent (adding a 12-foot paved shoulder while widening lanes by 4 feet). To determine the number of related accidents-per-mile-per-year that would be reduced due to lane or shoulder widening, multiply the number of related accidents-per-mile-per-year before the improvement (from the model) by the appropriate AR factor.

To illustrate the use of these tables, assume an existing two-mile section with an ADT of 1,000, a lane width of 10 feet, no shoulder, and a

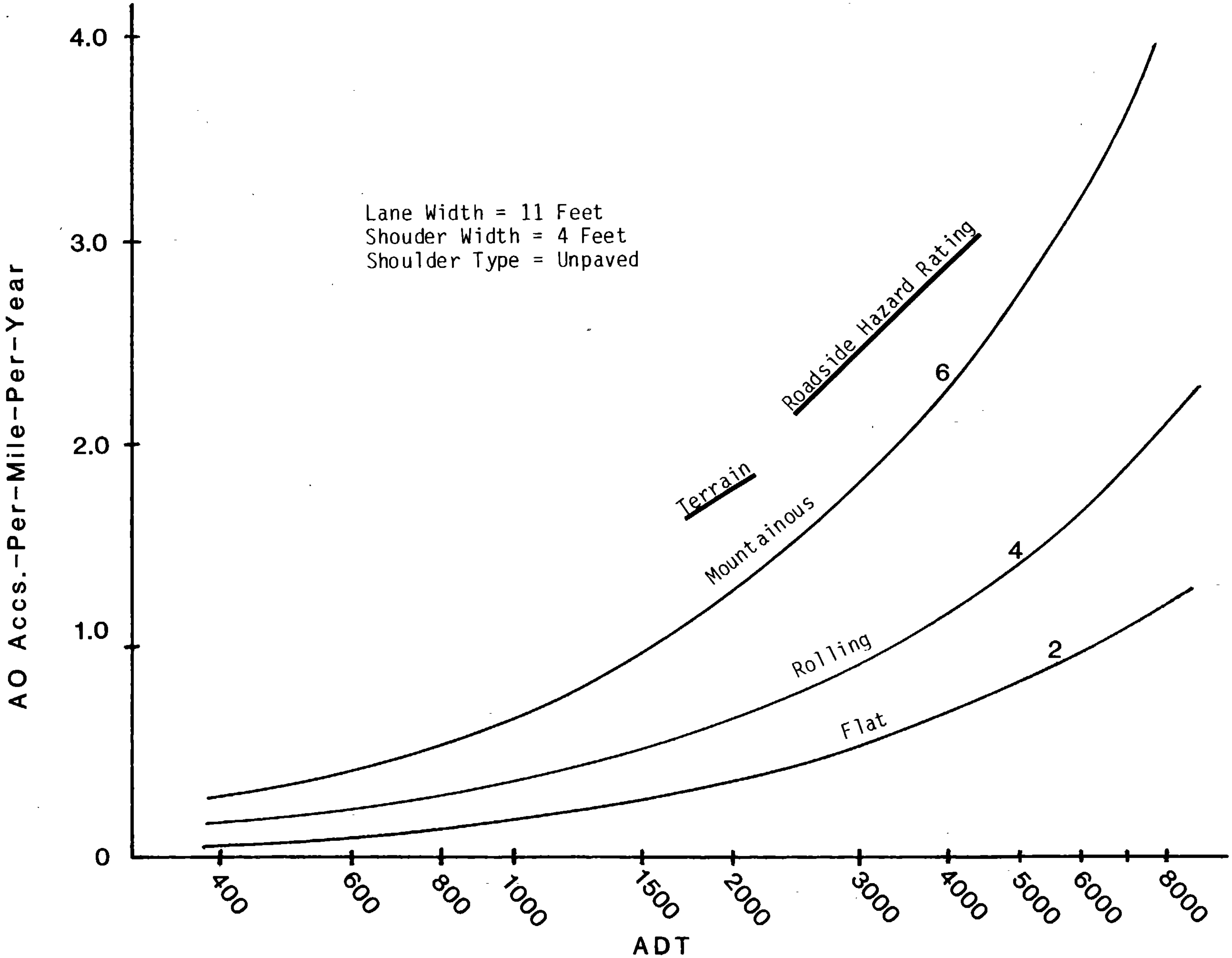


Figure 7. Plot of AO accidents-per-mile-per-year versus ADT using the selected model for a lane width of 11 feet, shoulder width of 4 feet, and unpaved shoulder.

Table 28. Percent accident reduction of related accident types for lane widening only.

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

Table 29. 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

Table 30. Accident reduction factors for related accident types for various combinations of lane and shoulder widening.

Existing Shoulder Width (Before Condition)			Percent Related Accidents Reduced Future Shoulder Width (After Condition)								
Amount of Lane Widening (ft.)	Shoulder Width	Surface Type	0 ft shoulder	3 ft. shoulder Paved	3 ft. shoulder Unpaved	6 ft. shoulder Paved	6 ft. shoulder Unpaved	9 ft. shoulder Paved	9 ft. shoulder Unpaved	12 ft. shoulder Paved	12 ft. shoulder Unpaved
4	0	N/A	40	54	52	64	61	72	68	78	74
	3	Paved	--	40	--	54	--	64	--	72	--
	3	Unpaved	--	43	40	55	52	65	61	73	68
	6	Paved	--	--	--	40	--	54	--	64	--
	6	Unpaved	--	--	--	45	40	57	52	67	61
3	0	N/A	32	47	45	59	56	68	64	75	71
	3	Paved	--	32	--	47	--	59	--	68	--
	3	Unpaved	--	35	32	49	45	61	56	69	64
	6	Paved	--	--	--	32	--	47	--	59	--
	6	Unpaved	--	--	--	37	32	51	45	62	56
	9	Paved	--	--	--	--	--	32	--	47	--
	9	Unpaved	--	--	--	--	--	40	32	53	45
2	0	N/A	23	40	38	53	49	64	59	72	67
	3	Paved	--	23	--	40	--	53	--	64	--
	3	Unpaved	--	26	23	42	38	55	49	65	59
	6	Paved	--	--	--	23	--	40	--	53	--
	6	Unpaved	--	--	--	29	23	45	38	57	49
	9	Paved	--	--	--	--	--	23	--	40	--
	9	Unpaved	--	--	--	--	--	32	23	47	38
1	0	N/A	12	32	29	47	43	59	54	68	62
	3	Paved	--	12	--	32	--	47	--	59	--
	3	Unpaved	--	16	12	34	29	49	43	60	54
	6	Paved	--	--	--	12	--	32	--	47	--
	6	Unpaved	--	--	--	19	12	37	29	51	43
	9	Paved	--	--	--	--	--	12	--	32	--
	9	Unpaved	--	--	--	--	--	22	12	39	29
	12	Paved	--	--	--	--	--	--	--	12	--
	12	Unpaved	--	--	--	--	--	--	--	25	12
0	0	N/A	*	22	19	40	35	53	47	64	57
	3	Paved	--	*	--	22	--	40	--	53	--
	3	Unpaved	--	4	*	25	19	42	35	55	47
	6	Paved	--	--	--	*	--	22	--	40	--
	6	Unpaved	--	--	--	8	*	28	19	44	35
	9	Paved	--	--	--	--	--	*	--	22	--
	9	Unpaved	--	--	--	--	--	11	*	31	19
	12	Paved	--	--	--	--	--	--	--	*	--
	12	Unpaved	--	--	--	--	--	--	--	15	*

* No change in roadway.

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

roadside hazard rating of 5. This would correspond to 0.68 related accidents per mile per year x 2 miles = 1.36 related accidents per year. Widening to 12-foot lanes and 6-foot gravel (unpaved) shoulders would result in a 49 percent reduction in related accidents according to table 30. This translates to (0.49 x 1.36) = 0.67 related accidents reduced per year on the two-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 3 feet of paved shoulder to a 10-foot lane with no shoulder would result in the same accident reduction percentage as adding 3 feet of shoulder to a 12-foot lane with an existing 6-foot paved shoulder. However, the actual number of related accidents reduced (per-mile-per-year) will be greater for adding the 3-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 3-foot shoulder to the 10-foot lane.

Table 31 illustrates the differences in related accidents for several examples of lane and shoulder-widening projects. Widening an 8-foot lane with no shoulder to an 11-foot lane with a 3-foot paved shoulder (net width increase of 6 feet) would result in a greater reduction in the number of related accidents (0.84 AO/M/Y) than widening a 10-foot lane with no shoulder to a 12-foot lane with a 6-foot paved shoulder (0.55 AO/M/Y) (net width increase of 8 feet). This illustrates the increased benefits for widening narrower lanes and shoulders, even though the actual amount of widening is less.

AR factors were also developed to determine the percentage of related (AO) accidents that would be reduced due to lowering the roadside hazard ratings as shown in table 32.

Table 31. Difference in related accidents (AO/M/Y) for before and after conditions*.

Existing Cross-Section Design (Before Condition)			Future Cross-Section Design (After Condition)							
			11 ft. lane width Shoulder width (feet)				12 ft. lane width Shoulder width (feet)			
			3 ft.		6 ft.		3 ft.		6 ft.	
Lane Width (ft.)	Shoulder Width (ft.)	Shoulder Type	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved	Paved	Unpaved
8	0	N/A	0.84	0.80	1.05	0.99	0.96	0.92	1.14	1.09
	3	Paved	0.45	----	0.65	----	0.56	----	0.74	----
	3	Unpaved	0.50	0.46	0.71	0.65	0.62	0.58	0.80	0.75
10	0	N/A	0.44	0.40	0.65	0.59	0.73	0.68	0.55	0.52
	3	Paved	0.13	----	0.34	----	0.24	----	0.43	----
	3	Unpaved	0.17	0.13	0.38	0.32	0.29	0.25	0.47	0.42

*ADT = 1,000 Terrain = Mountainous Roadside Hazard Rating = 7

Table 32. Accident reduction factors due to reducing roadside hazard rating.

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

The table indicates that a reduction in roadside hazard rating of 1 (i.e., from 7 to 6, 6 to 5, 5 to 4, ... or 2 to 1) due to a roadside improvement would be expected to reduce related (AO) accidents by 19 percent. Similarly, larger reductions in roadside hazard ratings will reduce a greater percent of related accidents. Thus, a reduction in roadside hazard of 5 (i.e., 7 to 2) would be expected to reduce related accidents by 65 percent.

Several questions may be raised regarding the effects of reducing roadside hazard. First of all, the roadside hazard scale is an ordinal scale and a hazard rating of 4 is not necessarily twice as hazardous as a rating of 2. Thus, it may be difficult to understand how a change in hazard rating of 7 to 5 would yield a similar accident reduction (34 percent) as a change from 3 to 1 (i.e., both would reduce hazard rating by 2). 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 <u>number</u> of accidents with a rating of 7 than for a rating of 3. Thus, a reduction in hazard ratings from 7 to 5 will result in greater accident benefits than a reduction from 3 to 1.

Accident reduction factors were also computed for various increases in the roadside recovery distance (RECC), as shown below in table 33. An

Table 33. Accident reduction factors due to increasing roadside clear recovery distance.

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

increase in recovery distance (measured from the outside edge of the shoulder) of five feet would reduce related (AO) accidents by 13 percent. Providing 20 feet of additional roadside recovery distance (e.g., from 5 to 25 feet) would reduce related accidents by 44 percent, according to the model.

One of the issues of importance in applying accident reduction factors in table 32 and 33 above is determining what action is needed to increase the recovery distance. Examples of such treatments may include:

- Tree removal
- Relocating utility poles
- Undergrounding utility lines
- Flattening sideslopes and removing obstacles
- Providing traversable culverts

Measures to reduce the hazard rating may include all of those cited above plus others such as:

- Installing guardrail in front of a steep slope or rigid objects
- Providing breakaway bases to light poles and/or sign posts.

Illustrations are given in chapter 7 of various roadside improvements and their corresponding costs and benefits.

CHAPTER 6 - ROADSIDE FEATURES ANALYSIS

The previous chapter involved analyses of expected accident reductions due to improving lane and shoulder widths, shoulder surfaces, and general measures of roadside hazard. More detailed information was desired of the accident effects of roadside features in urban and rural areas. This chapter summarizes the results of efforts to address eight specific issues considered of primary importance relative to roadside features.

Roadside Question 1. What are the relative effects of various roadside conditions on single-vehicle accidents?

In general, rates of single vehicle accidents decreased for wider lanes, wider shoulders, and increased roadside recovery distance. Flatter sideslopes were associated with lower rates of single-vehicle accidents for roads with ADT's above 1,000.

The first analysis to address this issue involved computing the single-vehicle accident experience for various ADT groups and for three roadside conditions: (1) sections with nonclear zones (assumed to be those with average recovery distances of 10 feet or less), (2) sections with reasonable clear zones and sideslopes of approximately 4:1 (includes sections with average recovery distances of greater than 10 feet and median sideslopes of 3:1, 4:1, or 5:1) and (3) sections with clear zones of 10 feet or more with sideslopes of 6:1 or flatter. These were considered to be roughly comparable to the three groups used by Graham and Harwood.[22]

A summary of results is given in table 34, which shows single-vehicle accidents-per-mile-per-year increasing with increasing ADT for each group, as expected. These rates are unadjusted for other roadway factors and the single-vehicle accident types (i.e., fixed object, rollover, and other run-off-road) are the same types included in earlier single-vehicle analyses. Single-vehicle accident rates (accidents per 100 MVM) decrease with increasing ADT, which agrees with the findings of Graham and Harwood and the Kentucky study by Zegeer.[7] Values of single-vehicle accidents-per-mile-per-year are roughly double for the sites with nonclear zones, com-

Table 34. Summary of single vehicle accidents (per-mile-per-year) by ADT group and recovery distance for rural sections in seven States.

ADT Group	Average Recovery Distance ≤ 10 ft.			Average Recovery Distance > 10 Feet					
				Sideslope 3:1, 4:1, or 5:1			Sideslope = 6:1 or Flatter		
	No. of Sample Sections	Acc/ 100 MVM	Acc/Mi/Yr	No. of Sample Sections	Acc/ 100 MVM	Acc/Mi/Yr	No. of Sample Sections	Acc/ 100 MVM	Acc/Mi/Yr
50-1,000	147	201	.42	137	109	.21	127	134	.22
1,001-2,000	149	147	.80	120	81	.42	101	77	.41
2,001-4,000	163	123	1.32	177	61	.66	161	48	.52
4,001-7,500	129	113	2.22	92	50	.94	129	43	.88

pared to the group with 10-foot clear zones. The single-vehicle accident rates are also higher for all ADT groups within the nonclear zone sites, compared to the others, by a factor of approximately two.

A comparison of the two groups with clear zones revealed that single-vehicle accidents-per-mile-per-year were about the same for ADT groups of 2,000 or less. For ADT's of 2,000 to 7,500, single-vehicle accidents-per-mile-per-year and the accident rates were slightly less for 6:1 clear zones than for 4:1 clear zones. The rate of single-vehicle accidents showed no consistent difference between the 4:1 and 6:1 clear zones. However, the table clearly indicates a lower rate of single-vehicle accidents associated with flatter slopes for roadways with ADT's above 1,000.

A comparison was made of the single-vehicle accident rates in table 34 with the findings from the clear zone study by Graham and Harwood (1982).[22] First of all, the mean rates and frequencies of single-vehicle accidents in the current seven-State study were approximately twice those presented by Graham and Harwood. This is believed to be partly explainable by lower levels of accident reporting of property damage accidents from one of the States where most of the data were obtained in the Graham and Harwood (1982) study. Otherwise, the general trends between the two data bases agreed in terms of higher rates and frequencies of single-vehicle accidents for sections with non-clear zones. The Graham and Harwood (1982) study, however, found more of a difference in accidents between the 4:1 and 6:1 clear zone sites. This could be due to different definitions of clear zone used in the two studies. For example, in the Graham and Harwood (1982) study, the clear zone was assumed to be the design policy used by the State for a given section.[22] However, in the current study, the clear zone definition was a median recovery distance of more than 10 feet.

Single-vehicle accident rates were also computed for various combinations of lane width, shoulder width, and average roadside recovery distance, as shown in table 35. Rates of single-vehicle accidents were adjusted for ADT. Rates of single-vehicle accidents decreased for wider lanes, wider shoulders, and increased roadside recovery distance. Of particular note was the low rate of single-vehicle accidents found for most cases of 17 to 30-foot roadside recovery distances.

Table 35. Results for lane width, shoulder width, and average roadside recovery distance using rural sections.

Mean Adjusted Single Vehicle Accidents/100 MVM

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.

Unadjusted single-vehicle accident rates for urban areas are given in table 36 for various lane width categories. Drastic reductions in single-vehicle accident rates may be observed for increases in average roadside recovery distances. These trends are consistent for all three lane width groups.

Roadside Question 2. What is the effect of sideslope on the rate of single-vehicle and rollover accidents?

Increased rates of single-vehicle and rollover accidents were found to be associated with steeper sideslopes, for rural, two-lane roadway sections having sideslopes of 2:1 or steeper, 3:1, 4:1, 5:1, 6:1, and 7:1 or flatter. The rate of single-vehicle accidents decreases linearly for sideslopes ranging from 3:1 to 7:1 or flatter. However, only a slight reduction in single-vehicle accidents was found for 3:1 sideslopes, compared to sideslopes of 2:1 or steeper. These results were based on log linear accident predictive models which include controls for the effects of ADT, lane width, shoulder width, and roadside recovery distance. Expected reductions in single-vehicle accidents due to sideslope flattening ranged from 2 to 27 percent, depending on the sideslope before and after the improvement. Rates of rollover accidents were significantly lower for sections with sideslopes of 5:1 or flatter, compared to those with sideslopes of 4:1 or steeper.

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 available. The rural sections were not used where only photolog "estimates" of sideslope were available, since a previous analysis found that sideslope estimates from photologs were of insufficient accuracy (compared to field measurements). Thus, even though a reduced sample of rural sections was used for this analysis, the greater accuracy of the sideslope measurements was considered desirable and the sample size was more than adequate for detailed analysis and accident modelling.

Table 36. 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.

This analysis consisted of fitting log linear regression models to two different dependent variables: single-vehicle accident rate (A_S) and rollover accident rate (A_R). The accident rates for A_S and A_R were in terms of accidents per 100 million vehicle-miles. Single-vehicle accidents include three types: fixed object, rollover, and other run-off-road accidents, and each accident was counted only once.

For each of the 595 sample sections, the median (i.e., 50 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 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 <u>outside</u> 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 categorical model forms showed that sideslopes of 3:1 or greater had significantly higher single-vehicle accident rates than those of 4:1 or flatter. Thus, the form of log-linear model for single-vehicle accident rate (A_S) using two categories of sideslope was as follows:

$$A_S = 793.58\ (1.191)^{SS}(0.845)^{W}(0.974)^{RECC}(0.99994)^{ADT}(0.908)^{SW} \quad \text{Equation (10)}$$

where,

A_S = The rate of single-vehicle accidents (in accidents/100 MVM)

SS = Median (50 percentile) sideslope measure, where SS = 1 if sideslope is 3:1 or steeper, or 0 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 (50 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 0 or 1, it follows that having a steep (i.e., 3:1 or steeper) slope is associated with a 19 percent higher rate of single-vehicle accidents than a flatter slope (i.e., 4:1 or flatter). This is because a factor of 1.191 (i.e., $1.191^1 = 1.191$) would be multiplied by the remaining terms for a steep sideslope, compared to a factor of 1.000 (i.e., $1.191^0 = 1$) for a sideslope of 4:1 or flatter.

While the results of this model are based on significant affects of sideslope (flat vs. steep) 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. Thus, the best sideslope model of this type was:

$$A_S = 731.16\ (0.839)^{W}(0.99995)^{ADT}(0.975)^{RECC}(0.909)^{SW}(1.373)^{SS1}(1.349)^{SS2}(1.238)^{SS3}(1.164)^{SS4}(1.091)^{SS5} \quad \text{Equation (11)}$$

where,

SS1 = 1 if sideslope = 2:1 or steeper, or 0 otherwise,

SS2 = 1 if sideslope = 3:1, or 0 otherwise,

SS3 = 1 if sideslope = 4:1, or 0 otherwise,

SS4 = 1 if sideslope = 5:1, or 0 otherwise,

SS5 = 1 if sideslope = 6:1, or 0 otherwise, Note that for a sideslope of 7:1, the last 4 terms of the equation would each become 1.0. For a sideslope of 2:1 or 1:1, the last three 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 8. Note that the figure shows a ratio of the single-vehicle accident rate for a given sideslope (e.g., 3:1) 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 8 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 would indicate 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, a table was developed of likely reductions in single-vehicle accidents due to various sideslope flattening projects, as given in table 37 below.

Table 37. Summary of expected percent reduction in single-vehicle accidents due to sideslope flattening.

Sideslope in Before Condition	Sideslope 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

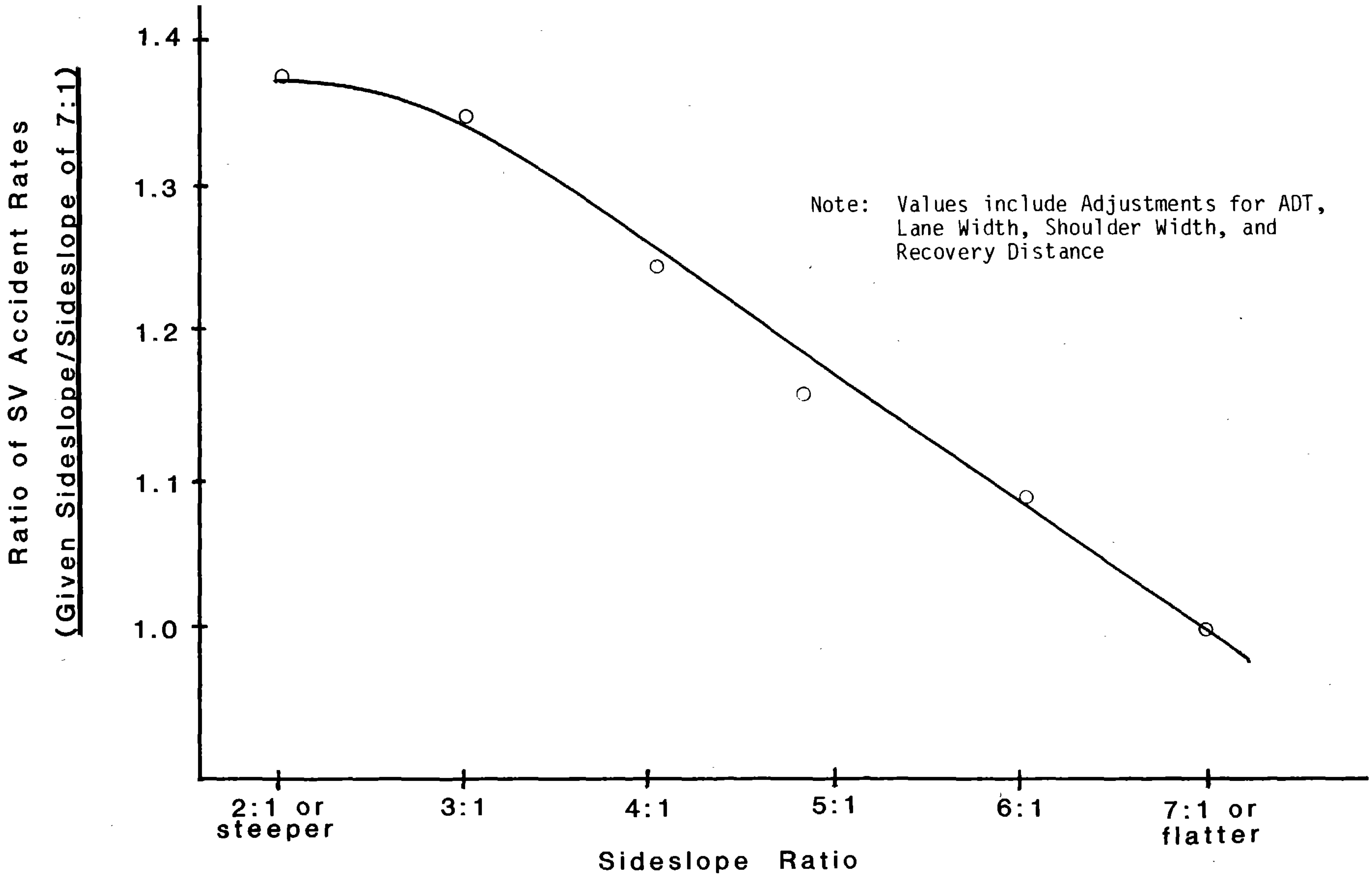


Figure 8. Plot of single-vehicle accident rate for a given sideslope versus single-vehicle accident rate for a sideslope of 7:1 or flatter.

From this table, assume an existing sideslope of 2:1 on a two-lane rural highway section. A sideslope flattening project would be expected to reduce single-vehicle accidents by only 2 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 of 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 this model was 0.19, which indicates that only 19 percent of the variation in single-vehicle accident rate is explained by the other variables. While this may appear to be less than desirable, it should be remembered that high R^2 values rarely result from predictive modelling of accident experience, due to random accident fluctuations, imperfect accident reporting systems, effects of driver and vehicle factors on accidents, etc. Also, accident rates tend to fluctuate widely, particularly on low volume roads.

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

An example is given in figure 9 of single-vehicle accident rates for six groups of sideslope and for lane widths of 9 to 12 feet 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-foot roadside recovery distance (beyond the shoulder edge). To illustrate the use of figure 9 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 9 can also be used to determine trade-offs of 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 sideslope were 2:1. Thus, in this example, one foot of lane widening at

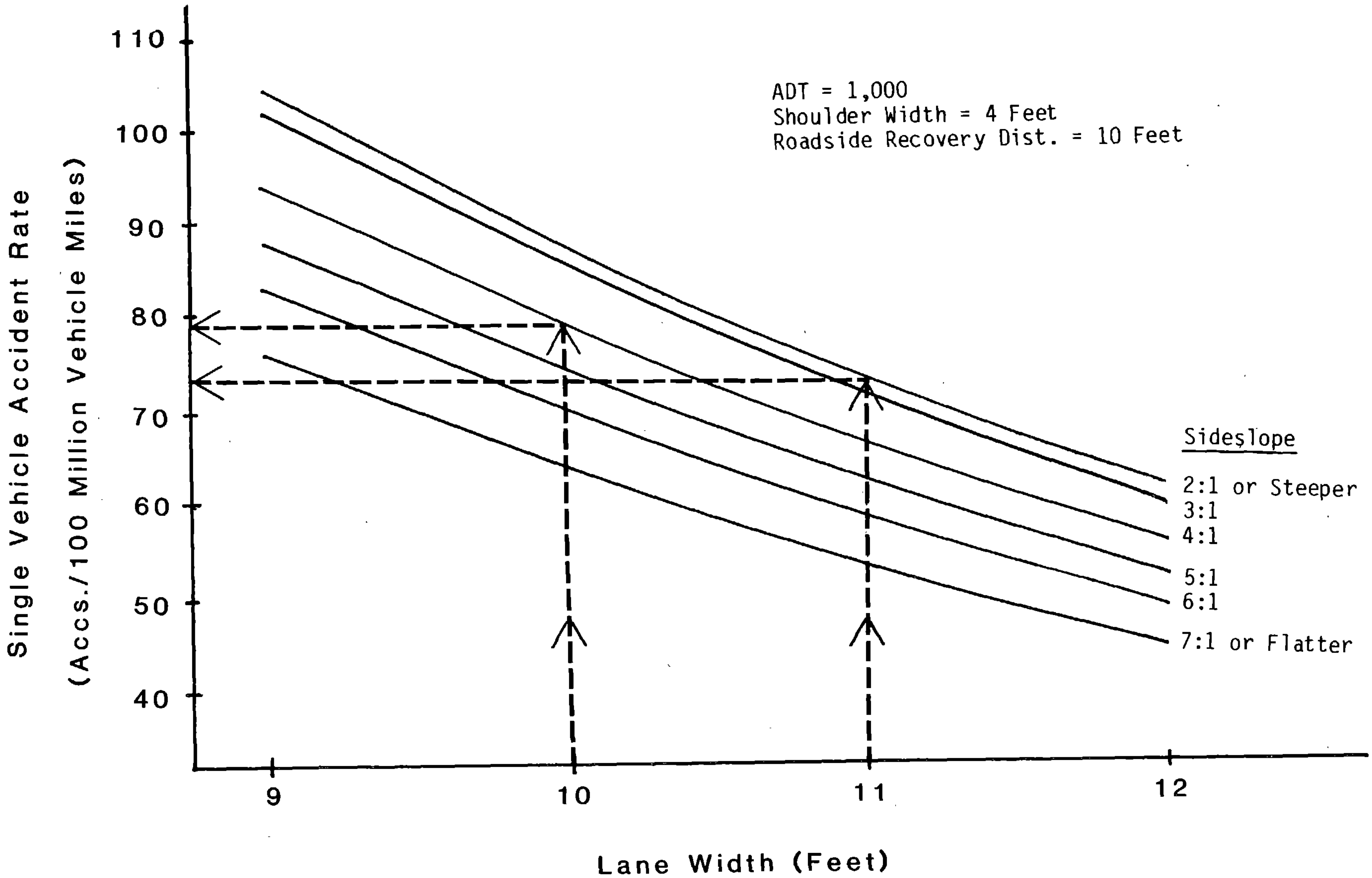


Figure 9. Illustration of single-vehicle accident rates for various lane widths and sideslopes.

the expense of a steeper sideslope should not adversely affect the rate of single-vehicle accidents. While other types of comparisons can also be made from figure 9, the use of the predictive equation would allow for comparing the effects of sideslope changes on single-vehicle accident rate versus lane and shoulder widening and roadside improvements.

Similar types of log linear models were tested using the rollover accident rate (A_R) as the dependent variable. The best model for the rollover accident rate was:

$$A_R = 192.99\ (1.319)^{SS}(0.849)^{W}(0.983)^{RECC}(0.99984)^{ADT}(0.958)^{SW} \quad \text{Equation (12)}$$

Where:

A_R = rollover accidents per 100 million vehicle miles

SS = 1 if sideslope is 4:1 or steeper, or 0 otherwise

This model only has 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 clearly 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 <u>each</u> of the sample sections, the recorded sideslope is the 50th percentile (median value) of all of the field measurements. A section labelled as having a 4:1 sideslope actually consists of a range of sideslopes (e.g., 2:1 to 6:1) with 4:1 as the median value. Thus, in the data base, each section labelled as 4:1 could have as much as 49 percent of the measurements which are steeper than 4:1 (i.e., 3:1 or 2:1) and the rest 4:1 or flatter. It is, therefore, quite possible that the "so-called" 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. The so-called 5:1 sideslope sections are more likely to consist of sideslopes primarily of 4:1, 5:1, and 6:1 and thus, have less likelihood of rollover accidents.

Another point worth mentioning is that rollover accidents represent only 23 percent of single-vehicle accidents (and only 8 percent of total accidents) in the data base, so relatively small samples of rollover accidents could cause less reliability than the use of single-vehicle accidents. Also, the actual density of roadside fixed objects (e.g., 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 a roadside obstacle before having a chance to rollover if the roadside is covered with trees close to the road. 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 still 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 Question 3. What are the relationships between various types of fixed objects and their corresponding accident types?

For each type of roadside obstacle tested (i.e., utility poles, mailboxes, culverts, signs, guardrail, fences, and trees), the specific types of fixed-object accidents-per-mile-per-year increased for (1) increasing ADT, (2) closer obstacle distance from the road, and (3) increasing numbers of obstacles per mile.

As discussed previously, a detailed roadside obstacle inventory was available for the total data base for specific types of point and continuous objects. Also, accident data by type of fixed object were available for several of the same obstacle types. However, not all States record all of the desired types of obstacles struck. For example, the only types of fixed object accidents available from Utah were those involving signs, utility poles, guardrails, and fences, whereas all 15 of the different types of obstacles coded for this research were available in the Alabama accident file. The following analysis includes sections in both urban and rural areas.

Detailed summaries of specific types of fixed object accidents-per-mile-per-year were made for the following: (1) utility poles, (2) mailboxes, (3) culverts, (4) signs, (5) guardrail, (6) fences, and (7) trees. Sections selected for use in the analysis were only those in which the corresponding obstacles existed. For example, the guardrail analysis only considered sections which contained between one and 60 percent guardrail coverage along the road. The analysis of utility pole accidents only included sections with five to 100 utility poles per mile. Other ranges of obstacles used for including sections were one to 50 signs per mile, 0.5 or more culverts per mile, one to 40 percent coverage of fences, one to 50 mailboxes per mile, and more than one percent coverage of trees. Thus, sections with trees but no guardrail were used in the tree analysis but not in the guardrail analysis. The selection of sections for each type of obstacle analysis was made independently of accident experience, to avoid bias.

For the summary tables (38-44), the obstacle accidents-per-mile-per-year are actual means and not adjusted for other factors. Thus, the values in these tables are more accurate representations of actual values of accidents by type of obstacle. Note that the values are summarized by grouping of ADT, number of obstacles, and distance from the road by type of obstacle so those factors are accounted for. In fact, past research indicates that these are the factors of most importance in fixed object accidents.

The results of the utility pole analysis are summarized in table 38, for conditions with five to 20 poles per mile (top table), 20.01 to 40 poles per mile (middle table) and 40.01 to 100 poles per mile (bottom table). Mean numbers of utility pole accidents-per-mile-per-year are given for five ADT groups and for average pole offsets of zero to 10, 10.01 to 20, and 20.01 to 30, with number of sample sections given in parenthesis. Thus, for example, for a section with 60 utility poles per mile within 10 feet of the roadway, and an ADT of 3,000, the average number of

Table 38. Summary of utility pole accidents (per-mile-per-year) by ADT group, average distance from travel time, and poles per mile.

Utility Poles per Mile 5 to 20				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 10	10.01 to 20	20.01 to 30	Totals
50 - 1,000	0.022(7)	0.024(68)	0.011(85)	0.017(160)
1,001 - 2,000	0.023(3)	0.036(81)	0.026(80)	0.031(164)
2,001 - 4,000	0.069(3)	0.051(63)	0.027(132)	0.035(198)
4,001 - 7,500	0.485(6)	0.089(50)	0.031(77)	0.073(133)
> 7,500	* (1)	0.193(19)	0.066(30)	0.113(50)
Totals	0.167(20)	0.057(281)	0.027(404)	0.043(705)

Utility Poles per Mile 20.01 to 40				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 10	10.01 to 20	20.1 to 30	Totals
50 - 1,000	* (2)	0.022(11)	0.083(7)	0.048(20)
1,001 - 2,000	0.078(3)	0.068(30)	0.023(16)	0.054(49)
2,001 - 4,000	0.195(8)	0.154(79)	0.052(49)	0.120(136)
4,001 - 7,500	0.574(15)	0.297(56)	0.093(58)	0.237(129)
> 7,500	0.503(4)	0.282(37)	0.063(16)	0.236(57)
Totals	0.392(32)	0.195(213)	0.068(146)	0.164(391)

Utility Poles per Mile 40.01 to 100				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 10	10.01 to 20	20.01 to 30	Totals
50 - 1,000	* (0)	0.022(3)	* (2)	0.013(5)
1,001 - 2,000	0.176(3)	0.253(5)	* (0)	0.224(8)
2,001 - 4,000	0.233(10)	0.313(23)	0.062(6)	0.254(39)
4,001 - 7,500	0.985(10)	0.362(42)	0.166(14)	0.414(66)
> 7,500	1.346(22)	0.522(49)	0.236(11)	0.705(82)
Totals	0.940(45)	0.404(122)	0.160(33)	0.484(200)

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

* = Accidents not given for cells with less than 3 sample sections.

Note: Sample sections include urban and rural sections in all seven States for sections with 5 to 100 utility poles per mile within 30 feet of the travel lane.

utility pole accidents per mile per year was 0.233. Notice that the accident experience generally increases as ADT increases, and also for poles closer to the roadway and for higher numbers of utility poles per mile.

A comparison was made between these utility pole accident levels and corresponding levels from the utility pole study by Zegeer for FHWA.[14] Two sets of sample conditions were selected from table 38. The first set of conditions includes: 20.01 to 40 poles per mile, 2,001 to 4,000 ADT, and poles 10.01 to 20 feet from the road.

The average utility pole accidents-per-mile-per-year for those conditions from table 38 is 0.154. Using the midpoint values of ADT, pole offsets, and poles per mile, the predictive equation from Zegeer would yield 0.227 utility pole accidents-per-mile-per-year for 30 poles per mile, 3,000 ADT, and 30 foot offsets. The value of 0.154 compares roughly the same order of magnitude as 0.227 from the Zegeer model. A second case tested was for an ADT of 4,001 to 7,500, poles 10.01 to 20 feet from the road, and 40.01 to 100 poles per mile. Table 38 gives a value of 0.362 utility pole accidents-per-mile-per-year. The predictive equation yields a value of 0.559 for midpoint values of 5,750 ADT, 70 poles per mile, and 15-foot pole offsets. Again the value in the table falls slightly below the result from the predictive equation. The slightly higher utility pole accidents from the Zegeer model may be largely due to the selection of sample sections in the Zegeer study, in which roadway sections were excluded if the utility poles were blocked by other obstacles, since a "clear" relationship was desired between utility pole accidents and pole density and offset. Also, pole density was expressed in terms of "clear" poles per mile (not blocked by other objects). In the current data base many of the utility poles are likely blocked by other obstacles.

Results of mailbox accidents in table 39 are given for one to five, 5.01 to 10, and 10.01 to 50 mailboxes per mile. Mailbox accidents generally increase with increasing ADT and increasing mailboxes per mile. However, the offset of mailboxes appears to have little effect on the mailbox accident experience. This may be due partly to small sample sizes in some cells, or other factors (i.e., a lower percentage of accidents involving vehicles hitting mailboxes at closer offsets are reported since many motorists involved in these accidents may drive away).

Table 39. Summary of mailbox accidents (per-mile-per-year) for sections by ADT levels and frequency of mailboxes.

Mailboxes per Mile = 1 to 5				
ADT Group	Average Distance from Travel Lane (ft.)			
	1 to 7	7.01 to 12	12.01 to 30	Totals
50 - 1,000	0.003(39)	0.008(35)	0.007(13)	0.005(87)
1,001 - 2,000	0.018(23)	0.012(65)	0.003(16)	0.012(104)
2,001 - 4,000	0.011(20)	0.012(83)	0.017(45)	0.013(148)
> 4,000	0.027(20)	0.039(80)	0.047(42)	0.040(142)
Totals	0.013(102)	0.020(263)	0.025(116)	0.019(481)

Mailboxes per Mile = 5.01 to 10				
ADT Group	Average Distance from Travel Lane (ft.)			
	1 to 7	7.01 to 12	12.01 to 30	Totals
50 - 1,000	0.007(11)	0.005(10)	* (2)	0.007(23)
1,001 - 2,000	0.009(7)	0.019(43)	0.014(5)	0.017(55)
2,001 - 4,000	0.051(13)	0.043(49)	0.032(25)	0.041(87)
> 4,000	0.077(22)	0.063(83)	0.072(33)	0.067(138)
Totals	0.047(53)	0.044(185)	0.050(65)	0.046(303)

Mailboxes per Mile = 10.01 to 50				
ADT Group	Average Distance from Travel Lane (ft.)			
	1 to 7	7.01 to 12	12.01 to 30	Totals
50 - 1,000	* (2)	* (1)	* (0)	* (3)
1,001 - 2,000	0.094(4)	0.020(18)	0.000(3)	0.030(25)
2,001 - 4,000	0.201(8)	0.111(25)	0.159(15)	0.141(48)
> 4,000	0.138(21)	0.113(56)	0.234(44)	0.162(121)
Totals	0.140(35)	0.095(100)	0.205(62)	0.137(197)

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

* = Accidents are not shown for cells with less than 3 sample sections.

Note: Sample includes rural and urban sections in 5 States (Utah and Montana excluded). Sections having less than 1 mailbox/mile or more than 50 mailboxes/mile were also excluded.

Culvert accidents (table 40) range from a low of 0.002 accidents-per-mile-per-year for low ADT's (50 to 1,000), low densities (0.5 to 2.5 per mile) and high offsets (15 to 30 per mile) to a high of 0.075 for high volumes ($\geq$4,000) closer culverts offsets (less than 8 feet) and more than 2.5 culverts per mile. The accident involvement of culverts generally increases with increasing ADT, closer placement to the road, and greater numbers of culverts per mile.

Sign accidents (table 41) were only summarized for rural areas, since only signs with large posts were inventoried in urban areas. The range of reported sign accidents varied from near zero to slightly above 0.10 accidents-per-mile-per-year, although there are likely to be many fixed object accidents involving signs which are unreported.

Summary tables for guardrail (table 42), fence (table 43), and tree accidents (table 44) are given with respect to ADT, offset of objects, and percent coverage of those objects along the roadway. For guardrail and fences, the length of these obstacles was computed as (number of photolog frames) x (52.8 feet per frame). The <u>percent coverage</u> of guardrail, for example, was computed for each section as:

$$\frac{\text{(Length of guardrail on the section for both directions)}}{\text{(Section length)x(2)}} \times 100 \quad \text{Equation (13)}$$

Since inventory measurements were taken in both directions, two miles of guardrail for a one-mile roadway would represent 100 percent coverage. For example, assume that for a two mile section guardrail length is two miles on one side of the road, (i.e., complete coverage) and one mile on the other side of the road. This would correspond to a guardrail coverage of:

$$\frac{(2.0 + 1.0)}{(2 \text{ miles}) \times 2} \times 100 = 75 \text{ percent} \qquad \text{Equation (14)}$$

Guardrail accidents were summarized for rural areas only in table 42, for percent coverage levels of one to 10 percent, 11 to 30 percent, and 31 to 60 percent. Guardrail accidents-per-mile-per-year ranged from approximately 0.01 to 0.486, and generally increased with increasing ADT, closer guardrail placement to the road, and a greater percent coverage of guardrail.

Table 40. Summary of culvert accidents (per-mile-per-year) by ADT group, average distance from travel lane, and culvert per mile.

Culverts per Mile = 0.5 to 2.5				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 8	8.01 to 15	15.01 to 30	Totals
50 - 1,000	0.020(23)	0.005(52)	0.002(22)	0.008(97)
1,001 - 2,000	0.015(15)	0.017(43)	0.007(26)	0.014(84)
2,001 - 4,000	0.012(14)	0.025(73)	0.010(42)	0.019(129)
> 4,000	0.026(10)	0.035(59)	0.009(40)	0.025(109)
Totals	0.018(62)	0.022(227)	0.008(130)	0.017(419)

Culverts per Mile > 2.5				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 8	8.01 to 15	15.01 to 30	Totals
50 - 1,000	* (1)	0.003(21)	0.000(19)	0.002(41)
1,001 - 2,000	0.032(10)	0.020(36)	0.015(21)	0.020(67)
2,001 - 4,000	0.025(17)	0.024(85)	0.019(47)	0.023(149)
> 4,000	0.075(25)	0.042(108)	0.012(57)	0.037(190)
Totals	0.049(53)	0.029(250)	0.013(144)	0.026(447)

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

* = Accidents not given for cells with less than 3 sample sections.

Note: Sample sections include urban and rural sections in five States (excludes Utah and W. Va.) for sections with 0.5 or more culverts per mile within 30 feet of the travel lane.

Table 41. Summary of sign accidents (per-mile-per-year) by ADT group, average distance from travel lane, and percent coverage of signs.

Coverage of Signs = 1 to 8 per Mile				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 10	10.01 to 13	13.01 to 30	Totals
50 - 1,000	0.007(127)	0.004(60)	0.003(44)	0.005(231)
1,001 - 2,000	0.020(57)	0.018(46)	0.017(50)	0.019(153)
2,001 - 4,000	0.021(44)	0.015(44)	0.022(52)	0.019(140)
4,001 - 7,500	0.048(20)	0.039(24)	0.042(24)	0.043(68)
> 7,500	0.099(3)	0.018(10)	0.024(3)	0.034(16)
Totals	0.017(251)	0.015(184)	0.018(173)	0.017(608)

Coverage of Signs = 8.01 to 12 per Mile				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 10	10.01 to 13	13.01 to 30	Totals
50 - 1,000	0.013(45)	0.004(26)	0.007(13)	0.009(84)
1,001 - 2,000	0.013(44)	0.022(29)	0.000(13)	0.014(86)
2,001 - 4,000	0.051(25)	0.017(31)	0.038(43)	0.035(99)
4,001 - 7,500	0.066(14)	0.069(23)	0.057(22)	0.064(59)
> 7,500	* (1)	0.092(8)	0.041(4)	0.069(13)
Totals	0.026(129)	0.031(117)	0.033(95)	0.030(341)

Coverage of Signs = 12.01 to 50 per Mile				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 10	10.01 to 13	13.01 to 30	Totals
50 - 1,000	0.012(46)	0.001(25)	0.000(11)	0.007(82)
1,001 - 2,000	0.019(47)	0.027(36)	0.037(28)	0.026(111)
2,001 - 4,000	0.028(33)	0.037(68)	0.039(66)	0.036(167)
4,001 - 7,500	0.061(20)	0.063(32)	0.044(57)	0.053(109)
> 7,500	0.108(5)	0.097(11)	0.135(14)	0.117(30)
Totals	0.027(151)	0.038(172)	0.046(176)	0.038(499)

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

* = Accidents are not shown for cells with less than 3 sample sections.

Note: Sample sections include rural sections only in seven States having 1 to 50 signs per mile within 30 feet of the travel lane.

Table 42. Summary of guardrail accidents (per-mile-per-year) in rural areas.

Coverage of Guardrail = 1 to 10 Percent				
ADT	Average Guardrail Distance From Travel Lane (ft.)			
	1 to 5	5.01 to 10	10.01 to 20	Totals
1 - 1,000	0.045(35)	0.012(13)	0.010(4)	0.034(52)
1,001 - 2,000	0.076(38)	0.041(35)	0.014(4)	0.057(77)
2,001 - 4,000	0.064(33)	0.044(55)	0.014(17)	0.045(105)
> 4,000	0.205(38)	0.150(61)	0.084(22)	0.155(121)
Totals	0.100(144)	0.080(164)	0.046(47)	0.083(355)

Coverage of Guardrail = 11 to 30 Percent				
ADT	Average Guardrail Distance From Travel Lane (ft.)			
	1 to 5	5.01 to 10	10.01 to 20	Totals
1 - 1,000	0.033(16)	0.046(6)	* (1)	0.035(23)
1,001 - 2,000	0.105(22)	0.201(12)	0.084(3)	0.135(37)
2,001 - 4,000	0.356(14)	0.173(27)	* (1)	0.230(42)
> 4,000	0.407(27)	0.397(37)	0.155(11)	0.365(75)
Totals	0.238(79)	0.269(82)	0.123(16)	0.242(177)

Coverage of Guardrail = 31 to 60 Percent				
ADT	Average Guardrail Distance From Travel Lane (ft.)			
	1 to 5	5.01 to 10	10.01 to 20	Totals
1 - 1,000	0.189(4)	* (2)	* (0)	0.149(6)
1,001 - 2,000	* (2)	0.146(7)	0.027(3)	0.167(12)
2,001 - 4,000	0.404(9)	0.389(15)	0.213(3)	0.374(27)
> 4,000	0.486(6)	0.383(8)	0.192(5)	0.365(19)
Totals	0.391(21)	0.314(32)	0.153(11)	0.312(64)

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

* = Accidents are not shown for cells with less than 3 sample sections.

Note: Sample sections includes rural sections only in all seven States, which have guardrail coverage over 1 to 60 percent within 20 feet of the travel lane.

Table 43. Summary of fence accidents (per-mile-per-year) by ADT group, average distance from road, and percent coverage of fence.

Fence Coverage 1 to 5 Percent				
ADT Group	Average Distance From Travel Lane (ft)			
	5 to 15	15.01 to 25	25.01 to 30	Totals
50 - 1,000	0.000(17)	0.017(30)	0.013(15)	0.011(62)
1,001 - 2,000	0.120(20)	0.015(34)	0.024(18)	0.046(72)
2,001 - 4,000	0.052(29)	0.017(44)	0.018(43)	0.026(116)
> 4,000	0.198(55)	0.070(72)	0.010(47)	0.094(174)
Totals	0.122(121)	0.038(180)	0.015(123)	0.055(424)

Fence Coverage 5.01 to 15 Percent				
ADT Group	Average Distance From Travel Lane (ft)			
	5 to 15	15.01 to 25	25.01 to 30	Totals
50 - 1,000	0.070(15)	0.013(38)	0.005(27)	0.021(80)
1,001 - 2,000	0.063(21)	0.013(33)	0.011(23)	0.026(77)
2,001 - 4,000	0.103(24)	0.082(48)	0.026(44)	0.065(116)
> 4,000	0.223(43)	0.061(42)	0.042(37)	0.112(122)
Totals	0.140(103)	0.046(161)	0.024(131)	0.063(395)

Fence Coverage 15.01 to 40 Percent				
ADT Group	Average Distance From Travel Lane (ft)			
	5 to 15	15.01 to 25	25.01 to 30	Totals
50 - 1,000	0.151(9)	0.064(31)	0.025(19)	0.065(59)
1,001 - 2,000	0.114(10)	0.020(32)	0.037(18)	0.041(60)
2,001 - 4,000	0.112(5)	0.058(21)	0.015(17)	0.048(43)
> 4,000	0.329(16)	0.188(23)	0.076(10)	0.211(49)
Totals	0.209(40)	0.076(107)	0.034(64)	0.089(211)

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

Note: Sample sections include urban and rural sections in six States (N.C. excluded) with fences 5 to 30 feet from the travel lane covering 1 to 40 percent of the roadside.

Table 44. Summary of tree accidents (per-mile-per-year) by ADT group, average distance from travel lane, and percent coverage of trees.

Tree Coverage of 1 to 15 Percent				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 12	12.01 to 20	20.1 to 30	Totals
50 - 1,000	0.000(5)	0.036(22)	0.027(20)	0.028(47)
1,001 - 2,000	0.038(9)	0.033(34)	0.040(31)	0.036(74)
2,001 - 4,000	0.192(7)	0.072(50)	0.028(81)	0.052(138)
> 4,000	0.137(13)	0.103(112)	0.056(123)	0.082(248)
Totals	0.102(34)	0.078(218)	0.043(255)	0.062(507)

Tree Coverage of 15.01 to 30 Percent				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 12	12.01 to 20	20.1 to 30	Totals
50 - 1,000	0.019(8)	0.090(24)	0.015(30)	0.044(62)
1,001 - 2,000	0.066(10)	0.094(57)	0.040(26)	0.076(93)
2,001 - 4,000	0.010(6)	0.139(77)	0.077(76)	0.104(159)
> 4,000	0.251(14)	0.168(85)	0.143(67)	0.165(166)
Totals	0.116(38)	0.134(243)	0.085(199)	0.112(480)

Tree Coverage of Greater Than 30 Percent				
ADT Group	Average Distance From Travel Lane (ft)			
	0 to 12	12.01 to 20	20.1 to 30	Totals
50 - 1,000	0.288(12)	0.065(71)	0.035(52)	0.073(135)
1,001 - 2,000	0.109(11)	0.065(62)	0.077(65)	0.074(138)
2,001 - 4,000	0.265(7)	0.136(59)	0.069(81)	0.105(147)
> 4,000	0.194(9)	0.267(52)	0.135(59)	0.197(120)
Totals	0.212(39)	0.125(244)	0.079(257)	0.110(540)

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

Note: Sample sections include urban and rural sections in six States (Utah excluded) for sections having 1 percent or more of roadside coverage of trees within 30 feet of the travel lane.

Fence accidents were summarized for rural and urban sections in table 43 for six States (excluding North Carolina). Fence accidents-per-mile-per-year ranged from zero to 0.329. The rate of tree accidents (table 44) ranged from zero to 0.267 per-mile-per-year for a coverage of one or more for six States (excluding Utah).

Roadside Question 4. What is the effect of using guardrail for various sideslopes and roadside conditions?

The rate of guardrail accidents increases with an increase in the percent of the section covered by guardrail for all terrains. No significant difference was found in the overall rate of single-vehicle or rollover accidents or in accident severity due to the presence of guardrail.

The effect of guardrail on accident rates was investigated with the current data base. The presence of various amounts of guardrail was tested against single-vehicle accidents per 100 MVM, rollover accidents per 100 MVM, and accident severity for a number of combinations of sideslope ratio and recovery distance, with a variety of control variables. In test after test, however, it was found that the presence of guardrail, for the data base in this research, had no discernible effect on the overall rates of single-vehicle or rollover accidents or on accident severity for various levels of sideslope or recovery distance.

This result may be partly due to the nature of the data base collected for this study. For example, accidents and physical characteristics were summarized within each of the sample sections, without knowledge of the presence of guardrail at each accident site. Thus, it was not possible to analyze accident severity for guardrail accidents, when compared to nonguardrail accidents occurring on various sideslopes. Instead, overall guardrail accidents for sections had to be used in the analysis as a function of the guardrail coverage of each section.

The effect of guardrail placement from the roadway edge can be seen from table 42 given previously. Clearly, sections with guardrail placements of 10.01 to 20 feet have fewer guardrail accidents than sections with guardrail placed closer to the roadway edge. Sections with guardrail placed within 5 feet of the travel lanes have the highest guardrail accidents in two of the three data groups.

It was also clear from the data that additional guardrail leads to additional guardrail accidents. Table 45 presents the results of an analysis of covariance on guardrail accidents. The guardrail accident rate increases with an increase in the percent of the section covered by guardrail for each terrain category. Presumably, the guardrail accident rate for a given amount of guardrail coverage is affected by lane width and shoulder width in a manner similar to the single-vehicle accident rate, though there was not sufficient data to explore this assumption.

Roadside Question 5. How do accident severities vary by obstacle type?

Roadside objects associated with the highest percent of severe accidents include culverts, trees, utility and light poles, bridges, rocks, and earth embankments. Those objects with lower percentages of severe accidents include signs, mailboxes, fire hydrants and fences.

It was impossible to determine the relative severity of accident types from the seven-State data base, 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 selected sections in those States as well as other rural two-lane roads, urban two-lane roads, and/or multilane roads. Nonetheless, the analysis afforded a reasonable look at the relative severity of different fixed object (FO) accident types. The data are presented in appendix H.

The severity of run-off-road fixed object accidents relative to other common accident types was investigated and the results are summarized in table 46. 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 percent-

Table 45. Relationship of guardrail accidents to the amount of guardrail present for different rural terrain categories.

Mean adjusted guardrail accidents/100 MVM		
	Percent of section with guardrail	
Terrain	0.01-10	10.01-60
Flat	4.5 (203)	16.5 (46)
Rolling	7.1 (179)	16.2 (88)
Mountainous	9.5 (116)	28.7 (105)

( ) = Numbers of sections are given in parenthesis.

Note: Controlled for ADT, lane width, shoulder width, and average recovery distance using the analysis of covariance.

Table 46. Severity of common accident types in several data bases.

Accident Type	Accident Severity	Percent of total accidents resulting in injury or fatality — Data Base: Michigan	Utah	Washington
Run-off-road fixed object	Injury Fatal	35 (10137) 0.8 (228)	36 (827) 2.0 (46)	44 (15902) 1.5 (532)
Run-off-road rollover	Injury Fatal	55 (6587) 1.1 (73)	55 (1076) 3.2 (63)	56 (6488) 2.1 (245)
Head on	Injury Fatal	41 (1922) 2.7 (127)	50 (237) 11.9 (56)	60 (803) 20.4 (272)
Sideswipe Opposite dir.	Injury Fatal	21 (27) 2.4 (3)	30 (162) 1.9 (10)	41 (1118) 2.0 (54)
Sideswipe Same dir.	Injury Fatal	13 (42) 1.6 (5)	11 (87) 0.2 (2)	20 (2012) 0.2 (20)
Rear end	Injury Fatal	27 (2228) 0.3 (27)	33 (2320) 0.2 (11)	43 (21239) 0.2 (96)
Pedestrian or bicycle	Injury Fatal	86 (1769) 7.0 (144)	84 (654) 7.8 (61)	90 (2007) 9.8 (218)
Angle	Injury Fatal	46 (3145) 1.1 (78)	31 (2768) 0.6 (55)	37 (13272) 0.5 (174)

Note: The Michigan data base consisted of all reported accidents on rural roads in 1983.[27] 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.

ages 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 in table 46. 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 in table 47. FO accidents resulted in from 25 to 55 percent of injuries and from 0.5 to 2.0 percent of fatalities. At the upper end of the severity ranges are FO accidents involving trees, culverts, bridges (bridge columns and bridge ends) rocks, utility poles, and earth embankments, while at the lower end are those involving signs, mailboxes, fire hydrants, and fences. Trees, utility and light poles, guardrails, and earth embankments are the objects which claim the most FO injury and fatal accidents.

Roadside Question 6. What types of roadside obstacles are most commonly struck on roads with various traffic volume conditions?

Overall, trees and utility poles are the roadside fixed obstacles most often struck, while guardrail, signs, mailboxes, and bridge ends were hit less frequently. On roads with ADT's of 4,000 or less, trees are the most often struck obstacle, while utility poles are the most frequently struck obstacle on roadways above 4,000 ADT.

The frequency of six types of fixed object accidents has been summarized for different ADT categories in table 48 from six of the States in the current data base. Utah accident data were not included because very few obstacle types were recorded in that State's accident file. Other types of fixed object accidents were defined or recorded differently in different States, making tabulation of those types impossible.

Table 47. 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 (rural and urban) in 1983 in which a fixed object was struck either as the primary or secondary object hit.[27] 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 48. 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 Obstacle	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)
Totals	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).

Overall, the most commonly struck obstacles from table 48 were trees (14.8 percent) and utility poles (14.1 percent). This finding agrees with Jones and Baum who cited these two obstacle types as among the most frequently struck fixed objects.[16] 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 48 includes all other obstacle types (including earth embankments being struck) and also obstacles which were not specifically coded by the police officers.

For roads with ADT's of 4,000 or less, trees are the 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 ADT's of 4,000 or greater, utility poles are the most frequent type of fixed object struck which indicates 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 7 percent of all fixed-object accidents on roads with ADT's of 1,000 or less, but 9.3 to 10.9 percent of fixed-object hits for roads with ADT's of 1,001 or greater. The values in table 48 represent only the frequency of accidents and do not account for the frequency or placement of these roadside objects.

Roadside Question 7. What combinations of roadway and geometric conditions are associated with particularly high rates of single-vehicle accidents (for which roadside treatments are of high potential benefit)?

The highest rates of single-vehicle accidents are found on roads which are narrow ($\leq$ 25 feet), combined with recovery distances of less than 10 feet.

A summary of mean single-vehicle accident rates are given in table 49 for various combinations of roadway (lane plus shoulder) width, terrain, and average recovery distance. Conditions with the highest rates (i.e., 150 acc/100 MVM or greater) are highlighted and include all cells with narrow ($\leq$25 feet) roadways, combined with recovery distances less than 10 feet. Other conditions with high rates of single-vehicle accidents include mountainous and rolling areas with recovery distances of 15 feet or

Table 49. Relationship of roadway width, terrain, and recovery distance to the single-vehicle rate for rural sections.

Single vehicle accidents per 100 MVM

Width of Lanes Plus Shoulders (ft)	Terrain	Average Recovery Distance, feet			
		0 to 5	6 to 10	11 to 15	≥ 16
≤ 25	Flat	* (3)	234(9)	137(15)	101(27)
	Rolling	307(10)	154(20)	152(17)	96(25)
	Mountainous	236(33)	162(46)	378(9)	* (1)
26 to 32	Flat	126(11)	106(36)	68(52)	56(106)
	Rolling	144(47)	137(100)	109(89)	66(134)
	Mountainous	174(62)	142(120)	250(21)	53(5)
> 32	Flat	* (1)	80(66)	71(159)	49(216)
	Rolling	* (1)	76(70)	69(96)	37(145)
	Mountainous	* (2)	100(25)	66(18)	44(4)

( ) = Number in parenthesis represents number of sample sections.

* = Accidents not given for cells with 3 or less sample sections.

▭ = Cells having 150 or more single vehicle accidents/100 MVM.

⬭ = Cells having 100 to 149 single vehicle accidents/100 MVM.

less and roadway widths of 32 feet or less. Sections generally associated with the highest incidences of single-vehicle accidents should have the greatest potential for accident reduction. However, it should also be mentioned that conditions which lead to high rates of single-vehicle accidents may be very costly to correct.

<u>Roadside Question 8. What are the roadside characteristics represented in the data base for various ADT levels in urban and rural areas?</u>

The most common roadside hazard ratings are those in the middle ranges, i.e., rating values of 3, 4, and 5 in both urban and rural areas. The distributions of roadside hazard rating and average recovery distance were observed and are summarized in tables 50 through 54 for a variety of different situations.

Table 50 shows that 98,526 ratings were made with the roadside hazard scale. For the urban and rural data base, 1,231 ratings of one were made (1.2 percent of the total) and a nearly equal number of ratings of seven were made. Ratings of two and six were each made approximately 6,500 times (6.6 percent of the total). Ratings of three were recorded 25,797 times (26.2 percent of the total) and ratings of five were recorded 21,822 times (22.1 percent of the total). Ratings of four were made most often (35,355 times or 35.9 percent of the total).

The distribution of hazard ratings by area (urban or rural) and terrain (flat, rolling, or mountainous) revealed several interesting and logical trends. Rural mountainous areas had by far the largest proportion of high (i.e., ratings of five, six, or seven) hazard ratings with 62.8 percent of all ratings (38.4 + 20.0 + 4.4), compared to 30.4 in rural rolling terrain, and 14.4 percent in rural, flat terrain, and 29.2 in urban areas.

Conversely, rural, flat terrain had the highest percent of low (i.e., ratings of three or less) roadside hazard ratings with 50.5 percent compared to only 7.4 percent in rural mountainous areas. These trends were expected, since roads in mountainous areas typically have roadsides with steep slopes and trees or other obstacles near the roadway, whereas roads in flat terrain often have more forgiving roadsides.

Table 50. Roadside hazard ratings by area type and terrain.

Area Type	No. of Sections	Number of Roadside Hazard Ratings							
		1	2	3	4	5	6	7	Totals
Rural - Flat	701	756 (2.0)	3,978 (10.7)	14,003 (37.8)	13,030 (35.2)	4,764 (12.9)	470 (1.3)	64 (0.2)	37,065 (100.0)
Rural - Rolling	754	143 (0.3)	2,096 (5.1)	9,939 (24.2)	16,363 (39.9)	9,804 (23.9)	2,374 (5.8)	285 (0.7)	41,004 (100.0)
Rural - Mountainous	346	21 (0.1)	162 (0.9)	1,097 (6.4)	5,110 (29.7)	6,601 (38.4)	3,428 (20.0)	762 (4.4)	17,181 (100.0)
Urban	143	311 (9.5)	320 (9.8)	758 (23.1)	852 (26.0)	653 (19.9)	271 (8.3)	111 (3.4)	3,276 (100.0)
Totals	1,944	1,231 (1.2)	6,556 (6.7)	25,797 (26.2)	35,355 (35.9)	21,822 (22.1)	6,543 (6.6)	1,222 (1.2)	98,526 (100.0)

( ) = Numbers in parenthesis represent percent of row values.

Tables of roadside hazard ratings are given in tables 51 and 52 for various combinations of lane and shoulder width. As may be expected, hazard ratings in rural areas are generally higher on roads with narrow lanes and shoulders. For example, on roads with eight and nine-foot lanes with zero to three-foot shoulders, high roadside ratings (i.e., ratings of five to seven) were made 61.7 percent of the time, whereas on roads with lane widths of 12 feet or more and wide (six to 13-foot) shoulders, roadside ratings of five or more were observed only 12.6 percent of the time. In urban areas (table 52), 45.6 percent of the ratings on roads with narrow lanes (10 feet or less) were high compared to 25.9 percent on roads with wide (12 feet or greater) lanes.

A summary of roadside hazard ratings is given for various ADT groups for rural and urban areas in table 53. In rural areas, ADT groups from 751 to 1,000 and from 1,001 to 2,000 had the largest percentages of high roadside hazard ratings. In urban areas, 61.8 of the roadside ratings on sections with ADT's of 10,000 or more were four or greater, while high percentages of roadside ratings of one and two were observed in ADT groups 2,001 to 5,000 and 5,001 to 10,000 (24.2 and 21.8 percent, respectively).

Average recovery area distance is summarized for urban areas and for rural areas by terrain condition in table 54. Of the 346 sections in mountainous areas 28 percent had average recovery distances of zero to five feet, and another 55.2 percent had recovery distances of six to ten feet. This compares with flat rural sections, where only 17.9 percent had recovery distances of ten feet or less. Overall, 37.8 percent of the sections in the data base had average recovery distances of ten feet or less.

Table 51. Roadside hazard ratings for rural area lane and shoulder width combinations.

Lane Width (ft)	Total Shoulder Width (ft)	No. of Sections	Number of Roadside Hazard Ratings							
			1	2	3	4	5	6	7	Totals
8 & 9	0-3	76	5 (0.1)	81 (1.9)	405 (9.6)	1,133 (26.7)	1,706 (40.3)	758 (17.9)	149 (3.5)	4,237 (100.0)
	4-5	126	20 (0.3)	195 (2.8)	1,403 (20.3)	2,152 (31.1)	2,097 (30.4)	873 (12.6)	161 (2.3)	6,901 (100.0)
	6-13	72	13 (0.4)	132 (4.0)	881 (26.4)	1,394 (41.8)	773 (23.2)	127 (3.8)	11 (0.3)	3,331 (100.0)
10	0-3	121	41 (0.6)	263 (4.0)	905 (14.0)	1,936 (30.0)	2,117 (32.8)	1,036 (16.0)	157 (2.4)	6,455 (100.0)
	4-5	107	23 (0.4)	136 (2.5)	934 (17.6)	2,113 (39.8)	1,724 (32.5)	336 (6.3)	42 (0.8)	5,308 (100.0)
	6-13	118	8 (0.1)	226 (3.5)	2,026 (31.2)	2,722 (41.9)	1,307 (20.1)	165 (2.5)	35 (0.5)	6,489 (100.0)
11	0-3	94	139 (2.5)	486 (8.8)	1,092 (19.8)	1,824 (33.1)	1,447 (26.2)	453 (8.2)	73 (1.3)	5,514 (100.0)
	4-5	159	21 (0.3)	399 (5.4)	1,424 (19.3)	2,631 (35.7)	2,165 (29.4)	623 (8.5)	105 (1.4)	7,368 (100.0)
	6-13	271	178 (1.1)	1,142 (7.2)	5,150 (32.5)	6,129 (38.7)	2,831 (17.9)	339 (2.1)	53 (0.3)	15,822 (100.0)
≥ 12	0-3	193	121 (1.1)	1,063 (9.7)	2,876 (26.1)	3,791 (34.4)	2,022 (18.4)	912 (8.3)	225 (2.0)	11,010 (100.0)
	4-5	140	44 (0.7)	454 (7.1)	1,714 (27.0)	2,493 (39.2)	1,240 (19.5)	346 (5.4)	68 (1.1)	6,359 (100.0)
	6-13	324	307 (1.9)	1,659 (10.1)	6,229 (37.9)	6,185 (37.6)	1,740 (10.6)	304 (1.8)	32 (0.2)	16,456 (100.0)

( ) = Numbers in parenthesis represent percent of row values.

Table 52. Roadside hazard ratings in urban areas by lane widths.

Lane Width (ft)	No. of Sections	Number of Roadside Hazard Ratings							
		1	2	3	4	5	6	7	Totals
≤ 10	40	28 (3.4)	102 (12.5)	141 (17.3)	173 (21.2)	224 (27.4)	94 (11.5)	55 (6.7)	817 (100)
11	43	70 (7.8)	82 (9.1)	238 (26.4)	255 (28.2)	184 (20.4)	52 (5.8)	22 (2.4)	903 (100)
≥ 12	60	213 (13.7)	136 (8.7)	379 (24.4)	424 (27.2)	245 (15.7)	125 (8.0)	34 (2.2)	1,556 (100)

( ) = Numbers in parenthesis represent percent of row values.

Table 53. Roadside hazard ratings by area type and ADT.

Area Type	ADT Group	No. of Sections	Number of Roadside Hazard Ratings							
			1	2	3	4	5	6	7	Totals
Rural	50 - 250	52	72 (2.4)	1,222 (13.7)	619 (20.5)	1,105 (36.5)	353 (11.7)	347 (11.5)	115 (3.8)	3,026 (100.0)
Rural	251 - 400	85	55 (1.0)	548 (10.3)	1,500 (28.1)	1,627 (30.5)	1,033 (19.3)	496 (9.3)	83 (1.6)	5,342 (100.0)
Rural	401 - 750	151	234 (2.4)	798 (8.2)	2,368 (24.3)	3,349 (34.3)	2,247 (23.0)	703 (7.2)	74 (0.8)	9,764 (100.0)
Rural	751 - 1,000	124	111 (1.5)	327 (4.4)	1,550 (20.7)	2,407 (32.2)	2,213 (29.6)	723 (9.7)	146 (2.0)	7,477 (100.0)
Rural	1,001 - 2,000	370	197 (0.9)	1,271 (5.9)	5,410 (25.1)	6,988 (32.4)	5,467 (25.4)	1,868 (8.7)	344 (1.6)	21,545 (100.0)
Rural	2,001 - 4,000	501	181 (0.7)	1,775 (6.9)	7,775 (30.0)	9,519 (37.0)	5,253 (20.4)	1,134 (4.4)	174 (0.7)	25,743 (100.0)
Rural	4,001 - 7,500	350	51 (0.3)	909 (5.8)	4,243 (27.1)	6,329 (40.5)	3,180 (20.3)	795 (5.1)	123 (0.8)	15,630 (100.0)
Rural	> 7,500	168	19 (0.3)	193 (2.9)	1,642 (24.5)	3,179 (47.3)	1,423 (21.2)	206 (3.1)	52 (0.8)	6,714 (100.0)
Urban	≤ 2,000	7	1 (0.9)	9 (8.4)	39 (36.4)	23 (21.5)	18 (16.8)	13 (12.1)	4 (3.7)	107 (100.0)
Urban	2,001 - 5,000	43	123 (12.1)	123 (12.1)	280 (27.5)	219 (21.5)	161 (15.8)	71 (7.8)	43 (4.2)	1,020 (100.0)
Urban	5,001 - 10,000	66	174 (11.0)	170 (10.8)	315 (20.0)	413 (26.2)	318 (20.2)	135 (8.6)	53 (3.4)	1,578 (100.0)
Urban	> 10,000	27	13 (2.3)	18 (3.2)	124 (21.7)	197 (34.5)	156 (27.3)	52 (9.1)	11 (1.9)	571 (100.0)

( ) = Numbers in parenthesis represent percent of row values.

Table 54. Recovery distance by area type and terrain.

Number of Sections, with Column Percentages in Parenthesis

Average Recovery Distance (ft)	Rural Sections			Urban Sections	All Sections
	Flat	Rolling	Mountainous		
0 to 5	15(2.1)	58(7.7)	97(28.0)	33(23.1)	203(10.4)
6 to 10	111(15.8)	190(25.2)	191(55.2)	41(28.7)	533(27.4)
11 to 15	226(32.2)	202(26.8)	48(13.9)	46(32.2)	522(26.9)
16 to 20	208(29.7)	174(23.1)	8(2.3)	15(10.5)	405(20.8)
21 to 30	141(20.1)	130(17.2)	2(0.6)	8(5.6)	281(14.5)
Totals	701(100.0)	754(100.0)	346(100.0)	143(100.0)	1,944(100.0)

CHAPTER 7 - COST OF ROADSIDE AND CROSS-SECTION IMPROVEMENTS

To determine the cost-effectiveness of cross-section and roadside improvements, the cost of implementing the improvements must be estimated. A review of the literature related to implementation costs, summarized in appendix I, revealed that no complete sources of cost estimates are available. Therefore, the costs for a variety of improvements were estimated during this research and a summary of those estimates is given in this chapter.

Estimation of implementation costs of various cross-section and roadside improvements for this research proceeded similar to a contract bid project. First, the existing conditions at a typical improvement site were assumed. Second, the condition at the improvement site after the improvement were assumed. Third, specific items of work necessary to achieve the "after" condition from the "before" condition were specified. Next, the quantities of each work item were estimated or assumed. Unit costs for each of these items were estimated on the basis of project bid documents or annual contract cost summaries obtained from ten States. Finally, the unit cost was multiplied by the quantity needed for each line item and the costs for each item were summed to arrive at a final project cost.

In general, assumptions were made on the basis of available data with an aim toward a cost estimate which was the most representative of projects of a similar type across the county. A more complete description of the cost estimation process and the assumptions made is given in appendix J. It is important to note that this procedure may be easily altered by an agency wishing to produce more individualized cost estimates. The assumptions used at any step, the items of work, or the unit costs may be altered based on local information and a new project cost estimate produced.

Implementation costs were estimated for several different types of projects, including:

- Lane and/or shoulder widening.
- Shoulder surfacing.
- Sideslope improvements.
- Roadside obstacle countermeasures.

The variances in implementation costs between project sites were expressed in terms of high, median, and low cost categories. Caution must be used when selecting the cost category which best fits a given project. Some factors which may influence project costs and the selection of a cost category include:

- Project size.
- Terrain.
- Weather.
- Traffic at the construction site.
- Distance to material sources.
- Rural or urban nature of the site.
- Type of contracting agency (construction or maintenance, for example).
- Prevailing labor rates.

The direct use of the high or low cost estimates is rarely a good idea for lane and/or shoulder widening, shoulder paving and sideslope flattening projects. The "high" total cost for a particular project is a sum using all the high line item unit cost estimates, and the "low" total cost is a sum using all the low line item unit cost estimates. The unit costs are not likely to be all high or all low for each line item of work for a particular project, however. Thus, it is recommended that the high and low cost estimates for those types of projects be used only as boundaries of cost ranges or for interpolation to find a "between category" cost estimate. Use of the high or low cost category for roadside obstacle countermeasures is more permissible because those projects could consist of only one line item of work.

Roadside Obstacle Countermeasure Costs

The estimated costs of some common roadside obstacles countermeasures are presented in table 55 and include improvements involving trees, signs, luminares, mailboxes, fire hydrants, impact attenuators, guardrail, and fences. On a per unit basis, these projects are relatively inexpensive. However, the high and low costs for particular improvements vary widely. The list of improvements in table 55 is not a complete list of all roadside obstacle countermeasures of interest in this research. Reliable data were not found on modifying bridge rail, moving culvert headwalls, and other countermeasures.

Table 55. Roadside obstacle countermeasure costs.

Action	Object	Unit Costs (1985 $)			
		Unit	High	Median	Low
Remove	Trees	Each	550	200	70
Relocate	Small sign	Each	440	200	70
Relocate	Large sign	Each	3,000	1,100	500
Remove	Small sign	Each	220	40	15
Remove	Large sign	Each	600	175	25
Relocate	Luminaire support	Each	1,500	600	300
Relocate	Mailboxes/newsboxes	Each	300	120	60
Relocate	Fire hydrant	Each	2,200	1,100	550
Remove	Fire hydrant	Each	340	250	175
Install New	Impact attenuator-foam type	Each	26,000	20,000	10,000
Install New	Impact attenuator-hydraulic type	Each	34,000	28,000	22,000
Install New	Impact attenuator-sand-filled type	Each	6,000	4,000	3,000
Clear and Grub	Trees	Acre	8,000	3,500	1,000
Relocate	Guardrail	L.F.	19.00	8.00	6.00
Remove	Guardrail	L.F.	5.50	1.50	0.70
Install New	Guardrail	L.F.	31.00	10.00	7.60
Install New	Guardrail end-anchor	Each	800	500	350
Relocate	Cable guardrail	L.F.	5.00	3.50	2.50
Remove	Cable guardrail	L.F.	3.00	1.10	0.75
Install New	Cable guardrail	L.F.	9.00	6.00	3.20
Relocate	Fence	L.F.	10.00	3.00	1.00
Remove	Fence	L.F.	5.00	0.80	0.20
Relocate	Chain-link fence	L.F.	20.00	13.00	10.00
Remove	Chain-link fence	L.F.	6.00	2.75	1.70

L.F. = Linear Foot

Sideslope Flattening Costs

The estimated costs of flattening several common types of sideslopes are given in table 56. It was assumed that every roadside after the improvement had at least a 4 to 1 or greater ratio sideslope for approximately 15 feet with a height of fill of 4 feet, a 3 to 1 ratio backslope and a 30-foot clear zone from the edge of the shoulder. For example, the median cost would be $88,000 for flattening a 2:1 slope with a 5-foot height of fill to a slope of 4:1 with a 4-foot height of fill. As shown on table 56, costs for improving sideslopes are generally similar within the high, median, and low categories for heights of fill of 2 or 3 feet. This is due to different unit costs and quantities for different types of earthwork (borrow, replace, disposal) involved. It should be mentioned that for many projects, it is not practical to provide sideslope flattening to a 4:1 ratio and clear zones of 30 feet. In such cases, other improvements may be made such as the installation of guardrail. The assumptions made above may be altered to allow the estimation of the costs of alternatives to sideslope flattening and providing clear zones.

Shoulder Surfacing Costs

The estimated cost of paving gravel or earth shoulders per foot width in 1985 dollars is $13,700 per mile for the high cost category, $6,000 per mile for the median cost category, and $3,400 per mile for the low cost category. No distinction is made between paving gravel and earth shoulders because the cost of excavating and disposing the existing shoulder was assumed to be similar for gravel and earth.

Lane and Shoulder Widening Costs

The estimated cost of a lane and/or shoulder widening project is found from the following equation:

$$C_T = M\,[(W_L)(C_L) + (W_S)(C_S) + E] \qquad \text{Equation (15)}$$

Where:

C_T = the total per mile widening project construction cost in 1985 dollars;

M = 1.095 (the adjustment factor to account for project costs associated with mobilization and traffic control);

W_L = travelled way width change in feet for both sides of the road;

C_L = cost of widening the lanes in 1985 dollars per foot of added width from table 57;

W_S = shoulder width change in feet for both sides of the road;

C_S = cost of widening the shoulders in 1985 dollars per foot of added width from table 57;

E = cost of altering the side and back slopes in 1985 dollars, from table 58.

The equation and component tables are applicable for any case where $W_L \geq 0$ and where $20 \geq (W_L + W_S) \geq 0$; for gravel or paved shoulders; and for the high, median or low cost categories. The items included in the cost for lane widening were assumed to be:

- Excavating and disposing of the earth, existing base, gravel, or existing pavement.
- Grading the top of the subgrade level.
- Purchasing and placing the base.
- Purchasing and placing the asphalt concrete.

The items for the shoulder widening portion were assumed to be the same as for the lane widening portion with the addition of an item for purchasing and placing gravel for the shoulder surface (if necessary). Pavement markings are required for each project and therefore no cost was included for them.

As an example of the use of the above equation and tables 57 and 58, assume a "before" construction condition of 10-foot lanes, 2-foot gravel shoulders, 4 to 1 sideslope ratio, 5-foot height of fill, 3 to 1 backslope ratio, 10-foot backslope length and 30-foot "clear zone" on both sides of a 6-mile long road. The "after" construction condition is assumed as a road with 12-foot lanes, 4-foot gravel shoulders, and the same sideslope and backslope dimensions as in the "before" condition. Median costs are also assumed. As a first step, W_L and W_S are computed to be 4 and 4, respectively. Then, the other factors in the equation are found from the tables, in 1985 dollars. The lane-widening cost per mile (C_L) is found in table 57 to be $12,400 for median costs for gravel shoulders. The shoulder widening cost per mile (C_S) is found from table 57 to be $4,100

Table 56. Sideslope flattening cost estimates.

Existing Sideslope		Costs ($1,000/mile)		
Ratio	Height of fill (ft.)	High	Median	Low
1.5:1	3	381	121	48
2:1	3	405	129	51
2.5:1	2	390	131	52
3:1	2	405	136	54
4:1	2	419	140	56
1.5:1	6	560	148	57
2:1	5	279	88	35
3:1	4	190	70	28

Table 57. Costs of lane and shoulder widening per foot of width.

Shoulder Type	Cost Category	1985 Lane Widening Cost ($1,000/mile), C_L	1985 Shoulder Widening Cost ($1,000/mile), C_S
Gravel	High	29.1	10.9
	Median	12.4	4.1
	Low	6.9	1.8
Paved	High	30.8	12.5
	Median	13.9	5.5
	Low	8.2	3.2

Table 58. Cost of slopework portion of widening project.

Total Width Added Both Sides, $W_L + W_S$, in feet	Existing Sideslope		1985 Costs ($1,000/mile), E		
	Ratio	Height of fill* (ft.)	High	Median	Low
4	2:1	3	387	127	49
	4:1	1	440	139	55
	6:1	1	408	128	49
	2:1	5	303	91	37
	4:1	3	117	41	15
	6:1	2	115	40	15
	4:1	5	188	59	23
	6:1	3	88	35	14
	4:1	7	199	64	25
8	2:1	3	475	153	62
	4:1	1	484	150	59
	6:1	1	449	139	56
	2:1	5	346	103	41
	4:1	3	219	73	29
	6:1	2	195	68	27
	4:1	5	280	80	31
	6:1	3	108	40	15
	4:1	7	318	91	34
16	2:1	3	529	169	68
	4:1	1	550	168	66
	6:1	1	508	156	62
	2:1	5	414	121	49
	4:1	3	358	113	46
	6:1	2	322	103	42
	4:1	5	445	117	44
	6:1	3	244	72	26
	4:1	7	559	145	56

*The height of fill was calculated based upon the sideslope length and sidelsope ratio and is rounded to the nearest foot.

for median costs for gravel shoulders. The sideslope cost per mile (E) is found from table 58, to be $80,000 for median costs with $W_L + W_S = 4 + 4 = 8$ feet, an existing sideslope ratio of four to one and an existing sideslope height of fill of 5 feet. Thus,:

$C_T = 1.095\ [(4 \times 12{,}400) + (4 \times 4{,}100) + 80{,}000]$ Equation (16)

$C_T = \$160{,}000$ per mile

The total project cost is then estimated as:

6 miles x $160,000 per mile = $960,000.

Maintenance Costs

The maintenance costs incurred by a highway agency on a section of road may change after a cross-section or roadside improvement. These cost changes should be analyzed along with the implementation costs in a cost-effectiveness analysis of a proposed improvement. However, a review of the literature showed that incremental maintenance costs were extremely difficult to quantify, since such costs are typically a function of administrative policies and normal maintenance practices and are not necessarily altered simply because a roadway is widened or because roadside improvements are made.

Studies which have identified incremental maintenance costs for some improvements often found conflicting results. Records of minor pavement maintenance from Nevada were analyzed in one study which found that it cost $80.00 per mile (1984) more to maintain a 24-foot wide pavement than a 20-foot wide pavement.[6] Another study, however, found that edge deterioration causes an increasing maintenance effort for pavements under 24-feet wide.[28] In another example of conflicting incremental maintenance cost estimates, survey results showed that Louisiana spends an average of $12.00 (1984) per shoulder mile more to maintain paved shoulders than unpaved shoulders, while Pennsylvania spends $143.00 per shoulder mile less on paved shoulders than on unpaved shoulders.[29]

For an agency wishing to include incremental maintenance costs in a cost-effectiveness procedure, the best solution is probably to develop an estimate based on the maintenance policies and prior experience of the particular agency. When policy or prior experience is no help, an assumption of no incremental maintenance costs for many projects may be reasonable.

Verification of Cost Estimates

Implementation costs estimated in this research were compared to cost estimates in the literature for several project types. Generally, project costs estimated for this study are similar to costs reported in the literature. A comparison of cost estimates for roadside obstacle countermeasures is shown in table 59. The costs reported in the literature were collected in several States over the past few years. Most of the costs fell well within the high to low cost category range given in this research and were generally close to the median costs. Comparisons involving the costs of lane and shoulder widening are given in table 60. In terms of lane widening, the costs from Kentucky correspond to the high estimates, while the Idaho estimates more closely match the low-cost category. This may be expected due to differences in terrain and other factors between the two States which affect construction costs. Shoulder widening costs from Kentucky closely match the median costs from this research.

Data were also gathered on nine shoulder surfacing projects (from March 1983 through March 1984) by the Michigan DOT for comparison with the cost estimated for shoulder surfacing in this research. The distribution of the costs from the nine projects, shown in table 61, fall within the high to low cost range estimated in this research.

Table 59. Comparison of current study cost estimates to previous research for roadside obstacle countermeasures.

Countermeasure	Estimate Source	Unit Costs (1985 $)
Remove trees (4 inches or more diameter)	Current study:	
	low	70
	median	200
	high	550
	Reference 25	71-270
	Reference 30	86
	Reference 19	120
	Reference 1	270
Relocate small sign	Current study:	
	low	70
	median	200
	high	440
	Reference 25	180
	Reference 30	180
	Reference 19	600
Install guardrail (per foot)	Current study:	
	low	7.60
	median	10
	high	31
	Reference 25	8
	Reference 1	10
	Reference 19	12

Table 60. Comparison of current study cost estimates to previous research for lane and shoulder widening.

Total Added Width, ft. (each side)	Estimate Source	Project cost/mile (1985 $ K)
Lane Widening		
2	Current study, high costs	255
	Current study, median costs	99
	Current study, low costs	47
	Kentucky (Ref. 7)	244
	Idaho, level terrain (Ref. 6)	20
	Idaho, difficult terrain (Ref. 6)	31
4	Current study, high costs	494
	Current study, median costs	188
	Current study, low costs	92
	Kentucky (Ref. 7)	350
Shoulder Widening		
2	Current study, high costs	176
	Current study, median costs	63
	Current study, low costs	24
	Kentucky (Ref. 7)	67
4	Current study, high costs	335
	Current study, median costs	116
	Current study, low costs	48
	Kentucky (Ref. 7)	113

Note: Current study conditions assumed as gravel shoulders and 4:1 side-slopes with a length of 10 ft. and a height of fill of 3 feet.

Table 61. Comparison of Michigan project data to current study cost estimates for shoulder surfacing.

Current Study	
Cost Category	Estimated shoulder surfacing costs ($1,000, 1985) per foot width per mile
High	13.7
Median	6.0
Low	3.4
Michigan Project Data	
Project	Estimated shoulder surfacing cost ($1,000, 1985) per foot width per mile
1	13.0
2	9.4
3	9.0
4	7.6
5	7.6
6	6.8
7	5.1
8	4.8
9	3.8

CHAPTER 8 - ECONOMIC ANALYSIS

Based on the determination of costs and expected accident reductions for lane and shoulder widening and roadside improvements, a cost-effectiveness analysis methodology was developed. The major topics addressed in this chapter are as follows:

- Selection of Economic Analysis Techniques
- Inputs Into the Cost-Effectiveness Procedure
- Other User Benefits
- Use of the Cost-Effectiveness Procedure

Selection of Economic Analysis Techniques

Numerous economic analysis techniques can be considered for evaluating individual projects. The benefit-cost method is a good method for analysis of individual projects due to its common use in other research studies, its ease of understanding, and the ease of manual computation. Also, unlike some other methods, it can be easily interpreted, and many agencies consider a project to be justified with a benefit-cost ratio of 1.0 or greater.

When comparing different project alternatives at a site, several economic analysis procedures can be considered such as the incremental benefit-cost ratio method, dynamic programming or integer programming. For this study, the incremental benefit-cost ratio method is recommended for use in evaluating multiple projects because of its validity and simplicity in computation and understanding, compared to the other methods. To apply the incremental benefit-cost ratio method, alternative countermeasures are ordered from lowest to highest cost. Then, the "increase" in benefit and cost are computed for the next higher priced alternative. If the change in benefit exceeds the change in cost, the higher priced option is justified (i.e., the added expense will pay for itself in terms of yielding accident benefits). An example of the incremental benefit-cost ratio method is provided in appendix C. The benefit-cost ratio method will be used in the example in this chapter because only one project will be evaluated.

Inputs Into the Cost-Effectiveness Procedure

To use the B/C and incremental B/C analysis techniques for economic analysis, several inputs must be known or assumed:

- Expected accidents reduced from improvement.
- Cost of improvement.
- Unit accident cost.
- Service life of the improvement.
- Salvage value of the improvement.
- Interest rate of money.

The following paragraphs describe each of these inputs.

Expected Accidents Reduced From Improvement(s)

To compute accident benefits due to roadway or roadside improvements, the user must estimate the expected numbers of accidents to be reduced per-mile-per-year, which may be obtained from any one of the following procedures:

1. The user may calculate the number of related accidents-per-mile-per-year using the final AO model (equation 7) for the existing roadway condition and future (i.e., post project) condition. The difference between those two values represents the expected number of related accidents which would be reduced as a result of the project.

2. The user may review accident records for a roadway section under study and determine the number of so called "related" accidents (i.e., the number of fixed object + rollover + other run-off-road + head-on + opposite direction sideswipe + same direction sideswipe, where each accident is counted only once) and divide by the number of years of accident data used and the section length (in miles). This will give a measure of related accidents-per-mile-per-year for the section. Using the accident reduction factor (AR factor) tables 28, 29, and 30, multiply the appropriate

AR factor by the number of related accidents-per-mile-per-year to give the expected number of related accidents to be reduced per-mile-per-year.

3. A user may use a different approach if he does not wish to calculate the number related accidents, knows the number of total accidents on the section, but cannot determine the number of related accidents (i.e., the total of the six accident types listed in item 2 above). In that case, the user needs an estimate of the percent of related accidents to the total, so he may apply the appropriate AR factor. This percent can be approximated from figure 10, which shows the percent of related accidents based on ADT (from 500 to 11,000) for curves of flat, rolling, and mountainous terrain. Thus, for a roadway with an ADT of 1,000 with rolling terrain, the related accidents (i.e., six types listed previously) would be expected to account for approximately 62 percent of the total accidents on that section. The user could then compute the total accidents per mile per year by dividing the total accidents by the section length (miles) and the accident time period (years). Then by multiplying the total accs/mi/year by the adjustment factor from figure 10 (i.e., 62 for 62 percent) the expected number of related accidents-per-mile-per-year can be determined. Then, the accident reduction factors (tables 28, 29, and 30) can be selected and multiplied by the related accidents-per-mile-per-year to determine the number of related accidents reduced (per-mile-per-year) due to the proposed improvements.

To illustrate the three options for determining the expected accident reduction, consider the following roadway improvements:

- Lane widening from 10 to 12 feet.
- Shoulder widening and surfacing from a 4-foot gravel shoulder to a 6-foot paved shoulder.
- Roadside improvements, which will reduce the roadside hazard rating from 4 to 2.

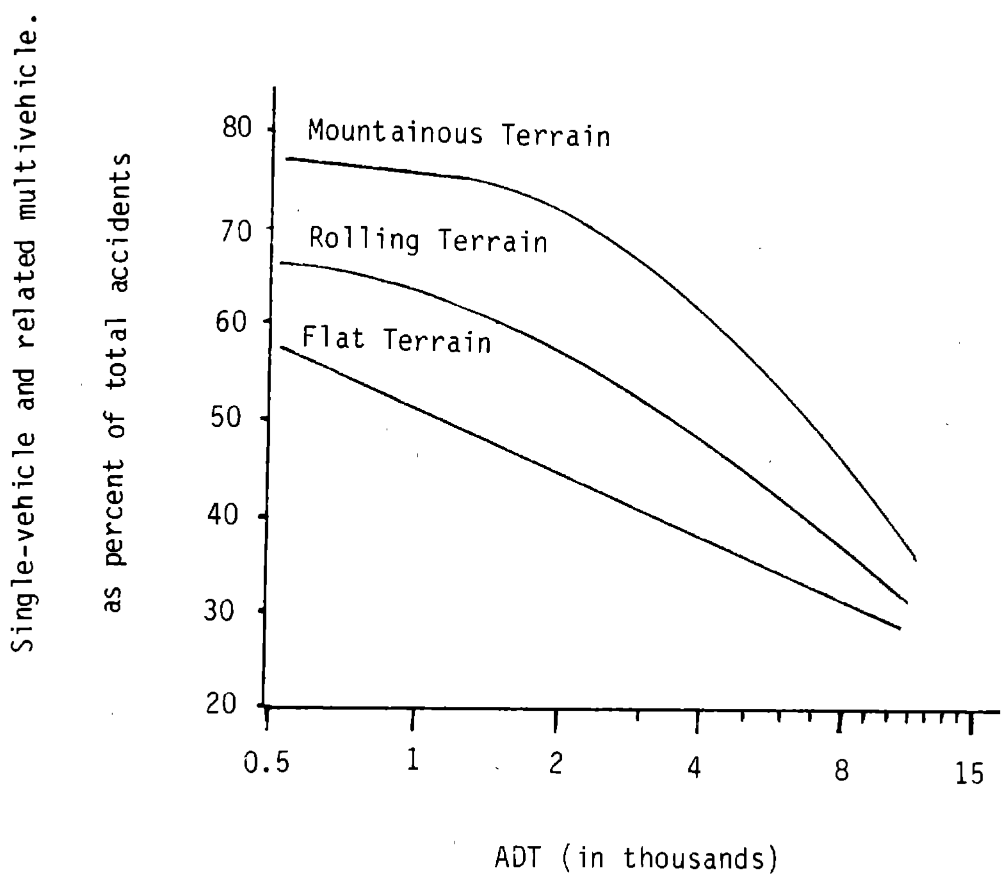


Figure 10. Proportion of single-vehicle and related multivehicle to total accidents on rural roads in relation to ADT and terrain.

Other features are as follows:

	Before Condition	After Condition (Proposed)
Terrain	Flat	Flat
Section Length	6 miles	6 miles
ADT	2,000	2,000
Lane Width (W)	10 feet	12 feet
Paved Shoulder Width (PA)	0 feet	6 feet
Unpaved Shoulder Width (UP)	3 feet (gravel)	0 feet
Roadside Hazard Rating (H)	4	2
Sideslope	4:1	4:1
Sideslope Height of Fill	5 feet	5 feet
Sideslope Length	20 feet	20 feet
Total Accidents per Year on the Section	10	Unknown
Related AO Accidents	Unknown	Unknown

Using the Predictive Model (equation 7) the related (AO) accidents for the before condition (AO_B) and after conditions (AO_A) may be computed as follows:

$$AO = .0019\ (ADT)^{.8824}(.8786)^{W}(.9192)^{PA}(.9316)^{UP}(1.2365)^{H}(.8822)^{TER1}(1.3221)^{TER2}$$

where TER1 = 1 if flat, 0 otherwise

TER2 = 1 if mountainous, 0 otherwise

For the before condition;

$$AO_B = (.0019)(2{,}000)^{.8824}(.8786)^{10}(.9192)^{0}(.9316)^{3}(1.2365)^{4}(.8822)^{1}(1.3221)^{0}$$

$$AO_B = (1.55)\ (.27)\ (1)\ (.81)\ (2.34)\ (.8822)\ (1)$$

AO_B = 0.70 related accidents-per-mile-per-year

Coverting to accidents over the 6-mile section; AO_B = (0.70 accidents-per-mile-per-year) x (6.0 miles) =

AO_B = 4.2 related accidents-per-year

In the <u>after condition</u>;

$$AO_A = (.0019)(2{,}000)^{.8824}(.8786)^{12}(.9192)^{6}(.9316)^{0}(1.2365)^{2}(.8822)^{1}(1.3221)^{0}$$

$$AO_A = (1.55)\ (0.21)\ (.60)\ (1)\ (1.53)\ (.8822)\ (1)$$

AO_A = 0.26 related accidents-per-mile-per-year, or

AO_A = (0.26 accidents-per-mile-per-year) x (6 miles) =

AO_A = 1.6 related accidents-per-year

Using the three options discussed above for determining the accident reduction factor yields the following:

<u>Option 1:</u>

This involves taking the difference between predicted accidents before and after the improvements to obtain the expected reduction in accidents-per-year. Thus,

$AO_B - AO_A$ = 4.2 - 1.6 = 2.6 related accidents-per-mile reduced due to the improvements.

<u>Option 2:</u>

This procedure makes use of actual accident experience on the roadway section, preferably if the number of related (i.e., fixed object + rollover + other run-off-road + head-on + opposite direction sideswipe + same-direction sideswipe) accidents is known. In this example, the total accidents (i.e., 10 per year on the 6-mile section, or 1.7 per-mile-per-year) are known, but not the related accidents. Therefore, the analyst should refer to Option 3.

Option 3:

This option makes use of the known (10 in this example) total accidents on a section without knowing how many of them are of the related type. Using figure 10, it may be estimated that for an ADT of 2,000 in flat terrain, approximately 45 percent of total accidents would be expected to be of the related type, or (.45) (10) = 4.5 related accidents per year on the 6-mile section.

For the lane and shoulder improvements, refer to table 30, to select the accident reduction factor. Thus, for 2 feet of lane widening on an existing 3-foot unpaved (gravel) shoulder improved to a 6-foot paved shoulder, a 42 percent reduction in related accidents is expected due to the lane and shoulder improvements only.

The effect of the roadside improvements must also be included. Using table 32, a reduction in roadside hazard rating of 2 will result in an estimated accident reduction of 34 percent.

To determine the combined accident reductions from all of the improvements, the reduction factors (i.e., 42 percent and 34 percent) cannot be numerically added. Instead, the overall accident reduction (R_A) may be computed as:

$$R_A = 1 - (1 - AR_1)(1 - AR_2) \qquad \text{Equation (17)}$$

Where:

AR_1 = the accident reduction factor from the first improvement(s) (i.e., in this case the 42 percent)

AR_2 = the accident reduction factor from the second improvement(s) (i.e., the 34 percent)

$RA = 1 - (1 - .42)(1 - .34) = 1 - (.58)(.66)$

RA = .62, or a 62 percent reduction in related accidents.

Thus, the reduction in related accidents using Option 3 is (4.5 related accidents/year) (.62) = 2.8 related accidents reduced per year.

This agrees closely with the 2.6 accidents reduced per year computed in Option 1, but differs slightly because actual accidents on the section were considered in Option 3, whereas predicted accidents (from the model) were used in Option 1.

Cost of Improvements

For the cost-effectiveness analysis procedure, the cost of the improvement can be input by the user if such information is known. If not, the costs developed in chapter 7 can be used. These costs do not include costs for additional right-of-way-acquisition or changes in maintenance costs. Such costs, if applicable, must be added. If these costs are not known, they can be assumed as zero.

Unit Accident Costs

After estimating expected reductions in related accidents, a unit accident cost will allow for computing accident benefits (savings) in terms of dollars. Numerous sources are available of such unit accident costs based on different assumptions and cost information. Examples of unit accident costs include: (1) States' costs; (2) National Safety Council (NSC) costs; (3) costs of the National Highway Traffic Safety Administration (NHTSA) costs, (4) cost values developed by Miller et al. based on 1980 NHTSA costs, and (5) costs by Hartunian et al. (see references 31, 33, 32, 34). Details of these cost values are given in appendix D.

The average cost per accident can be computed based on the cost per event and the number of injuries and fatalities per injury and fatal accident. For the 62,675 accidents in the total accident data base, it was found that 1.63 persons were injured per injury accident and 1.22 persons were killed per fatal accident. The percent injury and fatal accidents for the "related" accident types was determined from table 46 by averaging values from Michigan, Utah, and Washington, as follows:

Accident Type	% Injury	% Fatal
Fixed-Object	38.3	1.4
Rollover	55.3	6.4
Head-On	50.3	11.7
SS - Opposite Dir.	30.7	2.1
SS - Same Dir.	14.7	0.7

The overall average percent injury and fatal accidents can be determined based on the information above, and weighted by relative frequency of each of the related accident types. From table 10, the following accident frequencies were determined for rural sections:

Accident Type	Frequency	Percent
Fixed-Object	10,937	50.9
Rollover	4,122	19.2
Head-On	1,858	8.7
SS - Opposite Dir.	2,628	12.2
SS - Same Dir.	1,925	9.0
Total	21,470	100.0

Taking a weighted average of accident types by percent injury (i.e., (.383)(.509) + (.553)(.192) + ... + (.147)(.09) = 39.6 percent injury accidents. Similarly, weighted overall average for fatal accidents was 3.3 percent. PDO accidents would then account for 100 - 39.6 - 3.3 = 57.1 percent of all related accidents. A review of total accidents on all rural sections revealed 37.5 percent injury accidents and 1.6 percent fatal accidents. Thus, percent injury accidents and fatal accidents were higher for the "related" accident types than for the total rural data base.

The cost per accident, using NSC costs (as given in appendix D), was determined as follows:

$$C_A = \text{(percent PDO accidents)(cost/PDO accident)+(percent injury accidents)(cost/injury)(injuries/injury accident)+(percent fatal accidents)(cost/fatality)(fatalities/fatal accident)}$$

$$= (0.571)(\$1{,}190)+(0.396)(\$9{,}300)(1.63)+(0.033)(\$220{,}000)(1.22)$$

$$= 15{,}540 = \$15{,}500 \text{ per related accident} \qquad \text{Equation (18)}$$

Service Life

For each improvement under consideration, service life must be estimated for use in computing accident benefits. The user may select an appropriate service life, although a service life of 20 years is a reasonable assumption for most types of lane and shoulder widening projects.

Salvage Value

The salvage value is the dollar value of a project at the end of its service life. For most widening projects the salvage value is very small and generally assumed to be zero.

Interest Rate

The interest rate is an important value in the cost-effectiveness procedure. A different interest rate can affect the selection of a particular improvement, in some cases. Interest rates used by agencies can vary. The user should select an interest rate that reflects the policy of the particular agency, although interest rates of 4 to 10 percent are commonly used.

Other User Benefits

The major benefits of lane and shoulder widening, and roadside improvements are reduction in accidents. However, there may be other secondary benefits to motorists as a result of these improvements such as reduction in vehicle operating costs, travel time and delay, and increased comfort and convenience. Each of these secondary benefits are discussed below.

Vehicle Operating Costs

Vehicle operating costs consist of fuel costs, oil costs, tire wear, maintenance and depreciation costs attributed to highway mileage traveled. The effect of lane width, shoulder width and shoulder surface type on vehicle operating costs can be determined by determining the vehicle and highway factors which cause operating costs to vary. Lane width and shoulder width may have an effect on vehicle speeds (i.e., narrower lanes and shoulders may constrict vehicle movements, thereby reducing vehicle speeds), which would affect fuel consumption of vehicles. However, changes in vehicle operating costs due to changes in lane width, shoulder width and shoulder surface type have not been adequately quantified in the literature.

Travel Time and Delay

A wide range of values have been placed on the value of time and time savings. However, there has been very little done to correlate travel speed (and therefore travel time) with lane and shoulder width. One problem with this is that there are many factors related to travel speed including ADT, roadway capacity, surface, traffic mix, grade, horizontal curvature and several other factors. Since the time relationship and lane/shoulder width has not been adequately quantified, it will not be used as non-accident benefit for lane and shoulder widening in this study.

Comfort and Convenience

Comfort and convenience is a subjective factor relating to driver perception of driving conditions. In order to determine the comfort and convenience benefits, a relationship must be developed between lane width, shoulder width and shoulder surface type and comfort and convenience. Then a dollar value must be assigned to comfort and convenience. There have been very few studies conducted to determine this relationship. Therefore, because of the subjective nature of comfort and convenience benefits and the difficulty of quantifying this in dollar units, it is not recommended for use in the cost-effectiveness analysis.

Example of Lane and Shoulder Widening and Roadside Improvement Project

In order to illustrate the cost-effectiveness procedure, an example is provided of a project to widen the lanes, add 3-foot paved shoulders, and also to improve the roadside condition. The following assumptions were made for the economic analysis:

- Section length = 6 miles
- ADT = 1,000
- Terrain = rolling
- Interest rate = 10 percent
- Salvage value = $0
- Project life = 20 years
- Accident cost = $15,500 per related accident

	Before Condition	After Condition
Lane width	9 feet	11 feet
Shoulder width	0 feet	3 feet
Shoulder type	None	Paved
Roadside hazard rating	5	3
Sideslope	4:1	4:1
Sideslope height of fill	5 feet	5 feet
Sideslope length	20 feet	20 feet

Before the B/C ratio can be computed, the cost of the widening must be estimated using the cost estimation procedure from chapter 7.

The estimated cost of a lane and/or shoulder widening project is found from equation 15 from chapter 7:

$$C_T = M\,[(W_L \times C_L) + (W_S \times C_S) + E]$$

Where:

M = the project costs associated with mobilization and traffic control = 1.095

W_L = travelled way width change in feet for both sides of the road = 4 feet

C_L = cost of widening the lanes in 1985 dollars per foot of added width = \$13,900

W_S = shoulder width change in feet for both sides of the road = 6 feet

C_S = cost of widening the shoulders in 1985 dollars per foot of added width = \$5,500

E = cost of altering the side and back slopes in 1985 dollars = \$90,000 (by interpolation)

C_T = the total per mile widening project construction cost \$200,000/mile x 6 miles = \$1,200,000

The B/C ratio is computed as follows:

$$B/C = \frac{(A_B)\ (C_A)\ (R_A)}{C_T\ (CRF)} \qquad \text{Equation (19)}$$

Where:

B/C = Benefit-to-cost ratio

A_B = The expected number of related accidents per year before the improvements. A_B was determined using the predictive model for the ADT, terrain, lane width, shoulder width, and roadside hazard rating in the before condition.

C_A = cost of an accident = \$15,500

R_A = Percent reduction in related accidents due to the improvements. If more than one accident reduction factor is used, then;

$$R_A = 1 - (1 - AR_1)\ (1 - AR_2)$$

where AR_1 = accident reduction factor due to 2 feet of lane widening and 3 feet of shoulder widening = 40 percent, or 0.40 from table 30

and AR_2 = accident reduction factor due to decreasing the roadside hazard rating from 5 to 3 = 34 percent, or 0.34 from table 32

$$RA = 1 - (1 - 0.40)\ (1 - 0.34) = 0.60$$

CT = The initial construction cost for the improvement = \$1,200,000

CRF = The capital recovery factor to convert the construction cost into an annualized value. For a 20 year service life and 10 percent compound interest rate, the CRF = 0.1175

Therefore, the B/C = $\frac{(4.5)\ (\$15{,}500)\ (0.60)}{(1{,}200{,}000)\ (0.1175)}$

B/C = 0.3

For the improvement in this example, the accident benefits were much less than the project costs. The B/C ratio could change for a given improvement based on the accident costs used, interest rate, service life. The B/C ratio will also be affected by the cost category (high, medium, low) that is used in computing the construction costs of various improvements.

Note that the number of related accidents reduced per year was 4.5 x 0.60 = 2.7. Another way of computing accident reduction would be to compute the difference between the before and after predicted accidents from the accident model. In the after condition, the predicted accidents (A_A) would be:

$$A_A = (.0019)(1{,}000)^{.8824}(.8786)^{11}(.9192)^{3}(.9316)^{0}(1.2365)^{3}(.8822)^{0}(1.3221)^{0}$$

= 0.30 related accidents-per-mile-per-year x 6 miles = 1.8 accidents/year.

Then, the difference between before and after accidents would be 4.5 - 1.8 = 2.7. This is the same amount of accident difference found using the accident reduction factor and before accidents.

CHAPTER 9 - SUMMARY AND CONCLUSIONS

This study was intended to quantify the benefits and costs resulting from lane widening, shoulder widening, shouder surfacing, sideslope flattening, and roadside improvements. The study included a review and critique of past accident research related to lane width, shoulder width and type, and roadside condition. The development of accident relationships involved the collection and analysis of detailed accident, traffic, roadway, and roadside data from 4,951 miles of two-lane roads in seven U.S. States. An accident predictive model and detailed statistical tests were used to determine expected accident reductions related to various geometric improvements. Construction cost data from several States were used to develop a cost model for such projects.

The following are the key study results:

1. Based on the Chi-square analysis, the types of accidents found to be most related to cross-section features (i.e., lane width, shoulder width, shoulder type, and sideslope) and roadside characteristics included:

   - Single-vehicle (i.e., fixed-object, plus rollover, plus run-off-road other)

   - Related multivehicle (i.e., head-on, plus sideswipe opposite direction, plus sideswipe same direction)

   These combined types of "related" accidents listed above (i.e., single-vehicle plus related multivehicle) were termed AO accidents and used in the predictive model.

2. Based on the analysis of covariance, 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. Paved shoulders were associated with lower related (AO) accidents than unpaved shoulders, based on the predictive model. Steeper sideslopes (over a range of 3:1 to 7:1) were found to be associated with higher rates of single-vehicle accidents, while only a small difference was found between 3:1 and 2:1 sideslopes based on the results of the log-linear model.

3. Numerous logical predictive model forms were tested for rural, two-lane roads using the accident, traffic, and roadway variables of importance. Although several models were found to be acceptable (in terms of logical interactions of variables and good predictive ability), the model (equation 7) selected for developing accident reduction factors and predicted accidents is as follows:

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

where:

AO/M/Y = related accidents (i.e., single-vehicle plus head-on plus opposite direction sideswipe plus same direction sideswipe accidents) per-mile-per-year,

ADT = average daily traffic,

W = lane width,

PA = average paved shoulder width,

UP = average unpaved (i.e., gravel, stabilized, earth, or grass) shoulder width,

H = median roadside hazard rating

TER1 = 1 if flat, 0 otherwise, and

TER2 = 1 if mountainous, 0 otherwise.

The R^2 value for this model was 0.456, which implies that 45.6 percent of the variation in accidents is explained by the traffic and roadway variables. Also, the coefficients were reasonable in terms of the relative importance of 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) agrees closely with other prominant State and national research studies.

4. Based on the predictive model, the effects of lane width on related (AO) accidents were quantified. The first foot of lane widening (i.e., two feet of pavement widening) corresponds to a 12 percent reduction in related (AO) accidents; two feet of widening (e.g., widening lanes from 9 to 11 feet) results in a 23 percent reduction, three feet results in a 32 percent reduction, and four feet of widening would result in a 40 percent reduction. These reductions apply only for lane widths between 8 and 12 feet.

5. The effects of shoulder widening on related (AO) accidents was also determined from the predictive model for paved and unpaved shoulders. For shoulder widths between 0 and 12 feet, the percent reduction in related (AO) 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. Adding an unpaved shoulder 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.

6. The effects of general roadside improvements on related (AO) accidents were also determined from the predictive model. Using the seven-point roadside hazard scale, a reduction of one rating value (e.g., a 5 hazard rating to a 4 rating) due to a roadside improvement will result in a 19 percent reduction in related (AO) accidents. Other reductions include a 34 percent reduction for a two-point reduction in hazard rating, 47 percent reduction for a three-point decrease in roadside hazard, and a 52 percent accident reduction due to a four-point decrease in hazard rating. Similar accident effects were found due to increasing roadside recovery distance using a different predictive model. Reductions in related accidents were found to be 13 percent, 25 percent, 35 percent, and 44 percent, due to increasing the roadside recovery distance (as measured from the outside edge of shoulder to the nearest roadside obstacles and hazards) on a section by an additional 5 feet, 10 feet, 15 feet, and 20 feet, respectively.

7. The effects of sideslope on accident experience was 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 which 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 decreases steadily for sideslopes of from 3:1 to 7:1 or flatter. However, only a slight reduction 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 2 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.

8. Traffic volume (ADT) and terrain were also found to have significant relationships with related (AO) accidents. Overall, the

presence of mountainous terrain is a factor associated with 32 percent higher related accidents compared to rolling terrain. Flat terrain is associated with 12 percent less accident experience than rolling terrain. ADT has a direct, nonlinear effect on related (AO) accidents-per-mile-per-year. For example, a doubling of ADT (e.g., from 1,000 to 2,000) increases AO accidents-per-mile-per-year by a factor of 1.84. This nonlinear relationship between ADT and accidents is well-supported in the literature.

A more detailed analysis was also conducted on the effects of specific roadside features on accident experience. The following are the key findings based on various types of statistical analysis of two-lane roadway sections in rural and urban areas.

9. For each type of roadside obstacle tested (i.e., utility poles, mailboxes, culverts, signs, guardrail, fences, and trees), the specific types of fixed-object accidents-per-mile-per-year increased for (1) increasing ADT, (2) closer obstacle distance from the road, and (3) increasing numbers of obstacles per mile. Average accidents were computed for various categories of fixed object by these factors but this information was not sufficient for determining the effectiveness of tree removal, utility pole relocation, and other specific roadside treatments.

10. The rate of guardrail accidents increases with an increase in the percent of the section covered by guardrail for all terrains. However, no significant difference was found in the overall rate of single-vehicle or rollover accidents or in accident severity due to the presence of guardrail. This finding could be due to the fact that numerous roadway factors interact with guardrail presence in terms of affecting single-vehicle and rollover accidents. A data base containing details on each guardrail section compared to similar sections without guardrail would allow for more accurately quantifying accident effects of guardrail.

11. Roadside objects associated with the highest percent of severe (injury plus fatal) accidents include culverts, trees, utility and light poles, bridges, rocks, and earth embankments. Those with lower percentages of severe accidents include signs, mailboxes, fire hydrants, and fences.

12. Overall, trees and utility poles are the roadside fixed obstacles most often struck, while guardrail, signs, mailboxes, and bridge ends are less frequently struck. On roads with ADT's of 4,000 or less, trees are the most often struck obstacle, while utility poles are the most frequently struck obstacle on roadways above 4,000 ADT.

REFERENCES

1. Smith, S.A., Purdy, J., McGee, H.W., Harwood, D.W., St. John, A.D., and Glennon, J.C. "Identification, Quantification, and Structuring of Two-Lane Rural Highway Safety Problems and Solutions, Volumes I and II, Report Nos. FHWA/RD-83/021 and 83/022, Federal Highway Administration, Washington, D.C., June 1983, Unpublished reports.

2. Council, F. et al., "Accident Research Manual," Federal Highway Administration, Report No. FHWA/RD-80/016, University of North Carolina, February 1980.

3. Perkins, D.D., "Highway Safety Evaluation - Procedural Guide," Federal Highway Administration, Goodell-Grivas, Inc., March 1981.

4. Rinde, E.A., "Accident Rates vs. Shoulder Width," Report No. CA-DOT-TR-3147-1-77-01, California DOT, FHWA, September 1977.

5. Dart, O.K. and Mann, L., "Relationships of Rural Highway Geometry to Accident Rates in Louisiana," Transportation Research Record No. 312, TRB, pp. 1-16, 1970.

6. Shannon, P. and Stanley, A., "Pavement Width Standards for Rural, Two-Lane Highways," The Pacific Northwest Regional Commission, Idaho Transportation Department, December 1976.

7. Zegeer, C.V., Mayes, J.G., and Deen, R.C., "Cost-Effectiveness of Lane and Shoulder Widening of Rural, Two-Lane Roads in Kentucky," Bureau of Highways, Kentucky Department of Transportation, July 1979, also Record No. 806, Transportation Research Board, 1981.

8. Heimbach, C.L., Hunter, W.W., and Chao, G.C., "Paved Highway Shoulder and Accident Experience," Transportation Engineering Journal Proceedings, ASCE, Volume 100, No. TE4, pp. 889-908, November 1974.

9. Turner, D.S., Fambro, D.B., and Rogness, R.O., "Effects of Paved Shoulders on Accident Rates for Rural Texas Highways," Transportation Research Record No. 819, TRB, pp. 30-37, 1981.

10. Rogness, R.O., Fambro, D.B., and Turner, D.S., "Before-After Accident Analysis for Two Shoulder Upgrading Alternatives," Transportation Research Record No. 855, TRB, 1982.

11. Foody, T.J. and Long, M.D., "The Specification of Relationships Between Safety and Roadway Obstructions," Report No. OHIO-DOT-06-74, Ohio Dept. of Transportation, 1974.

12. "Cost and Safety Effectiveness of Highway Design Elemets, Roy Jorgensen & Associates, NCHRP Report No. 197, Transportation Research Board, 1978.

13. Zegeer, C. and Deacon J., "Effect of Lane Width, Shoulder Width, and Shoulder Type on Highway Safety: A Synthesis of Prior Literature," Transportation Research Board, March 1986.

14. Zegeer, C.V., and Parker, M.R., "Cost-Effectiveness of Countermeasures for Utility Pole Accidents," Goodell-Grivas, Inc., Federal Highway Administration, January 1983.

15. Mak, K.K., and Mason, R.L., "Accident Analysis - Breakaway and Non-Breakaway Poles Including Sign and Light Standards Along Highways," Federal Highway Administration, August 1980.

16. Jones, I.S., and Baum, A.S., "An Analysis of the Urban Utility Pole Problem," Calspan Field Services, Inc., Federal Highway Administration, U.S. DOT, December 1980.

17. Graf, L., Boos, J.U., and Wentworth, J.A., "Single-Vehicle Accidents Involving Utility Poles," Transportation Research Record 571, pp. 36-43, 1976.

18. Newcomb, F.D., and Negri, D.B., "Motor Vehicle Accidents Involving Collision with Fixed Objects," New York State Department of Motor Vehicles, 1971.

19. Rinde, E.A., "Conventional Road Safety: Phase 1 - A Study of Fixed Objects," California Department of Transportation, August 1979.

20. Hall, J.W., Burton, C.J., Coppage, D.G., and Dickinson, L.V., "Roadside Hazards on Non-Freeway Facilities," Transportation Research Record No. 601, 1976.

21. Perchonok, K., Ranney, T.A., Baum, S., Morrison, D.F., and Eppick, J.D., "Hazardous Effects of Highway Features and Roadside Objects," Calspan Field Service, Inc., Federal Highway Administration, U.S. DOT, 1978.

22. Graham, J.L., and Harwood, D.W., "Effectiveness of Clear Recovery Zones," NCHRP Report 247, Transportation Research Board, May 1982.

23. Weaver, J.D., and Marquis, E.L., "Roadside Slope Design for Safety," Transportation Engineering Journal, American Society of Civil Engineers, February 1976.

24. Edwards, T.C., Martinez, J.E., McFarland, W.F., and Ross, H.E., "Developement of Design Criteria for Safer Luminaire Supports," NCHRP Report No. 77, August 1968.

25. Glennon, J.C., and Wilton, C.J., "Effectiveness of Roadside Safety Improvements - Volume I - A Methodology for Determining the Safety Effectiveness of Improvements on All Classes of Highways," Report No. FHWA-RD-75-23, November 1974.

26. Cleveland, D.E., and Kitamura, R., "Macroscopic Modeling of Two-Lane Rural Roadside Accidents," Transportation Research Record 681, Transportation Research Board, Washington, D.C., 1978.

27. "Michigan Traffic Accident Facts 1983," Michigan Department of State Police.

28. Oglesby, C.H., and Altenhofen, M.J., "Economics of Design Standards for Low Volume Roads," NCHRP Report 63, 1969.

29. Downs, H.G., and Wallace, D.W., "Shoulder Geometrics and Use Guidelines," NCHRP Report 254, December, 1982.

30. Hunter, W., Council, F., Dutt, A., and Cole, D., "Methodology for Ranking Roadside Hazard Correction Programs," Transportation Research Record 672, TRB, Washington, DC, 1978.

31. "Estimating the Cost of Accidents, 1984," NSC Bulletin, National Safety Council, 1985.

32. Miller, T.R., Reinert, K.A., Whiting, B.E., "Alternative Approaches to Accident Cost Concepts: State-of-the-Art," FHWA Report No. FHWA-RD-83-079, January, 1984.

33. "The Economic Cost to Society of Motor Vehicle Accidents," National Highway Traffic Safety Administration, USDOT, Washington, DC, 1983.

34. Hartunian, N.S., Smart, C.S., and Thompson, M.S., The Incidence of Economic Costs of Major Health Impairments, Lexington Books, Lexington, MA, 1981.

APPENDIX A - REVIEW OF LITERATURE

As part of this study, a review and critique were conducted of articles, reports, and publications on the relationships of lane width, shoulder width, and shoulder type with accidents. This critical review was aimed not only at finding flaws with previous studies, but primarily to select the most reliable accident relationships with lane and shoulder factors. An extension of that review resulted in the development of a model for estimating the effects of lane width, shoulder width, and shoulder type on motor vehicle accidents on two-lane, rural roads.[13] The complete results of this effort were published elsewhere, and a summary of the key information is presented below. A separate review was also made of literature related to the effects of roadside features on accidents, and is also included.

Effects of Lanes and Shoulders

Criteria for Reviewing Studies

More than 30 articles and reports were reviewed relative to effects of lane and shoulder width and shoulder type. Criteria used to determine the major strengths and weaknesses of each source are listed in table 1 (presented earlier). Basic principles outlined in the Federal Highway Adminstration's (FHWA) "Accident Research Manual" (1980) and the User's Manual on "Highway Safety Evaluation" (1981) were also considered in the critical review.[2,3]

Initial review of the 30 articles found numerous major flaws in many of the accident studies, and only nine of them survived preliminary screening. Of these nine, the study by Rinde (1977) dealt with shoulder widening, while studies by Dart and Mann (1970), Shannon and Stanley (1976), and Zegeer, Mayes and Deen (1979) involved analyses of both lane and shoulder widths (see references 4,5,6,7). Studies by Heimbach, Hunter, and Chao (1974), Turner et al. (1981), and Rogness, et al. (1982) involved only shoulder type, while studies by Foody and Long (1974) and Jorgensen (1978) analyzed lane width, shoulder width, and shoulder type (see references 8,9, 10,11,12).

The studies by Rinde (1977) and Rogness, et al. (1982) were before/after studies of completed shoulder widening projects in which the authors controlled for external factors.[4,10] The remaining seven studies were comparative analyses, which 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 were desired which covered a wide range of lane- and shoulder-width and shoulder-type combinations. Also, data showing accident experience for the specific accident types most related to lane and shoulder deficiencies was considered most useful.

Critical Review and Analysis of the Literature

Review and analysis of the nine most reliable studies addressed four specific questions related to the most likely relationships between accident experience and cross-sectional elements:

- What dependent variable(s) -- i.e., accident measure(s) -- is(are) most appropriate for expressing the relationships between safety and lane width, shoulder width, and shoulder type?
- What other independent variables (e.g., widths, curvature, volume groups, roadside condition) should and can be included in developing accident relationships?
- What studies and data results are the most complete and reliable for determining the expected accident relationships?
- What is the most likely model for expressing the relationship between accident experience and lane width, shoulder width, and shoulder type?

Selection of Dependent Variable: The first major issue was to determine the types of accidents that are related to lane width, shoulder width, and shoulder type. Although total accidents had been commonly used in past accident studies, unrelated accident types influence the data base and mask the true effects of the lane or shoulder improvement. The importance of careful selection of the dependent safety variable has been emphasized in definitive procedural guides.[2,3]

Of the nine studies selected following preliminary screening of the literature, several analyzed total accidents by accident severity, pavement condition or by time of day. However, detailed accident types (i.e., run-off-road, head-on, rear end, right-angle, etc.) were analyzed in the studies by Zegeer, et al. (1979), Rinde (1977), and Rogness, et al. (1982).[7,4,10] Based on the results of those three studies, there is strong evidence that run-off-road (ROR) and opposite direction (OD) accidents (head-on and opposite direction sideswipe) are the primary accident types affected by lane and/or shoulder improvements. This was found to be particularly true for roads with low traffic volumes -- ADT's of 3,000 or less. Therefore, the rate of ROR and OD accidents was considered to be the primary dependent variable for developing the accident relationships with lane width, shoulder width, and shoulder type.

Selection of Independent Variables: Next, an examination was made of the other interacting independent variables whose levels might influence the effect of lane and shoulder conditions on highway safety. Ideally, all independent variables chosen for inclusion in an accident model should interrelate with the three variables of concern in affecting the related accident types.

A few studies have developed predictive accident models that account for interrelationships among roadway variables. For example, Jorgensen (1978) developed a predictive model for total accidents based on independent variables such as pavement width, shoulder width, shoulder type, ADT, and horizontal curvature.[12] However, the R^2 value for that model was only 0.08, indicating that only about eight percent of the accident variance was explained by the model. The predictive model of Dart and Mann (1970) also used total accident rate (accident rate per 100 million vehicle miles) as the primary dependent variable and yielded a much better R^2 value of 0.46 (46 percent of accident variance explained).[5] The independent variables in this model included various interactions among the percentage of trucks, traffic volume ratio, cross slope, horizontal alignment, traffic conflicts, lane width, and shoulder width. The wide difference in R^2 values between the two studies is not easily explainable.

Based on a review of the publications, it was concluded that numerous traffic, geometric, and roadway variables interrelate with lane and shoulder widths and shoulder type in affecting accidents on two-lane, rural roads. These include roadside characteristics, horizontal and vertical curvature, traffic volume, access points, intersections, and others. Thus, relationships of expected accident experience associated with various combinations of pavement and shoulder widening and/or shoulder surfacing should consider the combined effects of other factors to the extent possible.

Selection of Data for Accident Relationships: Data and information were carefully reviewed in each of the nine studies in order to select the most reliable accident relationships and the most complete information. Each study was characterized by both strengths and weaknesses, necessitating constant judgment about what information was the most reliable and complete.

Five of the nine studies were not used to build the accident model. For example, the Jorgensen (1978) study quantified only the total accident experience, and the mathematical model explained only eight percent of the variance in accidents.[12] Although the Shannon and Stanley (1976) study contained a rigorous statistical analysis of data from two states, it failed to analyze specific accident types and to provide accident experience for various lane- and shoulder-width combinations.[6] The Dart and Mann (1970) relationships explained a reasonable amount of the accident variance but only used total accidents as a dependent variable.[5] The study of Heimbach et al. (1974) was one of the better studies on shoulder type and safety, but it did not include an analysis of specific accident types and did not provide detailed accident rates.[8] Finally, the study of Turner et al. (1981) presented composite run-off-road and total accidents but did not provide information on the rates for various combinations of lane and shoulder widths.[9] Although not perfect by any means, the four studies selected for developing most likely safety relationships were those by Zegeer et al. (1979), Foody and Long (1974), Rinde (1977), and Rogness et al. (1982) (see references 7,11,4, 10).

The study by Zegeer, et al. (1979) in Kentucky used approximately 16,000 miles of data and nearly 17,000 accidents in one year to compute detailed accident rates for various combinations of lane and shoulder widths.[7] Adjustment factors from that study were developed in an attempt to control for the effects of traffic and other roadway variables. While not an ideal method of control, the higher accident rates for low ADT groups (with more sharp curves, more dangerous roadsides, and other deficiencies) were clearly seen for different pavement width classes. The authors then developed accident reduction factors that might realistically be anticipated as a result of lane and shoulder widening (tables 62 and 63).

Table 62. Percent reduction in run-off-road and opposite-direction accidents due to lane widening.[7]

Lane Width			
Before Widening (Feet)	After Widening (Feet)	Total Widening (Feet)	Percent Reduction in ROR[a] and OD[b] Accidents
7	8	2	10
7	9	4	23
7	10	6	29
7	11	8	39
8	9	2	16
8	10	4	23
8	11	6	36
9	10	2	10
9	11	4	29
10	11	2	23

a Run-off-road accident
b Opposite-direction accident

Table 63. Percent reduction in run-off-road and opposite-direction accidents due to shoulder widening.[7]

Shoulder Width Before Widening (Feet)	Shoulder Width After Widening (Feet)	Total Widening (Feet)	Percent Reduction in ROR and OD Accidents
None	1 to 3	4	6
None	4 to 6	10	15
None	7 to 9	16	21
1 to 3	4 to 6	6	10
1 to 3	7 to 9	12	16
4 to 6	7 to 9	6	8

The expected reduction in ROR and OD accidents from shoulder widening projects ranged from 6 to 21 percent, depending on the amount of widening. Lane widening was expected to cause greater accident reductions--10 to 39 percent after adjusting for other factors--again depending on the amount of widening.[7]

Foody and Long (1974) performed a detailed analyses of shoulder type or 1,400 miles of sections in Ohio using single-vehicle accidents.[11] Mean rates of single-vehicle accidents are given in table 64 for sections with both unstabilized and stabilized shoulders and for three pavement width categories, 16 to 20 feet, 20 to 24 feet, and 24 to 28 feet. These results show that shoulder stabilization or paving may be quite effective in reducing run-off-road accidents on narrow roadways, typically 20 feet or less in width, but are virtually ineffective on roads having widths of 24 feet or more. These rates (or rate differences) were apparently not adjusted for effects of other factors (curvature, roadside conditions, etc.)

Table 64. Rates of single-vehicle accidents for pavement width and shoulder type combinations in Ohio.[11]

Pavement Width (Ft) (Excluding Shoulder)	Base Rate of SV Accidents (ACC/MVM)		Difference in Accident Rate (D)
	Unstabilized Shoulder	Stabilized Shoulder	
16 to 20	3.57	1.11	2.46
20 to 24	2.04	1.40	0.64
24 to 28	1.02	0.98	0.04

The studies by Rinde (1977) in California and Rogness et al. (1982) in Texas reported results of actual pavement and/or shoulder widening projects.[4,10] The Rogness study sampled 214 miles where paved shoulders had been added to two-lane highways.[10] Rinde studied 143 miles where total pavement widths were increased either to 28 feet (from initial widths of 20 to 24 feet), to 32 feet (from initial widths of 18 to 24 feet), or to 40 feet (from initial widths of 20 to 26 feet).[4]

Accident reduction factors for the Rinde (1977) and Rogness et al. (1982) studies are summarized for comparative purposes in table 65.[4,10] These include percent accident reductions for total accidents with similar adjustments (of four to six percent) for single-vehicle accidents and head-on accidents in California. Reductions in total accidents ranged from 16 to 35 percent. Single-vehicle accidents dropped by as much as 55 percent as a result of widening but were unchanged in the ADT group of 5,000 to 7,000 on Texas highways. Head-on accidents were reduced by 45 to 51 percent, based on the California data. Some of the seemingly inconsistent patterns of accident reductions in table 65 were considered to be at least partly explainable by the differences in projects in the two States. For example, all of the projects in the Texas study involved adding paved, full-width shoulders to existing two-lane roads, whereas the California projects involved differing amounts of total pavement widening. Random accident fluctuations could also help to explain some of the inconsistencies.

Development of Safety Relationships

Although no satisfactory quantitative model relating accident rate to lane and shoulder conditions was found within the published literature, 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.

Table 65. Summary of accident reductions for pavement widening projects.[4,10]

Type of Project	ADT Range	Expected Percent Reduction in Accidents		
		Total Accidents	Single-Vehicle Accidents	Head-On Accidents
Widening 20 to 24-foot pavement to 28 feet	0-3,000	16 (C)	22 (C)	45 (C)
Widening 18 to 24-foot pavement to 32 feet	< 5,000	35* (C)	49* (C)	48* (C)
Widening 18 to 24-foot pavement to 40 feet	> 5,000	29* (C)	22* (C)	51* (C)
Adding full-width paved shoulders to two-lane roads	1,000-3,000	27* (T)	55* (T)	Unknown
Adding full-width paved shoulders to two-lane roads	3,000-5,000	12.5 (T)	21.4* (T)	Unknown
Adding full-width paved shoulders to two-lane roads	5,000-7,000	17.6* (T)	0 (T)	Unknown

(C) - Values from the Rinde study in California.
(T) - Values from the Rogness et al. study in Texas.
* - These percent differences were significant at the 95 percent level of confidence for California sites (C) and 90 percent confidence level at the Texas sites (T).

Note: The single-vehicle and head-on accident percentages for Califonia were adjusted by 4 to 6 percent to account for external effects. These adjusted percentages are now on the same basis as total accidents.

- 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 effect of shoulder-width increments is 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.

- Nonstabilized shoulders, including loose gravel, crushed stone, raw earth, and turf, exhibit larger accident rates than stabilized (i.e., tar with gravel) or paved (i.e., bituminous or concrete) shoulders.

These qualitative relationships served in large part as the basis for developing a quantitative accident model in a detailed study for TRB (1986) [13] Data for calibration of the model was extracted from the 1979 Kentucky study (by Zegeer, Mayes, and Deen) and the 1974 Ohio study (by Foody and Long).[7,11] Adjustments were made in an attempt to remove unwanted effects of other confounding variables -- such as curvature, ADT, roadside condition, etc. -- and to assure appropriate consideration of shoulder-width effects for roadways having wider lanes.

The model developed from previous literature was defined as follows:

$$AR = 4.1501\ (0.8907)^{L}(0.9562)^{S}(1.0026)^{LS}(0.9403)^{P}(1.0040)^{LP}$$

Equation (20)

in which AR = number of ROR and OD accidents per million vehicle miles; L= lane width in feet; S = shoulder width in feet (including stabilized and unstabilized components); and P = width in feet of stabilized component of shoulder ($0 \leq P \leq S$). Stabilized shoulders are those made of bituminous surfacess or tar plus gravel mixture, while unstabilized shoulders include loose gravel, earth, or dirt. Details on the model development are given in the full report on this topic.[13]

Because of the many assumptions necessary in its development and the reliance on available data bases from only two States for its calibration and validation, this model is not considered to be a precise representation of the effects of lane and shoulder conditions on accident rates for all possible situations. However, it was considered as a useful first approximation of such effects. It does represent the best information available prior to 1986, and its most legitimate use is in developing accident reduction factors that can be applied to actual accident rates to estimate likely reductions due to lane and shoulder improvements.

Limitations of the accident predictive model include the following:

- The model only applies to lane widths of 7 to 12 feet and shoulder widths of zero to 10 feet. Furthermore, combinations of lane and shoulder widths that can be reasonsably modeled are limited to those shown in figure 11.
- The results relate to two-lane, two-way roads on state primary and/or secondary systems.
- The results relate to rural, homogeneous roadway sections and generally exclude signalized intersections and corresponding intersection accidents.
- The results apply to paved roadways and include sections with curves and tangents and various types of terrain and roadway conditions.

Effects of Roadside Features

In general, considerable research has been conducted in the past on the frequency and severity of run-off- road accidents and related factors. However, the literature also indicated a definite need to better quantify roadsides and to develop a means to accurately predict run-off-road accidents for a variety of traffic, roadway, and roadside conditions. There is also a need for clear, concise definitions which can describe roadsides for highway safety purposes. A brief summary of the results of the literature review, presented on the following pages, is organized into the following categories: (1) roadside features and accident frequency, (2) roadside features and accident severity, and (3) roadside accident prediction models.

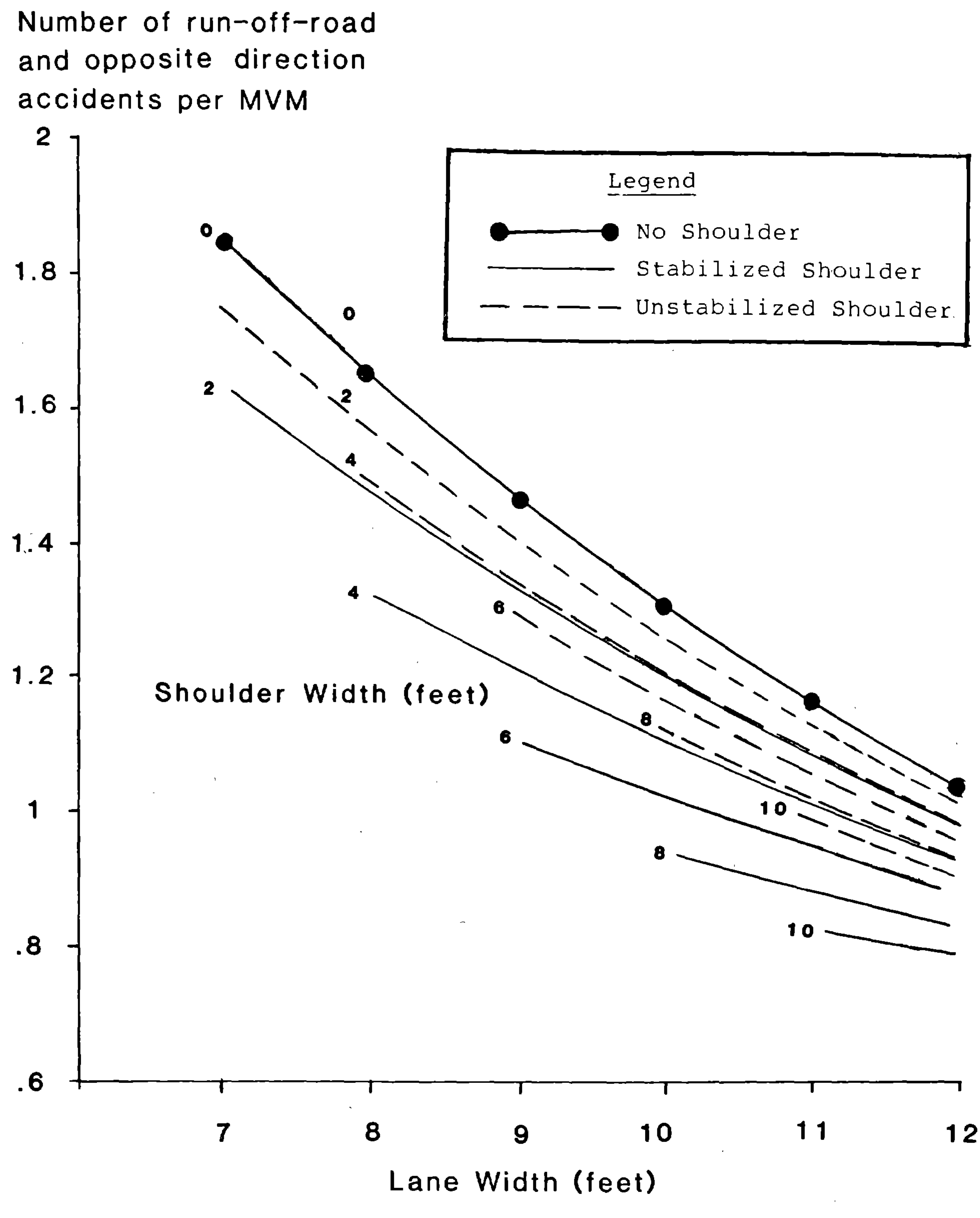


Figure 11. Rate of ROR and OD accidents from the predictive model.[13]

Roadside Features and Accident Frequency

Several studies have examined the effects of roadside features on the frequency of roadside accidents. According to the studies, the frequency of roadside accidents is primarily dependent upon fixed object characteristics (i.e, number, type and offset from the road), sideslope, and roadway geometrics.

Fixed Objects: Several studies have investigated fixed-object accidents by the type of object struck. Studies by Newcomb and Negri (1971), Rinde (1979), Foody and Long (1974), and Hall, Burton, Coppage, and Dickinson (1976) indicate that utility poles are among the most frequent fixed objects involved in roadside accidents (see references 18,19,11,20). Other frequently struck roadside objects include trees, sign posts, guardrails, ditchembankments, and bridge structures. None of these studies, however, took into consideration how often drivers were exposed to each object type.

Other studies indicate that the number of fixed objects and their offset influences roadside accident frequency. For example, Zegeer et al. (1983) found that utility pole accidents increased significantly with a decrease in pole offset or an increase in ADT or pole density.[14] Relationships between utility pole accidents and pole offset and density are shown in in figure 12. Mak and Mason (1980) also found that pole density and pole offset had an effect on the frequency of pole accidents.[15] Jones and Baum (1980) found that the number of poles and pole spacing was highly related to the probability of a utility pole accident.[16]

Hall, Burton, Coppage, and Dickinson (1976) 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.[20] Foody and Long (1974) 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.[11]

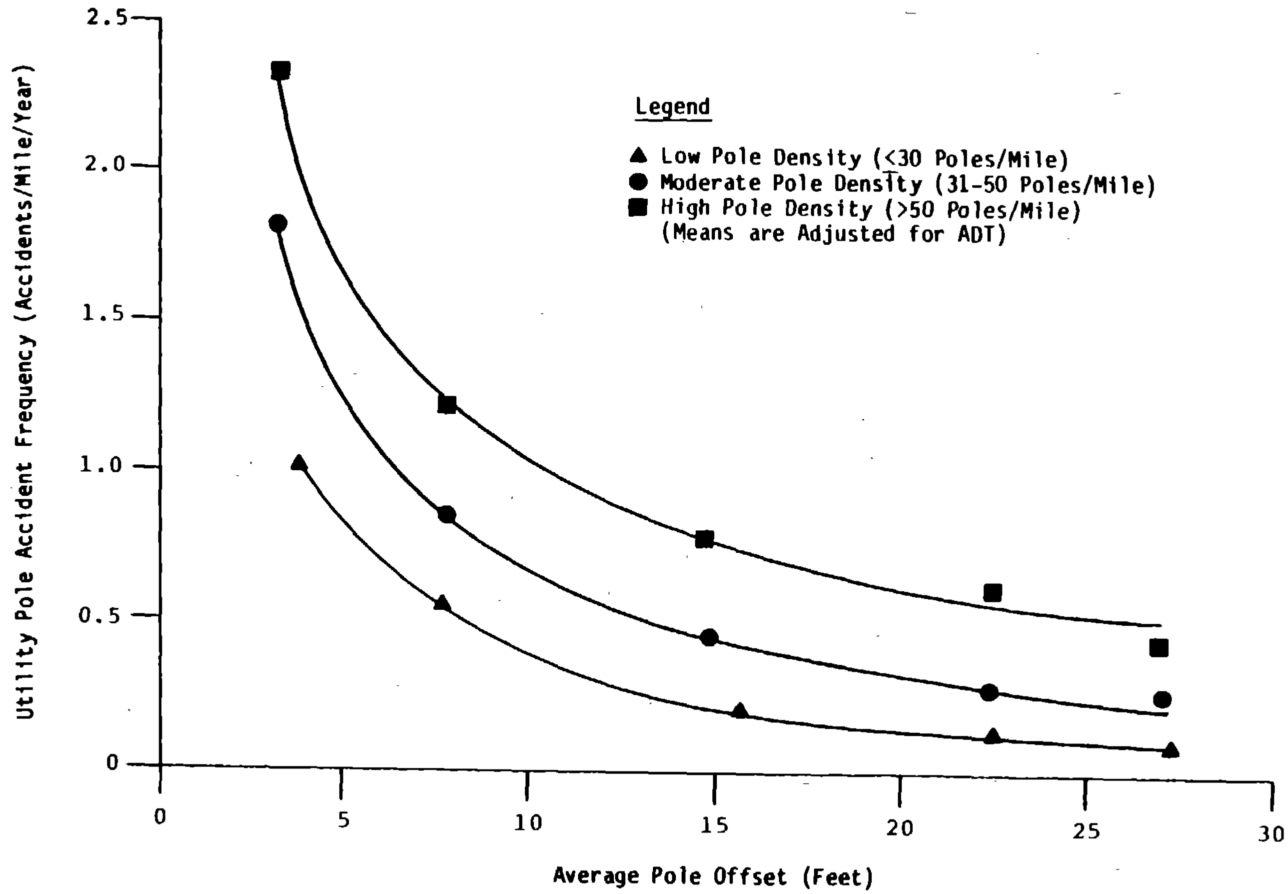


Figure 12. Relationship between utility pole accident frequency and pole offset for three levels of pole density.[14]

Sideslope: Relationships have also been reported between the degree of sideslopes and roadside accident frequency. Graham and Harwood (1982) 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.[22] Weaver and Marquis (1976) simulated various roadside slope designs and discovered that vehicles leaving the roadway were less likely to roll over if the slope was fairly flat.[23] Perchonok et.al., (1978) found that higher land fills and deeper ditches caused more vehicle rollovers.[21]

Roadway Geometrics: Roadway geometrics, such as horizontal curvature and grade, have been reported to affect the number of run-off-road and fixed-object accidents as found by Jones and Baum (1980), Hall, Burton, Coppage, and Dickinson (1976) and Perchonok et al.(1978).[16,20,21]

Factors Affecting Accident Severity

Relationships have also been reported between roadside features and the severity of run-off-road and fixed-object accidents. The major factors contributing to this relationship include the type of fixed object and the vehicle speed.

Type of Fixed Object: Jones and Baum (1980) 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). 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 (1976) stated 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.

Vehicle Speed: Vehicle speeds have influenced the severity of roadside accidents. Higher speeds are generally associated with greater accident severity. Mak and Mason (1980) investigated the relationship between the severity of pole accidents and vehicle impact speed.[15] 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. Jones and Baum (1980), 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. The discrepancy in results between these two studies could be partly due to difficulties in estimating impact speed and/or inacurracies 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. (1968) developed what is probably the most widely-known model for determining hazardous roadside obstacles.[24] 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 (1974) modified the model to include other roadway types, including urban arterial streets, rural two-lane highways and rural multilane highways.[25] The model is based on encroachment frequency and angle, severity index for each object type, dimensions of the obstacle (length, width, and lateral placement), lateral displacement of the encroaching vehicle, traffic volume, and probability that the lateral displacement of the encroaching vehicle will exceed the lateral placement of the obstacle. The model relies on accurate estimates of vehicle encroachments which has been a topic of uncertainty in recent years.

Cleveland and Kitamura (1978) developed a group of multiplicative regression equations to predict the frequency of run-off-road accidents on rural two-lane highways in Michigan.[26] 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 with roadside objects within 10 feet, and object stiffness. Although reported R^2 values for the models ranged from 0.26 to 0.49, model validation revealed less than desired results due to data outliers.

Zegeer and Parker (1983) tested ten different models to predict annual utility pole accidents per mile.[14] 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 in that it not only had the highest R^2 value (0.63), but it also made reasonable intuitive sense. A nomograph was developed that allows easy estimation 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, applied only to utility pole accidents and not to other roadside accident types (i.e., trees, rollover accidents, etc.).

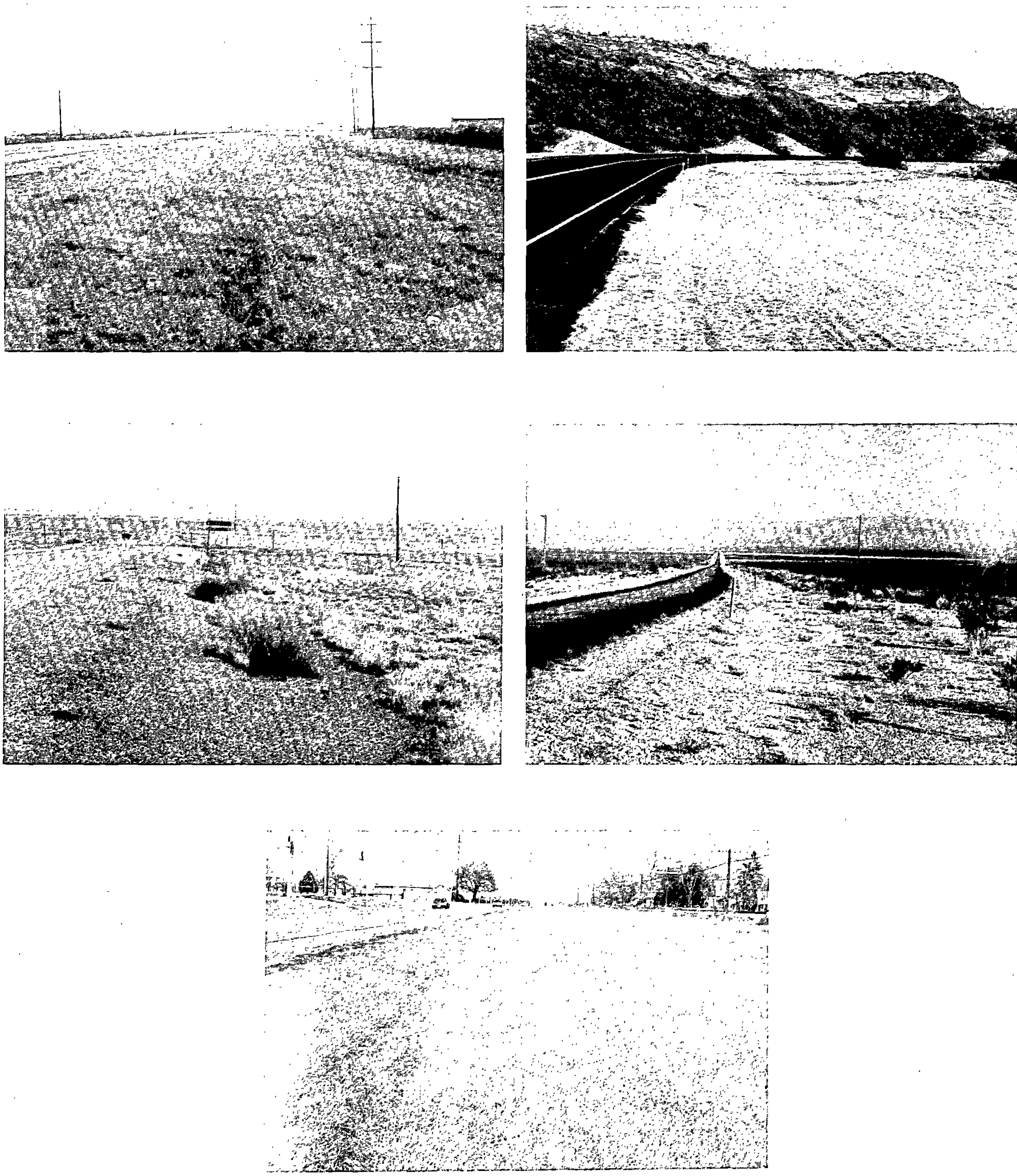


Figure 13. Rural roadside hazard rating of 1.

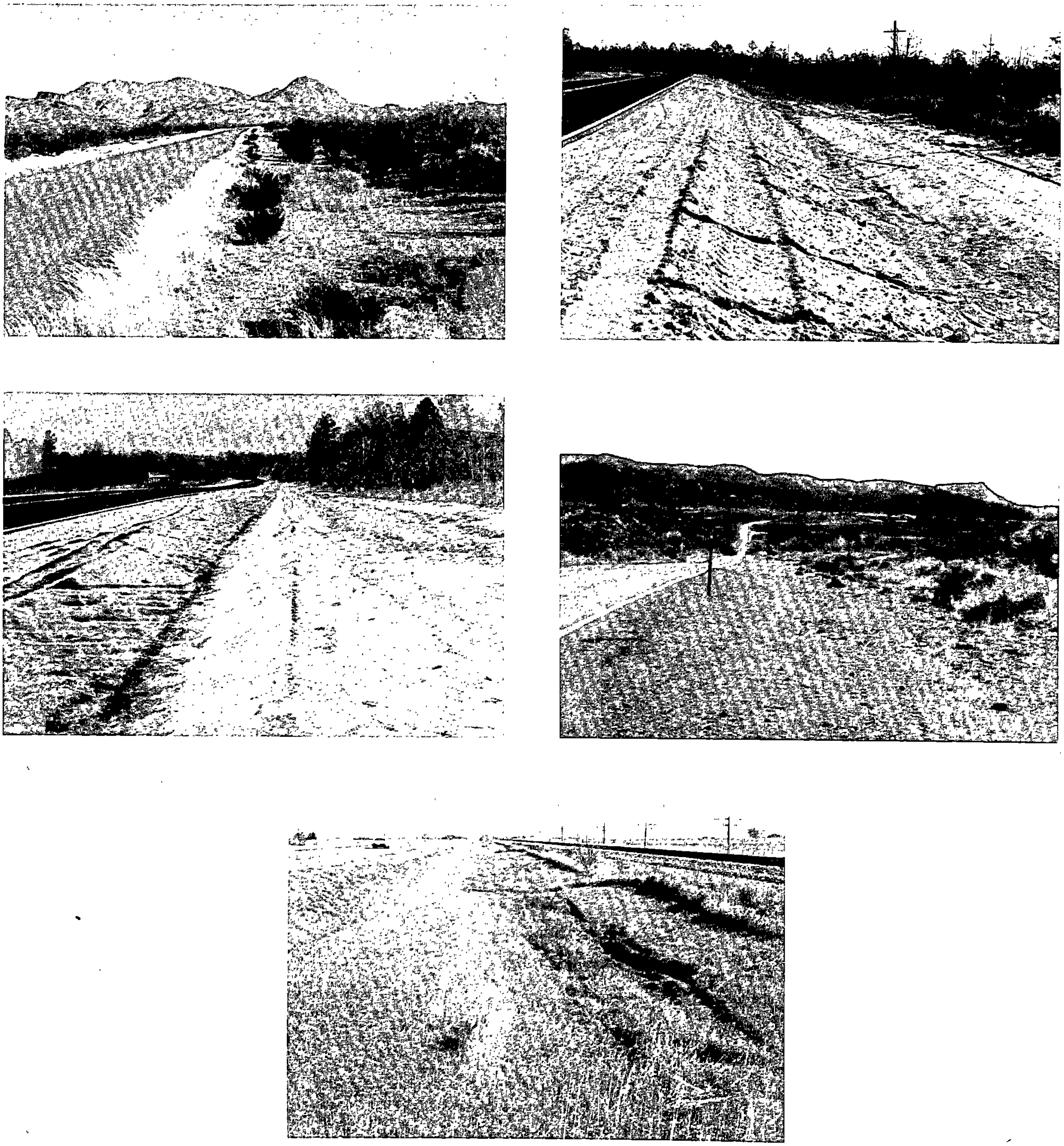


Figure 14. Rural roadside hazard rating of 2.

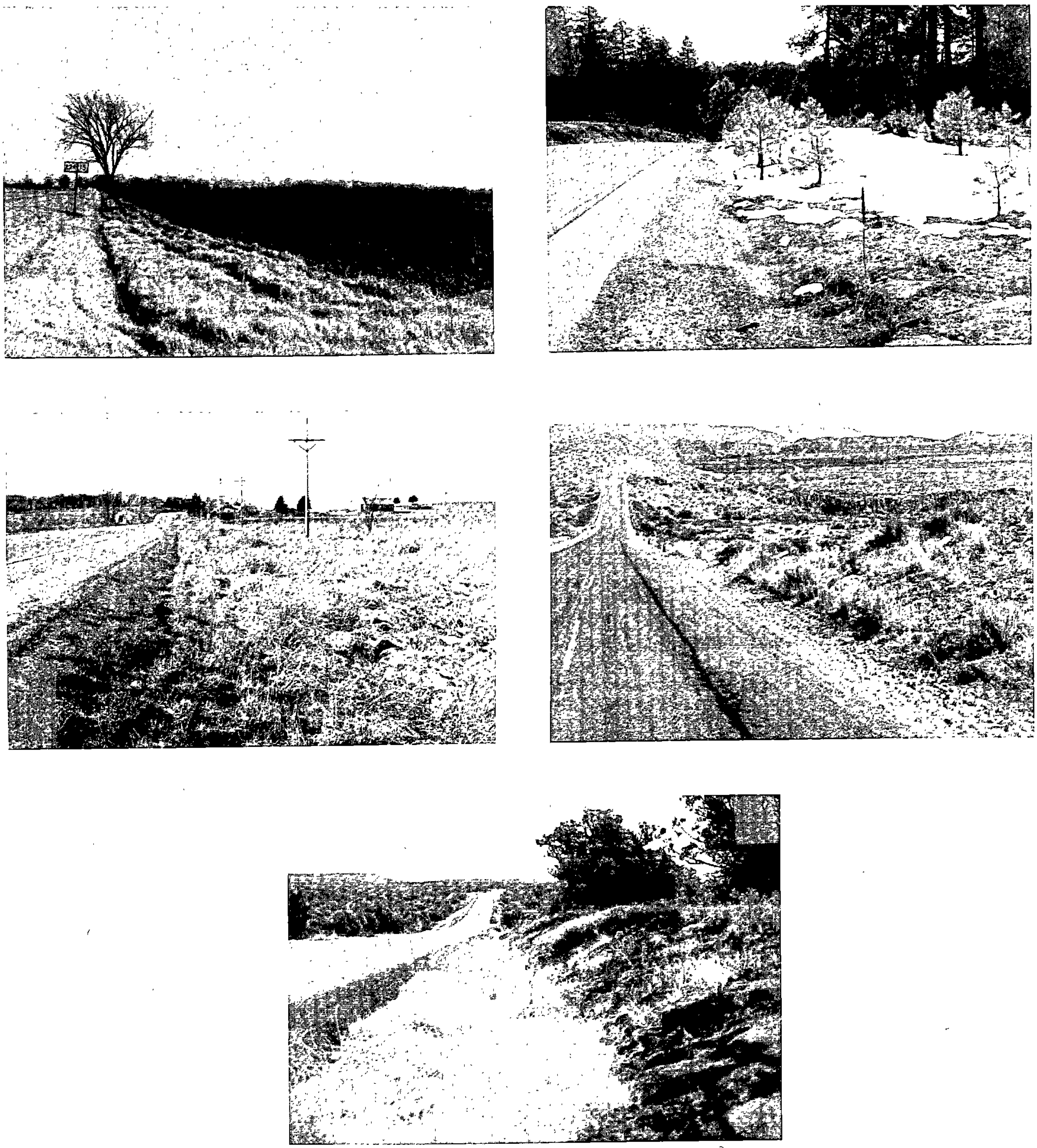


Figure 15. Rural roadside hazard rating of 3.

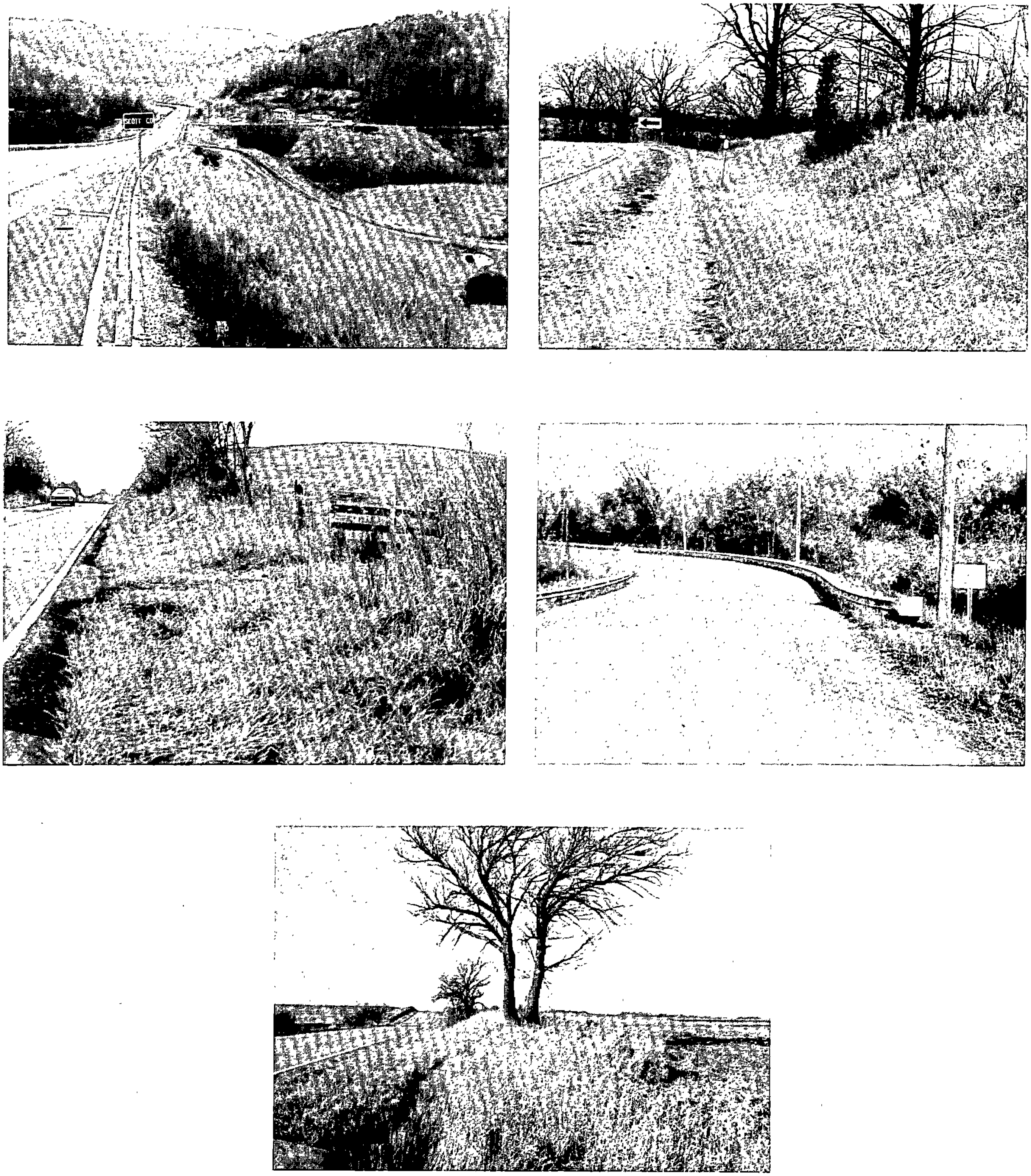


Figure 16. Rural roadside hazard rating of 4.

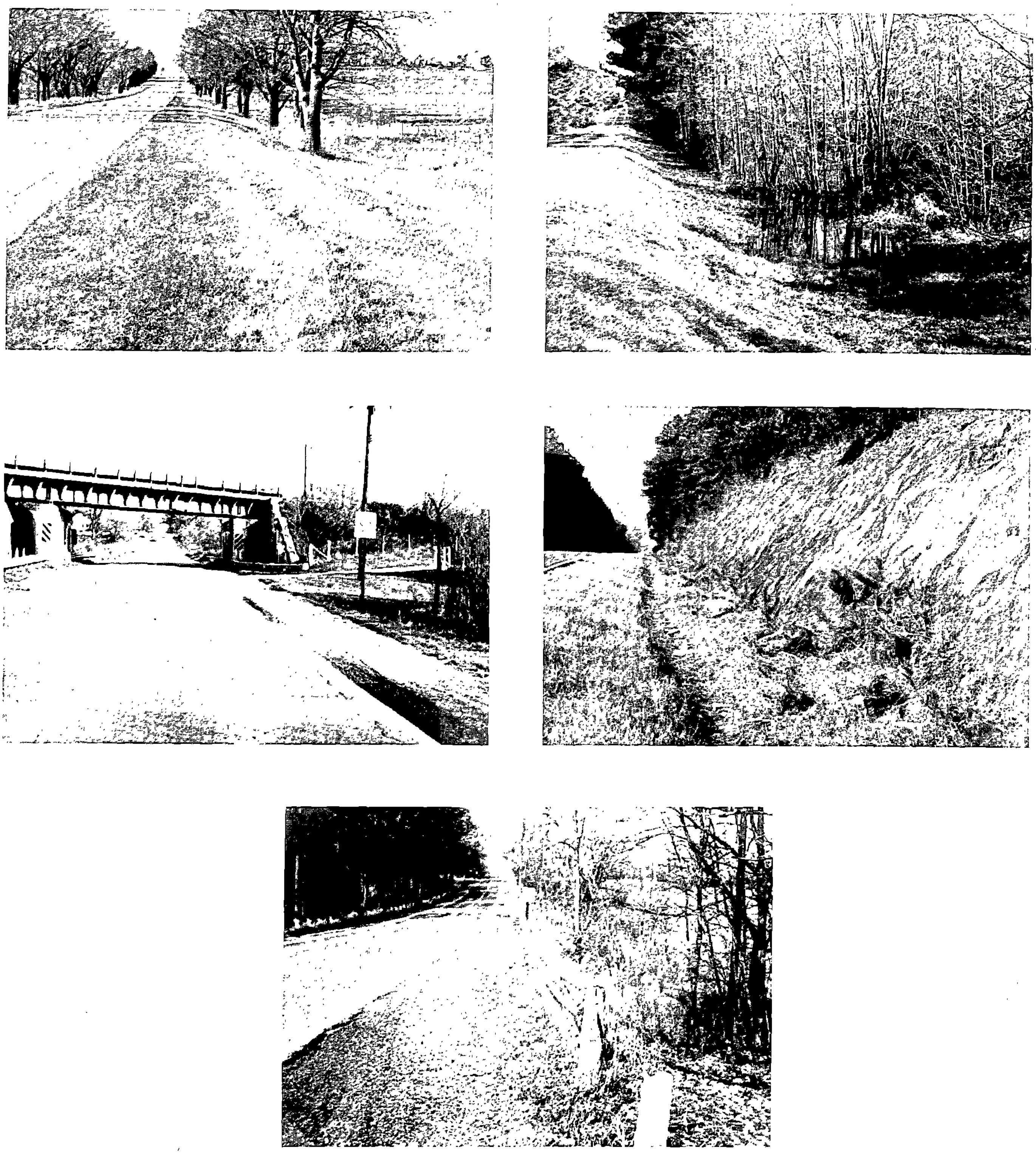


Figure 17. Rural roadside hazard rating of 5.

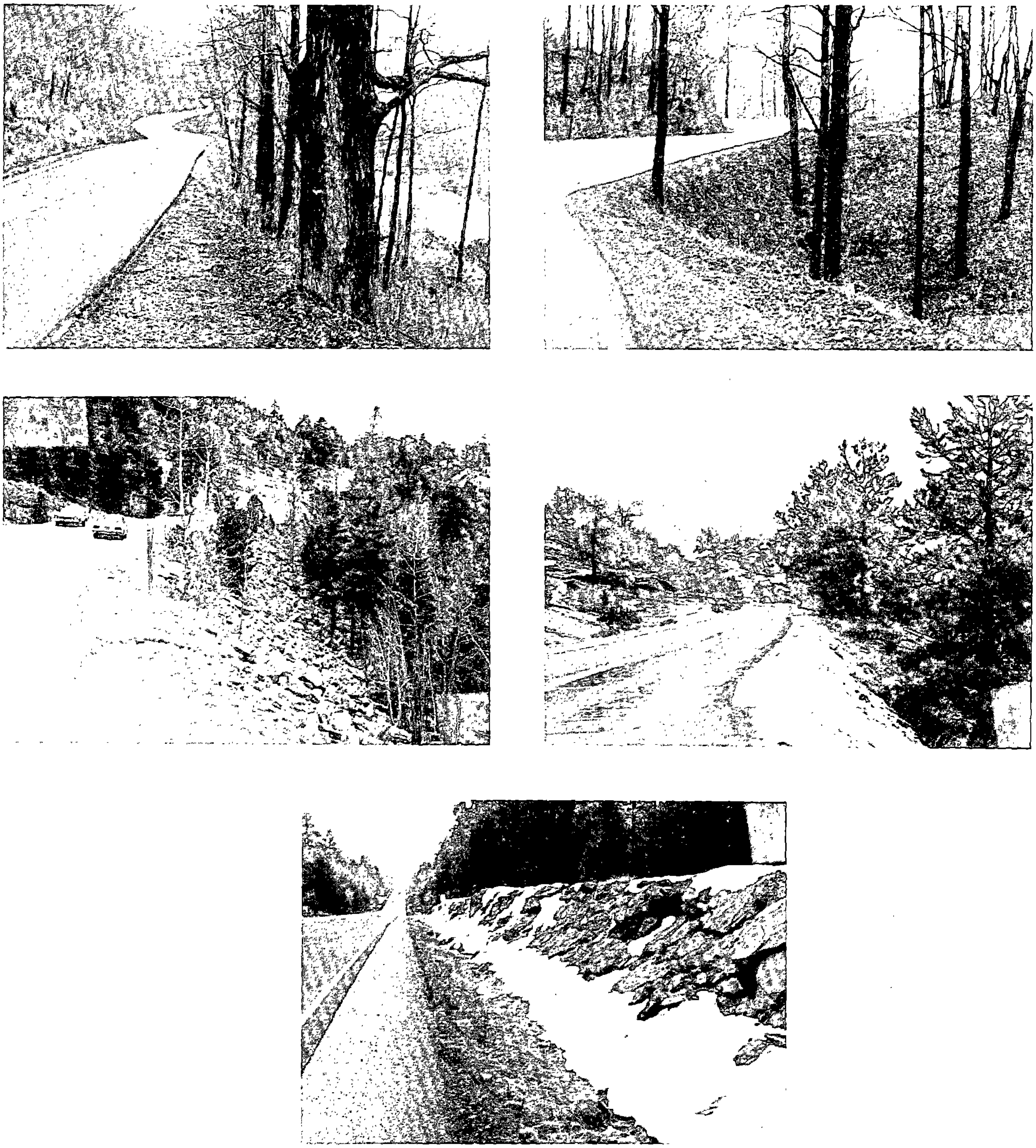


Figure 18. Rural roadside hazard rating of 6.

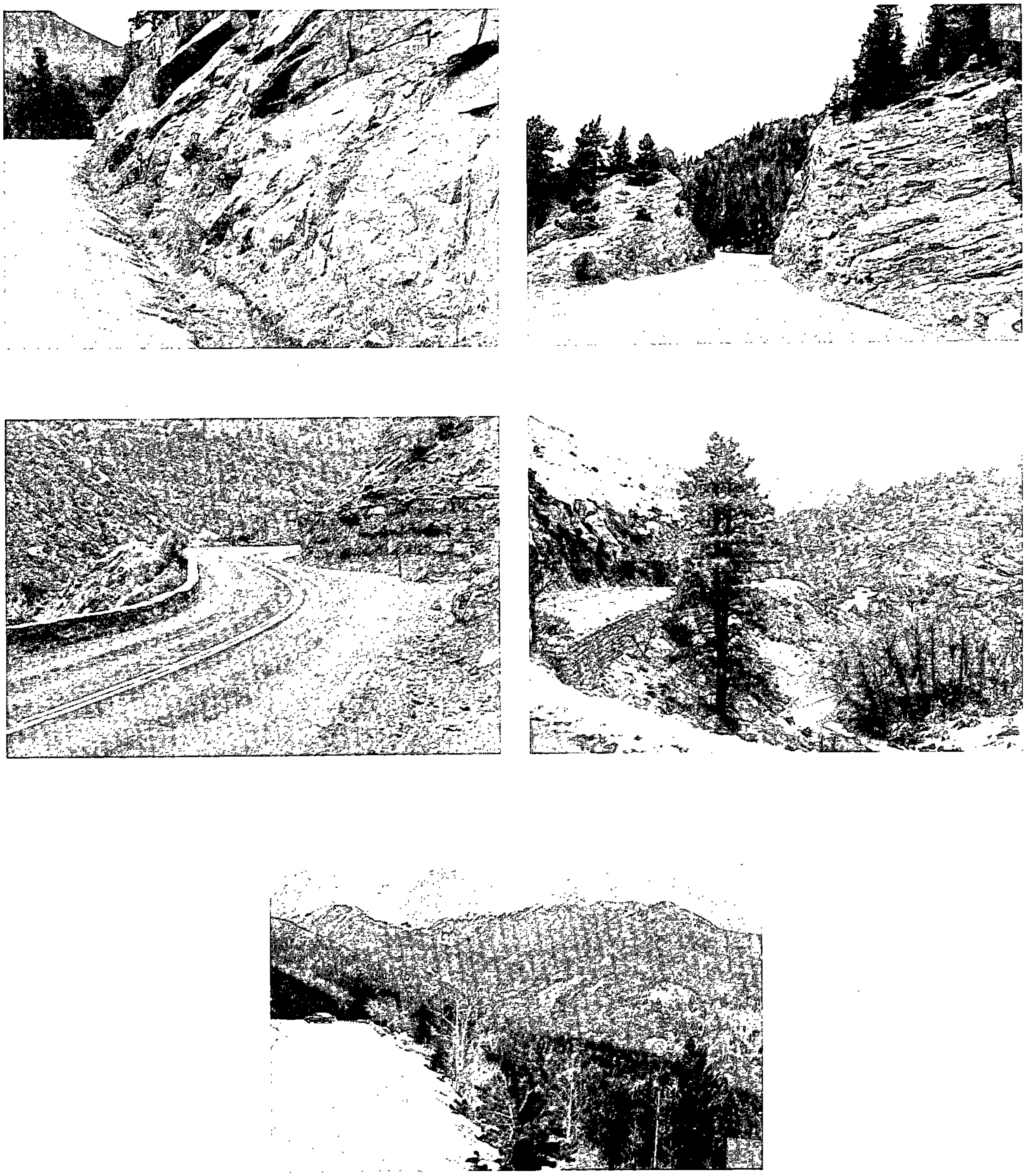


Figure 19. Rural roadside hazard rating of 7.

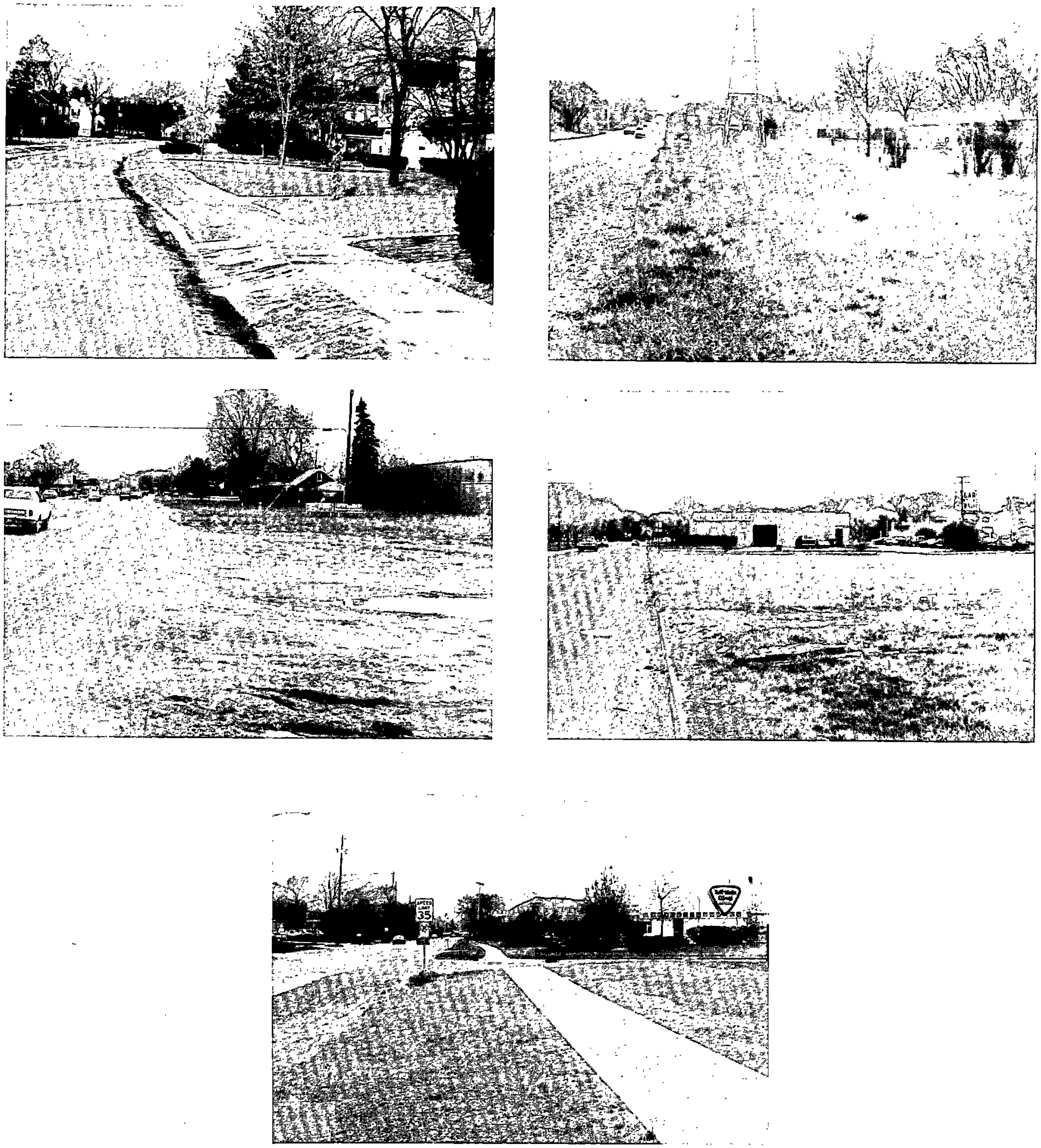


Figure 20. Urban roadside hazard rating of 1.

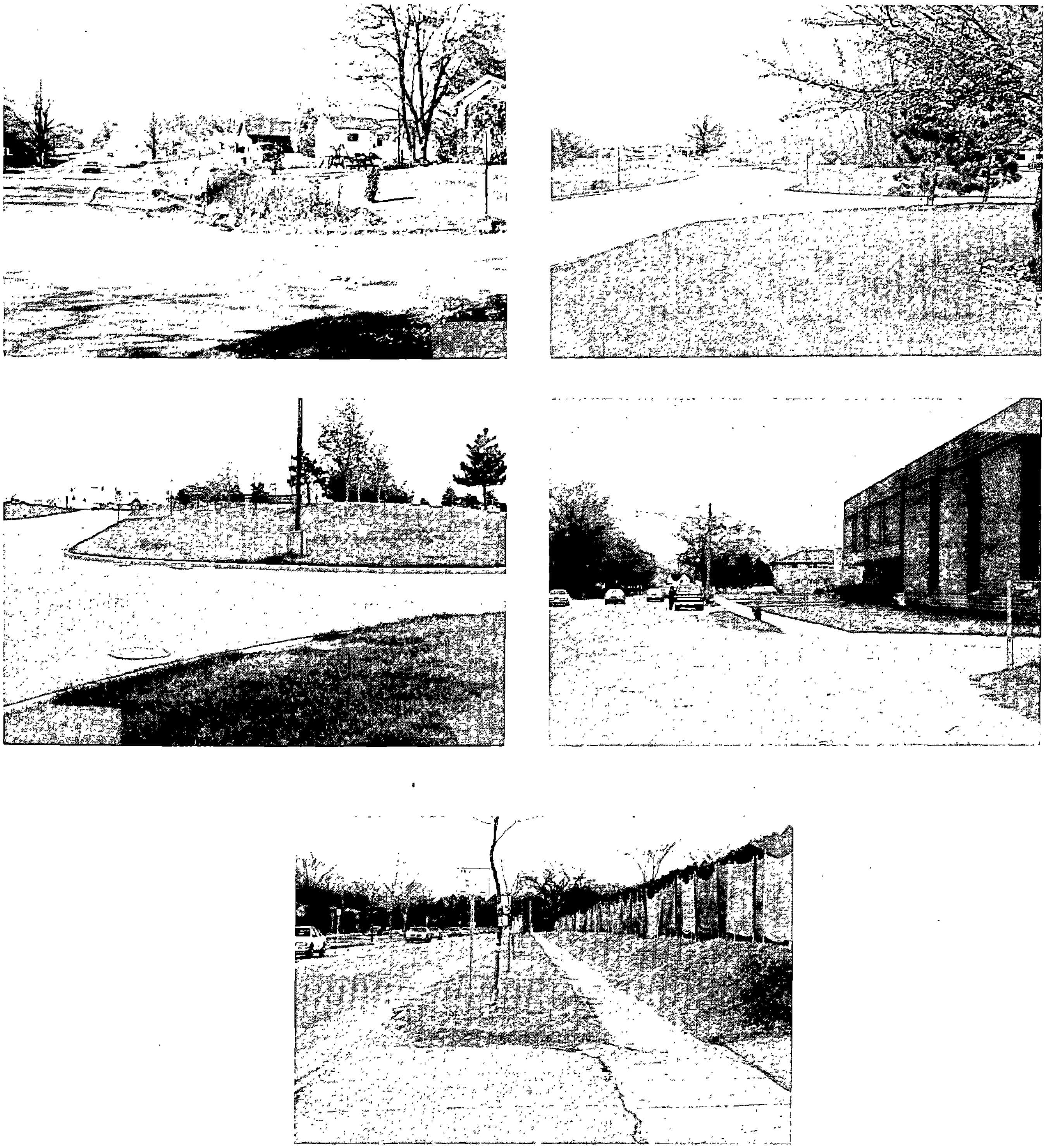


Figure 21. Urban roadside hazard rating of 2.

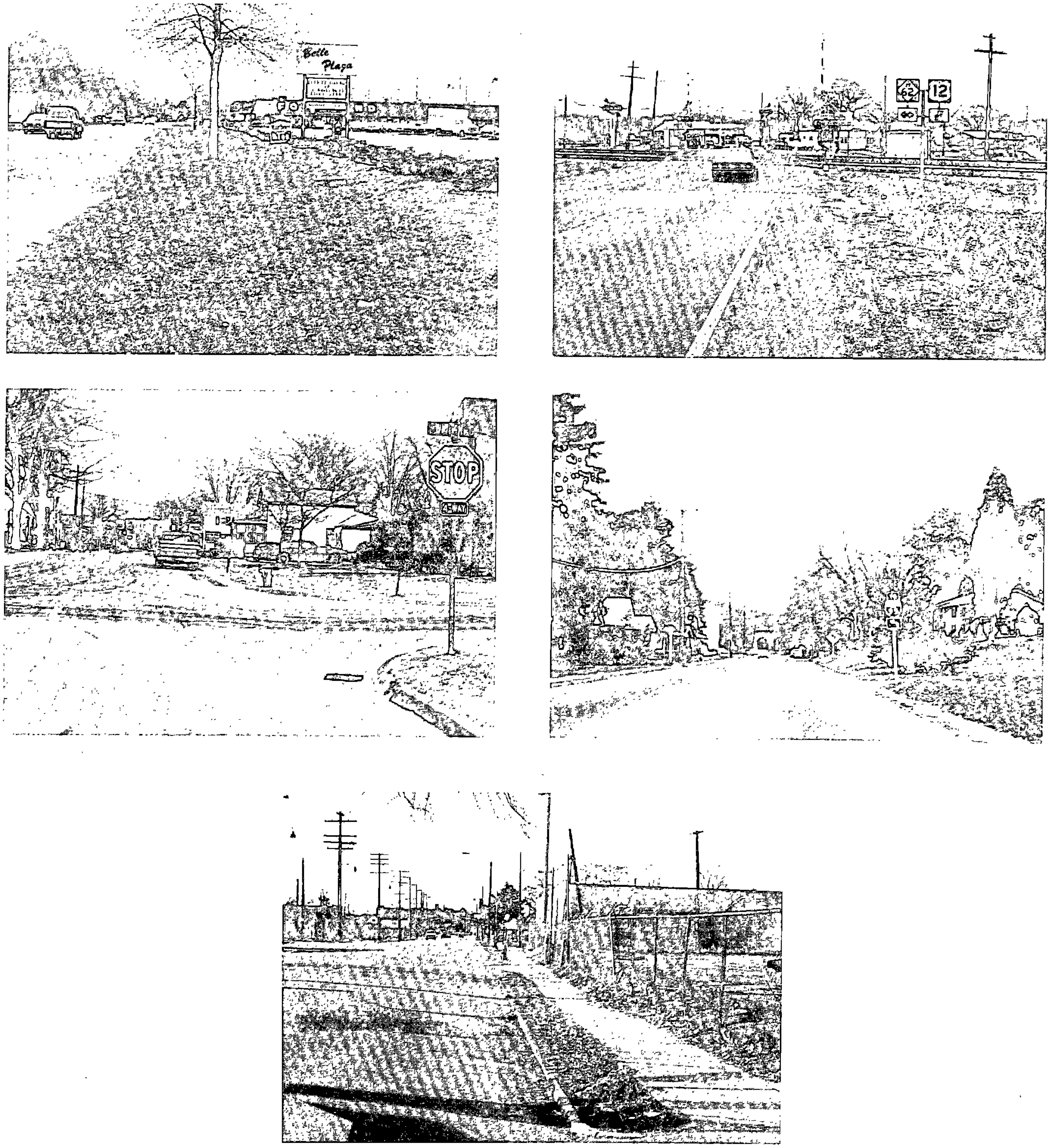


Figure 22. Urban roadside hazard rating of 3.

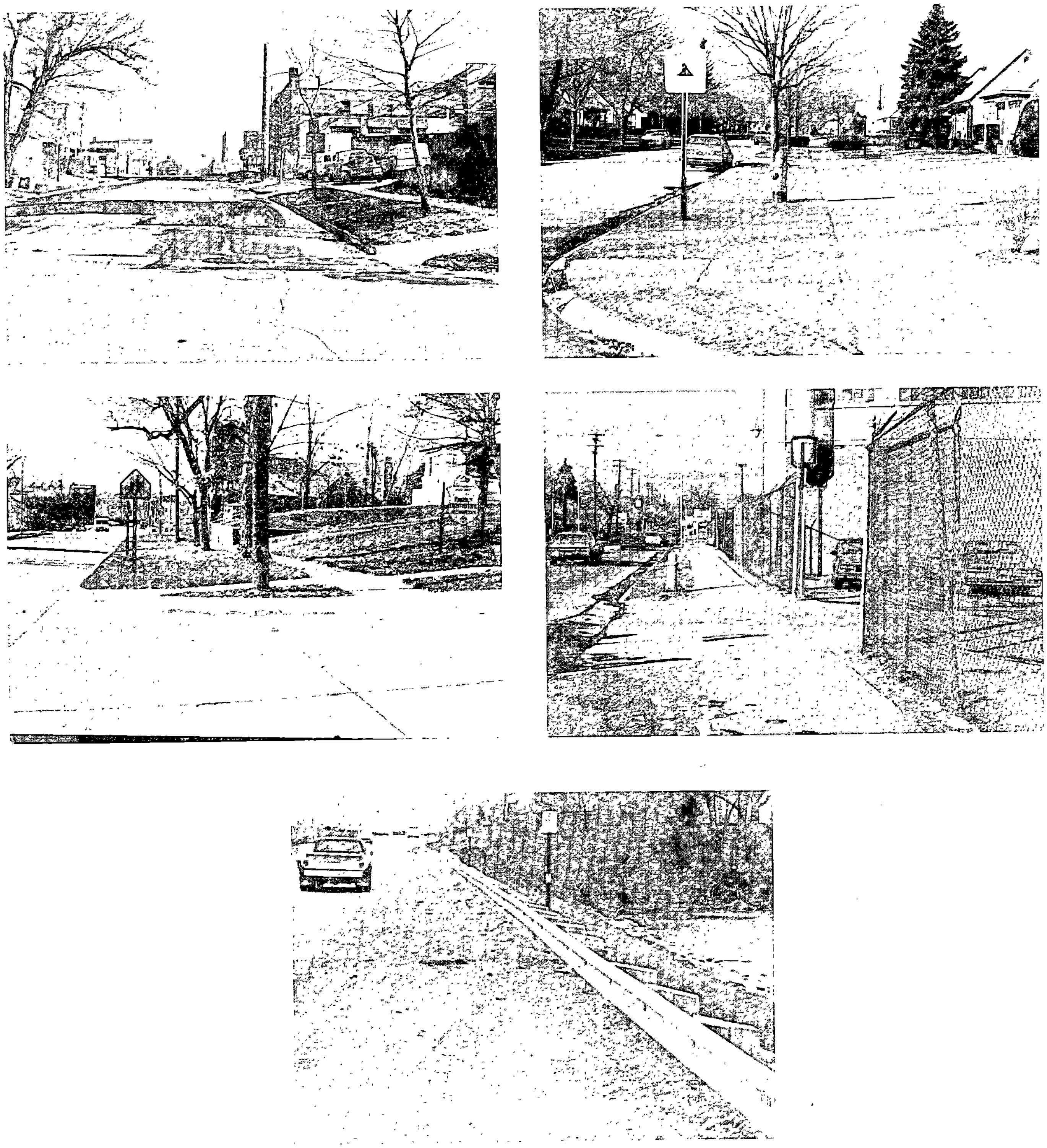


Figure 23. Urban roadside hazard rating of 4.

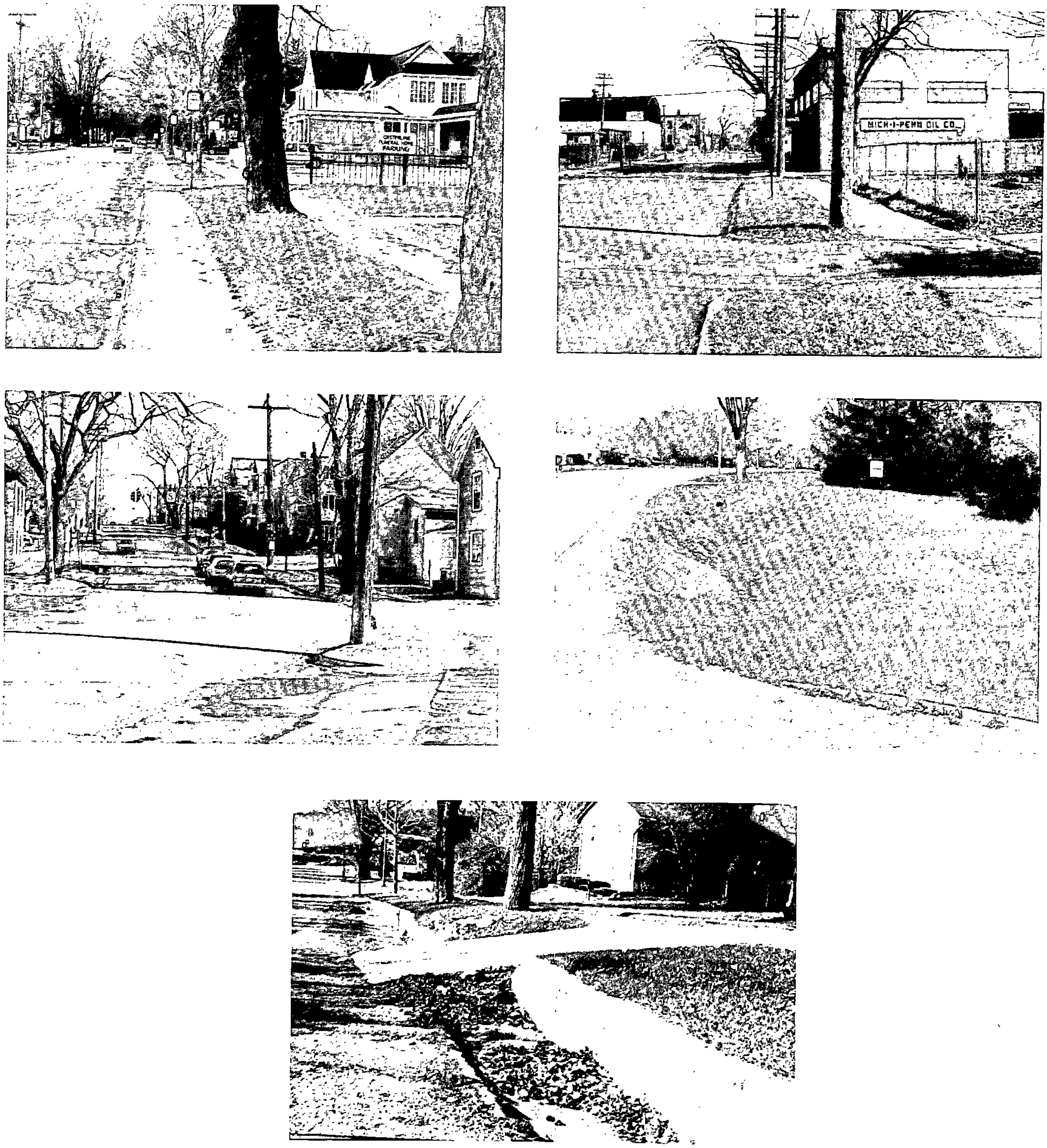


Figure 24. Urban roadside hazard rating of 5.

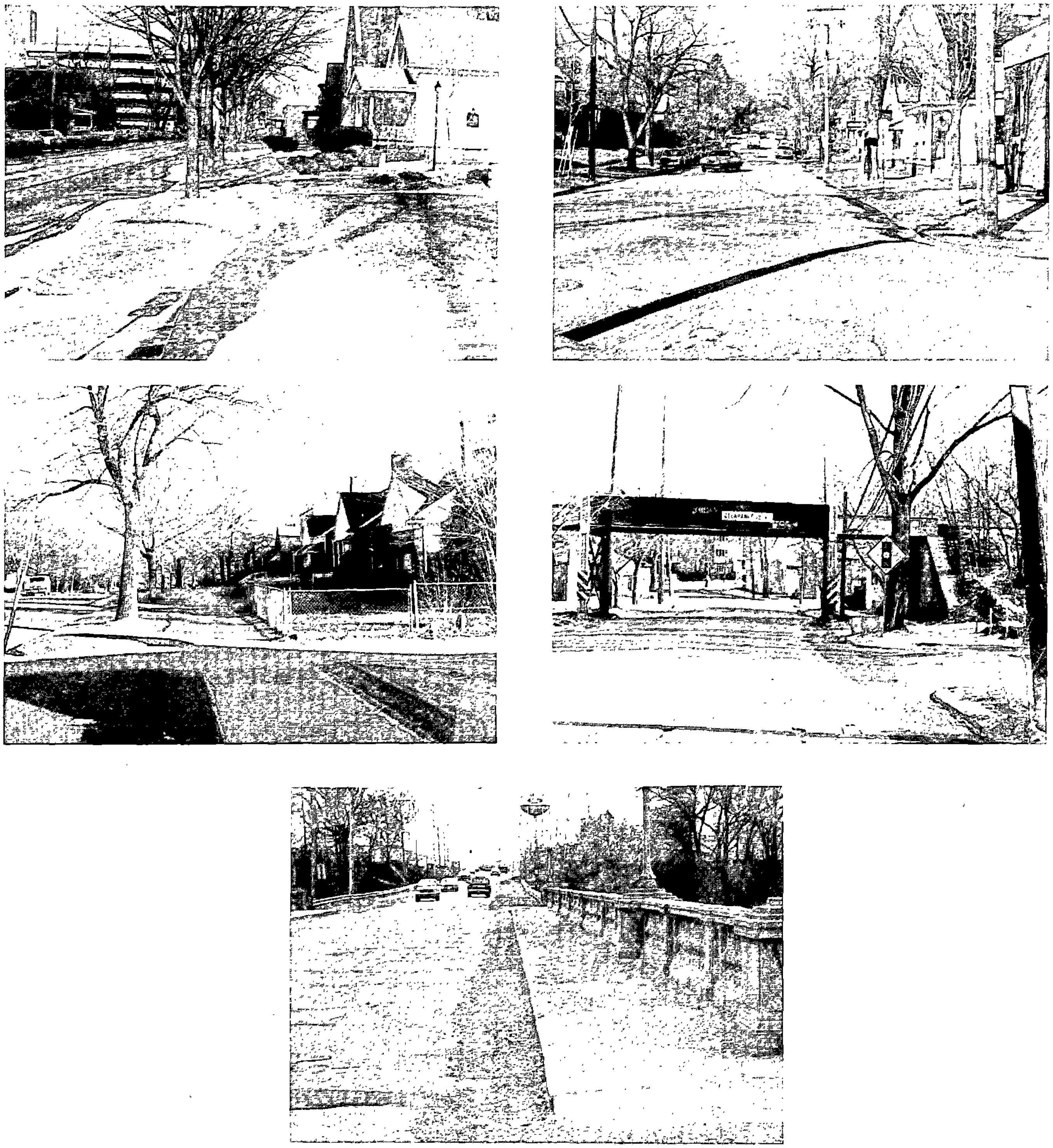


Figure 25. Urban roadside hazard rating of 6.

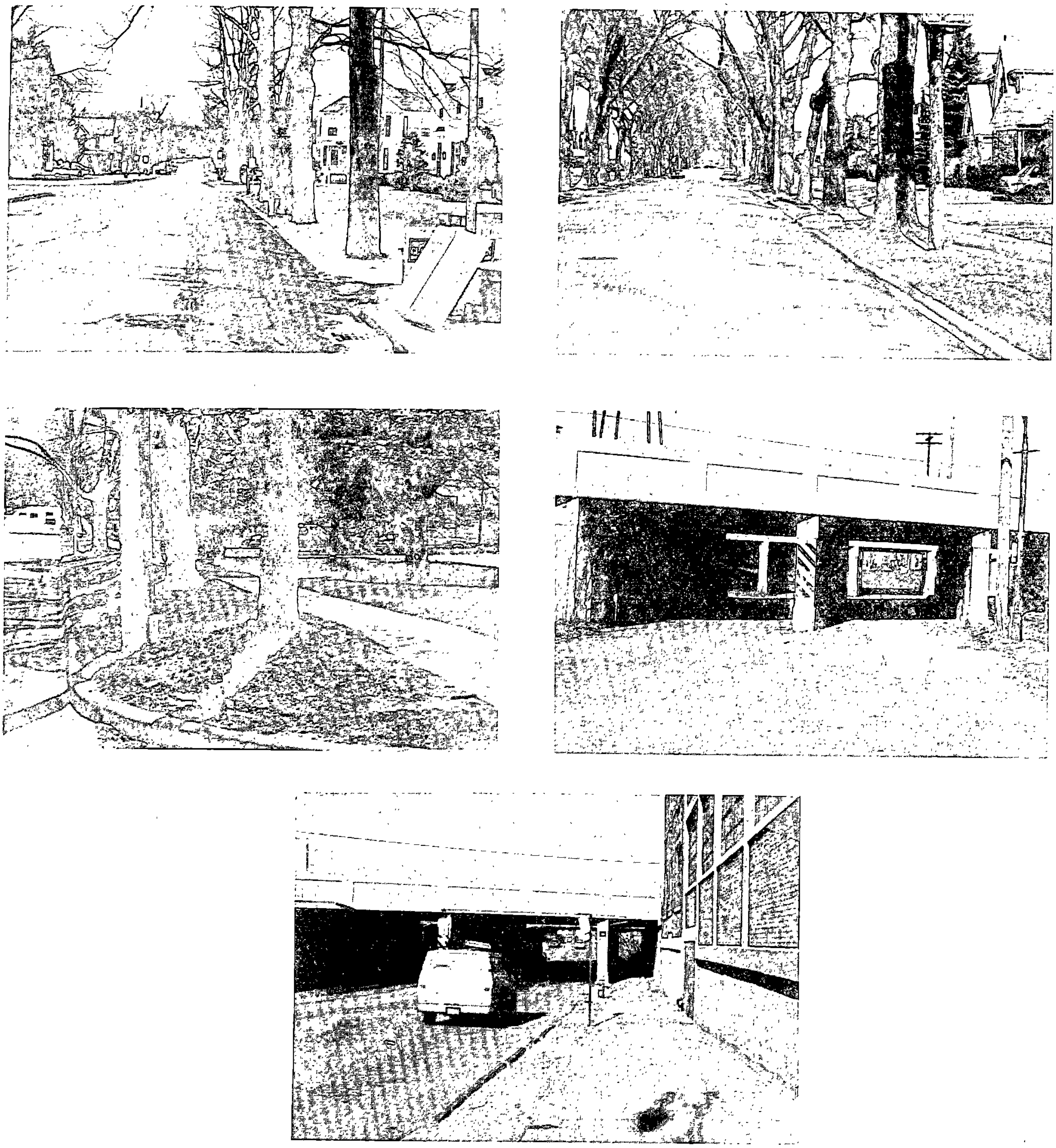


Figure 26. Urban roadside hazard rating of 7.

APPENDIX C - EXAMPLE OF INCREMENTAL BENEFIT-COST RATIO METHOD

To illustrate the incremental benefit-cost method, assume the following improvement alternatives W through Z at a given project site:

Alternative	Project Cost ($1,000)	Accident Benefits ($1,000)	B/C Ratio	Alternative Compared	Change in Benefits	Change in Costs
W	50	150	3.0	W+X	250	150
* X	200	400	2.0	X+Y	200	300
Y	500	600	1.2	X+Z	400	800
Z	1,000	800	0.8			

* = Alternative Selected

Projects were ordered from lowest to highest cost. The benefit cost ratios are given for each project, which shows the highest B/C ratio (3.0) for alternative W, followed by X (B/C of 2.0) , Y (B/C of 1.2), and Z (B/C of 0.8). Thus, using the simple Benefit/Cost ratio method would result in the selection of alternative W.

The incremental B/C ratio method would involve computing the change in benefit (ΔB) and change in costs (ΔC) for pairs of alternatives. When project alternatives W and X are compared ΔB (due to selecting project B instead of A) would be 400 - 150 = $250. Similarly, C between alternative W and X is 200 - 50 = $150. Thus ΔB is greater than ΔC, so alternative X would be selected over alternative W. Next, alternative X (i.e., the better of those two alternatives) is compared with the next lowest cost alternative, which is alternative Y. For this comparison of alternatives X and Y ΔB = 200 and ΔC = 300, and the change in benefits is less than the change in costs (i.e., the extra expense for alternative Y does not produce at least an equivalent amount of added benefits). Thus, alternative X would be preferred over alternative Y. Thus, comparing alternative X (i.e., the better of alternative X and Y) with alternative Z again reveals that alternative X is preferred (i.e., $\Delta B < \Delta C$). Therefore, alternative X is selected using the incremental B/C method even though alternative W is selected using the simple B/C ratio method.

APPENDIX D - EXAMPLES OF UNIT ACCIDENT COSTS

After estimating expected reductions in related accidents, a unit accident cost must be used to compute dollars of accident savings (benefits). The two most commonly used unit accident costs are National Safety Council (NSC) costs and National Highway Traffic Safety Administration (NHTSA) costs. NSC costs are as follows:[31]

	NSC (1984)
Cost per fatality	$220,000.00
Cost per injury	9,300.00
Cost per property damage only (PDO) accident	1,190.00

NHTSA (1980) costs are based on the AIS scale (table 66) and are presented in table 67.

A 1984 FHWA study by Miller, Reinert, and Whiting critically analyzed accident costs developed by various sources.[32] From this review, they developed a revised set of costs based on 1980 NHTSA costs and costs developed by Hartunian, Smart, and Thompson in 1981.[33,34] In developing their costs, they also utilized the AIS which was used by Hartunian and NHTSA. Recommended accident costs by Miller et al., are shown in table 68 based on 1980 dollars.[32] Two accident costs are given for fatal accidents. The higher costs include an adjustment based on willingness to pay for life.

In summary, although many different unit costs are currently in use, four primary sources of accident costs should be considered for use: (1) States costs; (2) NSC accident costs; (3) 1980 NHTSA costs, and (4) those revised by Miller based on the 1980 NHTSA, and Hartunian costs. Any of the above costs may be used in the cost-effectiveness procedure. However, the NSC costs will be used in the examples presented later since they are widely accepted, provide current costs, and assume a more conservative cost for a fatality.

Table 66. Representative motor vehicle injuries by abbreviated injury scale level.[32]

AIS Code	Injury-Severity Level	Representative Injuries
1	Minor injury	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness (no other neurological signs).
2	Moderate injury	Major abrasion or laceration of skin; cerebral concussion (unconscious less than 15 minutes); finger or toe crush/amputation; closed pelvic fracture with or without dislocation.
3	Serious injury	Major nerve laceration; multiple rib fracture (but without flail chest); abdominal organ contusion; hand, foot, or arm crush/amputation.
4	Severe injury	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs (unconscious less than 24 hours).
5	Critical injury	Spinal cord injury (with cord transection); extensive second- or third-degree burns; cerebral concussion with severe neurological signs (unconscious more than 24 hours).
6	Maximum injury (currently untreatable, immediately fatal)	Decapitation; torso transection; massively crushed chest.

Table 67. Summary of unit societal costs of motor vehicle accidents.[33]

	PER UNINVOLVED MOTORISTS	PROPERTY* DAMAGE ONLY	PER PERSON INJURED OR KILLED					
			1	2	3	4	5	FATALITY
MEDICAL COSTS			166	1,377	3,153	9,598	97,023	1,370
PRODUCTIVITY LOSSES			98	555	1,567	12,931	69,030	236,865
PROPERTY DAMAGED		379	811	1,354	2,120	2,865	2,845	3,406
LEGAL AND COURT		8	532	583	2,668	5,147	7,864	13,394
CORONER/MEDICAL EXAMINER								168
EMERGENCY COSTS		6	61	114	127	201	252	290
INSURANCE EXPENSE	77	90	549	549	549	12,538	12,538	12,538
PUBLIC ASSISTANCE ADMIN.			4	4	16	398	399	576
GOVERNMENT PROGRAMS		1	70	71	75	66	74	135
TOTAL	77	484	2,291	4,607	10,275	43,744	190,025	268,742

Notes: 1) All costs given in $1980.
2) The values shown are average costs assuming they apply to all victims. Some victims do not receive insurance benefits, so the unit insurance cost considering only those covered would be greater than shown.
3) There are slight differences among the totals shown in this table and those obtained by dividing the totals in Table 10 by the incidence of Table 1. These are due to rounding.

* For analytical convenience, the values in this column are referenced to the 44,783,000 property-damage-only-accidents, which including both reported and unreported PDO accidents. Some of these categories are actually costs only for reported accidents.

Table 68. Recommended total cost estimates (1980 dollars).[32]

	Per Vehicle	PER VICTIM					
		MAIS Category					
Category	PDO	1	2	3	4	5	Fatality
Total Direct Costs	$716	$1,601	$3,442	$ 8,089	$18,467	$138,684	$ 18,294
Total Indirect Capital Costs[a]	132	690[b]	1,165	2,217[b]	$32,564[b]	$122,897[b]	$370,341[b]
Adjusted WTP/HK Value	--	--	--	--	--	--	$710,770[c]
Total Capital Costs[a]	848	2,291	4,607	10,306	$51,031	$261,581	$388,635
Total Costs Based on Adjusted WTP/HK[a]	$848	$2,291	$4,607	$10,306	$51,031	$261,581	$742,521

[a] Does not include estimates of State motor vehicle agency costs, State and local highway department costs, and psychosocial costs.

[b] Based on a 4-percent discount rate and a 1.5 percent productivity growth rate.

[c] Based on a 4-percent discount rate and a 1.0 percent productivity growth rate.

* U.S. Government Printing Office: 1987 0-202-862 #60041