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Safety Cost-Effectiveness of Incremental Changes in Cross-Section Design--Informational Guide

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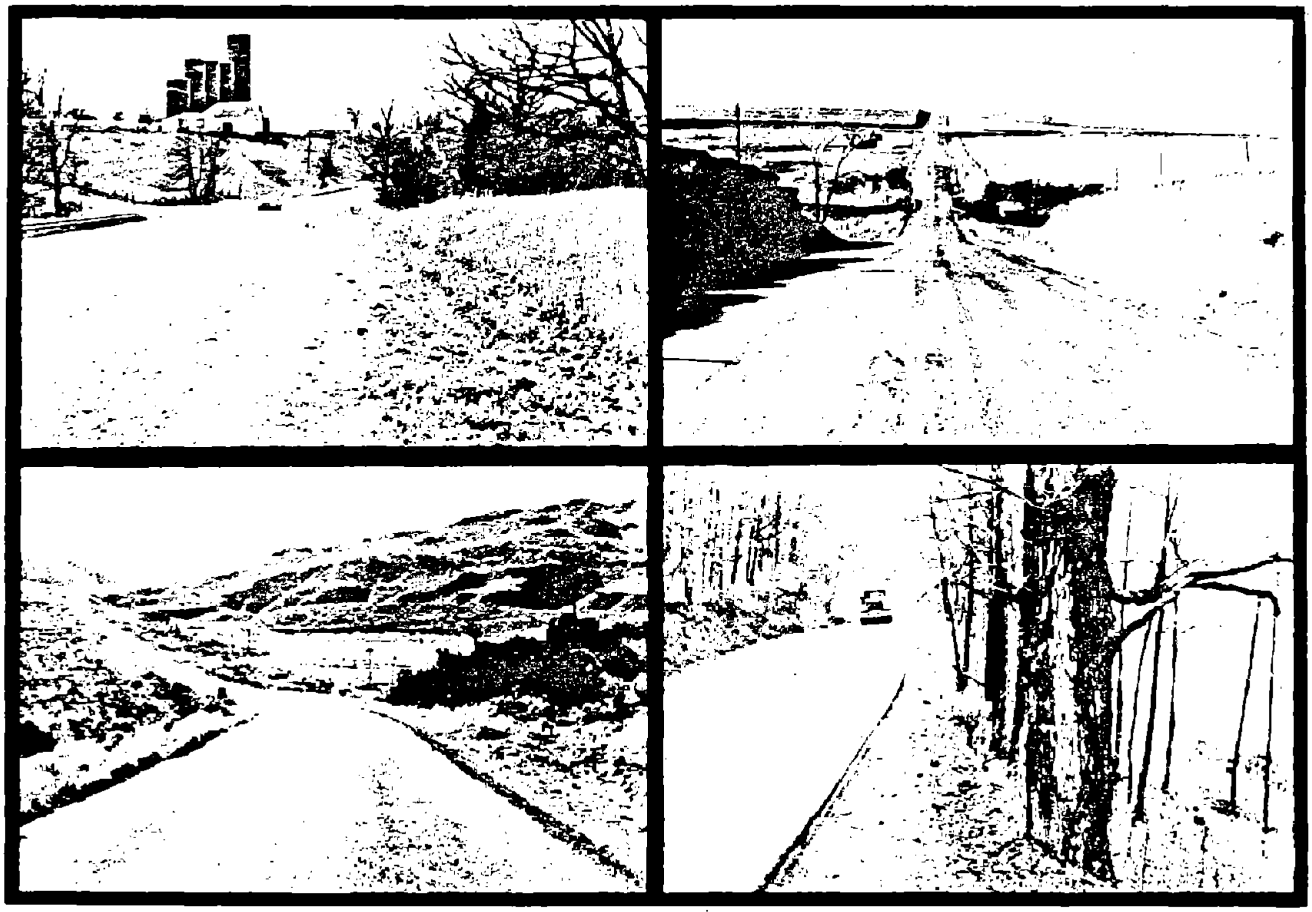

U.S. Department of Transportation
Federal Highway Administration

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

FOREWORD

This report contains information for estimating the costs and safety benefits which might be expected due to various improvements on specific sections of rural, two-lane roads. The information in this report will be of interest to highway engineers concerned with the design of 3R type projects.

The report contains accident reduction factors for different types of improvements such as lane widening, shoulder widening, and roadside improvements. However, when considering improvement alternatives, it is important to consider more than just one roadway element. That is, roadside improvements should be considered in addition to lane and shoulder improvements. The accident reduction factors for lane and shoulder widening assume that the sideslope is not made steeper by a construction project, since more rollover and other severe accidents may result from steeper sideslopes.

Sufficient copies of Report No. FHWA/RD-87/094 are being distributed to provide a minimum of two copies to each region office, two copies to each division office and four copies to each 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.

RJ Betsold

R. J. Betsold, Director
Office of Safety and Traffic
  Operations R&D
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NOTICE

Technical Report Documentation Page

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16. Abstract

This guide presents information for estimating the costs and safety benefits which would be expected due to various improvements on specific sections of rural, two-lane roads. Such improvements covered in this guide include lane widening, shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvements. This guide will be useful to those involved with the design of 3R-type projects, particularly for improvement projects which will be constructed on existing vertical and horizontal alignment and within the existing right-of-way.

The accident relationships with roadway geometrics and cost data contained in this guide resulted from research conducted for the Federal Highway Administration. FHWA research report FHWA/RD-87/008 entitled "Safety Effects of Cross-Section Design for Two-Lane Roads, Volume I, Final Report" contains the major results and conclusions of the study. FHWA research report number FHWA/RD-87/009 subtitled "Volume II, Appendixes" contains details on the data base and the data analysis.

17. Key Words Two-Lane Roads, 3R Projects, Improvements, Safety, Economic Evaluation, Benefits, Costs, Accident Prevention	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service Center, Springfield, Virginia 22161

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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			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
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
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

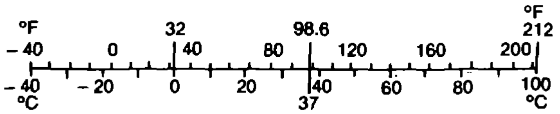
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	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
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

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



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

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* SI is the symbol for the International System of Measurements

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LIST OF SYMBOLS

Benefit Calculations

ADT_B = Average daily traffic before improvement

ADT_F = Average daily traffic in future (e.g., project period)

A_{TB} = Total accidents per year from historical data before improvement

A_{RB} = Related accidents per year from historical data before improvement

A_{RU} = Related accidents per year in the future untreated condition

A_{RT} = Related accidents per year in the future treated condition

F_A = Adjustment factor for determining future ADT (ADT_F)

F_{FC} = Adjustment factor for adjusting historical accidents for future ADT

$R_{R/T}$ = Ratio of related to total accidents

R_A = Accident reduction factor

AR_1 = Accident reduction factor for the first improvement

AR_2 = Accident reduction factor for the second improvement, etc.

L = Section length in miles

ΔA = The net reduction in accidents

C_A = The average cost per related accident

B_A = Expected annual accident benefits due to the reduced accidents

Cost Calculations

CT = The total per mile widening project contruction cost in 1985 dollars

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

WL = The number of feet added to each lane

CL = Cost of widening each lane by one foot (from table 11) in 1985 dollars

LIST OF SYMBOLS

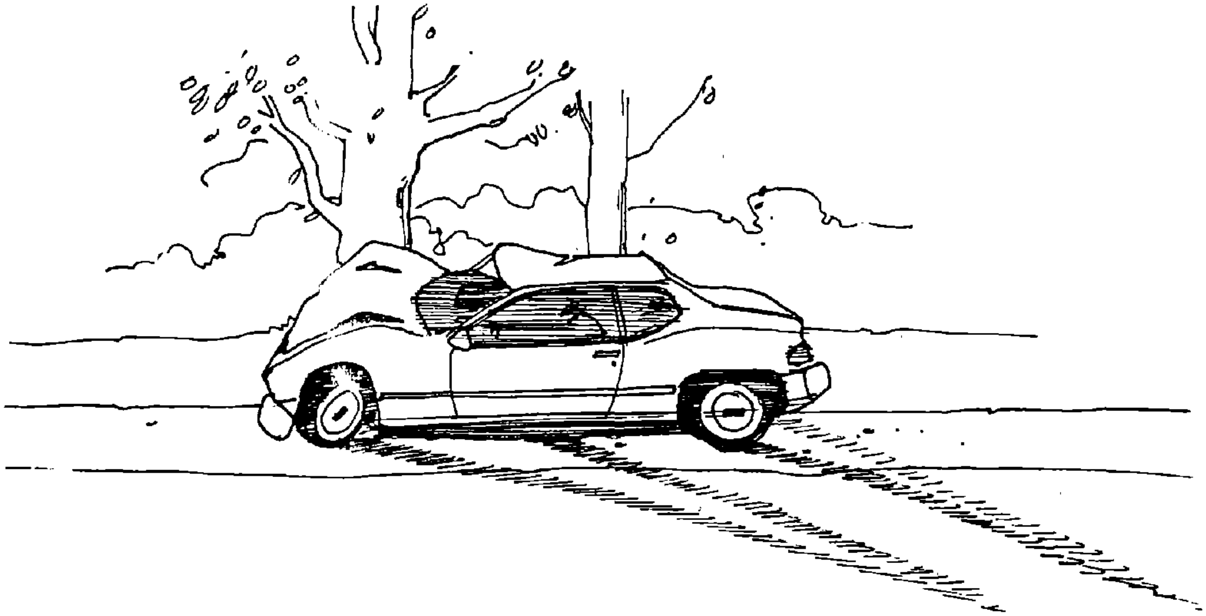
Cost Calculations (Continued)

WS = The number of feet added to each shoulder

CS = Cost of widening each shoulder by one foot (from table 11) in 1985 dollars

E = Cost of altering the side and back slopes (from table 12) in 1985 dollars

CHAPTER 1 - INTRODUCTION



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. Most of these roads carry relatively low traffic volumes, with approximately 80 percent of them having an average daily traffic of less than 400. Much of the rural two-lane highway system is in rolling terrain (58.9 percent) or mountainous areas (9.6 percent), with only 31.5 percent in flat areas. Common geometric problems of rural two-lane roads include:

- Narrow lanes (59.5 percent have lane widths of 10 feet or less).
- Narrow shoulders (36.1 percent have shoulders of two feet or less).
- Unstabilized shoulders (only 12.4 percent have paved shoulders).
- Unsafe roadsides (steep sideslopes and/or cluttered with trees, utility poles, and other rigid objects close to the roadway).[1]

In recent years, there has been increased concern by highway officials and the public regarding the deterioration of the U.S. highway network, particularly on two-lane rural roads. Efforts have continued by highway agencies to maintain the structural integrity of highways through various improvement programs, such as 3R (resurfacing, restoration, and rehabilitation). Safety enhancements should also be considered as an important part of 3R and other roadway improvement projects.

Efforts to improve two-lane rural highways to full standards have been severely hampered by limited funding. Also, the relative safety benefits for various improvement projects may be difficult to quantify for certain roadway and traffic conditions. Thus, the best improvement for a given roadway section is often difficult to determine.

This guide presents information for estimating the costs and safety benefits which would be expected due to various improvements on specific sections of rural, two-lane roads. Such improvements covered in this Guide include lane widening, shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvements. This guide will be useful to those involved with the design of 3R projects, particularly for improvement projects which will be constructed on existing vertical and horizontal alignment and within the existing right-of-way.

Chapter 2 provides a summary of the results of a recent research study which is the basis of this guide, and chapter 3 provides definitions of key terms and discusses assumptions and inputs needed for computing accident benefits. Detailed procedures are given in chapter 4 for determining accident benefits for various improvements to lanes, shoulders, and/or roadside conditions for various traffic and roadway conditions. Chapter 5 contains information for estimating project costs for many types of roadway improvements.

Procedures for conducting an economic analysis of project alternatives are discussed in chapter 6. These procedures include the simple benefit-to-cost ratio method and the incremental benefit-to-cost ratio method. Finally, a case study is provided in chapter 7 to illustrate the use of the procedures in the guide to solve real-world problems.

CHAPTER 2 - SUMMARY OF RESEARCH FINDINGS

The information contained in this guide is based on a recently completed research study [2] intended 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 benefits and construction costs were quantified for lane and shoulder widening, shoulder surfacing, sideslope flattening, and roadside improvement projects.

To examine accident relationships with geometric and roadway features, detailed accident, traffic, roadway and roadside data were collected and analyzed for 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). Three variables were used 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 using a pictorial scale, where a 1 represents the least danger, and a 7 represents the most danger to a run-off-road vehicle), and (3) actual counts of 20 specific types of point and continuous roadside objects (e.g., trees, utility poles) and the lateral distances of each type from the road.

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 for 1,776 miles of rural two-lane roads in three of the States. Detailed information was also collected on traffic volumes as well as driveways, 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 national Highway Performance Monitoring System (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. 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, and other run-off-road accidents).
- Related multivehicle (i.e., head-on, sideswipe opposite direction, and sideswipe same direction accidents).

<u>The combination of these accident types listed above were termed related accidents.</u>

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. Paved shoulders were associated with lower related accidents than unpaved shoulders. Also, steeper sideslopes were found to be associated with higher rates of single vehicle accidents, also only a small difference in single vehicle accidents was found between 3:1 and 2:1 sideslopes.

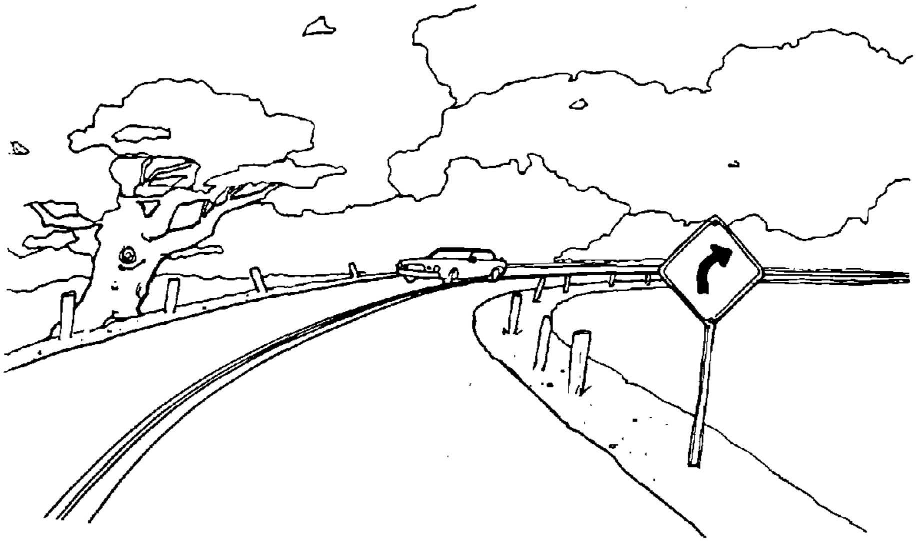
Specific relationships were developed between accidents and various traffic and roadway variables on two-lane rural roads using numerous candidate predictive models. The primary model selected for estimating related accidents was one which included measures of average daily traffic (ADT), lane width, shoulder width, average paved shoulder width, average unpaved shoulder width, roadside hazard rating, and terrain (i.e., flat, rolling, or mountainous). Details of this accident predictive model are given in appendix A. This model was used to develop an accident prediction nomograph (appendix D) and to compute expected accident reductions which will result from various combinations of lane widening, shoulder widening, shoulder surfacing, and roadside improvements.

A second accident predictive model was developed which contained the variable "roadside recovery distance," which was defined as the distance from the edgeline to the closest fixed objects or steep (i.e., 3:1 or steeper) slopes. Using this model, a series of accident reduction factors for related accidents were computed which may be expected due to various projects involving clearing roadside objects. A third accident predictive model was developed which was used to determine the reduction in single-vehicle accidents resulting from flattening sideslopes.

The three accident predictive models were found to be quite logical and reliable in terms of their ability to predict accidents, when compared to the results of previous studies. In spite of the random nature of accidents and the many factors that often interact to cause accidents, the primary accident predictive model was found to explain 46 percent of the variation in accident occurrence which compares favorably with prior attempts to model accidents on two-lane roads. Models developed in this study are the most reliable which have been developed to date.

While the predictive models were the basis for determining accident benefits for numerous types of roadway and roadside improvements, detailed construction cost data were also compiled from several States and a cost model was developed for similar projects. The basic information for computing benefits and costs for various projects as determined from that research study has been provided in this guide. A user may apply these principles to specific two-lane rural roadway sections to compare the benefits and costs of one or more types of highway improvement. The user may also use their own cost values and accident predictive models, if such reliable information is available.

CHAPTER 3 – PROCEDURE INPUTS AND ASSUMPTIONS



The procedures described in the following chapters are designed to evaluate the costs and benefits of various roadway improvements on two-lane rural roads. The methodology requires that certain types of information is known for each roadway section relative to physical site features and countermeasure alternatives. This chapter provides details for the following:

- Definitions of Key Terms.
- Procedure Assumptions.
- Use of the Accident Predictive Nomograph.

Definitions of Key Terms

Average Daily Traffic (ADT) - The average number of vehicles per day which travel in both directions over a highway section.

Terrain - A description of the vertical and/or horizontal curvature along a highway section, as defined by the following:[3]

- Flat Terrain - Terrain where highway sight distances are generally long and there are few vertical curves or slopes present.
- Rolling Terrain - Terrain with natural slopes which consistently rise above and fall below the highway grade line. Occasionally these slopes restrict normal sight distance.

- Mountainous Terrain - Terrain with abrupt longitudinal and transverse changes in the elevation of the ground with respect to the highways.

Lane Width - The distance measured from the middle of the roadway centerline to the outside edge of the edgeline, or if no edgeline is visible, to the visible joint separating the lane from the paved shoulder. If no paved shoulder exists, the lane width is measured to the edge of the paved surface.

Paved Shoulder Width - The width of the concrete or bituminous surface adjacent to the lane.

Unpaved Shoulder Width - The width of the prepared surface of grass, dirt, gravel, stone, or gravel with tar (i.e., stabilized) surface adjacent to the travel lanes (or adjacent to a paved shoulder in some cases).

Roadside Hazard Rating - A subjective measure of the hazard associated with the roadside environment. The rating values indicate the accident damage likely to be sustained by errant vehicles on a scale from one (low likelihood of an off-roadway collision or overturn) to seven (high likelihood of an accident resulting in a fatality or severe injury).

The ratings are determined from a 7-point rural pictorial scale, as shown in figures 1 through 7. The data collector should choose the rating value (1 through 7) that most closely matches the roadside hazard level for the roadway section in question. In many cases, the roadside hazard along a section will vary considerably, so the roadside hazard rating should represent a "middle" value (e.g., if ratings generally range from 4 to 6 along a section, a rating of 5 should be used to best represent the roadside hazard rating of the section).

Roadside Recovery Distance - The roadside recovery area is a relatively flat unobstructed, and smooth area adjacent to the outside edge of the shoulder 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:

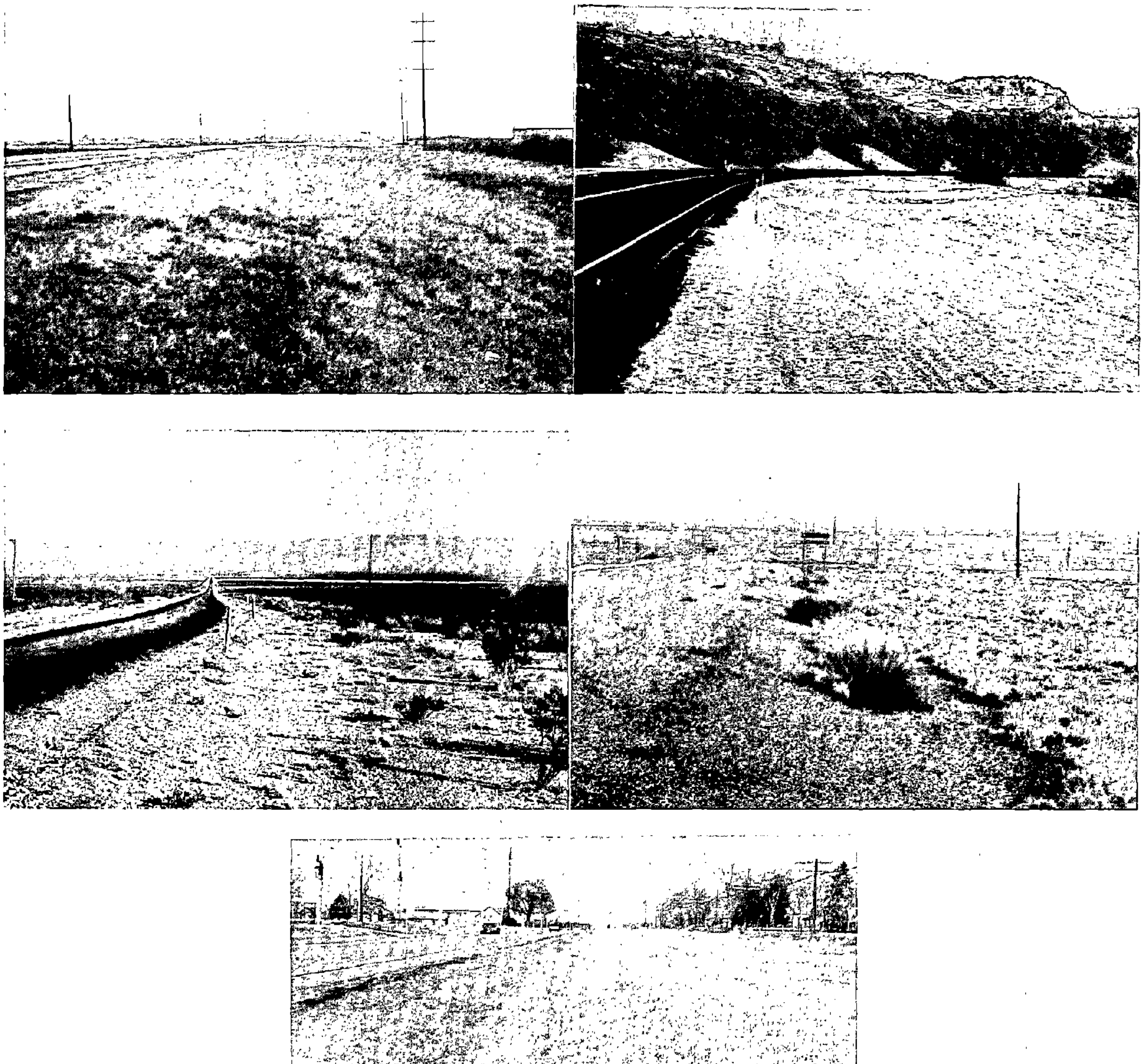


Figure 1. Rural roadside hazard rating of 1.

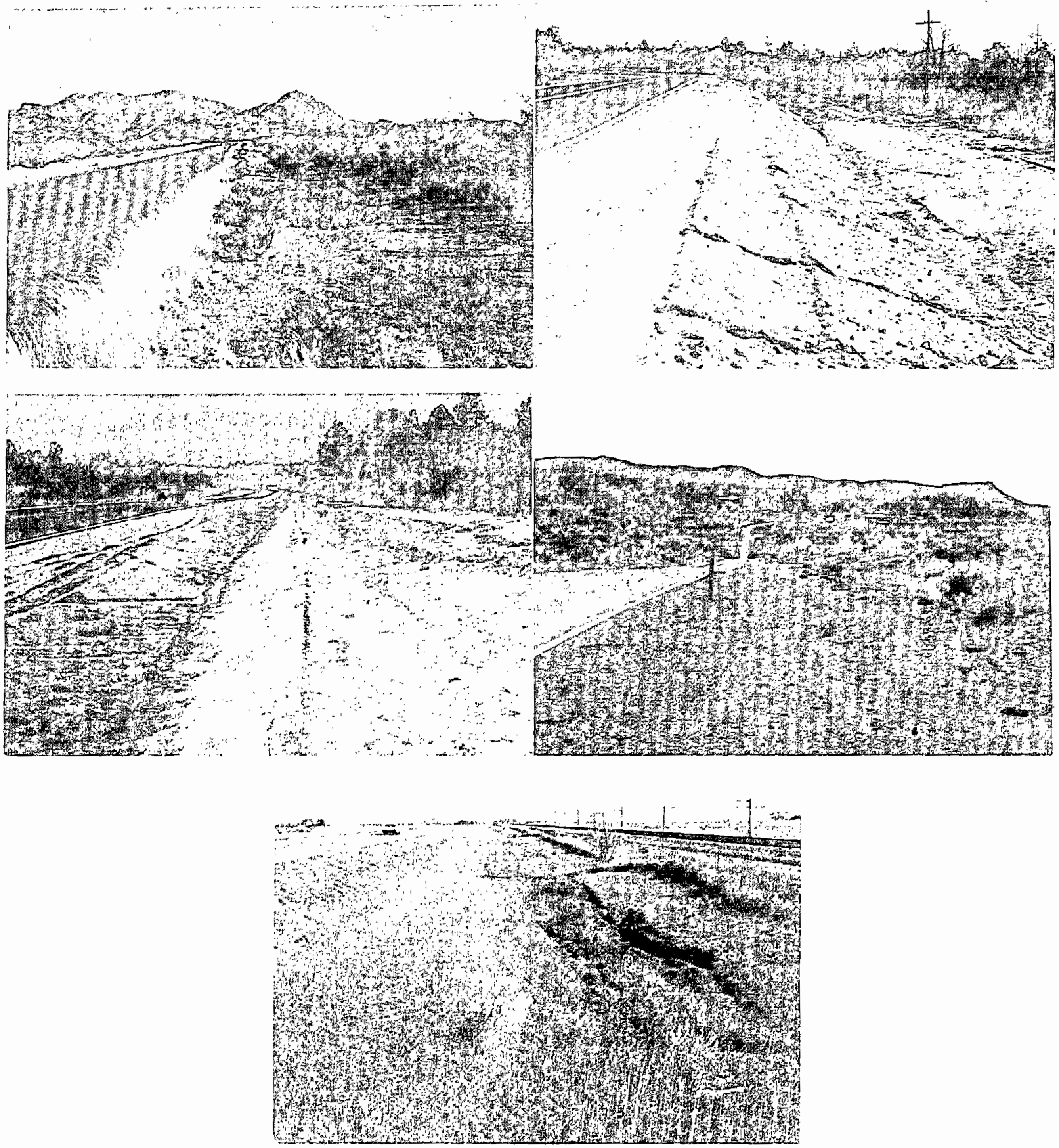


Figure 2. Rural roadside hazard rating of 2.

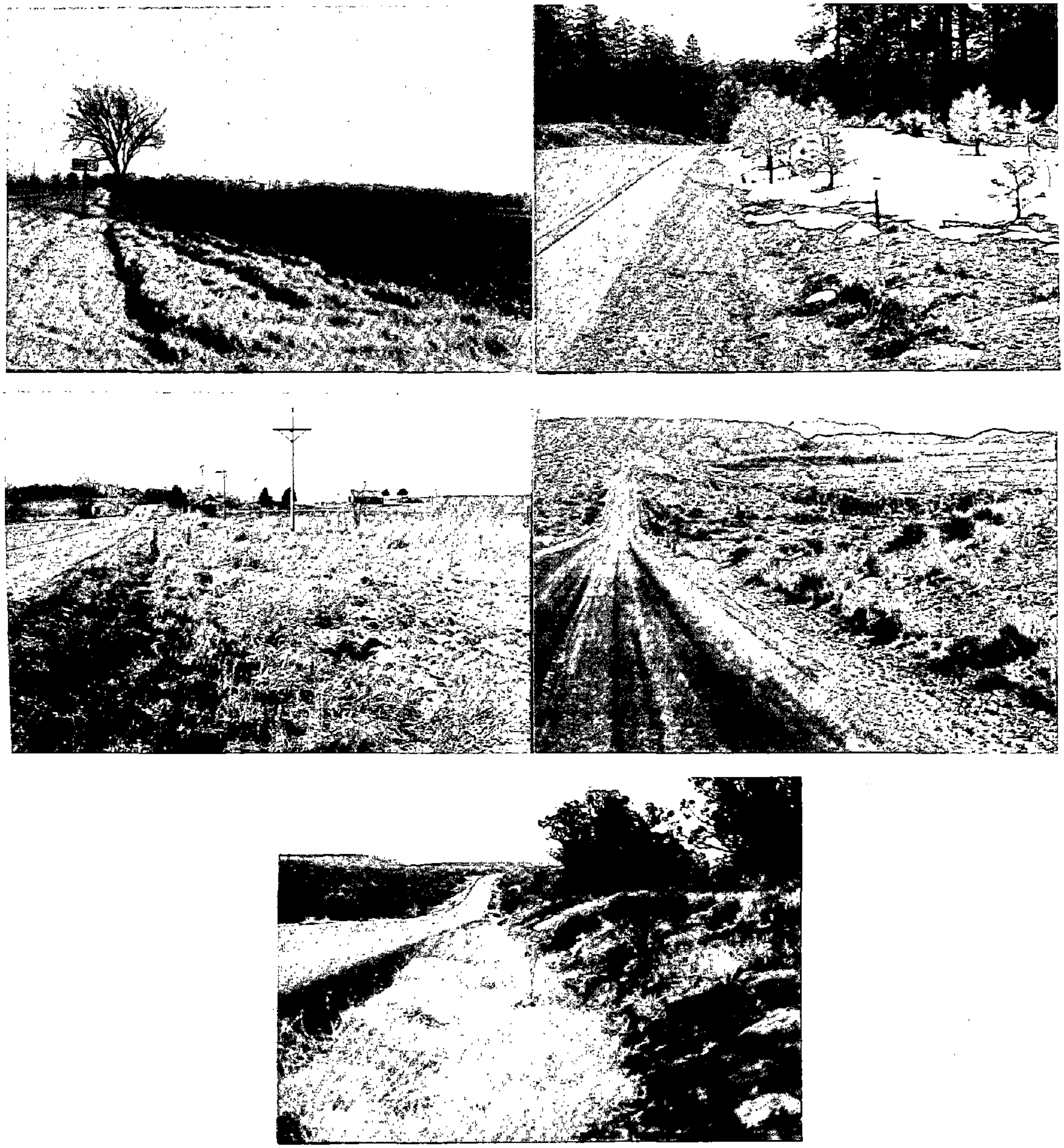


Figure 3. Rural roadside hazard rating of 3.

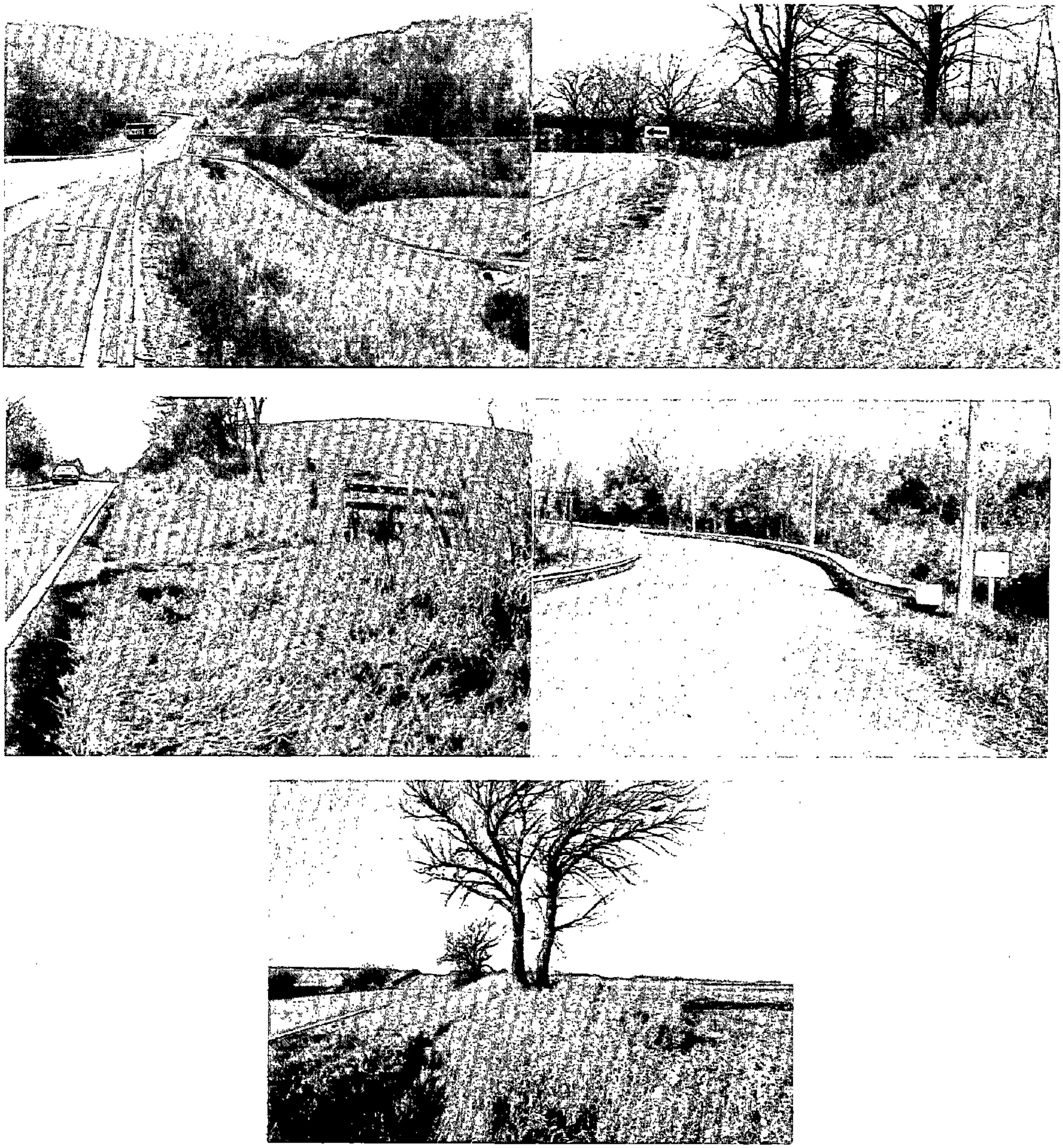


Figure 4. Rural roadside hazard rating of 4.

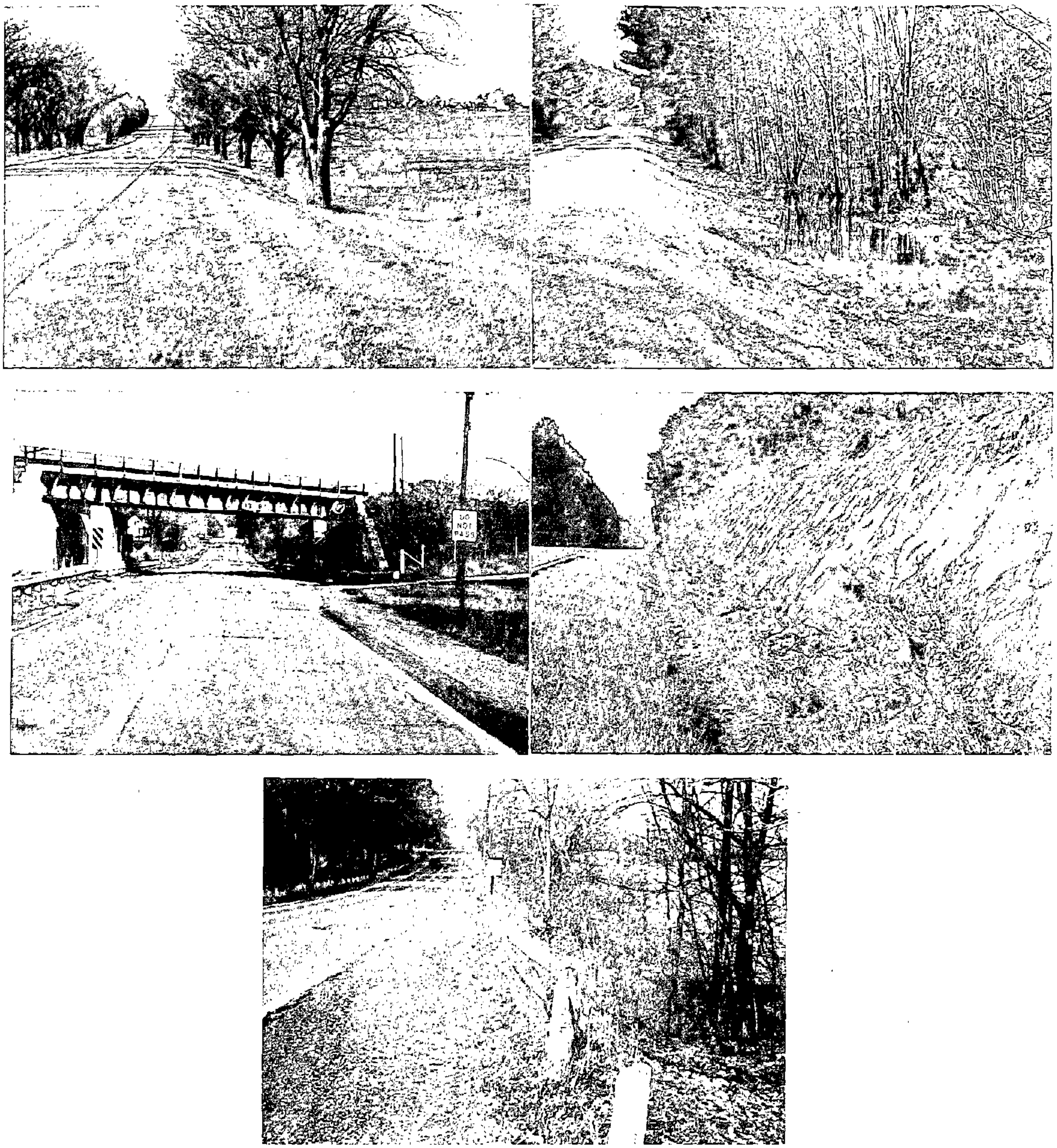


Figure 5. Rural roadside hazard rating of 5.

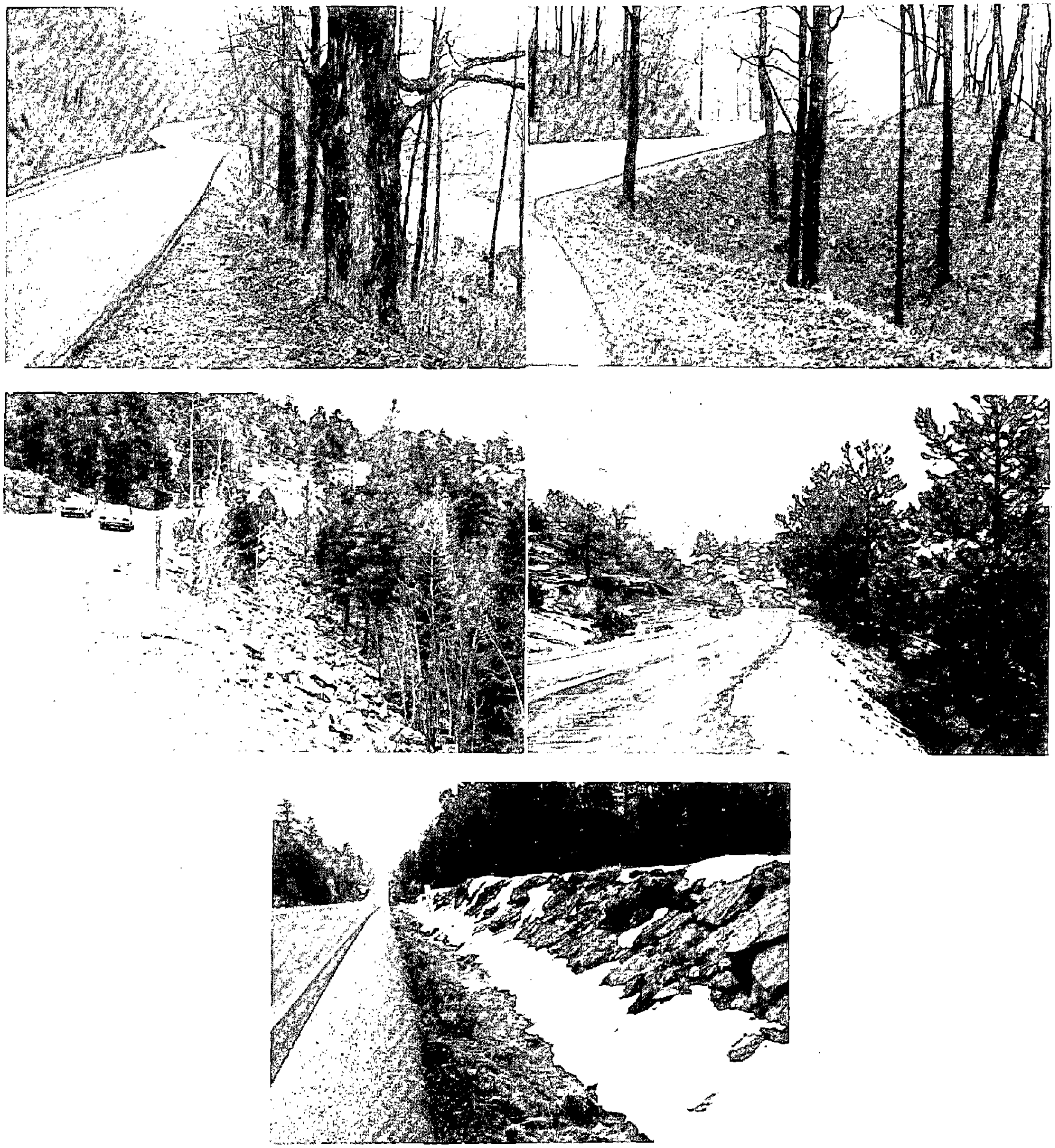


Figure 6. Rural roadside hazard rating of 6.

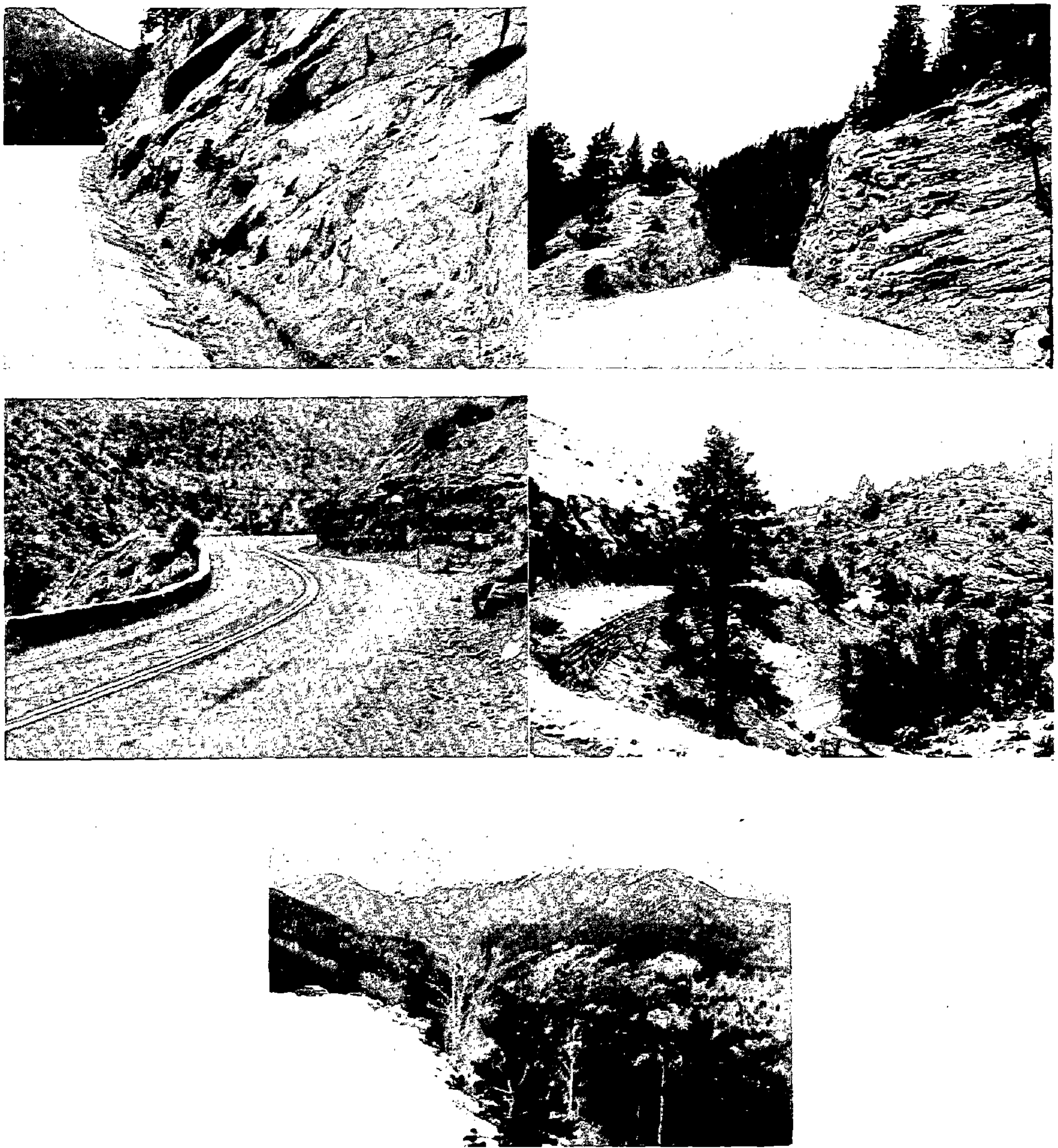


Figure 7. Rural roadside hazard rating of 7.

- 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).
- Other features, such as a rough or irregular surface, loose rocks, or a watercourse that pose a threat to errant vehicles.

Along most roadway sections, the roadside recovery distance may vary considerably from near 0 (trees next to the travel lane) to 30 feet or more. A single measurement is made by locating a 0.1-mile (528-foot) length of highway section, selecting the obstacle (or steep slope) along that section which is closest to the roadway, and then measuring the distance of that obstacle from the edge of shoulder. For a given roadway section, the single measure of roadside recovery distance is the average of these distances measured (or estimated) every tenth of a mile. For long sections, a representative sample of subsections may be used to make measurements instead of measuring the recovery distances at each 0.1 mile throughout the section. Use a roadside recovery distance of 30 feet for cases where the distance is ≥ 30 feet.

<u>Related Accidents</u> - Based on a previous research study [2] for which this Informational Guide was developed, there are six accident types which were found to be related to lane and shoulder widening, shoulder paving, and roadside improvements. These accident types include:

- Run-off-road fixed object.
- Run-off-road rollover.
- Run-off-road other.
- Head-on.
- Opposite-direction sideswipe.
- Same direction sideswipe.

For use in this guide, these six accident types constitute the group referred to as related accidents.

Procedure Assumptions

The procedures used in this Informational Guide are based on data and information compiled and analyzed only for highway sections under the following conditions:

- Two-lane rural roads with an average daily traffic (ADT) of between 100 and 10,000.
- Lane widths of eight to twelve feet.
- Shoulders (0 to 12 feet wide) which are paved, unpaved, or partly paved and partly unpaved.

Accident Prediction Nomograph

An accident prediction nomograph (appendix D) has been developed which represents the relationships between related accidents and the following roadway variables:

- ADT.
- Terrain.
- Roadside hazard rating.
- Lane width.
- Paved shoulder width.
- Unpaved shoulder width.

Thus, by knowing the roadway variables listed above for a roadway section, the expected number of related accidents per-mile-per-year can be determined.

The following steps illustrate how to use the nomograph.

1. Draw a vertical line from the ADT to the roadway terrain curve.
2. From that point, draw a horizontal line to the roadside hazard rating line.
3. Draw a line up to the lane width line; and then horizontally to the line of the paved shoulder width.

4. Next, draw a line up to the unpaved shoulder width line and then over to the accident scale.
5. Read the value of the predicted number of related (AO) accidents per-mile-per-year.

For example, assume the following roadway conditions:

- ADT = 2,500.
- Rolling terrain.
- Roadside Hazard Rating = 5.
- Lane Width = 10 feet.
- Paved Shoulder Width = 0.
- Unpaved Shoulder Width = 0.
- Section Length = 3.4 miles.

Entering the nomograph **(appendix D)** with these values would result in an estimated 1.5 related accidents per-mile-per-year. Thus, a 3.4 mile section would be expected to experience 1.5 x 3.4 = 5.1 related accidents per year.

CHAPTER 4 – DETERMINING BENEFITS FROM ROADWAY IMPROVEMENTS

This chapter may be used to compute the accident benefits which are expected due to one or more proposed roadway improvements on a specific section of two-lane rural road. A series of eight steps are provided for computing accident benefits, based on the use of several forms and tables, an accident prediction nomograph, and a few simple calculations. Form A is used to summarize the existing conditions at the site, and Form B is used to compute the accident benefits due to each roadway improvement. An improvement project may involve changing only one roadway feature (e.g., lane widening) or changing several roadway features in the same project (e.g., widening lanes, adding paved shoulders and flattening sideslopes).

In chapter 5, Form C will be discussed for use in computing project costs. Chapter 6 includes Form D for conducting an economic analysis of two or more roadway improvements at a site. Finally, examples of completed Forms A through D are shown for a case study in chapter 7.

The following procedure may be used for computing estimated accident benefits for two-lane rural roads for which one or more of the following improvements are being considered:

- Lane widening.
- Shoulder widening.
- Shoulder surfacing.
- Sideslope flattening.
- Other roadside improvements.

For 3R-type improvements, it is assumed that pavement resurfacing will be the basic improvement and one or more of the improvements listed above may also be added. The procedure for computing accident benefits involves the following steps:

Step 1 - Complete the Site Description Form (Form A)

Step 2 - Complete the Improvement Description on Form B

Step 3 - Compute the Average Daily Traffic Over the Project Life (ADT_F)

Step 4 - Determine the Number of Related Accidents Per-Mile-Per-Year Without Improvement (A_{RU})

Step 5 - Determine the Accident Reduction Factor (R_A)

Step 6 - Compute the Estimated Number of Accidents Reduced (ΔA)

Step 7 - Determine the Average Cost per Related Accident (C_A)

Step 8 - Compute Expected Accident Benefits Due to the Reduced Accidents (B_A)

The details of each step are described in the following paragraphs.

Form B is the worksheet for completing steps 2 through 8. To assist the reader, the appropriate section of Form B is shown in bold print following the description of each step. Also, a complete Form B is included in appendix C with Forms A, C, and D.

Step 1 - Complete the Site Description Form (Form A)

The characteristics of each site should be recorded on Form A, which is shown in figure 8. Each site should be relatively homogeneous in features such as terrain, traffic volume, lane width, shoulder width, shoulder type, and roadside condition. If conditions along a section change

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM A - SITE DESCRIPTION

1. Road Name or Route Identification:______________________________

2. Milepoint Beginning:_______ Ending:_______ Length:________(Miles)

3. Area Type (Check): ______Rural

   ______Urban (If urban, procedures in this manual do not apply.)

4. Terrain Condition (Check One):

   ________Flat ________Rolling ________Mountainous

5. Present Average Daily Traffic (ADT_B):__________

6. Expected Annual Traffic Growth Rate = g = __________

7. Lane Width: __________Feet

8. Paved Shoulder Width: __________Feet

9. Unpaved Shoulder (e.g., Dirt, Gravel, Turf, Stabilized)
   Width = __________Feet

10. Typical Sideslope (Check One):

    ___2:1,or steeper, ___3:1, ___4:1, ___5:1, ___6:1, ___7:1 or flatter

11. Median Value of Roadside Hazard Rating (Check One):

    ______1; ______2; ______3; ______4; ______5; ______6; ______7

12. Average Roadside Recovery Distance = _____ Feet (Optional)

13. Reliable Accident Data for the Section (Check One):

    ________ Available ________ Unavailable

    Note: If reliable accident data are unavailable, skip lines 15-17, and use accident prediction nomograph for estimating accident experience on the section.

14. Total Accidents = ________ for ________ years

15. Total Accidents per Year = $\frac{\text{Number of Total Accidents}}{\text{(Years of Data)}}$ =

    A_{TB} = ______ Total Accidents per Year Before Improvement

16. Number of Related Accidents by Type for ______ Years:

    Single Vehicle (Run-Off-Road) = _______, or _______Per Year

    Head-On = _______, or _______Per Year

    Opposite Direction Sideswipe = _______, or _______Per Year

    Same Direction Sideswipe = _______, or _______Per Year

Sum of Related Accidents = A_{RB} _______, or _______Per Year
Before Improvement

Figure 8. Worksheet used to summarize existing conditions at the site (Form A).

considerably, the section should be subdivided, and a separate analysis should be conducted for each subsection. For example, the following inconsistencies within a roadway section may justify analyzing the subsections separately:

- Lane width changes by one foot or more from one segment to another.
- Shoulder width changes by more than three feet (e.g., a three-foot shoulder on one portion of the section and a seven-foot shoulder on another portion).
- Shoulder type paved on part of the section and gravel or dirt on another part.
- Terrain basically flat on part of a section and rolling on another part.
- The roadside character basically clear of obstacles and flat on part of a section and has a steep slope and/or rigid obstacles on another part.
- Traffic volume 500 on one portion of a roadway, but past a major intersection the traffic volume of 1,200.

Minor fluctuations in traffic volume, shoulder width, roadside condition, and other factors can be tolerated for a site without sacrificing much accuracy.

When sections must be broken up into subsections for analysis purposes, avoid making section lengths too small. A minimum length of one mile is recommended, while sections up to 10 miles long are appropriate for analysis purposes (as long as traffic and roadway conditions are relatively uniform). Sections longer than 10 miles should be split into two or more sections for best results.

Note that the definitions of the key variables are discussed in the previous chapter, along with how to collect such information for each roadway section. The inclusion of accident data (and specifically related accidents) is optional. If accident data are available for the highway section of concern, it should be included on Form A. If accident data are unavailable, the accident prediction nomograph may be used to estimate the number of related accidents per-mile-per-year based on the existing traffic and roadway characteristics.

Step 2 - Complete the Improvement Description on Form B

One or more alternative improvements may be considered for each two-lane roadway section, and a separate Form B should be used for each alternative for each roadway section. For example, consider three possible alternatives for a highway section:

- Alternative 1 - Pave four-foot shoulders.
- Alternative 2 - Widen lanes by one foot plus increase gravel shoulders from four to six feet.
- Alternative 3 - Widen lanes by one foot, plus flatten sideslope from 3:1 to 4:1, plus remove trees within 10 feet of the roadway.

For each of these three alternatives, a separate Form B would be completed. Note that a group of several treatments should be considered as one alternative, as long as they are being considered to be completed together as one project. The procedure thus allows a highway agency to compare the benefits and costs of projects where only one roadway feature is improved (e.g., paving shoulders) or numerous features are improved as a part of the same alternative (e.g., widening lanes and improving the roadside).

After completion, the top portion (Step 2) of Form B describes one proposed project alternative along with a listing of conditions before and after treatment. This information is then readily available for use in the accident prediction nomograph and for determining accident reduction factors from tables, as described later. Step 2 is given on Form B as follows (in bold type):

Step 2: Complete the Following Information on the Proposed Improvement:

Road Name or Route I.D.________________________________

Milepoint Beginning:__________Ending:__________Length:______Miles

Alternative Number ____________ of ____________

Description of Alternative________________________________

____

____

____

Roadway Feature	Before Treatment	After Treatment
Lane Width		
Paved Shoulder Width		
Unpaved Shoulder Width		
Roadside Hazard Rating		
Avg. Roadside Recovery Distance		
Typical Sideslope		

Step 3 - Compute the Average Daily Traffic Over the Project Life (ADT_F)

The purpose of this step is to estimate the average traffic volume over the future project life. This is needed since traffic volumes at most sites will not stay constant over a 20-or 30-year period, and changes in traffic volume will have an effect on accidents. The assumed project service life depends on the type of project. For any project involving roadway widening, shoulder surfacing, and/or roadside improvement, the selected service life should correspond to such improvements (e.g., 20 years) even though the resurfacing may only last 4 to 8 years. A separate cost would be added in the benefit-cost analysis to include added costs for 2 or 3 additional resurfacing projects over the 20-year period.

To determine the average daily traffic volume over the future project life (ADT_F) based on the before ADT (ADT_B), the user must first estimate the yearly growth rate (g) for a given project service life using table 1. For example, assume that a lane and shoulder widening alternative is under consideration. The before ADT (ADT_B) on that roadway is 2,000 and is expected to increase at the rate of three percent per year for a 20-year project life. Using table 1, an adjustment factor (F_A) of 1.40 is selected. Thus, the average ADT to be assumed over the 20-year future project life (ADT_F) would be (2,000) x 1.4 = 2,800.

Step 3 is given on Form B as follows (in bold type):

Step 3: Compute the ADT Over the Project Life (ADT_F)

ADT before improvement = ______________ = ADT_B

Project service life = _______ years

Annual growth rate = g = _______ percent per year

Adjustment factor = __________ = F_A (from Table 1)

Future ADT = ADT_F = (ADT_B) x (F_A) = _______ x _______ = ______

Table 1. Adjustment factors (F_A) for determining average daily traffic volumes (ADT_F).

Annual Traffic Growth Rate (g)	Project Service Life in Years (n)					
	5	10	15	20	25	30
- 5%	0.89	0.80	0.73	0.68	0.64	0.61
- 3%	0.93	0.87	0.82	0.77	0.73	0.70
- 2%	0.95	0.91	0.87	0.83	0.80	0.77
0% (no change)	1.00	1.00	1.00	1.00	1.00	1.00
+ 2%	1.05	1.11	1.17	1.24	1.32	1.41
+ 3%	1.08	1.17	1.28	1.40	1.55	1.71
+ 5%	1.14	1.31	1.54	1.83	2.19	2.66
+ 7%	1.20	1.48	1.88	2.43	3.21	4.31
+ 8%	1.23	1.58	2.09	2.83	3.92	*
+10%	1.30	1.80	2.59	3.86	*	*
+12%	1.38	2.05	3.24	*	*	*

* Adjustment factors in these cells represent values higher than those likely to occur. In other words, high traffic growth rates (e.g., 8 to 12 percent are not likely to continue for 20 or more years.

Step 4 - Determine the Number of Related Accidents Per-Mile-Per-Year Without Improvement (A_{RU})

As discussed previously, the types of accidents found to be related to improvements to lanes, shoulders, and the roadside include:

- Single-vehicle accidents (i.e., run-off-road fixed object, run-off-road rollover, and other run-off-road accidents).
- Head-on accidents.
- Sideswipe-opposite direction accidents.
- Sideswipe-same direction accidents.

Thus, these are the only accident types to be considered in determining accident benefits from such roadway improvements.

The number of related accidents without the improvement may be determined from either step 4A or step 4B below, where:

- Step 4A should be used if reliable historical accident data is unavailable for three or more years (so the predictive nomograph is used).
- Step 4B should be used if historical accident data is available, and the user chooses to use this data instead of the accident predictive nomograph.

These two steps are discussed below.

Step 4A - The accident predictive nomograph may be used to estimate related future accidents. This method is necessary when the actual accident experience for a section is unknown, or if less than three years of accident data is known for the section.

To obtain the estimated number of related accidents without the improvement, the accident predictive nomograph in this step uses future ADT (ADT_F) but current (i.e., existing) roadway geometrics. Begin using the nomograph (appendix D) by entering the bottom left of the nomograph with the ADT_F (i.e., the future average daily traffic over the project period). Do not use the current ADT (i.e., ADT_B); use ADT_F instead. Proceed up to the appropriate curve for terrain (flat, rolling or mountainous). Draw a line horizontally over to the existing roadside hazard rating (1 through 7), and then up to the existing lane width (8 to 12 feet). Proceed left to the existing width of paved shoulder, and then up to the existing width of unpaved shoulder. At that point, proceed horizontally to the right and read the estimated number of related accidents per-mile-per-year without treatment. Then, multiply this value by section length, L, to yield untreated related accidents per year, A_{RU}.

Step 4A is given on Form B as follows (in bold type):

- **Step 4A: Accident Predictive Nomograph**

  Use future ADT = ADT_F with current (i.e., without improvement) values of lane width, paved shoulder width, unpaved shoulder width, roadside hazard rating, and terrain with the nomograph to determine related accidents per-mile-per-year without improvement.

  A_{RU} = __________ Related accidents per mile per year without improvement (from nomograph).

  A_{RU} x Section Length = _________ Related accidents per year.

Step 4B - If the user knows the number of "total" accidents on the section (A_{TB}) for three or more years before the improvement and/or the number of "related" accidents before improvement (A_{RB}), this step may be used. If only total accidents are known, but not the number of related accidents, figure 9 may be used based on the ADT_B (ADT before improvement) and terrain to determine an estimate of the ratio of related accidents to total accidents ($R_{R/T}$). For example, for an ADT_B of 3,500 on mountainous terrain, the user should enter the figure at the 3,500 ADT point. Then, proceeding up to the top curve (for mountainous conditions), and turning to the left, read the corresponding value at the left of the figure. In this example, a value of 64 percent ($R_{R/T}$ = 0.64) results.

Next, the user must convert the current (e.g., previous three years) number of related accidents to the number of future accidents in the untreated condition based on the future ADT. If ADT is expected to be unchanged in the future (i.e., a growth rate of zero percent), then this next adjustment is unnecessary. This adjustment factor for future condi-

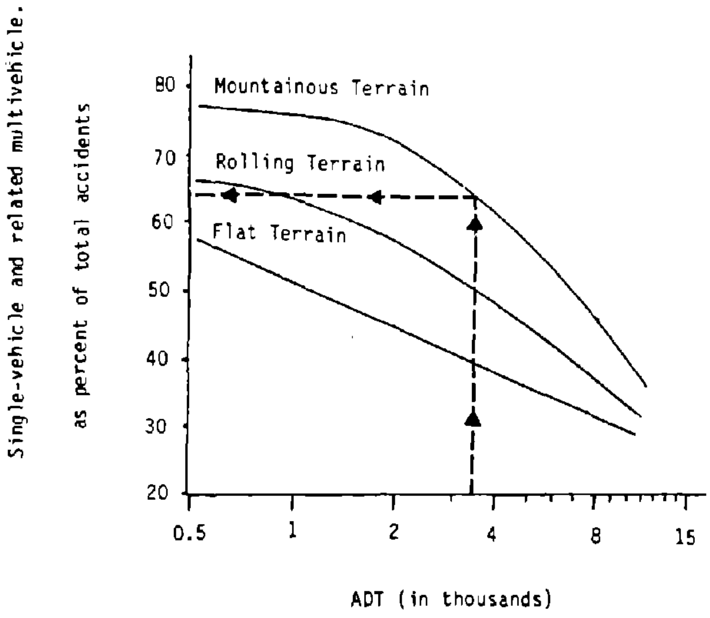


Figure 9. Proportion of single-vehicle and related multivehicle to total accidents on rural roads in relation to ADT and terrain.

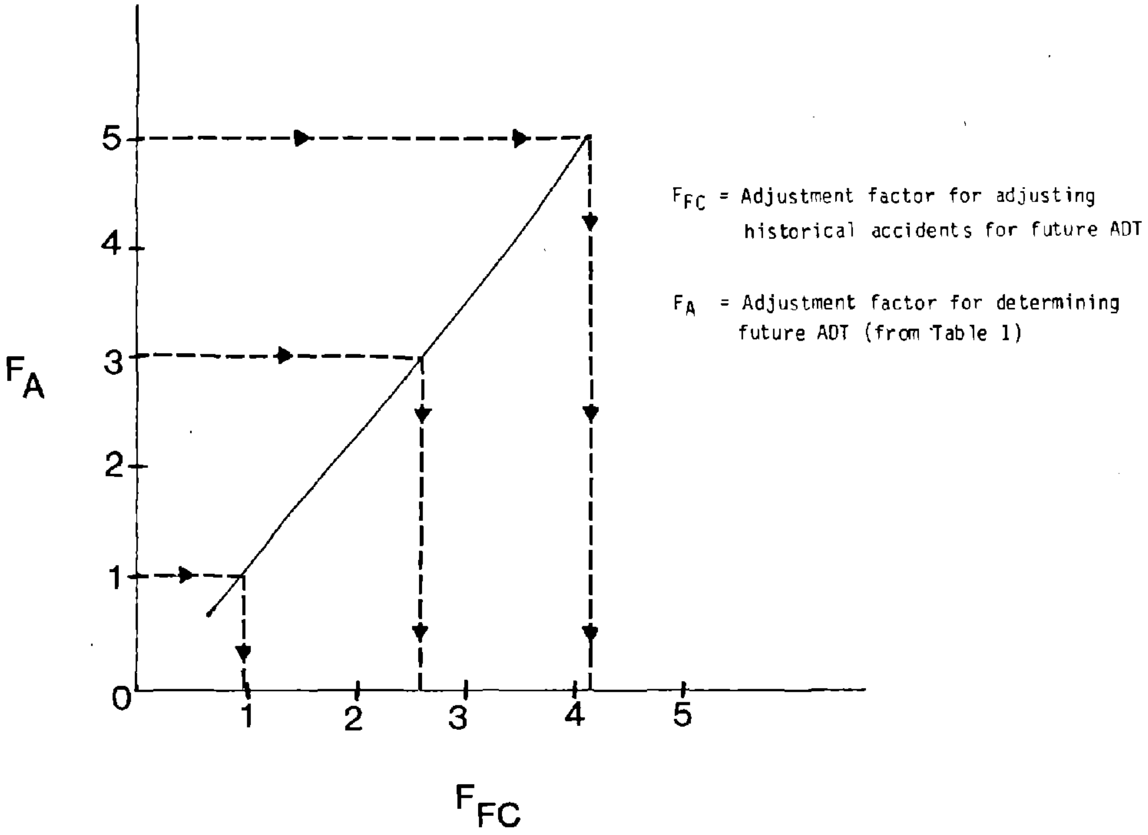


Figure 10. Adjustment factor to convert historical accidents to future accidents (F_{FC}).

tion, F_{FC}, is simply obtained from figure 10. By knowing F_A (the factor obtained from table 1 based on project life and traffic growth factor), simply enter figure 10 on the y-axis, with the appropriate F_A value and proceed to the right to the curve and down to the value of F_{FC}. For example, for a F_A value of 3.6, the $F_{FC} = 3.1$.

The number of future related accidents per year in the untreated condition (A_{RU}) may then be estimated by:

$$A_{RU} = (R_{R/T})(A_{TB})(F_{FC}) \qquad \text{(Equation 1)}$$

Where:

$R_{R/T}$ = the ratio of related to total accidents

A_{TB} = the total accidents per year on the section before improvement (= total accidents during the analysis period ÷ the number of years)

F_{FC} = factor obtained from figure 10.

Thus, assume 24 total accidents occurred on a 2.7 mile section over a three-year period with an ADT (i.e., ADT_B) of 3,500 in mountainous terrain. The proposed lane widening project is estimated to have a 20-year service life and a five percent annual traffic increase. In this example, $F_A = 1.83$ from table 1, A_T = (24 total accidents) ÷ (3 years) = 8 total accidents per year. The ratio of related to total accidents, $R_{R/T} = 0.64$ (from figure 9). The value of F_{FC} from figure 10 is 1.70 (using a F_A of 1.83). Thus, the number of future accidents in the untreated condition is computed as:

$$A_{RU} = (R_{R/T})(A_{TB})(F_{FC}) =$$

$A_{RU} = (0.64)(8)(1.70) = 8.7$ related future accidents per year (in the untreated condition)

If the historical number of <u>related</u> accidents in the before period (A_{RB}) on a section are known for at least three years, an adjustment must again be made for future ADT, so the equation for A_{RU} is:

$$A_{RU} = (A_{RB})(F_{FC}) \qquad \text{(Equation 2)}$$

Thus, in the last example, assume that 13 of the 24 total accidents during the three-year period on the section were related accidents. Then,

A_R = 13 accidents/3 years = 4.33 accidents/year

A_{RU} = (4.33)(1.70) = 7.4 related accidents per year (in the future untreated condition)

If historical data are used to determine A_{RU}, compare this value of A_{RU} with the value of related accidents from the nomograph. If the two values differ greatly, try to determine the reason (e.g., unusually dangerous section). If the actual accident experience fluctuates widely, it may have been due to an unusual occurrence in one year, such as an ice storm, a change in accident reporting levels, or other circumstances. If a large fluctuation in accident data is evident, or if only one or two years of accident data are available, then the number of related accidents generated from the nomograph will probably be more reliable and should be used. If the accident experience for a section is consistent but much lower than that predicted by the nomograph, this may be due to an unrealistically high reporting level (such as injury accidents only or tow-away accidents being used as a reporting threshold). If this is the case, then the nomograph value must be used, as determined in Step 4A.

Step 4B is given on Form B as follows (in bold type):

- **Step 4B: Convert Total Accidents to Related Accidents**

  A_{TB} = ________ Total accidents per-mile-per-year on the section before treatment

  $R_{R/T}$ = Ratio of related accidents to total accidents from figure 10 based on ADT_B and terrain.

  $R_{R/T}$ = ________ (factor less than 1.0)

  F_{FC} = ________ (from figure 10)

  A_{RU} = ($R_{R/T}$) x (A_{TB}) x (F_{FC}) = _____ x _____ x _____ = _____

  = number of related accidents per year in the untreated condition.

If historical related accidents (A_{RB}) are known, then
A_{RB} = ______, and

A_{RU} = (A_{RB}) x (F_{FC}) = ______ x ______ = ______

Step 5 - Determine the Accident Reduction Factor (R_A)

The expected percent reduction in related accidents which will result due to an improvement project is referred to as the accident reduction factor or the AR factor. Determining AR factors may be accomplished in one or more ways, depending on the type(s) of improvement, as follows (from Form B):

Roadway Improvement Type	Source of AR Factor
1. Lane widening only	Nomograph (use Step 5A) or table 2 (see Step 5B)
2. Shoulder widening only	Nomograph (use Step 5A) or table 3 (see Step 5B)
3. Shoulder resurfacing and/or changing both the lane and shoulder width	Nomograph (use Step 5A)
4. Improving roadside hazard rating	Nomograph (use Step 5A) or table 4 (see Step 5B)
5. Increasing roadside recovery distance	table 5 (see Step 5B)
6. Flattening sideslope only	table 6 (see Step 5B)
7. Any combination of improvements to lanes, shoulders, and/or roadside hazard	Nomograph (use Step 5A) or see Step 5C
8. Any combination of improvements to lanes, shoulders, and roadside recovery distance	See Step 5B plus Step 5C
9. Flattening sideslopes in conjunction with any improvements to lanes, shoulders, and/or roadside hazard	table 6 (see Step 5B) plus Step 5C

Note: Resurfacing is assumed to be included with each type of improvement.

The accident reduction factors presented in tables 2 through 6 were based on an accident predictive model developed from approximately 4,000 miles of two-lane rural roads in seven U.S. States. The model and accident reduction factors are the most reliable developed to date for two-lane rural roadways. However, the model was developed to best fit the total data base, and thus, the accident reduction factors actually experienced at a given site may vary from the expected value. Also, these accident reduction factors apply only to roadways with an ADT of between 50 and 10,000; lane widths of 8 to 12 feet; and shoulders of 0 to 12 feet which are paved or unpaved (or partly paved and partly unpaved). When considering various improvement alternatives, it is important to consider more than just one roadway element, so roadside improvements should be seriously considered in addition to lane and shoulder improvements. Accident reduction factors for lane and shoulder widening improvements assume that the sideslope is not made steeper from the project, since more rollover and other severe accidents may result from steepened sideslopes.

Table 2. Percentage of accident reduction of related accident types for lane widening only.

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

Table 3. Percentage of 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 4. Accident reduction factors due to reducing roadside hazard rating.

Reduction in Roadside Hazard Rating	Percent Reduction in Related Accident Types
1	19
2	34
3	47
4	52
5	65

Table 5. Accident reduction factors due to increasing roadside clear recovery distance.

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

Table 6. Summary of expected percentage reduction in related accident types 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	7	11	15	20
3:1	-	6	10	14	19
4:1	-	-	4	9	14
5:1	-	-	-	4	10
6:1	-	-	-	-	6

The corresponding steps for determining accident reduction factors (R_A) are discussed below.

Step 5A - This step is to be used for any combination of improvements involving lane widening, shoulder widening, shoulder surfacing, and/or roadside improvements (where the roadside hazard rating is used). Use the value of A_{RU} (untreated number of related accidents per year), as computed in Step 4 based on ADT_F (i.e., future ADT) and existing roadway geometrics. To find the expected future related accident experience (A_F), use the nomograph a second time with the same future traffic volume (ADT_F), and enter the proposed lane width, shoulder width, shoulder type, and roadside hazard rating which would exist with the countermeasure. Then multiply the related accidents/mile/year from the nomograph by the section length (L) to get the answer in terms of related accidents per year. The accident reduction factor (R_A) is computed as follows:

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}} \qquad \text{(Equation 3)}$$

Where:

A_{RU} = The number of related accidents per year in the untreated condition based on average traffic volumes (ADT_F) calculated from the nomograph (regardless if existing accident data are used).

A_{RT} = The number of related accidents per year in the treated condition based on future average traffic volumes (ADT_F) taken from the nomograph in appendix D. Note values of A_{RU} and A_{RT} should both be expressed the same in terms of either related accidents/year or accidents/mile/year.

The value of the accident reduction factor (R_A) must be between 0 and 1.0.

Step 5A is given on Form B as follows (in bold type):

- Step 5A: Use of Nomograph for Determining Accident Reduction Factor (R_A)

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}}$$

Where:

A_{RU} = Related accidents per-mile-per-year in untreated after condition (use ADT_F) from nomograph; A_{RU} = ________

A_{RT} = Related accidents per-mile-per-year in treated after condition (use ADT_F) from nomograph; A_{RT} = ________

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}} = \_\_\_\_\_\_\_\_$$

Step 5B - Use of AR factor tables - The use of tables may be appropriate for determining AR factors for the following types of improvements:

- Lane widening only: Use table 2. Thus, one foot of lane widening would be expected to reduce related accidents by 12 percent, two feet of lane widening would reduce related accident by 23 percent, and so on. Note that one foot of lane widening (e.g., from 10-foot to 11-foot lanes) corresponds to two feet of total widening for the two lanes.

- Shoulder widening only (with no change in shoulder type): Use table 3. For example, widening a two-foot paved shoulder to a six-foot paved shoulder (i.e., four feet of widening) would be expected to reduce related accidents by 29 percent. A similar widening project on an unpaved (e.g., gravel) shoulder would result in a 25 percent reduction in related accidents.

- Roadside improvements: AR factors may be determined from tables 4, 5, and/or 6 for various types of roadside improvements. For example, the AR factor due to reducing roadside hazard rating is shown in table 4. Table 4 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 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 (e.g., 7 to 2) would be expected to reduce related accidents by 65 percent.

AR factors are also given due to increasing the roadside clear recovery distance, as shown in table 5. An increase in recovery distance (measured from the outside edge of the shoulder) of five feet would be expected to reduce related accidents by 13 percent. Providing 20 feet of additional roadside recovery distance (e.g., from five 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 tables 4 and 5 above is determining what action is needed to increase the recovery distance. Examples of such treatments may include:

- Tree removal.
- Relocating utility poles.
- Flattening sideslopes and removing obstacles.
- Providing traversable drainage stuctures.

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 fixed objects.
- Providing breakaway bases to light poles and/or sign posts.

The expected reductions in related accidents due to sideslope flattening are given in table 6 for various sideslopes before and after improvement. For example, using table 6, 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 two percent, if flattened to 3:1; seven percent if flattened to 4:1; and 20 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 14 percent reduction in related accidents.

For roadway improvements where only one AR factor was needed (e.g., use only one AR factor table) go directly to Step 6. However, for improvements involving the selection of two or more AR factors (e.g., lane widening plus roadside improvements), then these AR factors cannot be added together. Instead use Step 5C to correctly determine the overall AR factor.

Step 5B is given on Form B as follows (in bold type):

- **Step 5B: Use of tables 2 through 6**
  - **Lane widening only (use table 2): R_A = ______**
  - **Shoulder widening only (use table 3): R_A ______**
  - **Roadside improvements (use tables 4, 5, and/or 6): R_A = ___**

Step 5C - Combine Individual AR Factors

This step is only necessary to determine the combined effect of two or more AR factors. This situation will occur when:

- Two or more of the AR factor tables are used.
- The nomograph is used (Step 4B) to compute the AR factor for changes to the lane, shoulder and/or roadside hazard.
- A sideslope improvement is considered to be a part of that same project (i.e., and table 6 must also be used).

Assume that a proposed improvement will involve widening an existing 10-foot lane to 12 feet (an AR factor of 23 percent from table 2) and also a reduction of roadside hazard from 5 to 3 (i.e., a 34 percent AR factor from table 5) due to tree removal. The combined effect of the AR factors of 23 and 34 must not be simply added. Instead, the overall accident reduction (R_A) may be computed as follows:

$R_A = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)$....(Equation 4)

Where:

AR_1 = the accident reduction factor from the first improvement (i.e., in this case 23 percent)

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

AR_3 = the accident reduction factor from the third improvement, etc.

$R_A = 1 - (1 - 0.23)(1 - 0.34) = 1 - (0.77)(0.66) = 1 - (0.51)$

$R_A = 0.49$, or a 49 percent reduction in related accidents.

The process can be repeated with numerous AR factors being combined, but the value of R_A will never exceed a 100 percent reduction in accidents. The combined accident reduction factor is then used in computing accident benefits in Step 6 below.

Step 5C is given on Form B as follows (in bold type):

- **Step 5C: Combine Individual AR Factors**

  Overall accident reduction (R_A) from more than one improvement

  $R_A = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)$......

Where:

AR_1, AR_2 and AR_3 are accident reduction factors for project 1, 2, and 3, etc., respectively

R_A = 1 (1 - _____)(1 - _____)(1 - _____) = _____

Step 6 - Compute the Estimated Number of Accidents Reduced (ΔA)

The net number of related accidents reduced per year (ΔA) is computed as follows:

$\Delta A = (A_B) \times (R_A) \times (L)$ (Equation 5)

Where:

A_B = The number of related accidents per-mile-per-year before treatment (from Step 4).

R_A = The accident reduction factor (from Step 5).

L = Section length in miles.

Thus, for an improvement with four related accidents per-mile-per-year over a five-mile section and an R_A of 30 percent, the $\Delta A = (4)(0.30)(5)$ = six accidents reduced per year.

Step 6 is given on Form B as follows (in bold type):

Step 6: Compute the Estimated Number of Accidents Reduced (ΔA)

The net number of related accidents reduced per year is computed as follows:

$$\Delta A = (A_B) \times (R_A) \times (L)$$

Where:

A_B = Number of related accidents per-mile-per-year before improvement (from Step 4)

R_A = Accident reduction factor (from Step 5)

L = Section length (in miles)

ΔA = ______ x ______ x ______ = ______ accidents reduced per year

Step 7 - Determine the Average Cost per Related Accident (C_A)

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 cost estimates include: (1) recently completed FHWA study using willingness-to-pay concepts; (2) States' costs; (3) National Safety Council (NSC) costs; (4) National Highway Traffic Safety Administration (NHTSA) costs; (5) cost values developed by Miller et al. based on 1980 NHTSA costs; and (6) costs by Hartunian et al. Details of these cost values are given in appendix B.

The average cost per accident can be computed based on unit accident costs along with the percentage of accidents by severity for related accidents. As found in the FHWA research study mentioned previously, "related" accident types consisted of:

Property Damage Only (PDO) Accidents = 57.1 percent
Injury Accidents = 39.6 percent
Fatal Accidents = 3.3 percent
Total = 100.0 percent

Further, it was found that 1.63 persons were injured per injury accident and 1.22 persons were killed per fatal accident, and there were approximately 1.5 vehicles involved per accident (i.e., about half of the accidents were single-vehicle). The cost per accident may be determined as follows:

$$\begin{aligned} C_A = {} & (\text{percent PDO accidents})(\text{cost/PDO accident}) \qquad (\text{Equation 6}) \\ & +(\text{percent injury accidents})(\text{cost/injury})(\text{injuries/injury accident}) \\ & +(\text{percent fatal accidents})(\text{cost/fatality})(\text{fatalities/fatal accident}) \end{aligned}$$

Assume, for example, costs from a recent FHWA report (at \$1,000 per vehicle involved in a PDO accident or 1.5 x \$1,000 = \$1,500 per PDO accident; \$7,000 per person injured, and \$1,200,000 per person killed), C_A would be computed as:

$$= (0.571)(\$1{,}500)+(0.396)(\$7{,}000)(1.63)+(0.033)(\$1{,}200{,}000)(1.22)$$

$$= \$53{,}687 = \text{approximately } \$53{,}700 \text{ per related accident}$$

This is only an example of how C_A may be determined, and the users should select the base accident costs which they believe to be most appropriate.

Step 7 is given on Form B as follows (in bold type):

Step 7: Determine the Average Cost per Related Accident (C_A)

C_A = ________ (use \$53,700, if unknown)

Step 8 - Compute Expected Accident Benefits (B_A) Due to a Reduction in Accidents)

Accident benefits (B_A) due to a net reduction in accidents are calculated on a yearly basis, computed based the net accident reduction (ΔA) and the average cost of an accident (C_A), or

$$B_A = (\Delta A) \times (C_A) \qquad \text{(Equation 7)}$$

Thus, a roadway improvement which would reduce 1.8 related accidents per year at a cost of $53,700 per accident would yield an annual benefit of $96,660.

Step 8 is given on Form B as follows (in bold type):

Step 8: Compute Annual Accident Benefits (B_A)

$B_A = (\Delta A) \times (C_A) =$ ______ x ______ = ______

Where:

B_A = Accident benefits per year based on the net reduction in accident occurrences

A = Net reduction in accidents (see Step 6)

C_A = Average cost of a related accident (see Step 7)

CHAPTER 5 – DETERMINING THE COSTS OF CROSS-SECTION IMPROVEMENTS

This chapter focuses on the direct costs to a highway agency for implementing cross-section improvements on 3R-type projects. Because of the variability in maintenance costs, no attempt was made to estimate these costs for this study. Implementation costs are presented in this chapter for several common 3R-type projects for general guidance purposes only. Each agency should draw upon its own data and expertise to obtain implementation cost estimates. This is because the example costs given in this chapter are based on data from 10 States and may not reflect the differences in construction practices, material sources, wage rates, climate and other factors which cause costs to vary widely from agency to agency. In like fashion, an agency may have readily available maintenance and cost data which can be added to the implementation costs shown here.

General Comments Concerning Cost Data Developments

In 3R-type projects resurfacing is almost always included. In addition to pavement resurfacing, other roadway improvements which may be a part of 3R-type projects include:

- Lane widening.
- Shoulder widening and/or resurfacing.
- Sideslope flattening.
- Roadside improvements (including guardrail installation).

Sideslope flattening and roadside improvements are the primary types of projects which (along with shoulder widening) affect the roadside hazard rating.

The cost estimates that follow were produced using a procedure similar to preparing an engineer's estimate for a construction project (i.e., assume current and future conditions; estimate necessary work items, quantities, and unit costs; multiply the quantity by the unit cost for each work item; and sum the costs of the work items). The assumptions and estimates made during the procedure may be altered by an agency to more accurately determine an individualized project cost estimate. More detail on the assumptions is available in an appendix to the research report.[4]

The variances in implementation costs are presented in terms of high, median (i.e., middle, or 50th percentile), and low 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 type and length.
- Terrain.
- Weather.
- Traffic.
- Rural or urban area.
- Type of contracting agency (i.e., construction or maintenance).
- Prevailing labor rates.
- Availability of materials.

The direct use of the high or low cost estimates is rarely a good idea for lane widening, shoulder widening and/or surfacing, 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 work item for a particular project, however. The high and low cost estimates for those types of projects should 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 improvements is more permissible because those projects could consist of only one line item of work.

Roadside Improvement Costs

The estimated costs of some common roadside improvements are presented in table 7 and include improvements involving trees, signs, luminaires, mailboxes, fire hydrants, impact attentuators, guardrail, and fences. On a per unit basis, mitigating these hazards can be relatively inexpensive. However, the high and low costs for particular improvements vary widely.

Other roadside improvements that are often used are retrofitting signs and luminaires with breakaway devices. However, the costs also tend to vary widely among projects, and the user is advised to follow agency procedure in determining these costs.

Relocating utility poles or burying utility lines underground are other typical roadside improvement. Because types of poles and lines vary so widely, the costs for these improvements are shown separately in tables 8 and 9.

Sideslope Flattening Costs

The estimated costs of flattening several common types of sideslopes are given in table 10. The rows of the table show the before condition, and the costs refer to obtaining an after-improvement condition of at least a 4:1 or greater ratio sideslope for approximately 15 feet with a height of fill of 4 feet and a 3:1 ratio backslope. For example, the median (i.e., 50th percentile) 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 (from edge of shoulder to the original ground at the toe of the fill slope or to the bottom of the ditch). As shown in table 10, 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 (excavation, borrow, waste) involved. It should be mentioned that for many projects, it is not practical to provide sideslope flattening to a 4:1 ratio. In such cases, other improvements may be made such as the

Table 7. Roadside improvement costs.

Action	Object	Unit	Unit Costs (1985 $)		
			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

Table 8. Summary of costs for relocating utility poles.

Type of Utility Poles or Lines	Range of Installation Costs (Dollars per Pole)		Average Installation Cost (Dollars per Pole)	
	Rural	Urban	Rural	Urban
Wood Telephone Poles	$160-$600	$160-$754	$345	$425
Wood Power Poles Carrying <69 KV Lines	$150-$4,000	$150-$4,000	$1,270	$1,440
Non-Wood Poles (Metal, Concrete or Other)	$630-$3,250	$630-$3,370	$1,740	$1,810
Heavy Wood Distribution and Wood Transmission Poles	$580-$5,500	$500-$7,100	$2,270	$2,940
Steel Transmission Poles	$10,000-$30,000	$20,000-$40,000	$20,000	$30,000

Based on information from 31 utility companies in 20 States throughout the U.S. (1982).

[Source: Zegeer, C.V. and Parker, M.R., "Cost-Effectiveness of Countermeasures for Utility Pole Accidents," January 1983.][6]

Table 9. Summary of costs for undergrounding utility lines.

Type of Utility Line	Range of Installation Costs (Dollars per Mile)		Average Installation Cost (Dollars per Mile)	
	Rural	Urban	Rural	Urban
Telephone Lines	$4,450-$30,817	$10,500-$85,000	$18,000	$36,000
Electric Distribution Lines <69 KV, Direct Bury, One Phase	$17,000-$29,000	$30,000-$45,000	$24,000	$38,000
Electric Distribution Lines <69 KV, Direct Bury, Three Phase	$29,000-$220,000	$45,000-$225,000	$105,000	$161,000
Electric Distribution Lines <69 KV, Conduit	$200,000-$650,000	$400,000-$1,050,000	$430,000	$650,000
Electric Distribution Lines ≥69 KV	$728,000-$1,728,000	$728,000-$1,728,000	$1,228,000	$1,228,000

Based on information from 31 utility companies in 20 States throughout the U.S. (1982).

[Source: Zegeer, C.V. and Parker, M.R., "Cost-Effectiveness of Countermeasures for Utility Pole Accidents," January 1983.][6]

Table 10. Estimated costs for flattening sideslopes to 4:1 (both sides of road).[2]

Before Sideslope Condition		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
1.5:1	7	560	148	57
2:1	5	279	88	35
3:1	3	190	70	28

*-Vertical distance from edge of shoulder to the original ground at the toe of the fill slope or to the bottom of ditch.

installation of guardrail. (See the AASHTO publication "Guide for Selecting, Locating, and Designing Traffic Barriers" for guidelines on the use of guardrail.[5]) 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 to pave one foot of gravel or earth shoulder on each side of the road in 1985 dollars is $27,200 per mile for the high cost category, $12,000 per mile for the median cost category and $6,800 per mile for the low cost category. Thus, it would cost 6 x $12,000 = $72,000 per mile to pave six-foot shoulders assuming median costs.

Lane and Shoulder Widening Costs

For 3R-type lane and shoulder widening projects, the major cost improvements are for the increased width of the lanes and shoulders, along with the costs associated with altering the side and back slopes. These may be expressed in the following equation:

$$CT = M\,[(WL)(CL) + (WS)(CS) + E] \qquad \text{(Equation 8)}$$

Where:

CT = 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);

WL = the number of feet added to each lane;

CL = cost of widening each lane by one foot from table 11 in 1985 dollars;

WS = the number of feet added to each shoulder;

CS = cost of widening each shoulder by one foot from table 11 in 1985 dollars; and

E = cost of altering the side and back slopes from table 12 in 1985 dollars.

Table 11. Costs of adding one foot to each lane or one foot to each shoulder (i.e., both directions).[2]

Shoulder Type	Cost Category	1985 Lane Widening Cost ($1,000/mile), CL	1985 Shoulder Widening Cost ($1,000/mile), CS
Gravel	High	58.2	21.8
	Median	24.8	8.2
	Low	13.8	3.6
Paved	High	61.6	25.0
	Median	27.8	11.0
	Low	16.4	6.4

Table 12. Cost of slopework portion of widening project.[2]

Total Width Added to Each Side (WL + WS) in Feet	Sideslope[1]		1985 Costs ($1,000/Mile), E		
	Ratio Before Imp.	Height of Fill (ft.)[2]	High	Median	Low
2	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
4	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
8	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

[1] The procedure assumes that slope work results in sideslopes of 4:1 or flatter; simple "vee" ditches where the sideslope and backslope intersect; and backslopes of 3:1.

[2] Vertical distance from edge of shoulder to the original ground at the toe of the fill slope or to the bottom of ditch.

Tables 11 and 12 reflect widely varying State estimates and thus include high, median, and low cost categories. For gravel or paved shoulders, Equation 8 and tables 11 and 12 are applicable where: $WL \geq 0$, and $10 \geq (WL + WS) \geq 0$. It was assumed that the cost of altering the side and back slopes, E, included the cost to flatten a deficient sideslope to a four to one ratio as well as the cost to provide room for the widened roadway.

The following example will illustrate the use of the equation and tables:

Before Condition: 10-foot lanes, 2-foot gravel shoulders, 4:1 sideslope ratio, and 5-foot height of fill for a 6-mile section of roadway.

After Condition: 12-foot lanes, 4-foot gravel shoulders, 4:1 sideslope ratio, and 5-foot height of fill for the same 6-mile section.

Step 1 - Compute the lane and shoulder width changes.

WL = 2, the widening from 10-foot to 12-foot lanes
WS = 2, the widening from 2-foot to 4-foot shoulders

Step 2 - Compute the net width change.

$WL + WS = 2 + 2 = 4$ feet

Step 3 - Select the lane and shoulder widening costs, CL and CS, from table 11.

Assume median costs with gravel shoulders. The cost to add each foot to each lane (both directions) in 1985 dollars is $24,800. The cost to add each foot to each gravel shoulder (both directions) in 1985 dollars is $8,200.

Step 4 - Determine the slopework costs, E, from table 12.

Since WL + WS = 4, enter the table here. For a 4:1 sideslope and 5-foot height of fill, median costs for E are $80,000 per mile for adding 4 feet to each side (both directions).

Step 5 - Compute the project cost per mile, CT.

$$\begin{aligned} CT &= 1.095\ [(WL)(CL) + (WS)(CS) + E] \\ &= 1.095\ [(2)(\$24,800) + (2)(\$8,200) + \$80,000] \\ &= \$159,870 \text{ or } \$160,000 \text{ per mile} \end{aligned}$$

Step 6 - Compute the total project cost.

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

Step 7 - Compute annualized cost = C_A = total project cost x Capita Recovery factor (see table 13 for values of CRF).

For a 20-year project life and a 10 percent interest rate, the CRF = 0.117. Thus C_A = $960,000 x 0.117 = $112,320.

A work sheet for the calculation of lane and shoulder widening costs (Form C) is provided in figure 11.

For any projects involving roadway widening, shoulder surfacing, and/or roadway improvements, service lives of 15 to 25 years may be considered appropriate. However, the pavement overlay may last only 4 to 8 years, and pavement resurfacing may be needed several more times over the 15 to 25-year project life. Thus, a user may estimate the additional costs from future resurfacing projects, annualize them over the entire project period, and add these additional annual costs to the annualized cost, C_A. However, such future maintenance costs would be needed even if no cross-section improvements had been made, so the net change in annual maintenance costs due to the project may be assumed to be negligible.

A few caveats are in order for this procedure. First, in table 11, the difference in costs per mile for paved versus gravel shoulders is small. This reflects an assumption of removing 3 inches from the top of the existing shoulder and adding a 3-inch asphalt overlay, with no further sub-base development. Second, in table 12, the procedure for calculating the slopework costs assumes that the before and after sideslopes are similar. Third, net width change must be used in table 12, so that if the lanes are widened 3 feet and the shoulders are narrowed 1 foot, then the net width change is WL + WS = 3 + (-1) = 2 for entry into table 12. Finally, improvement costs like these vary so much among States that the user is advised to adopt the cost calculation strategy routinely used by his or her agency.

Table 13. Factors for annual compounding of interest.

Interest Rate (Percent)	Service Life (Years)	Capital Recovery Factor, CR	Sinking Fund Factor, SF
4	1	1.0400	1.0000
	2	0.5302	0.4902
	3	0.3604	0.3204
	4	0.2755	0.2355
	5	0.2246	0.1846
	10	0.1233	0.0833
	15	0.0899	0.0499
	20	0.0736	0.0336
	25	0.0640	0.0240
6	1	1.0600	1.0000
	2	0.5454	0.4854
	3	0.3741	0.3141
	4	0.2886	0.2286
	5	0.2374	0.1774
	10	0.1359	0.0759
	15	0.1030	0.0430
	20	0.0872	0.0272
	25	0.0782	0.0182
8	1	1.0800	1.0000
	2	0.5608	0.4808
	3	0.3880	0.3080
	4	0.3019	0.2219
	5	0.2505	0.1705
	10	0.1490	0.0690
	15	0.1168	0.0368
	20	0.1018	0.0218
	25	0.0937	0.0137
10	1	1.1000	1.0000
	2	0.5762	0.4762
	3	0.4021	0.3021
	4	0.3155	0.2155
	5	0.2638	0.1638
	10	0.1628	0.0628
	15	0.1315	0.0315
	20	0.1175	0.0175
	25	0.1102	0.0102
12	1	1.1200	1.0000
	2	0.5917	0.4717
	3	0.4163	0.2963
	4	0.3292	0.2092
	5	0.2774	0.1574
	10	0.1770	0.0570
	15	0.1468	0.0268
	20	0.1339	0.0139
	25	0.1275	0.0075

Source: [7]

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM C - WORKSHEET FOR CALCULATION OF LANE AND SHOULDER WIDENING COSTS

Before Condition: ____________________

____

____

After Condition: ____________________

____

____

Step 1 - Compute the lane and shoulder width changes.

WL = ___ . the change in lane width

WS = ___ . the change in shoulder width

Step 2 - Compute the net width change.

WL + WS = ___ + ___ = ___

Step 3 - Select the lane and shoulder widening costs from table 11.

Assume high, median, or low costs. Select shoulder type. Obtain values from table 11.

CL = _________ (both directions)

CS = _________ (both directions)

Step 4 - Determine the slopework costs from table 12.

From Step 2, use the sum of WL + WS = ___ to enter table 12. Pick the appropriate sideslope and height of fill to yield the slopework costs, E = ____ (choose high, median, or low costs).

Step 5 - Compute the project cost per mile.

$CT = 1.095\ [(WL)(CL) + (WS)(CS) + E]$

$= 1.095\ [(\_\_)(\_\_\_\_\_\_\_\_\_) + (\_\_\_\_\_\_)(\_\_\_\_\_\_\_) + \_\_\_\_\_\_\_]$

= _____________

Step 6 - Compute the total project cost.

Multiply CT from Step 5 times the length of the section in miles.

C_I = Total cost = CT x _____ miles

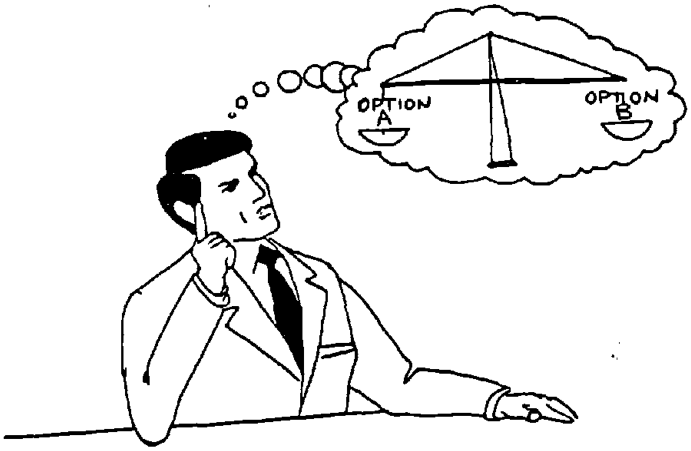
= _________

Step 7 = Compute annualized cost = $C_A = C_I$ x CRF = __________ x ______

= $_________/year

Figure 11. Worksheet for calculation of lane and shoulder widening costs (Form C).

CHAPTER 6 - ECONOMIC ANALYSIS PROCEDURES FOR DETERMINING PROJECT COST-EFFECTIVENESS



This chapter allows the user to either compare the economic consequences of two or more project alternatives at a location or to compare project alternatives at two or more locations. Several economic inputs are needed to conduct the cost-effectiveness analysis, including:

- Project Service Life: For each improvement under consideration, service life must be estimated for use in computing accident benefits. A service life of 20 years is often regarded as a reasonable assumption for most types of lane and shoulder improvements, while service lives of 10 to 15 years are commonly used for many types of roadside improvements.

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

- Interest Rate: The interest rate of money is an important input in the cost-effectiveness procedure. A different interest rate can affect the selection of a particular improvement alternative in many cases. Interest rates used by agencies vary widely. The user should select an interest rate that reflects the policy of the particular agency, although interest rates of 4 to 12 percent are commonly used.

Numerous economic analysis methods are available for use in selecting project alternatives, including simple benefit-to-cost ratio, incremental benefit-to-cost ratio, net benefit, rate of return method, time of return method, and others. Some of the examples and information in this chapter were taken from a previous users' manual on utility pole accidents.[8] Agencies should use their own prefered method(s) for conducting economic analysis. For purposes of illustration in this Informational Guide, however, the benefit-to-cost ratio and the incremental benefit-to-cost ratio methods are illustrated in the following steps:

Step 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the Benefit-to-Cost Ratio (B/C)

The B/C ratio for the project is the total benefits divided by the total project costs as follows:

$$B/C = \frac{B_T}{C_T}$$

Where:

B/C = The benefit-to-cost ratio for the improvement.

B_T = The total accident benefits per year.

C_T = The total countermeasure costs per year.

The B/C ratio should be computed separately for each project alternative on figure 12 (Form D) for up to 4 project alternatives per location. The benefits and costs, may both be expressed on a per year basis or both on a present worth basis (with the same B/C ratio).

Of these economic measures, any one of them are appropriate for determining the economic feasibility of a given project (i.e., the B/C ratio is 2.3, the net benefit is $120,000, the rate of return is 22 percent per year, etc.). However, when comparing between two or more alternatives, the simple ranking of projects often does not give the best economic results. For example, at a highway section, four options being considered as part of a 3R project, are: Option A - sideslope flattening; Option B -

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM D - COMPARISON OF PROJECT ALTERNATIVES

(Use This Form Only if 2 or More Project Alternatives are
Being Considered at the Same Location)

STEP 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the B/C Ratio

Complete Columns A, B, C, and D below

	Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H
Rank	Improvement Number	Total Annual Cost (C_T)	Total Annual Benefits (B_T)	B/C Ratio	Compare	Incremental Change in Costs (ΔC)	Incremental Change in Benefits (ΔB)	Incremental Benefit/Cost Ratio $\Delta B/\Delta C$
Lowest Cost (CT)								
2nd Lowest Cost								
3rd Lowest Cost								
4th Lowest Cost								
Highest Cost								

STEP 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$)

Complete Columns E, F, G, and H above

STEP 3 - Evaluate Available Funding and Other Agency Constraints

Select the remaining improvement with the highest incremental benefits to highest incremental costs.

Improvement No. and Description:____________________

Improvement Cost: $____________ per year

Is funding available to complete project (Yes or No)________

Do any other agency constraints prohibit implementation (Yes or No)
____

If Yes, Describe:______________________________

Figure 12. Worksheet for comparison of project alternatives (Form D).

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM D - COMPARISON OF PROJECT ALTERNATIVES (CONTINUED)

If the improvement with the best incremental benefit-cost ratio is unacceptable for other reasons, select the improvement with the next highest incremental benefits to incremental costs.

Improvement No. and Description:______________________________

Improvement Cost: $_________________ per year

STEP 4 - Record Project Details

Selected Improvement:____

Project Cost: $_________________ per year

Total Project Cost: $_________________

Change in Annual Maintenance Costs: $_________________

Annual Accident Benefits: $_________________

Related Accidents Reduced per Year:_________________

B/C Ratio = _____________

Figure 12. Worksheet for comparison of project alternatives (Form D)(continued).

lane and shoulder widening; Option C - shoulder surfacing; and Option D - lane and shoulder widening plus roadside obstacle removal. Consider the benefits and costs of each option:

Option	Annual Costs	Annual Benefits	B/C Ratio
C	80,000	88,000	1.10
A	100,000	125,000	1.25
B	150,000	170,000	1.13
D	200,000	230,000	1.15

In this example, the priority of alternatives based on the simple benefit-to-cost ratio method would be A, D, B and C. It should be noted that a priority ranking based on the simple B/C ratio will usually result in selecting the lower-cost options, while the simple net benefit method usually results in selecting the higher cost options. However, as mentioned previously simple ranking of projects is not considered appropriate. The most economically desirable solutions can be found using the incremental benefit-cost ratio method, as discussed below.

Step 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis (ΔB/ΔC)

The incremental benefit-to-cost ratio method can be used to determine whether extra increments of cost (e.g., a lane and shoulder widening project versus a lane widening project only) are justified for a particular location or for considering improvements at two or more locations. The method assumes that the relative merit of a project is measured by its change in benefits and costs, compared to the next lower-cost alternative.

The steps for using the incremental benefit-to-cost ratio method are given below, as discussed in the "Highway Safety Improvement Program" manual:[7]

1. Determine the benefits, costs and the benefit-to-cost ratio for each improvement.

2. List of improvements with a B/C ratio greater than 1 (or some other minimum value) in order of increasing cost.
3. Calculate the incremental B/C ratio of the second lowest-cost improvement compared to the first.
4. Continue in order of increasing costs, to calculate the incremental B/C ratio for each improvement compared to the next lower cost improvement.
5. Stop when the incremental B/C ratio is less than 1.0.

To illustrate the use of this method, consider the example given previously (with options ordered from lowest to highest cost):

Option	Annual Costs	Annual Benefits	B/C Ratio	Comparison of Options	Δ Benefits	Δ Costs	Δ B/Δ C
C	80,000	88,000	1.10				
				C and A	37,000	20,000	1.85
A	100,000	125,000	1.25				
				A and B	45,000	50,000	0.90
B	150,000	170,000	1.13				
				A and D	105,000	100,000	1.05
D	200,000	230,000	1.15				

From this example, Option A is preferred to Option C (Δ B/Δ C = 1.85), and Option C would be excluded from consideration. Option A is also preferred to Option B (Δ B/Δ C = 0.90), since spending an additional $50,000 for Option B would yield only $45,000 of additional benefits. Then a comparison of Option A with Option D will result in an incremental cost increase of $200,000 - $100,000 = $100,000, and an increase in benefits of $230,000 - $125,000 = $105,000. Thus, the Δ B/Δ C = 1.05, so Option D (lane and shoulder widening plus roadside obstacle removal) is the optimal solution based on incremental benefits and costs. This solution would, of course, be subject to funding availability, political considerations, environmental constraints, etc.

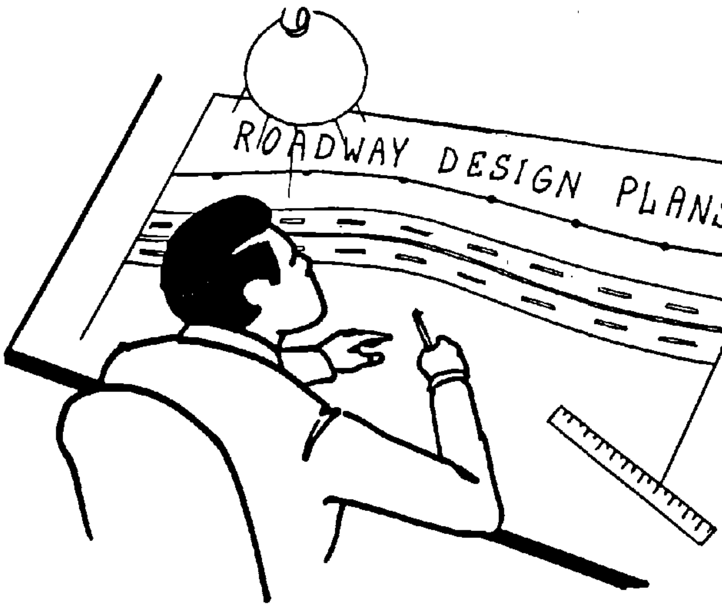
Step 3 - Evaluate Available Funding and Other Agency Constraints

This step involves summarizing critical details for the selected project alternative, such as:

- The improvement cost.
- Whether sufficient funding is available to complete the project.
- A listing of other constraints (environmental considerations, effect on highway capacity, need for additional right-of-way, etc.) which could affect the practical implementation of the project.

Step 4 - Record Project Details

The project details of the selected countermeasure should be documented for future reference on Form D, such as project planning and implementation and for conducting cost-effectiveness evaluations at other sites. Copies of the blank worksheets are given in appendix C.



CHAPTER 7 - CASE STUDY

The following is a discussion of the steps needed to compute expected accident benefits and project costs for a proposed improvement project. Following the discussion, Forms A, B, C, and D are filled out for this same example.

Existing Conditions

6.2 mile two-lane rural highway section
Mountainous area
ADT = 500
Roadside hazard rating = 6
Sideslope = 2:1 (height of fill = 5 feet)
Lane width = 9 feet
Two-foot earth shoulders on each side of road
Accident data = unknown

Proposed Alternative:

In addition to a pavement overlay, consideration is being given to widening the lanes to 11 feet and adding a two-foot paved shoulder. Assume 20-year project life.

After Conditions:

ADT increases at 3 percent per year
Lane width = 11 feet
Two-foot paved shoulders
Other conditions unchanged

Computing Accident Benefits

Steps 1 and 2: Complete the Site and Improvement Description Information

Step 3: Compute the ADT Over the Project Life

Assuming 3 percent traffic growth per year over 20 years, an adjustment factor (F_A) of 1.40 is obtained from table 1.

Future ADT = $ADT_A = (ADT_C)(F_A) = (500)(1.40) = 700$

Step 4: Determine Related Accidents per-Mile-per-Year Without Treatment

Since actual accidents are unknown on the section, use the nomograph with ($ADT_A = 700$), nine-foot lane width, two-foot unpaved shoulder, roadside hazard rating of 6, and mountainous terrain. Related accidents/ mile/ year = 0.8.

Step 5: Determine the Accident Reduction Factor

Lane width and shoulder type will both be altered (i.e., lane width will increase from 9 to 11, while shoulder will be changed from two-foot unpaved to two-foot paved after treatment). Thus, use the nomograph to determine the related accidents in the untreated condition (A_{RU}) and the treated condition (A_{RT}), using ADT_F (future ADT) in both cases. Use accidents per-mile-per-year from the nomograph. The user need not multiply both A_{RU} and A_{RT} by section length for computing R_A, since the answer would be the same (values of L in the numerator and denominator would be cancelled out).

From the nomograph: $A_{RU} = 0.8$; $A_{RT} = 0.6$

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}} = \frac{0.8 - 0.6}{0.8} = \frac{0.2}{0.8} = 0.25$$

Thus, the countermeasure should be expected to reduce related accidents by 25 percent.

Step 6: Compute the Estimated Number of Accidents Reduced (ΔA) per year.

$\Delta A = (A_B) \times (R_A) \times (L)$ = (0.8 accidents/mile/year)(0.25)(6.2 miles)
= 1.24 related accidents reduced per year

Step 7: Determine the Average Cost per Related Accidents (C_A).

In this case, a cost of $53,700 is considered appropriate.

Step 8: Compute the Expected Annual Accident Benefits (B_A)

$B_A = (\Delta A) \times (C_A)$ = (1.24)($53,700) = $66,600 in accident benefits per year (rounded to the nearest $100)

Computing Project Costs

Step 1: Compute the Lane and Shoulder Width Changes

WL = 2, the widening from 9 to 11-foot lanes

WS = 0, since shoulder width was unchanged (i.e., from 2 feet, unpaved to 2 feet, paved)

Step 2: Compute the Net Width Change

WL + WS = 2 + 0 = 2 feet

Step 3: Select the Lane and Shoulder Widening Costs CL and CS from table 11

Assume median costs, the cost to add one foot to each lane (both directions) in 1985 dollars is $24,800.

Step 4: Determine the Slopework Costs, E, from table 12

Since WL + WS = 2, enter the table with a 2 in the first column with a 2:1 sideslope and 5-foot height of fill. This corresponds to a median cost of $91,000 per mile.

Step 5: Compute the Project Cost per Mile, CT

CT = 1.095 [(WL)(CL) + (WS)(CS) + E]
= 1.095 [(2)($24,000) + (0)($8,200) + $91,000]
= 1.095 [$49,600 + $91,000)
= $154,000 per mile (rounded to the nearest $1,000)

Step 6: Compute the Total Project Cost

$154,000 per mile x 6.2 miles = $954,800

Step 7: Compute Annualized Cost = C_A = Total Project Cost x Capital Recovery Factor

For a 20-year project life and a 10-percent interest rate, the CRF = 0.117. Thus,

C_A = ($954,800) x (0.117) = $111,700 per year

The expected benefit to cost ratio of the project would be:

$$B/C = \frac{\$66,600}{\$111,700} = 0.60$$

Thus, the B/C ratio is less than 1.0, which is often the case for costly improvements on sections with low traffic volumes.

The transportation agency must then decide whether to implement a project based on its expected benefit/cost ratio and also on other factors (e.g., available budget, other projects being considered, environmental considerations). A benefit-cost ratio of 1.0 should <u>not</u> be considered as a magic number in deciding whether to implement a project. Instead, the expected accident benefits and project costs of each project relative to other roadway improvements should be one of several important considerations in selecting projects to be implemented. A benefit/cost ratio of 0.60 may be among the most favorable for some highway agencies, while such a value may be far down on the priority list for other agencies.

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM A - SITE DESCRIPTION

1. Road Name or Route Identification: Case Study

2. Milepoint Beginning: 0.00 Ending: 6.20 Length: 6.2 (Miles)

3. Area Type (Check): [✓ Rural]

_____ Urban (If urban, procedures in this manual do not apply.)

4. Terrain Condition (Check One):

_____ Flat _____ Rolling [✓ Mountainous]

5. Present Average Daily Traffic (ADT_B): 500

6. Expected Annual Traffic Growth Rate = g = 3%

7. Lane Width: 9 Feet

8. Paved Shoulder Width: 0 Feet

9. Unpaved Shoulder (e.g., [✓ Dirt], Gravel, Turf, Stabilized)
Width = 2 Feet

10. Typical Sideslope (Check One):

[✓ 2:1, or steeper], ___ 3:1, ___ 4:1, ___ 5:1, ___ 6:1, ___ 7:1 or flatter

11. Median Value of Roadside Hazard Rating (Check One):

_____ 1; _____ 2; _____ 3; _____ 4; _____ 5; [✓ 6]; _____ 7

12. Average Roadside Recovery Distance = Unk. Feet (Optional)

13. Reliable Accident Data for the Section (Check One):

_____ Available [✓ Unavailable]

Note: If reliable accident data are unavailable, skip lines 15-17, and use accident prediction nomograph for estimating accident experience on the section.

NA

~~14. Total Accidents = _____ for _____ years~~

~~15. Total Accidents per Year =~~ $\frac{\text{Number of Total Accidents}}{\text{(Years of Data)}}$ =

A_{TB} = _____ ~~Total Accidents per Year Before Improvement~~

~~16. Number of Related Accidents by Type for _____ Years:~~

~~Single Vehicle (Run-Off-Road) = _____, or _____ Per Year~~

~~Head-On = _____, or _____ Per Year~~

~~Opposite Direction Sideswipe = _____, or _____ Per Year~~

~~Same Direction Sideswipe = _____, or _____ Per Year~~

~~Sum of Related Accidents =~~ A_{RB} ~~Before Improvement _____, or _____ Per Year~~

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM B - ACCIDENT BENEFITS CALCULATION

(Complete One of These Forms for Each Project Alternative)

Step 1: Complete the Site Inventory Form (Form A)

Step 2: Complete the Following Information on the Proposed Improvement:

Road Name or Route I.D. Case Study

Milepoint Beginning: 0.00 Ending: 6.20 Length: 6.2 Miles

Alternative Number 1 of 1

Description of Alternative Widen lanes from 9 to 11 feet plus add a 2-foot paved shoulder

Roadway Feature	Before Treatment	After Treatment
Lane Width	9	11
Paved Shoulder Width	0	2
Unpaved Shoulder Width	2	0
Roadside Hazard Rating	6	6
Avg. Roadside Recovery Distance	Unk.	Unk.
Typical Sideslope	2:1	2:1

Step 3: Compute the ADT Over the Project Life (ADT_F)

ADT before improvement = 500 = ADT_B

Project service life = 20 years

Annual growth rate = g = 3 percent per year

Adjustment factor = 1.4 = F_A (from Table 1)

Future ADT = ADT_F = (ADT_B) x (F_A) = 500 x 1.4 = 700

Step 4: Determine Related Accidents per Year Without Treatment (A_{RU}). Select one step based on available information.

- Step 4A: Accident Predictive Nomograph

Use future ADT = ADT_F with current (i.e., without treatment) values of lane width, paved shoulder width, unpaved shoulder width, roadside hazard rating, and terrain with the nomograph to determine related accidents per-mile-per-year without treatment.

A_{RU} = 0.8 Related accidents per mile per year without treatment (from nomograph).

A_{RU} x Section Length = $0.8 \times 6.2 = 4.96$ Related accidents per year.

- ~~Step 4B: Convert Total Accidents to Related Accidents~~

~~A_{TB} = ______ Total accidents per-mile-per-year on the section before treatment~~

~~$R_{R/T}$ = Ratio of related accidents to total accidents from figure 10 based on ADT_B and terrain.~~

NA

~~$R_{R/T}$ = ______ (factor less than 1.0)~~

~~F_{FC} = ______ (from figure 10)~~

~~A_{RU} = ($R_{R/T}$) x (A_{TB}) x (F_{FC}) = ______ x ______ x ______ = ______~~

~~= number of related accidents per year in the untreated after condition.~~

~~If historical related accidents (A_{RB}) are known, then~~
~~A_{RB} = ______, and~~

~~A_{RU} = (A_{RB}) x (F_{FC}) = ______ x ______ = ______~~

Step 5: Determine the Accident Reduction Factor (R_A)

Roadway Improvement Type	Source of AR Factor
1. Lane widening only	Nomograph (use Step 5A) or table 2 (see Step 5B)
2. Shoulder widening only	Nomograph (use Step 5A) or table 3 (see Step 5B)
3. Shoulder resurfacing and/or changing both the lane and shoulder width	Nomograph (use Step 5A)
4. Improving roadside hazard rating	Nomograph (use Step 5A) or table 4 (see Step 5B)
5. Increasing roadside recovery distance	table 5 (see Step 5B)
6. Flattening sideslope only	table 6 (see Step 5B)
[✓ 7. Any combination of improvements to lanes, shoulders, and/or roadside hazard]	[✓ Nomograph (use Step 5A)] or ~~see Step 5C~~
8. Any combination of improvements to lanes, shoulders, and roadside recovery distance	See Step 5B plus Step 5C
9. Flattening sideslopes in conjunction with any improvements to lanes, shoulders, and/or roadside hazard	table 6 (see Step 5B) plus Step 5C

- Step 5A: Use of Nomograph for Determining Accident Reduction Factor (R_A)

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}}$$

Where:

A_{RU} = Related accidents per-mile-per-year in untreated after condition (use ADT_F) from nomograph; A_{RU} = 0.8

A_{RT} = Related accidents per-mile-per-year in treated after condition (use ADT_F) from nomograph; A_{RT} = 0.6

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}} = 0.25$$

NA

- ~~Step 5B: Use of tables 2 through 6~~
  - ~~Lane widening only (use table 2): R_A = _____~~
  - ~~Shoulder widening only (use table 3): R_A _____~~
  - ~~Roadside improvements (use tables 4, 5, and/or 6): R_A = ____~~

NA

- ~~Step 5C: Combine Individual AR Factors~~

  ~~Overall accident reduction (R_A) from more than one improvement~~

  ~~$R_A = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)......$~~

~~Where:~~

~~AR_1, AR_2 and AR_3 are accident reduction factors for project 1, 2, and 3, etc., respectively~~

~~R_A = 1 (1 - _____)(1 - _____)(1 - _____) = _____~~

Step 6: Compute the Estimated Number of Accidents Reduced (ΔA)

The net number of related accidents reduced per year is computed as follows:

$\Delta A = (A_B) \times (R_A) \times (L)$

Where:

A_B = Number of related accidents per-mile-per-year before improvement (from Step 4)

R_A = Accident reduction factor (from Step 5)

L = Section length (in miles)

ΔA = 0.8 x 0.25 x 6.2 = 1.24 accidents reduced per year

Step 7: Determine the Average Cost per Related Accident (C_A)

C_A = $53,700 (use $53,700, if unknown)

Step 8: Compute the Expected Annual Accident Benefits (B_A)

$B_A = (\Delta A) \times (C_A)$ = 1.24 x $53,700 = $66,588 ≈ $66,600

Where:

B_A = Accident benefits per year based on the net reduction in accident occurrences

ΔA = Net reduction in accidents (see Step 6)

C_A = Average cost of a related accident (see Step 7)

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM C - WORKSHEET FOR CALCULATION OF LANE AND SHOULDER WIDENING COSTS

Before Condition: 9 foot lanes 2 foot unpaved shoulders

After Condition: 11 foot lanes 2 foot paved shoulders

Step 1 - Compute the lane and shoulder width changes.

WL = 2 . the change in lane width

WS = 0 . the change in shoulder width

Step 2 - Compute the net width change.

WL + WS = 2 + 0 = 2

Step 3 - Select the lane and shoulder widening costs from table 11.

Assume high, [✓ median], or low costs. Select shoulder type. Obtain values from table 11.

CL = $24,800 (both directions)

CS = NA (both directions)

Step 4 - Determine the slopework costs from table 12.

From Step 2, use the sum of WL + WS = 2 to enter table 12. Pick the appropriate sideslope and height of fill to yield the slopework costs, E = 91,000 (choose high, median, or low costs).

Step 5 - Compute the project cost per mile.

CT = 1.095 [(WL)(CL) + (WS)(CS) + E]

= 1.095 [(2)(24,800) + (0)(8,200) + 91,000]

= $154,000

Step 6 - Compute the total project cost.

Multiply CT from Step 5 times the length of the section in miles.

C_T = Total cost = CT x 62 miles

= $954,800

Step 7 = Compute annualized cost = C_A = C_T x CRF = 954,800 x 0.117

= $111,700 /year

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM D - COMPARISON OF PROJECT ALTERNATIVES

(Use This Form Only if 2 or More Project Alternatives are Being Considered at the Same Location)

STEP 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the B/C Ratio

Complete Columns A, B, C, and D below

NA

	Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H
Rank	Improvement Number	Total Annual Cost (C_T)	Total Annual Benefits (B_T)	B/C Ratio	Compare	Incremental Change in Costs (ΔC)	Incremental Change in Benefits (ΔB)	Incremental Benefit/Cost Ratio $\Delta B/\Delta C$
Lowest Cost (CT)								
2nd Lowest Cost								
3rd Lowest Cost								
4th Lowest Cost								
Highest Cost								

STEP 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$)

NA Complete Columns E, F, G, and H above

STEP 3 - Evaluate Available Funding and Other Agency Constraints

Select the remaining improvement with the highest incremental benefits to highest incremental costs.

Improvement No. and Description: Lane and shoulder widening

Improvement Cost: $ 111,700 per year

Is funding available to complete project (Yes or No) Yes

Do any other agency constraints prohibit implementation (Yes or No) No

If Yes, Describe: ______

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM D - COMPARISON OF PROJECT ALTERNATIVES (CONTINUED)

If the improvement with the best incremental benefit-cost ratio is unacceptable for other reasons, select the improvement with the next highest incremental benefits to incremental costs.

NA

Improvement No. and Description: ________

Improvement Cost: $________ per year

STEP 4 - Record Project Details

Selected Improvement: widen lanes to 11 feet add 2 foot paved shoulder

Project Cost: $ 111,700 per year

Total Project Cost: $ 954,800

Change in Annual Maintenance Costs: $ —

Annual Accident Benefits: $ 66,600

Related Accidents Reduced per Year: 1.24

B/C Ratio = 0.60

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APPENDIX A - ACCIDENT PREDICTIVE MODEL

Based on the previous research, the model 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

More details of the model may be found in the final report.[2]

APPENDIX B - 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:[9]

	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 14) and are presented in table 15.[10]

A 1986 study for FHWA was conducted to develop costs for traffic accidents based on willingness to pay concepts. The study entitled "Alternative Approaches to Accident Cost Concepts," determined the following motor vehicle accident costs.[11]

Cost per fatality:	$1,200,000
Cost per injury:	$7,000
Cost per vehicle involved:	$1,000

A 1984 FHWA study by Miller, Reinert, and Whiting critically analyzed accident costs developed by various sources.[12] 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.[10,13] 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 16 based on 1980 dollars.[12] Two accident costs are given for fatal accidents. The higher costs include an adjustment based on willingness to pay for life.

Table 14. Representative motor vehicle injuries by abbreviated injury scale level.[10]

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 15. Summary of unit societal costs of motor vehicle accidents.[10]

	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 16. Recommended total cost estimates (1980 dollars).[12]

	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.

In summary, although many different unit costs are currently in use, four primary sources of accident costs should be considered for use: (1) costs from a recent FHWA study, (2) States costs; (3) NSC accident costs; (4) 1980 NHTSA costs, and (5) 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 FHWA costs are used in the example presented earlier since they provide the most current costs.

APPENDIX C - BLANK FORMS

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM A - SITE DESCRIPTION

1. Road Name or Route Identification:____________________

2. Milepoint Beginning:_______ Ending:_______ Length:_______(Miles)

3. Area Type (Check): ______Rural

   ______Urban (If urban, procedures in this manual do not apply.)

4. Terrain Condition (Check One):

   ________Flat ________Rolling ________Mountainous

5. Present Average Daily Traffic (ADT_B):__________

6. Expected Annual Traffic Growth Rate = g = __________

7. Lane Width: __________Feet

8. Paved Shoulder Width: __________Feet

9. Unpaved Shoulder (e.g., Dirt, Gravel, Turf, Stabilized) Width = __________Feet

10. Typical Sideslope (Check One):

    __2:1,or steeper, __3:1, __4:1, __5:1, __6:1, __7:1 or flatter

11. Median Value of Roadside Hazard Rating (Check One):

    ______1; ______2; ______3; ______4; ______5; ______6; ______7

12. Average Roadside Recovery Distance = _____ Feet (Optional)

13. Reliable Accident Data for the Section (Check One):

    ________ Available ________ Unavailable

    Note: If reliable accident data are unavailable, skip lines 15-17, and use accident prediction nomograph for estimating accident experience on the section.

14. Total Accidents = ________ for ________ years

15. Total Accidents per Year = $\frac{\text{Number of Total Accidents}}{\text{(Years of Data)}}$ =

    A_{TB} = ______ Total Accidents per Year Before Improvement

16. Number of Related Accidents by Type for ______ Years:

    Single Vehicle (Run-Off-Road) = _______, or _______Per Year

    Head-On = _______, or _______Per Year

    Opposite Direction Sideswipe = _______, or _______Per Year

    Same Direction Sideswipe = _______, or _______Per Year

    Sum of Related Accidents = A_{RB} _______, or _______Per Year
    Before Improvement

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM B - ACCIDENT BENEFITS CALCULATION

(Complete One of These Forms for Each Project Alternative)

Step 1: Complete the Site Inventory Form (Form A)

Step 2: Complete the Following Information on the Proposed Improvement:

Road Name or Route I.D.______________________________

Milepoint Beginning:__________Ending:__________Length:______Miles

Alternative Number __________ of __________

Description of Alternative______________________________

____

____

____

Roadway Feature	Before Treatment	After Treatment
Lane Width	________	________
Paved Shoulder Width	________	________
Unpaved Shoulder Width	________	________
Roadside Hazard Rating	________	________
Avg. Roadside Recovery Distance	________	________
Typical Sideslope	________	________

Step 3: Compute the ADT Over the Project Life (ADT_F)

ADT before improvement = ____________ = ADT_B

Project service life = _______ years

Annual growth rate = g = ______ percent per year

Adjustment factor = _________ = F_A (from Table 1)

Future ADT = $ADT_F = (ADT_B) \times (F_A)$ = ______ x ______ = ______

Step 4: Determine Related Accidents per Year Without Treatment (A_{RU}). Select one step based on available information.

- Step 4A: Accident Predictive Nomograph

  Use future ADT = ADT_F with current (i.e., without treatment) values of lane width, paved shoulder width, unpaved shoulder width, roadside hazard rating, and terrain with the nomograph to determine related accidents per-mile-per-year without treatment.

  A_{RU} = ____________________ Related accidents per mile per year without treatment (from nomograph).

  A_{RU} x Section Length = __________ Related accidents per year.

- Step 4B: Convert Total Accidents to Related Accidents

  A_{TB} = ________________ Total accidents per-mile-per-year on the section before treatment

  $R_{R/T}$ = Ratio of related accidents to total accidents from figure 10 based on ADT_B and terrain.

  $R_{R/T}$ = __________ (factor less than 1.0)

  F_{FC} = __________ (from figure 10)

  A_{RU} = ($R_{R/T}$) x (A_{TB}) x (F_{FC}) = _____ x _____ x _____ = _____

  = number of related accidents per year in the untreated after condition.

If historical related accidents (A_{RB}) are known, then
A_{RB} = ______, and

A_{RU} = (A_{RB}) x (F_{FC}) = ______ x _____ = ______

Step 5: Determine the Accident Reduction Factor (R_A)

Roadway Improvement Type	Source of AR Factor
1. Lane widening only	Nomograph (use Step 5A) or table 2 (see Step 5B)
2. Shoulder widening only	Nomograph (use Step 5A) or table 3 (see Step 5B)
3. Shoulder resurfacing and/or changing both the lane and shoulder width	Nomograph (use Step 5A)
4. Improving roadside hazard rating	Nomograph (use Step 5A) or table 4 (see Step 5B)
5. Increasing roadside recovery distance	table 5 (see Step 5B)
6. Flattening sideslope only	table 6 (see Step 5B)
7. Any combination of improvements to lanes, shoulders, and/or roadside hazard	Nomograph (use Step 5A) or see Step 5C
8. Any combination of improvements to lanes, shoulders, and roadside recovery distance	See Step 5B plus Step 5C
9. Flattening sideslopes in conjunction with any improvements to lanes, shoulders, and/or roadside hazard	table 6 (see Step 5B) plus Step 5C

- Step 5A: Use of Nomograph for Determining Accident Reduction Factor (R_A)

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}}$$

Where:

A_{RU} = Related accidents per-mile-per-year in untreated after condition (use ADT_F) from nomograph; A_{RU} = _______

A_{RT} = Related accidents per-mile-per-year in treated after condition (use ADT_F) from nomograph; A_{RT} = _______

$$R_A = \frac{A_{RU} - A_{RT}}{A_{RU}} = \underline{\qquad\qquad}$$

- Step 5B: Use of tables 2 through 6
  - Lane widening only (use table 2): R_A = ______
  - Shoulder widening only (use table 3): R_A ______
  - Roadside improvements (use tables 4, 5, and/or 6): R_A = ____
- Step 5C: Combine Individual AR Factors

  Overall accident reduction (R_A) from more than one improvement

  $R_A = 1 - (1 - AR_1)(1 - AR_2)(1 - AR_3)(1 - AR_4)......$

Where:

AR_1, AR_2 and AR_3 are accident reduction factors for project 1, 2, and 3, etc., respectively

R_A = 1 (1 - ______)(1 - ______)(1 - ______) = ______

Step 6: Compute the Estimated Number of Accidents Reduced (ΔA)

The net number of related accidents reduced per year is computed as follows:

$\Delta A = (A_B) \times (R_A) \times (L)$

Where:

A_B = Number of related accidents per-mile-per-year before improvement (from Step 4)

R_A = Accident reduction factor (from Step 5)

L = Section length (in miles)

ΔA = ______ x ______ x ______ = ______ accidents reduced per year

Step 7: Determine the Average Cost per Related Accident (C_A)

C_A = __________ (use $53,700, if unknown)

Step 8: Compute the Expected Annual Accident Benefits (B_A)

$B_A = (\Delta A) \times (C_A)$ = ______ x ______ = ______

Where:

B_A = Accident benefits per year based on the net reduction in accident occurrences

ΔA = Net reduction in accidents (see Step 6)

C_A = Average cost of a related accident (see Step 7)

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM C - WORKSHEET FOR CALCULATION OF LANE AND SHOULDER WIDENING COSTS

Before Condition:____
____
____

After Condition:____
____
____

Step 1 - Compute the lane and shoulder width changes.

WL = ___ . the change in lane width

WS = ___ . the change in shoulder width

Step 2 - Compute the net width change.

WL + WS = ___ + ___ = ___

Step 3 - Select the lane and shoulder widening costs from table 11.

Assume high, median, or low costs. Select shoulder type. Obtain values from table 11.

CL = _________ (both directions)

CS = _________ (both directions)

Step 4 - Determine the slopework costs from table 12.

From Step 2, use the sum of WL + WS = ___ to enter table 12. Pick the appropriate sideslope and height of fill to yield the slopework costs, E = ____ (choose high, median, or low costs).

Step 5 - Compute the project cost per mile.

CT = 1.095 [(WL)(CL) + (WS)(CS) + E]

= 1.095 [(__)(_________) + (______)(_______) + _______]

= _____________

Step 6 - Compute the total project cost.

Multiply CT from Step 5 times the length of the section in miles.

C_I = Total cost = CT x _____ miles

= _________

Step 7 = Compute annualized cost = $C_A = C_I$ x CRF = ___________ x ______

= $_________/year

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM D - COMPARISON OF PROJECT ALTERNATIVES

(Use This Form Only if 2 or More Project Alternatives are Being Considered at the Same Location)

STEP 1 - Rank Project Alternatives by Cost (Lowest to Highest) and Calculate the B/C Ratio

Complete Columns A, B, C, and D below

	Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H
Rank	Improvement Number	Total Annual Cost (C_T)	Total Annual Benefits (B_T)	B/C Ratio	Compare	Incremental Change in Costs (ΔC)	Incremental Change in Benefits (ΔB)	Incremental Benefit/Cost Ratio $\Delta B/\Delta C$
Lowest Cost (CT)								
2nd Lowest Cost								
3rd Lowest Cost								
4th Lowest Cost								
Highest Cost								

STEP 2 - Conduct Incremental Benefit-to-Cost Ratio Analysis ($\Delta B/\Delta C$)

Complete Columns E, F, G, and H above

STEP 3 - Evaluate Available Funding and Other Agency Constraints

Select the remaining improvement with the highest incremental benefits to highest incremental costs.

Improvement No. and Description:______________________________

Improvement Cost: $__________________ per year

Is funding available to complete project (Yes or No)____________

Do any other agency constraints prohibit implementation (Yes or No)

____

If Yes, Describe:____

TWO-LANE ROAD CROSS-SECTION DESIGN

FORM D - COMPARISON OF PROJECT ALTERNATIVES (CONTINUED)

If the improvement with the best incremental benefit-cost ratio is unacceptable for other reasons, select the improvement with the next highest incremental benefits to incremental costs.

Improvement No. and Description:________________________________

Improvement Cost: $__________________ per year

STEP 4 - Record Project Details

Selected Improvement:____

Project Cost: $___________________ per year

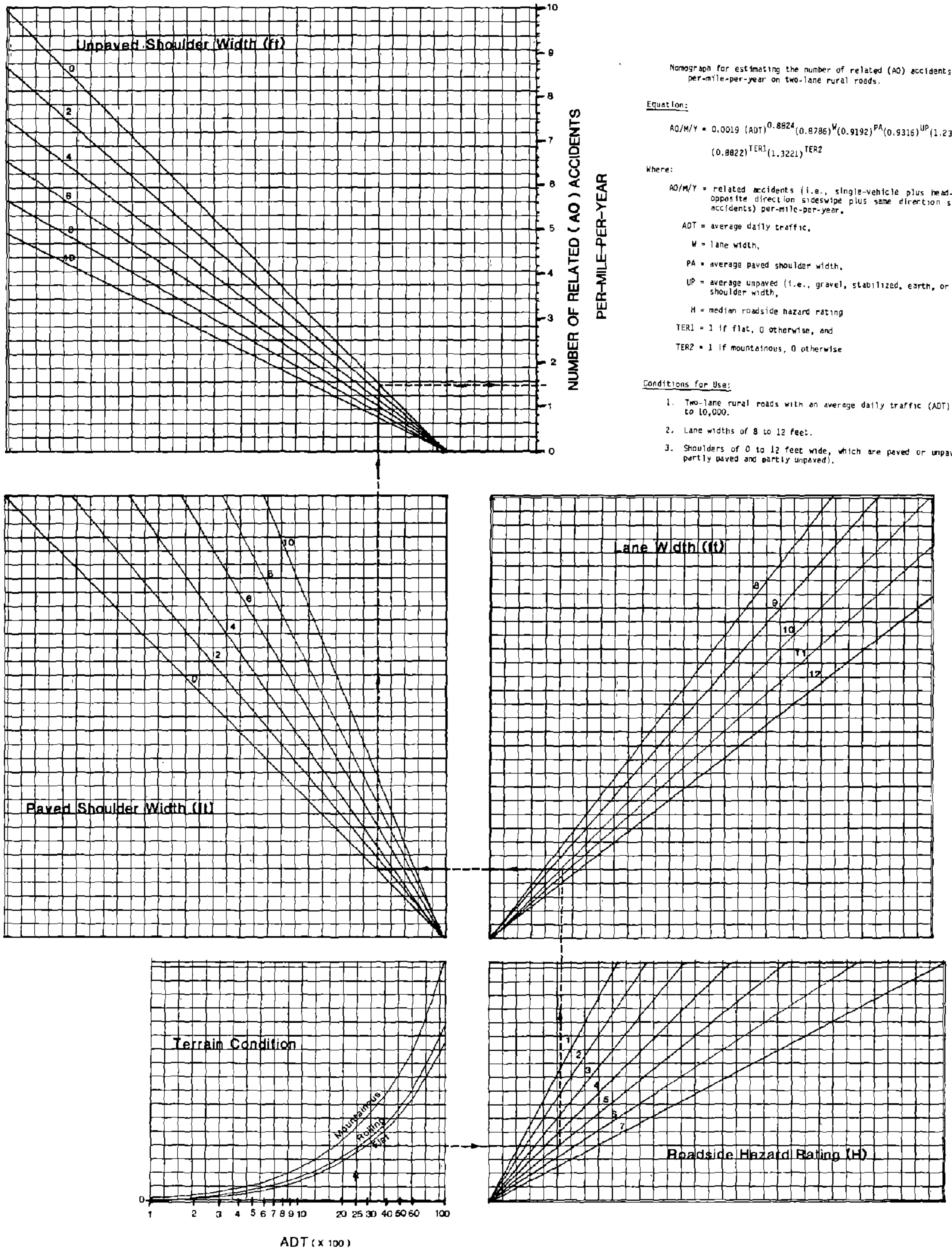
Total Project Cost: $___________________

Change in Annual Maintenance Costs: $___________________

Annual Accident Benefits: $___________________

Related Accidents Reduced per Year:___________________

B/C Ratio = ______________



Nomograph for estimating the number of related (AO) accidents per-mile-per-year on two-lane rural roads.

Equation:

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

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

Conditions for Use:

1. Two-lane rural roads with an average daily traffic (ADT) of 100 to 10,000.
2. Lane widths of 8 to 12 feet.
3. Shoulders of 0 to 12 feet wide, which are paved or unpaved (or partly paved and partly unpaved).

APPENDIX D - ACCIDENT PREDICTIVE NOMOGRAPH