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Contract Manager, Phebe D. Howell, HRS-41

16. Abstract

Under this research study, the effect of various delineation treatments on accident rates was assessed by analyzing accident data from more than 500 roadway sites in 10 States for tangent, winding and isolated horizontal curve sections on two-lane rural highways. Cost-benefit and cost models for evaluating specific delineation treatments were developed and guidelines formulated by executing the cost-benefit models for selected delineation treatments.

This Volume is the research report and describes all aspects of the study. It includes a discussion of the study design, site selection, data collection, and analysis, results of model development and delineation guidelines. Other volumes produced under this research study are:

Vol.	FHWA No.	Report Title
I	78-50	Executive Summary
III	78-52	Appendix A, Site Selection and Data Collection
IV	78-53	Appendix B, Dev. & Descrip. of Computerized Data Base
V	78-54	Appendix C, Statistical Model Development
VI	78-55	Appendix D, Cost of Roadway Accidents and Appendix E, Cost and Service Life of Roadway Delineation Treatments.

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PREFACE

This document and its appendices constitute the final report for the study "Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments." The study was conducted by Science Applications, Inc., with the assistance of Alan M. Voorhees and Associates, Inc., Dr. James I. Taylor, University of Notre Dame, and Mr. John Glennon, for the Federal Highway Administration under contract DOT-FH-11-8587.

Science Applications, Inc., and FHWA wish to acknowledge the assistance of the many people who participated in this study, particularly Robert Felsburg of AMV, Sandra Morrow, SAI, and the key individuals in the ten states, listed below, where data collection took place. Without their cooperation this study would not have been possible.

States	Key Personnel
Arizona, Department of Transportation	Mr. Ross E. Kelley, Traffic Engineer, Safety Projects Services
California, Department of Transportation	Mr. Perry Lowden, Chief, Sign and Delineation Section
	Mr. James B. Dobbins, County Traffic Engineer for the County of Riverside
Connecticut, Department of Transportation	Dr. Charles E. Dougan, Chief of Research and Development
Georgia, Department of Transportation	Mr. Archie C. Burnham, Jr., State Traffic and Safety Engineer
	Mr. Arthur Durshimer, Jr., Traffic and Safety Engineer
Idaho, Department of Transportation	Mr. James L. Pline, Traffic Engineer

Louisiana, Department of Highways	Mr. Grady Carlisle, State Traffic and Planning Engineer
	Mr. John E. Evanco, Highway Planning and Needs Engineer
Maryland, Department of Transportation	Mr. Pierce E. Cody, III, Chief, Bureau of Highway Maintenance
	Mr. Paul S. Jaworski, Chief Bureau of Accident Studies
Ohio, Department of Transportation	Mr. John LeGrand, Chief, Bureau of Transportation Safety
	Mr. John H. White, Assistant, Systems Facilities
Virginia, Department of Highways and Transportation	Mr. A.L. Thomas, Assistant, State Traffic and Safety Engineer
	Mr. P.J. Stenger, Associate Traffic Engineer
Washington, State Highway Commission	Mr. J.A. Gallagher, Traffic Engineer
	Mr. W.R. Curry, Traffic Operations Engineer

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METRIC CONVERSION FACTORS

Several customary units appear in the text of this report. Generally, it is the policy of FHWA to express measurements in both customary and SI units. The purpose of this policy is to provide an orderly transition to the use of SI exclusively. It was decided that dualization of tables was not warranted because of the additional cost and delay in making this research available. Instead, the following conversion table is included.

To Convert	To	
in	mm	Multiply by 25.4*
ft	m	Multiply by 0.3048*
mi	km	Multiply by 1.609
mi/h	km/h	Multiply by 1.609
ft^2	m^2	Multiply by 0.0929
gal	L	Multiply by 3.785
°F	°C	Subtract 32 and multiply by 5/9
$\frac{\text{accidents}}{\text{MVM}}$	$\frac{\text{accidents}}{\text{MVkm}}$	Divide by 1.609
lb	kg	Multiply by 0.4536

The pound is a measure of force (weight) and the kilogram is a measure of mass. Mass and weight are not equivalent. For an object weighed under normal gravitational conditions, however, the above relationship may be used.

The Federal Highway Administration recognizes the "Standard for Metric Practice," E380 of the American Society for Testing and Materials, as the authority for SI usage.

*Denotes exact conversion factor

1. BACKGROUND

Delineation treatments are used extensively throughout the nation to aid drivers in the driving task, particularly at night and under adverse weather conditions. Benefits include increased safety and decreased driver stress.

That these systems have strong intuitive appeal and presumed cost justification, is shown by the extensiveness of their application. However, the selection and design of these treatments varies widely for similar highway situations among the various states, and even within a particular state. While some lack of uniformity is attributable to climatic or other environmental differences, much is due to the lack of specific information on the cost-effectiveness of various treatments.

The history of roadway delineation is primarily one of test and development, with relatively little benefit analysis. New devices and methods have been developed from time to time and put into use, and some evaluation of their performance has been done. There has been considerable research directed at certain aspects of delineation treatments such as service life and associated costs. A major effort in this field was by Chaiken.[1,2] These efforts have been aimed at providing the "same effectiveness" at reduced cost through improved service life, use of less expensive materials, or through variations in spacing of delineators, width of lines, etc. The implicit assumption in most of these studies is that the original treatment was cost-justified and lower costs will simply make the treatment more cost-effective.

A few studies have endeavored to evaluate the impact of specific delineation treatments on accidents, but these were mostly isolated efforts dealing almost exclusively with the effectiveness of edgelines.[3,4] Additional attempts at safety effectiveness evaluation using traffic conflicts, erratic maneuvers, and operational measures have been and are being made. However, a comprehensive safety evaluation of delineation treatments has not been undertaken and the relationships between various effectiveness measures and costs are yet to be established.

2. INTRODUCTION

In the Federal-Aid Highway Act Congress authorized funds for installation of delineation treatments on our nation's highways. As part of the same legislation, safety evaluations were required and the Federal Highway Administration was directed to conduct an evaluation of delineation treatments. It was intended that this evaluation would encompass both the safety and cost-effectiveness aspects of delineation with the ultimate goal of establishing guidelines for installation of various treatments, giving consideration to the traffic and geometric characteristics of the highway as well as the treatment costs.

A multi-faceted approach to the problem was developed and resulted in three contractual efforts. The objective of one contract was to develop models relating accident rate to several operational measures for specified delineation treatments on tangent and winding sections of roadway and at horizontal curves.(5) The results of this study were not available in time for input to the cost-benefit model developed within the study reported here.

The relationships between delineation treatments and driver performance and comfort was the subject of another contract. The driving performance measures resulting from this contract preclude direct applicability to the cost-benefit model at this time but do provide insights into some of the basic human factor requirements of delineation.(6)

The final contract, which is the subject of this report, had as its objectives:

1. to develop a cost-benefit methodology for evaluation of specific delineation treatments

2. to develop cost-effective guidelines for delineation of various highway situations under differing geometric, traffic, and climatic conditions.

The relationships between particular delineation treatments and monetary benefits are arrived at through analyses of accident experience on the assumptions that accident rate reduction can be expressed in monetary terms and that these reductions constitute the primary benefits to be derived from delineation.

The variations in possible delineation treatments, highway situations, geometrics, and environmental factors precluded evaluation of all possible combinations. Thus the focus of this study was directed toward the rural highway system for the following reasons:

- The number of miles of highway in this category far exceeds those in other categories. Hence, the potential for meaningful changes in safety and costs are greatest for these roadways.
- Delineation has more impact on the driving task and driver behavior on rural highways than in urban settings.
- Rather well-defined delineation standards for high-design facilities, such as the Interstate, have been established.

3. ORGANIZATION OF RESEARCH REPORT

All the major efforts of this study, study design, site selection, data collection, accident analysis, model development, and delineation guidelines, are discussed in the following sections of this volume. Details on each of these areas are presented in the appendices, which are briefly described here.

Appendix A describes both site selection and data collection processes including state visits, site reviews, and data coding. It also discusses accident data formats, accident locating systems, and delineation application and maintenance practices.

Appendix B provides a detailed description of the development of the computerized data base used in this study, including a description of the basic data tape file and how it was utilized. Coding formats and problems are also discussed.

Development of the statistical model is explained in detail in Appendix C, which describes theoretical modeling, descriptive statistics, matching-control analysis, and before-after analysis. This volume also discusses candidate delineation treatments, selection of matching-control sites and before-after sites, and the selection of alternative dependent variables.

Appendix D discusses the cost of roadway accidents, and Appendix E discusses the cost and service life of roadway delineation treatments, especially pavement stripes, raised pavement markers, and post delineators.

4. RESEARCH APPROACH

In order to meet the study objectives, the following work plan was developed:

- Literature pertaining to roadway delineation systems was reviewed and evaluated to assess the state-of-the-art.
- Accident, geometric, and traffic data on rural highway sections were collected in an effort to relate accident experience to delineation treatments.
- Accident analyses were conducted to estimate change in accident rate with variation in delineation treatment.
- A cost-benefit model was developed to predict the advantages of various treatments.
- Delineation guidelines were deduced from the results of the above analyses.

4.1 State-of-the-Art

A state-of-the-art report on roadway delineation systems was prepared during the early portion of this project.(7) In the first part of that report, studies documented since publication of NCHRP Report 130(8) are reviewed. In the second part, recommendations on delineation applications under different highway situations based upon the literature review are presented. The report not only contains updated information on cost, service life, and effectiveness of delineation treatments currently in use, but also presents general guidelines for the application of the treatments.

4.2 Study Design and Data Collection

It was determined early in the study that the primary economic benefit, for purposes of cost-benefit, would be reductions in accident experience. Consequently, the study design centered on selecting a suitable number of study sites representing meaningful combinations of delineation treatments, highway situations, and environmental conditions for which concomitant accident experience could be obtained from existing records.

A preliminary statistical analysis plan was developed. The following criteria were formulated under this plan for site selection and had to be met for a site to be included in the study.

- rural highway
- sites where a significant change in delineation had occurred two or three years ago to provide for before-and-after analysis

  or

  pairs of sites where site characteristics other than delineation treatment were similar to provide for test-and-control analysis
- no major geometric change over analysis period
- no experimental delineation treatments

- adequate maintenance of the delineation treatment throughout the analysis period

- no overhead illumination

- at least two years of accident experience.

All states were invited to participate in the study. Participation by a state required assistance in identifying test sites where new delineation treatments had recently been installed and provided access to accident, geometric, and traffic data for those sites. Initially, 28 states responded positively to the invitation to participate.

Each of these states provided details on the availability of required information. Eighteen states were then selected as potential participants.

Prior to final selection of participating states, a pilot site visit was conducted in two states using detailed site selection criteria and data forms.

The purposes for these visits were:

1. to allow the staff to personally describe to the state officials the objectives and needs of the research program and the reasoning behind the site selection criteria

2. to allow the staff to receive reactions and comments to the criteria and forms which had been developed

3. to allow the staff to view the data retrieval capabilities of the states, the difficulties that may arise in this process, and the approximate length of time necessary to compile the data, and

4. to allow the staff to generally review the availability of various types of sites and delineation treatments.

The "pilot test" visits proved to be very beneficial. The most important findings resulting from these meetings were as follows:

1. The criteria for site selection were not sufficiently detailed for sites to be properly selected.

2. The data collection forms which had been prepared were basically sufficient. Only some minor modifications were necessary.

3. The site selection and data collection process would require considerably more involvement by the study team than was originally expected because the states were unable to commit the anticipated manpower effort to assist in this study.

Considering these findings, it was evident that the site selection criteria needed to be further refined, and that additional staff involvement would be required in the site selection process. Further, there was a need to obtain data on a sufficient number of sites to maintain statistical validity. Within these constraints, it was determined that participation by 10-12 states would be possible.

Therefore, the following criteria were developed to select participating states:

1. *Availability and Accessibility of Records* - Records of interest included geometric, traffic, delineation, and accident records. It was important that such records be available and readily accessible. For example, the existence of photologs and computer retrieval capabilities made participation by a state desirable.

2. *Diversity of Terrain and Climatic Conditions* - Because both terrain and climate were viewed to influence the guidance effectiveness of the various delineation treatments and materials, it was important that the analysis include a diversity of such conditions. For this purpose, all states were classified geographically as well as by typical weather conditions.

3. *Availability of Sites with Appropriate Characteristics and Delineation Treatments* - It was anticipated that the availability of sites with the desired characteristics would vary considerably from state to state. Some states have

been able to provide numerous sites representing a wide range of charcteristics, while others may have been able to supply only a few types of sites. It was considered desirable to include those states which could provide the most sites.

As a result of the site selection process, only two-lane rural highway sections were identified in sufficient quantity to allow meaningful analysis. Three types of roadway situations were selected as representative of a large portion of rural two-lane roads for study in this analysis. They were:

- *Tangent* - A predominantly straight roadway with horizontal curves of 3 degrees or less,
- *Winding* - A predominantly curved roadway with degrees of curvature greater than 3 degrees and tangents of less than 1,500 feet (457.20 m) between curves, and
- *Horizontal Curves* - A predominantly isolated curve that is at least 0.3 miles (0.48 km) from adjacent curves in both directions with degree of curvature equal to or greater than 3 degrees.

A number of states participated in the selection of sites meeting the criteria outlined above. In all, data were obtained for more than 500 sites in the ten states shown in Figure 1. It was originally intended to obtain needed data from existing records. However, some information was not available and it was frequently necessary to make field visits to specific sites to supplement the information available in the files. This was most frequently true in obtaining information on delineation treatment installation.

4.2.1 Site Review

A study team visited each of the ten participating states to become familiar with the types of record systems in use, review potential study sites designated by the states, add any additional sites as may be required, and to collect site data required for the study.

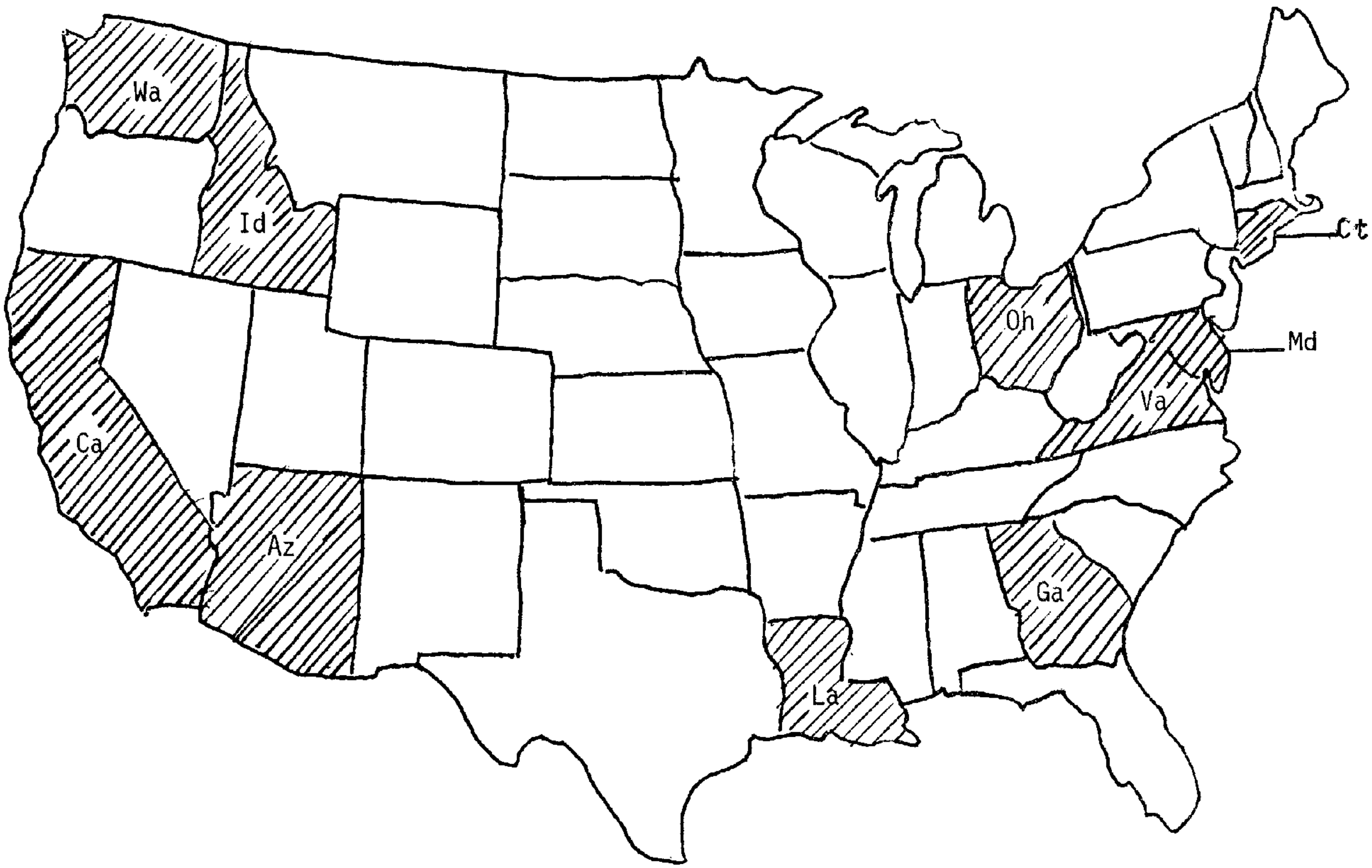


Figure 1. Geographic distribution of participating states.

4.2.2 Data Collection

The collected data were divided into two categories: site data and accident data. Site data are those data which describe the physical and operational characteristics of the highway section defined as a site. Included are geometric data, roadway environmental features, traffic volumes, and delineation treatment characteristics. The accident data are those data which provide a history of the accident occurrence at the selected sites. The information contained in these data are utilized in an attempt to identify the possible relationship between the accident and accident causal factors.

Two types of data collection forms were developed for use by the study steam. The first type is the Information Checklist Form which documents detailed data on the geometric, delineation, traffic, and environmental characteristics on each site. Two versions of this form were developed; Figure 2 illustrates the form for general situations (tangent and winding) and Figure 3 represents the version for horizontal curves.

The second type of form is the Accident Data Form, Figure 4. This was used to record data on all accidents which have occurred at each site during the period of analysis.

4.2.2.1 Geometrics

The major geometric characteristics of interest were the roadway and shoulder widths for all sites and the degrees of curvature for horizontal curve sites.

Roadway Width and Shoulder Width

These basic geometric characteristics were always first determined through the use of some form of roadway log or road inventory. The width measurements were then verified by review of the photolog. If the observed width and the recorded width were reasonably similar, the recorded width was assumed to be accurate. If considerable differences were observed, the photolog measurement was used. In cases where specific

INFORMATION CHECKLIST FORM

General Situation

State

Site Number
(Assigned by Project Staff)

Route Number and Location ________________________

Functional Classification ________________________

1. Type of Section

______ Tangent
______ Winding

2. Number of Lanes

______ Two
______ Four

3. Description of Delineation Treatment

Comments
(Gap-to-mark ratio; type of paint or RPM such as reflectorized, non-reflectorized; spacing of post delineators, etc.)

Centerline

______ None
______ Paint ________________________
______ Thermoplastic
______ Raised Pavement Markers on Paint ________________________

Lane Lines (4-Lane Roads Only)

______ Paint ________________________
______ Thermoplastic
______ Raised Pavement Markers on Paint ________________________

Edgelines

______ None
______ Paint ________________________
______ Thermoplastic
______ Raised Pavement Markers on Paint ________________________

Figure 2 . Information checklist form for general situations.

Outside Shoulder

_____ None
_____ Continuous Post Delineators (Spacing 0.1 Mile or Less)
Noncontinuous, but Post Delineators at Culverts, Bridges, Hazards, etc.

4. Roadway Width _____ feet

5. Volume (ADT)

1974 _____	19__ _____
1973 _____	19__ _____
1972 _____	19__ _____
1971 _____	19__ _____

List previous years appropriate for "before-after" sites.

6. Shoulder Width _____ feet

7. Length of Section _____ miles

8. Posted Speed Limit _____ mph

9. List Horizontal Curves Within Section*

Station From	Station To	Direction of Curve (Left or Right)	Degree of Curvature

10. Shoulder Treatment

_____ Contrasting Color
_____ Contrasting Texture
_____ Rumble Strips
_____ Undistinguished
_____ Unstabilized, Grass
_____ Unstabilized, Gravel
_____ Other (Specify) _____

Figure 2. Information checklist form for general situations (continued).

11. Surface Type

_______ Portland Cement Concrete
_______ Asphaltic Concrete
_______ Other (Specify) ______________________________

12. Access Control

_______ None
_______ Partial
_______ Full

13. Number of Intersections Within the Section ______________

14. Number of Driveways Within the Section* ______________

15. General Vertical Alignment

_______ Flat
_______ Rolling
_______ Mountainous

16. Number of Grades Within Section*

% Grade	Number
Less than 2%	_______
2% - 4%	_______
Greater than 4%	_______

17. Unintentional Delineation

		Station From	Station To	Comments
_______	Fence Line	_____	_____	______________
_______	Tree Line	_____	_____	
_______	Pole Line	_____	_____	______________
_______	Guardrails	_____	_____	
_______	Other (Specify)	_____	_____	______________

18. Comments (Special Signing or Traffic Control Measures; Roadside Development; Unique Geometric Features, etc.)

____

____

____

*This information should only be collected if readily available.

Figure 2. Information checklist form for general situations (continued).

INFORMATION CHECKLIST FORM

Specific Situation
Horizontal Curve

State________________________ Site Number______________
(assigned by project staff)

Route Number and Location______________________________________

Functional Classification______________________________________

1. Number of Lanes

______ Two
______ Four

2. Description of Delineation Treatment

Comments
(Gap-to-mark ratio; type of paint or RPM such as reflectorized, non-reflectorized, etc.)

Centerline

______ None
______ Paint ________________________
______ Thermoplastic
______ Raised Pavement Markers on Paint ________________________

Lane Lines (4-Lane Roads Only)

______ Paint ________________________
______ Thermoplastic
______ Raised Pavement Markers on Paint ________________________

Edgelines

______ None ________________________
______ Paint
______ Thermoplastic ________________________

Figure 3. Information checklist for horizontal curves.

Outside Shoulder

______ None ______________________________

______ Continuous post delineators (spacing 0.1 mile or less) ______________________________

______ Noncontinuous, but post delineators at culverts, bridges, hazards, etc. ______________________________

3. Degree of Curvature_______________________degrees

4. Roadway Width__________________feet

5. Volume (ADT)

1974	_________	19__	_________
1973	_________	19__	_________
1972	_________	19__	_________
1971	_________	19__	_________

List previous years appropriate for "before-after" sites.

6. Shoulder Width________________feet

7. Length of Curve_________________feet

8. Posted Speed Limit________________mph

9. Superelevation________________ft./ft.

10. Shoulder Treatment (more than one may be appropriate)

______ Contrasting Color
______ Contrasting Texture
______ Rumble Strips
______ Undistinguished
______ Unstabilized, Grass
______ Unstabilized, Gravel
______ Other (Specify) ____

11. Surface Type

Portland Cement Concrete
Asphaltic Concrete
Other (Specify) ____

Figure 3. Information checklist form for horizontal curves (continued).

12. Access Control in Vicinity of Curve

_______ None
_______ Partial
_______ Full

13. Unintentional Delineation

	Station* From	Station* To	Comments
_______ Fence Line	_____	_____	_______________
_______ Tree Line	_____	_____	
_______ Pole Line	_____	_____	_______________
_______ Guardrails	_____	_____	
_______ Other (Specify)	_____	_____	_______________

14. Approximate Distance to Adjacent Curves

Distance	Direction from Study Curve (N,S,E,W)
_______	_______________
_______	_______________

15. Comments: (Special Signing or Traffic Control Measures; Roadside Development; Unique Geometric Features, etc.)

____

____

____

____

____

*This information should only be collected if readily available.

Figure 3. Information checklist form for horizontal curves (continued).

SITE ________________ STATE ________________

POST MILE OR STATION: FROM _______ TO _______

☐ "MATCHING CONTROL" SITE:

TOTAL NUMBER OF ACCIDENTS _______

TIME PERIOD: FROM _______ TO _______

☐ "BEFORE/AFTER" SITE:

BEFORE

TOTAL NUMBER OF ACCIDENTS __________

TIME PERIOD: FROM _______ TO _______

AFTER

TOTAL NUMBER OF ACCIDENTS __________

TIME PERIOD: FROM _______ TO _______

ACCIDENT SPECIFIC INFORMATION
(PLEASE COMPLETE THE FOLLOWING FOR EACH ACCIDENT AT THIS SITE).

1		2 TYPE OF ACCIDENT								3 NO. OF CARS		4 TIME		5 SEVERITY			6 ROADWAY CONDITIONS			7 WEATHER			8	9	10	
ACCIDENT NO.	DATE	HEAD-ON	SIDE-SWIPE (SAME DIRECTION)	SIDE-SWIPE (OPPOSITE DIRECTION)	REAR-END	RUN-OFF-ROAD	RIGHT-ANGLE COLLISION	FIXED OBJECT (NOTE IN COMMENTS)	OTHER (EXPLAIN IN COMMENTS)	SINGLE	MULTIPLE	DAYLIGHT	DARKNESS	FATALITY	PERSONAL INJURY	PROPERTY DAMAGE ONLY	WET	DRY	SNOW OR ICE	CLEAR	RAIN, SNOW, SLEET	FOG	PROBABLE CAUSAL FACTOR	ESTIMATED PROPERTY DAMAGE (IN DOLLARS)	COMMENTS	NEAREST MILEPOST (TENTH OF A MILE)

Figure 4. Accident data form.

measurements were made at the site, those measurements were used in the analysis.

Degree of Curvature

One of the major difficulties encountered in the site selection and the data collection processes was the lack of data on the degree of curvature for horizontal curves. All states used construction or "as built" drawings of the roadways as the source of this information. However, using this source posed several problems. First, it was difficult and time consuming to locate the plans because the archives are usually voluminous and the filing and recording systems are not typically set up for quick reference by milepost. Second, many of the secondary roads being analyzed in this study were constructed many years ago and have not been redesigned in recent years. Therefore, the plans were no longer on file and/or possibly the road was built without engineering drawings. In any event, the use of such plans for data collection had limited utility.

4.2.2.2 Traffic Volumes

The traffic data used in this study were the annual average daily traffic (AADT) as reported by the states. Traffic data were not collected specifically for this study but rather existing information based on the continuous record of traffic collected at a selected number of permanent automatic traffice recorder (ATR) stations was used.

4.2.2.3 Delineation Data

The records on type of delineation present on any specific roadway is not well maintained in most states. Particularly at the headquarters level, information on even the presence or absence of a centerline or edgelines is usually sketchy. The few exceptions are those roadways on which a centerline or edgelines have been installed under the Section 205 Pavement Marking Demonstration Program. In these cases, a special record of these installations is maintained by the central staff.

In most cases, personnel at the district level were able to provide the necessary information. In some of the districts, the District Traffic Engineer maintains a color-coded map which serves as an inventory of the delineation on the highways in the district. Even if an inventory or other form of record is not maintained, district personnel were familiar with the roads on a day-to-day basis and were able to recall the type of delineation in place.

4.2.2.4 Roadway Environment

There is very little information available on the surrounding roadway environment (i.e., location of houses, developments, presence of driveways, cross streets) in any of the record systems available in the participating states. Thus, most of this information was gathered by reviewing photologs or during site visits.

4.2.2.5 Accident Data

In all of the participating states, the accident data have been computerized in a summary form for each accident.

Retrieval of data for a specific study site required inputs of the route number, the mileposts of the site boundaries, and the time period (year) for which the data are desired. In a few states, it was also necessary to indicate the county in which the site was situated.

4.3 Development of Data Base for Analysis

For the statistical analysis of site and accident data, it was necessary to computerize the data in order to provide rapid access to the information on more than 500 sites and 13,000 accidents. Appendix B discusses the development of the computerized data base. It also details the data base itself, and briefly describes how it was and can be utilized.

Vast amounts of hard copy data in a variety of formats were gathered by the site selection team. The basic plan was to first standardize and code this information onto computer cards, then to read the cards into the computer to create a permanent tape.

From the start, the site data desired for each site was clearly defined and standardized. The Information Checklist Forms (Figures 2 and 3) were developed, and a copy of this form was completed for each site. Coded forms were then prepared, one set for each state. These coded forms contained the site data relevant for the analysis as extracted from the Information Checklist Forms. With some modifications, these forms were suitable for keypunching.

In contrast, accident data were not received in a standardized format. Each state had a unique method for maintaining accident data, usually computerized. In view of the quantity of data requested (the sites averaged 30 accidents each), it was easiest for the states to provide accident data in the format used by their computer facilities. The task of reducing these data to a standardized set was done by project personnel.

4.3.1 Coding Formats

The first step in organizing the data was to define a standardized set of variables and subclassifications for the site and accident data. The selection of these variables and subclassifications was tempered by what information was actually available. Important variables with their subclassifications considered are listed below:

Site Data

- Site Identification (State, Route Number, Mileposts)
- Site Geometry
    - general highway
        - tangent sections
        - winding sections
    - horizontal curves
- Site Type for Analysis
    - matching-control site
    - before-after site

- Functional Classification
  - federal aid primary
  - federal aid secondary
  - non-federal aid
- Delineation
  - centerline (type and date installed)
  - edgeline (type and date installed)
  - post delineators (system and date installed)
  - guardrail (for horizontal curves only)
  - unintentional delineation (e.g., guardrail lines, fence posts, or utility poles)
- Traffic Volume (Average Annual Daily Traffic)
- Posted Speed Limit
- Roadway Width and Pavement Surface Type
- Shoulder Width and Type
- For General Highway Sites Only
  - number of intersections
  - driveway frequency
  - general vertical alignment
    - flat
    - rolling
    - mountain
- For Horizontal Curves Only
  - degree of curvature
  - distance to adjacent curves
  - signing
- Average Number of Precipitation Days per Year
- Average Number of Snow Days per Year
- Average Number of Foggy Days per Year

- Time Period Covered in Accident Data
- Total Number of Accidents

Individual Accident Data

- Identification (Accident Report Number)
- Location (Milepost)
- Date
- Type of Accident
  - head-on
  - sideswipe (same direction)
  - sideswipe (opposite direction)
  - rear-end
  - run-off-road, overturn, hit fixed object off pavement
  - angle collision
  - foreign object in road
  - other
- Accident Severity
  - fatal
  - injury
  - property damage only
- Number of Vehicles
  - number of passenger cars
  - number of trucks and buses
  - number of other vehicles
- Time of Day
  - daylight
  - dark
  - dusk
  - dawn

- Roadway Lights (On/Off)
- Road Defects (Yes/No)
- Surface Conditions
  - dry
  - wet
  - snow or ice
- Weather
  - clear or overcast
  - rain or snow
  - fog
- Intersection Related/Non-Related
- Delineation Related/Non-Related

For the analysis, sites were selected and classified as either before-after sites or matching-control sites. In addition, general highway situations were selected and defined as tangent or winding sections. Horizontal curves were treated independently.

Before-after sites were those where accident data were available for similar periods both before and after a specific delineation treatment was installed. These sites were intended as the basic units for the statistical analysis of accident rate changes related to delineation treatments. Matching-control sites were those where the delineation treatment remained unchanged during the analysis periods. These sites, therefore, were intended to provide control data for the before-after experiment in order to account for any systematic variance in the accident data.

To computerize the data base, variable names and numerical codes were developed for the variables listed in the classification table shown earlier. A detailed description of these names and codes is given in Appendix B.

With the appropriate variables identified, data coding schemes and card formats were developed. For each study site, there was a Site

Identification Card, a Delineation Treatment Card, a Traffic Volume Card, a Road Site Geometry Card, an Accident Header Card, and Individual Accident Cards. These card formats are described in Appendix B.

Appendix B also describes the additional steps that were necessary to code and reformat the data before it could be placed on magnetic tape and checked for internal consistency and correctness. These additional steps were required because of the occurrence of special cases, data anomalies, and information voids. For example, because accident data varied in content and format from state-to-state, detailed data translation guides had to be developed to produce internally consistent accident data coding. These are discussed briefly in the following section. Other problems encountered included: (1) within site changes, chronologic changes, or absence of route mileposting; (2) within site variations of delineation treatments; (3) violation of original criteria for "matching-control vs. before-after" site description; (4) traffic volume data missing for some years; (5) lack of constant roadwith or shoulder width over their defined length (in these cases the variation was sufficiently small so that an average value was used); (6) codes for unintentional delineation had to be devised.

4.3.2 Accident Data Translation Guides

As mentioned previously, raw data varied in content and format from state-to-state and year-to year or region-to-region within a state. Therefore, data translation guides were developed, one for each distinct set of raw data. Essentially each data translation guide is a mini-report, consisting of a set of rules, usually in the form of tables, for translating state codes into standardized data codes. Table 1 is an example of some of the simpler data translation tables.

Some additional criteria had to be established on a state-by-state basis:

1. In one set of accident data, it was impossible to distinguish head-on accidents from sideswipe opposite direction accidents. Thus in coding,

Table 1. Example of a data translation table.

SAI	Louisiana (Cols. 34-35)
PC = Passenger Cars	A. Passenger Car G. Taxicab
TC = Trucks & Buses	C. Truck or Truck Tractor D. Truck Tractor, Semi-Trailer E. Other Truck Combination H. Bus I. School Bus
OV = Other Vehicles	B. Passenger Car and Trailer F. Farm Tractor and/or Farm Equipment J. Motorcycle K. Motor Scooter or Motor Bicycle M. Emergency (Including Private Owner) N. Military Vehicles O. Other Publicly Owned Vehicle P. Others and Not Stated
Non-Vehicles	L. Bicycle

all such accidents were arbitrarily classified as sideswipe opposite direction.

2. The number of types of vehicles involved in an accident was not always known.

   a. Only a "single" vs. "multiple" vehicle accident code was given in one state's data, so the multiple vehicle accidents were coded as having two vehicles.

   b. Only the details on the first two vehicles in an accident were known for several sets of data even though the total number of vehicles was given and could have been more than two. For such data, any vehicles beyond the first two were classified as "Other Vehicles."

   c. Vehicle types were unknown for some sets of data. One state codes only "Truck Involvement." The vehicles for such accidents were arbitrarily coded as though they were all trucks.

   d. For one state the TRUCK code actually included motorcycles. These data were included in the truck and bus category.

Due to the different recording procedures of the accident data by the states, it was often difficult to categorize accidents according to delineation/non-delineation related and intersection/non-intersection related as described below.

4.3.3 Intersection-Related Accidents

One state identifies an intersection-related accident by locating it (by milepost) at the intersection irrespective of whether or not the accident actually occurred at the intersection. In contrast, most states merely classify all accidents occurring at intersections as intersection accidents and make no statements as to whether or not they actually were intersection-related.

4.3.4 Delineation Related

The identification of accidents which could have been related to the existing delineation treatment at the site was viewed as a crucial task in the project. If accidents which were in fact related to the existing delineation treatments are eliminated from the analysis due to erroneous decision criteria, the sample size would be reduced and perhaps bias the results. On the other hand, if accidents which are unrelated to delineation treatments were included in the analysis, they would spread the distribution of the data (that is, increase sample variance) and therefore would reduce the confidence associated with the derived results. It was, therefore, important that a serious attempt be made to try to develop a rational procedure for eliminating those accidents which could not possibly have been related to the existing roadway delineation treatments.

Several procedures were proposed. The earliest involved weighting and rating the various information components of each accident, summing up these weighted factors, and producing a numerical rating for delineation relatedness for each accident. The objective in such a scheme had been to create a relatively objective decision procedure. However, it was not clear that despite all the efforts required to assign ratings and compute the numbers, this method would be any less subjective than any other method, for there is inherent subjectivity associated with the assignment of rates to each factor. Also, there is no allowance for interaction between different factors in the weighted sum. Furthermore, it was not feasible to follow such a time-consuming scheme for the vast amount of accident data to be analyzed. Consequently, alternative procedures were formulated along different directions.

The first alternative idea was that a researcher well-conversant with the associated problems could probably make the decision regarding an accident's delineation relatedness equally well by visually reviewing all the available data. In fact, a decision which is made by reviewing all of the available information regarding an accident would also take into consideration the interaction between different causal factors in an integrated fashion, and therefore, may be superior to any other procedure. The big disadvantage is that the decision would be a function of the decision maker. Hence, if different decision makers were used, or even if one decision maker was used but the decision process stretched over a "long" period, then a bias in the results might be introduced. Nevertheless, the idea appeared promising given the time and money constraints for the project.

Tentative guidelines were established to provide a general framework for the decision maker's task. In these guidelines, lighting and weather conditions were adjudged to be most critical. The hypothesis being that nighttime or inclement weather conditions placed an added demand on the driver, hence, in these conditions, his performance was likely to be more sensitive to existing delineation.

The subjective decision guidelines eventually gave way to a definite list of characteristics for identifying those accidents which were adjudged not related to delineation. It was decided that accidents would be classified into two categories; those which are obviously not delineation related, and those which are possibly delineation related. The specific category definitions are:

1. those accidents for which the presence or absence of the site delineation would have had no effect on the accident occurrence (i.e., accidents that could not possibly be related to the at-site roadway delineation treatment)

2. those accidents where improved delineation could have reduced the likelihood of its occurrence.

A general set of accident characteristics was developed to identify those accidents falling into category 1. All the other accidents were assumed to fall into category 2. Accidents with one or more of the following characteristics were identified to be in category 1:

- Collision Type
  - train
  - animal
  - fixed object within the travel lanes
- Maneuver
  - U-turn
  - starting
  - parking
  - backing
  - improper turning
- Traffic Control
  - police officer
  - railroad crossing
- Major Factor
  - driver related
    - improper turn
    - backing into roadway
    - stopped in roadway
    - sudden incapacitation (heart attack, epilepsy, etc.)
    - avoid animal or object in travel lanes
  - vehicle related
    - defective equipment
    - struck by object
  - roadway related
    - construction, repair zone
    - flooded
- Vehicle Type
  - farm truck
  - emergency vehicle

So, it was hypothesized that an accident with one or more of the above general characteristics could not possibly be related to the existing roadway delineation treatments, and this was the basis for the final delineation relatedness/non-relatedness criteria.

Having so classified the accident information data, tapes were created to facilitate the planned analysis. Information on these tapes included all accidents as well as delineation-related accidents.

5. STATISTICAL ANALYSES

This section describes the statistical analyses of the traffic accident data collected in this study. The objectives of these analyses were: (a) to investigate the effect of various roadway delineation treatments on traffic accidents under various highway and traffic conditions; and (b) to develop prediction models to quantitatively measure the accident reduction associated with the application of various roadway delineation treatments.

The original plan was a before-after experiment with matching-control sites to account for any systematic variance of accident data. However, the before-after sites were generally difficult to find, and it was even more difficult to find a matching-control site to correspond with a selected before-after site. Also, the available project time and resources did not permit site visits to select matching-control sites. For these reasons, separate statistical analyses were performed for matching-control sites and for before-after sites, with the emphasis on the matching-control analyses.

For the reasons previously discussed, it was initially decided that only delineation-related accidents would be useful in the analysis. In addition, the dependent variable selected was accident rate. However, during the initial stages of analysis some tests were conducted to determine whether other forms for the dependent variable (e.g., severity index, total accident rate, nighttime accident rate) were more sensitive to the changes in roadway delineation treatments. This analysis to select additional dependent variables was conducted within the matching-control analysis and is reported in that section.

The statistical analyses presented here can be broadly classified as follows:

1. theoretical modeling
2. descriptive statistics
3. matching-control analysis
4. before-after analysis

At the start, theoretical models describing the distribution of accident rate were developed. These were utilized to develop a weighting scheme for the remaining analyses.

5.1 Theoretical Modeling

5.1.1 Distribution of Accident Rate

Accident rate, denoted here by $\lambda(\phi)$, can be defined by:

$$\lambda(\phi) = \frac{N(\phi)}{\phi}$$

where $N(\phi)$ is the number of accidents occurring over an exposure ϕ, and where exposure ϕ is measured in million vehicle-miles (MVkm) for longitudinal sections and million vehicles for isolated highway situations such as horizontal curves.

The distribution of $\lambda(\phi)$ was modeled by considering traffic accidents as events resulting from repetitive independent trials. The trials are the traversing of the vehicles through the test sections, and the events are the accidents.

The following assumptions were made:

- A trial corresponds to (a) the traversing of a vehicle through the test section for isolated highway situations such as horizontal curves; and (b) the traversing of a vehicle through one mile of the test section for longitudinal situations.
- The event corresponds to the occurrence of an accident.

- For multiple-vehicle accidents (accidents involving more than one vehicle), all vehicles involved constitute one event.

- There is a fixed probability, denoted by p, that an individual trial would result in the occurrence of an event. In other words, there is a probability p that a vehicle would be involved in an accident while traversing the section (or traversing a mile of the test section in the case of longitudinal situations).

Under the above noted assumptions, $N(\phi)$ will have a binomial distribution given by

$$P[N(\phi) = x] = \binom{\phi}{x} p^x (1 - p)^{\phi - x}$$

This distribution, as shown in Appendix C, can be approximated by either a Poisson or a normal distribution. Under the Poisson assumption, the distribution of $N(\phi)$ is given by

$$P[N(\phi) = x] = \frac{e^{-c} c^x}{x!}$$

where $c = \phi p$. The distribution of accident rate is then given by

$$P[\lambda(\phi) = \ell] = \frac{e^{-\lambda\phi}(\lambda\phi)^{\ell\phi}}{(\ell\phi)!} \quad , \quad \ell = 0, \frac{1}{\phi}, \frac{2}{\phi}, \frac{3}{\phi}, \ldots$$

where λ is the mean accident rate defined by

$$\lambda = \frac{c}{\phi} \quad .$$

The mean and variance of $\lambda(\phi)$ are

$$E[\lambda(\phi)] = \lambda$$

$$\mathrm{Var}[\lambda(\phi)] = \lambda/\phi \quad .$$

Under slightly different assumptions $\lambda(\phi)$ is shown to approximate a normal distribution with mean and variance again given by

$$E[\lambda(\phi)] = \lambda$$

$$Var[\lambda(\phi)] = \lambda/\phi \quad .$$

Because of the obvious advantages in using a normal approximation to the accident rate distribution, and because the premises for applying a normal approximation to a binomial or Poisson distribution were satisfied by the data, the accident rate was assumed normally distributed with mean and variance as given above.

5.1.2 Non-Homogeneity of Variance

From the expression for variance of accident rate, it is evident that computed accident rates for sites with dissimilar exposures would have non-homogeneous variance. Since most of the statistical procedures require the homogeneity of variance, this particular problem was more than a mathematical technicality.

To address the problem, alternative approaches were investigated. The details and results of this investigation can be found in Appendix C. The approach found most suitable for this analysis was to weight each site by the site exposure suitably normalized. The appropriate normalization factor for a particular analysis was the total number of sites in the analysis divided by the total exposure of these sites. In other words, if ℓ sites with a total exposure of ϕ are used in a particular analysis, the weight for a site i with exposure ϕ_i is given by

$$\frac{\phi_i \ell}{\phi}$$

This weighting scheme was used for both the matching-control and before-after analyses.

5.2 Descriptive Statistics

Prior to the statistical analysis, site statistics were compiled for the selected test sites. Accident statistics for these sites were also computed.

Site statistics of test sites were compiled and stratified by state and site type (tangent, winding, and horizontal curve site). No distinction was made between a "matching-control" site and "before-after" site.

Table 2 provides the distribution of sites by type and state. Review of this table indicates approximately 20% of all sites and slightly over 40% of the horizontal curve sites were in Maryland. The remaining states represented from 6% to 13% of the data. Data for each site also included:

- length in miles
- analysis period for which site accident data are available
- total site exposure

Total site exposure was computed from the following formulas.

(a) For general highway sites

$$\text{Total Site Exposure (MVM)} = L \times 365 \times \left[\left(ADT_1 \times f_1 \right) + \sum_{i=2}^{n-1} ADT_i + \left(ADT_n \times f_n \right) \right] .$$

(b) For horizontal curves

$$\text{Total Site Exposure (MV)} = 365 \times \left[\left(ADT_1 \times f_1 \right) + \sum_{i=2}^{n-1} ADT_i + \left(ADT_n \times f_n \right) \right] .$$

Table 2. Number of selected sites by state and type of site.

Jurisdiction	Type of Site			
	Tangent	Winding	Horizontal Curve	Total
Arizona	23	12	19	54
California	41	21	6	68
Connecticut	11	9	12	32
Georgia	5	24	3	32
Idaho	18	12	6	36
Louisiana	18	6	9	33
Maryland	11	10	81	102
Ohio	11	16	6	33
Virginia	17	25	14	56
Washington	17	13	38	68
Total	172	148	194	514

Where

ADT_i = average daily traffic for the year i

L = length of the general site

f_1 = fraction of the first year for which the accident data are available

f_n = fraction of the last year for which the accident data are available.

For some sites, the ADT was unavailable for some of the years. These missing data were estimated by interpolation or extrapolation. If the ADT for both a preceding and a succeeding year were available, the missing ADT was estimated through linear interpolation. If the missing ADT was for the first or last year of the analysis period, the ADT for the missing year was assumed equal to that of the adjacent year.

Table 3 provides general accident statistics for the various section types contained in the data base. For general highway situations, such as tangent and winding sites, only those accidents within the test sites are included in the computations. For horizontal curve sites, accidents located within 750 feet (229 m) of the point of curvature (PC) and point of tangency (PT) are also included (the reasons for choosing 750-foot (229 m) criterion is discussed in Appendix B). Because site length data were not available for some of the horizontal curve sites, a site length of 0.4 mile (0.64 km) was assumed for these sites.

As with site statistics, the accident statistics were also compiled by state and site type (tangent, winding, and horizontal curves). The accident data were organized according to the following stratifications:

- All Accidents
- Delineation/Non-Delineation Related
- Intersection/Non-Intersection Related
- Time of Day
  - day
  - night/dusk/dawn

Table 3. Number of accidents, accident rate by type of section.

Type of Section	Number of Sections	Total Length (1) (Miles)	Exposure (2)	Number of Accidents	Accident Rate (3)
Tangent	172	1139.5	4675.6	7479	1.6
Winding	148	901.1	1807.7	4932	2.7
Total (General Sites)	320	2040.6	6483.3	12411	1.9
Horizontal Curves	194	N/A	618.6	755	1.2
Total	514			13166	

(1) 1 mile = 1.609 km

(2) Exposure for Tangent and Winding Sites is Million Vehicle-Miles (MVkm)
Exposure for Horizontal Curves is Million Vehicles

(3) Accident Rate for Tangent and Winding Sites is Accidents Per Million Vehicle Miles (Acc/MVkm)

Accident Rate for Horizontal Curves is Accidents per Million Vehicles

- Pavement Surface Condition at the Time of the Accident
  - dry
  - wet
- Nighttime Wet Pavement Accidents
- Accident Severity
  - fatal
  - injury
  - PDO
- Type of Accident
  - head-on
  - side-swipe opposite direction
  - rear end
  - side-swipe same direction
  - angle
  - run-off-the-road

5.3 Matching-Control Analysis

The matching-control analysis refers to the accident analysis of those test sites where matching-control sites could also be identified. The delineation treatment on the control site had to have remained unaltered during the analysis period. This analysis is organized under the following steps:

- selection of test delineation treatment categories
- selection of test sites and control sites for the analysis
- statistical analysis with accident rate as the dependent variable
  - t-test and one-way analysis of variance
  - two-way and higher order analysis of variance and covariance analysis
  - regression analysis.

5.3.1 Candidate Delineation Treatments

During the data collection phase, many variations of delineation treatments (dashed centerline vs. solid centerline, for example) were recorded. However, for the analysis, these variations presented an excessively large number of treatments. Therefore, delineation treatments were organized into a few major treatment categories. Besides reducing the number of treatments to a manageable number, this categorization also increased the effective number of sites for each treatment analyzed, thereby increasing confidence in the results.

The selected treatment categories are given in Table 4. The treatment variations within each category are also given. Throughout the remaining analyses (matching-control as well as before-after analyses), these are the delineation treatment categories evaluated for their effect on accidents.

5.3.2 Selection of Matching-Control Sites

The matching-control analysis required that:

- the site delineation treatment remain unaltered over the analysis period, and
- the analysis period be large enough to produce statistically reliable results.

To ensure these conditions, all the test sites were evaluated against an established criterion.

The initial review of test sites indicated that several of the sites originally designed MC (matching-control) sites did not meet the requirements listed above. Several sites, for example, had changes in delineation treatments during the period for which accident data were available. Although for most of the MC-designated sites, this change had occurred either near the beginning or the end of the period, an adjustment of the analysis period was nevertheless required.

Table 4. Selected delineation treatment categories for analysis.

Site Type	Selected Treatment Category		
	Identification Number	Abbreviated Name(1)	Detailed Description
General Sites (Tangent Sections, Winding Sections)	0	Other	If none of treatments 1-6
	1	No Treatment	No continuous treatment
	2	Paint CL	Painted centerline only
	3	RPM CL	Raised pavement marker centerline only
	4	CL+EL	Any centerline (paint or RPM) *and* solid white paint edgeline
	5	CL+POST	Any centerline (paint or RPM) *and* continuous post delineators
	6	CL+EL+POST	Any centerline (paint or RPM) *and* white paint edgeline, *and* continuous post delineators on right side of the road
Horizontal Curves	10	Other	If none of treatments 11-16
	11	No Treatment	No continuous treatment
	12	CL	Centerline only (paint or RPM)
	13	Guardrails	Guardrails with *any other* treatment
	14	CL+EL	Any centerline (paint or RPM) *and* white paint edgeline
	15	CL+POST	Any centerline (paint or RPM) *and* continuous post delineators
	16	CL+EL+POST	Any centerline *and* white paint edgeline *and* continuous post delineators on right side of road

(1) CL = Centerline
RPM = Raised Pavement Marker
EL = Edgeline
POST = Post Delineator

Table 4. Selected delineation treatment categories for analysis (continued).

Site Delineation Treatments — Explanations
"Paint Centerline" includes Paint - dashed Paint - solid one side, dashed on other side Paint - double solid Paint - unknown pattern "Raised Pavement Marker" means RPM's - reflective markers only between paint gaps RPM's - reflective markers between paint gaps with ceramic markers on paint RPM's - continuous reflective markers RPM's - only ceramic markers "Continuous Post Delineators" include Continuous - crystal reflectors on one side Continuous - crystal reflectors on both sides Continuous - reflectorized paddles on one side Continuous - reflectorized paddles on both sides Continuous - crystal reflectors on paddles, both sides The following post delineation systems are considered equivalent to *no* post delineation for tangent and winding sections Noncontinuous - delineators at culverts, bridges, hazards, etc. Noncontinuous - reflectors on sharp curves Noncontinuous - reflectorized paddles on sharp curves Noncontinuous - reflectors on paddles on sharp curves "Guardrails" include Galvanized Steel Rail Painted Steel Rail Cable Type Expandable Mesh Type

Similarly, a check on sites originally designated BA sites (sites suitable for before-after analysis only) indicated that some of them (where a change in delineation treatment occurred either near the beginning or the end of the analysis period) were also suitable for matching-control analysis. Adequate accident data had to be available either for the before period or the after period to justify their inclusion in the matching-control analysis.

The criterion utilized to select sites for matching-control analysis was originally designated MC site, BA site, or undesignated sites is fully discussed in Appendix C.

5.3.3 Statistical Analysis of Matching-Control Sites

This analysis was conducted with one specific objective – to investigate the effect of roadway delineation treatment on accident rate to its fullest extent. To achieve this objective, both hypothesis testing and estimation procedures were utilized. Hypothesis testing procedures were used to assess whether the changes in accident rate resulting from changes in site delineation treatment are statistically significant. The procedures included t-test, one-way analysis of variance (one-way ANOVA), two-way and higher order analysis of variance (ANOVA), and covariance analysis. One-way ANOVA and t-tests identify statistically significant differences in mean accident rates under different treatment categories. Two-way and higher order ANOVA and covariance analysis provided a means for studying how these differences were affected by other roadway geometric, operational and climatic parameters. Estimation procedures included t-test and regression analysis. These quantify the changes in accident rate resulting from the changing treatment, geometric, and traffic operational conditions.

The analysis outlined above was first completed with accident rate using all accidents as the dependent variable. An exploratory analysis was undertaken to identify if other forms for the dependent variables would be more sensitive to the changing delineation treatment. Selected statistical analyses were repeated with these alternative forms of a dependent variable. The following three alternative dependent variables were found to have *some* sensitivity to the delineation changes:

- all accident severity index [1/]
- wet non-intersection accident rate
- wet non-intersection severity index.

Surprisingly, the dependent variables derived from the accidents classified as "delineation-related" did not exhibit any dependence on delineation treatments.

5.3.3.1 One-Way Analysis of Variance and t-Test

Although Appendix C describes the analysis as it was conducted, the results obtained with different dependent variables are consolidated here under the specific analysis conducted. Results of the analysis are reported at the more rigorous test used, .05 level. Additional testing was done at the .20 level. These results are reported in Appendix C. Some of these less rigorous results are also used in Section 7 for illustrative purposes. A brief description of these results follows:

For the one-way ANOVA, the null hypothesis is:

$$H_0: \lambda_1 = \lambda_2 = \lambda_3 = \ldots\lambda_k = \lambda$$

where λ_i's are category means. If the means are not found to be significantly different, it *cannot* be assumed that the category means are equal. However, if the means are signficantly different, it can be safely assumed that they are indeed different. The actual testing is done by comparing the computed F-ratio (F = between groups mean square/within-groups mean square), which is reported in the analysis of variance table, to the known sampling distribution of the F-ratio. The SPSS computer subroutine utilized for the analysis automatically computes the F-value and the level of significance.

[1/] Severity index is a weighted sum of accidents where the weights are assigned in proportion to accident severity (for detail, see Appendix C).

For the t-test, the hypotheses are:

null (H_0): $\lambda_1 = \lambda_2$

alternative (H_1): $\lambda_1 > \lambda_2$, where

λ_1 and λ_2 denote accident rate for sites with treatments 1 and 2 respectively. Accident rate is hypothesized to decrease with the installation of treatment 2. An SPSS subroutine was again utilized for the analysis. The variance of the sub-populations was assumed unequal. For statistically significant different means, confidence bands for the mean difference were also computed.

The results of the one-way ANOVA and t-tests are shown in Table 5 for general sites and Table 6 for horizontal curves. Considering that statistical significance for the dependent variable indicates an accident reduction effectiveness for the added treatment, the following general conclusions can be drawn:

1. Painted centerlines are effective for tangent and winding sections.

2. RPM centerlines are more effective than painted centerlines for tangent sections.

3. Post delineators are effective when used with any centerline on tangent and winding sections.

4. Little or no effectiveness is indicated for edgelines.

5. Little or no effectiveness is indicated for any treatments on horizontal curves.

For clarity, the dependent variable (total) accident rate was utilized in the remaining analyses and results reported are based on that variable.

5.3.3.2 Analysis of Variance and Covariance Analysis

One-way analysis of variance and t-tests described in the previous section were designed to assess the effect of only one accident causal factor and the roadway delineation treatment. How this

Table 5. One-way analysis of variance and t-test results for general sites.

Statistical Procedure	S.No.	Hypothesis Tested	Level of Significance: General Sites – Accident Rate	General Sites – All Accident Severity Index	Tangent Sites – Accident Rate	Tangent Sites – All Accident Severity Index	Winding Sites – Accident Rate	Winding Sites – All Accident Severity Index	Winding Sites – All Wet-Non-intersection Accident Rate	Winding Sites – All Wet-Non-intersection Severity Index
One-Way Analysis of Variance	1.	H_0: $\lambda_{tangent} = \lambda_{winding}$	S.	S.	—	—	—	—	—	—
	2.	H_0: $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6$	S.	S.	S.	S.	N.S.	N.S.	S.	S.
	3.	H_0: $\lambda_2 = \lambda_4 = \lambda_5$	S.	S.	S.	S.	—	—	—	—
	4.	H_0: $\lambda_1 = \lambda_2 = \lambda_4 = \lambda_5$	—	—	—	—	N.S.	N.S.	S.	S.
t-Test	1.	H_0: $\lambda_1 = \lambda_2$ H_1: $\lambda_1 > \lambda_2$	S.	S.	S.	S.	N.S.	N.S.	S.	S.
	2.	H_0: $\lambda_2 = \lambda_3$ H_1: $\lambda_2 > \lambda_3$	N.S.	N.S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.
	3.	H_0: $\lambda_{2,3} = \lambda_4$ H_1: $\lambda_{2,3} > \lambda_4$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	4.	H_0: $\lambda_{2,3} = \lambda_5$ H_1: $\lambda_{2,3} > \lambda_5$	S.	S.	S.	S.	N.S.	N.S.	S.	S.
	5.	H_0: $\lambda_4 = \lambda_6$ H_1: $\lambda_4 > \lambda_6$	N.S.	N.S.	N.S.	N.S.	S.	S.	S.	S.

Notation: λ_i = Accident rate under treatment i where
1. No treatment
2. Painted centerline
3. RPM centerline
4. Any centerline + painted edgeline
5. Any centerline + post delineators
6. Any centerline + painted edgeline + post delineator

S. = Mean rates are different at significance level 0.05.
N.S. = Mean rates are not different at significance level 0.05.
— = Not applicable.

Table 6. One-way analysis of variance and t-test results for horizontal curves.

Statistical Procedure	S.No.	Hypothesis Tested	Significance: Accident Rate	Significance: All Accident Severity Index
One-Way Analysis of Variance	1.	$H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6$	S.	N.S.
	2.	$H_0: \lambda_2 = \lambda_4 = \lambda_5 = \lambda_6$	N.S.	N.S.
t-Test	1.	$H_0: \lambda_1 = \lambda_2$ $H_1: \lambda_1 > \lambda_2$	N.S.	N.S.
	2.	$H_0: \lambda_2 = \lambda_4$ $H_1: \lambda_2 > \lambda_4$	N.S.	N.S.
	3.	$H_0: \lambda_2 = \lambda_5$ $H_1: \lambda_2 > \lambda_5$	N.S.	N.S.
	4.	$H_0: \lambda_4 = \lambda_6$ $H_1: \lambda_4 > \lambda_6$	N.S.	N.S.

Notation: λ_i: Accident rate under treatment i where

1 = No treatment

2 = Centerline

3 = Guardrail

4 = Centerline + Edgeline

5 = Centerline + Post

6 = Centerline + Edgeline + Post

S. : Mean rates are different at significance level 0.05.

N.S.: Mean rates are not different at significance level 0.05.

effect is altered by the changing roadway geometric and traffic characteristics was ignored. It is through two-way and higher order analysis of variance (ANOVA) and covariance analysis, presented here, that these interactions were investigated.

In the analysis of variance (ANOVA) and covariance analysis, the independent variables (the variables whose effect on roadway accidents is being investigated) can all be nonmetric (categorical) or a combination of metric and nonmetric variables. If an independent variable is a categorical variable (or treated as such even though each category may represent some metric value), it is called a factor. If all the variables are factors, the associated analysis is called ANOVA. If the effect of both factors and metric variables are investigated, the analysis is referred to as analysis of covariance. In such analysis, the metric independent variables are called covariates.

The objective of the analysis of covariance within this study was to assess the effect of certain roadway geometric, traffic, and delineation treatment parameters and how they interact with each other after the adjustment has been made for the climatic variables. These climatic variables are considered a completely disjoined set of variables from the geometric, traffic, and treatment factors. Hence, climatic variables were chosen as covariates.

The ANOVA and covariance analysis utilizing twelve factorial designs were conducted[1/]. For ANOVA, the classic experimental approach was used. In covariance analysis, the effect of covariates are adjusted for prior to assessing the effect of factors. The only *covariates* considered in these analyses are climatic variables, and they are:

1. average number or precipitation days per year

[1/] Three factorial designs used wet-non-intersection accident rate as the dependent variable. The results of that analysis indicated no relationship between delineation variables and wet non-intersection accident rate.

2. average number of snow days per year

3. average number of foggy days per year.

The various *factors* considered are listed in the tables. The various geometric and traffic operational variables which were considered important and therefore categorized as factors, including the roadway delineation treatments, were:

1. general roadway alignment (tangent vs. winding) for general sites
2. roadway width
3. shoulder width
4. traffic volume
5. degree of curvature for horizontal curves
6. roadway delineation treatments.

The detailed statistical results given in Appendix C are consolidated here in Tables 7 and 8. Table 7 presents results for the general sites, and Table 8 presents results for the horizontal curve sites. The general interpretation of these tables indicates the following:

<u>General Highway Sites</u>

- Climatic variables, as a whole, were found to have some effect on roadway accidents.
- Among the climatic variables considered, number of days of precipitation was found to have the strongest effect.
- The factors that were found to have the strongest effect on roadway accidents were:
  - centerline
  - post delineators
  - traffic volume.

Table 7. Comparison of analysis of variance and covariance analysis results for general sites.

	Significance of F – (0.05 Level)					
	Dependent Variable = Accident Rate					
	Factorial Design 1		Factorial Design 2		Factorial Design 3	
	Cov. Anal.	ANOVA	Cov. Anal.	ANOVA	Cov. Anal.	ANOVA
Covariates	No		Yes		Yes	
Precipitation	No		Yes		Yes	
Snow	No		No		No	
Fog	No		Yes		No	
Main Effect	No	No	No	No	Yes	Yes
Treatment						
Centerline	Yes	Yes				
Edgeline			No	No	No	No
Post Delineators					No	Yes
Site Type	No	No	No	No	No	No
Traffic Volume					Yes	Yes
Roadway Width	No	No				
Shoulder Width	No	No	No	No		
2-Way Interaction	No	No	No	No	No	No
CL x EL						
CL x Post Del.						
CL x Site Type	No	No				
CL x Traf.Vol.						
CL x Road.Width	No	No				
CL x Shldr.Width	No	No				
EL x Post Del.					No	No
EL x Site Type			No	No	No	No
EL x Traf.Vol.					No	No
EL x Road.Width						
EL x Shldr.Width			No	No		
Post x Site Type					No	No
Post x Traf.Vol.					No	No
Post x Road.Width						
Post x Shldr.Width						
Site Type & Traf.Vol.					No	No
Site Type x Road.Width	No	No				
Site Type x Shldr.Width	Yes	Yes	No	No		
Traf.Vol. x Road.Width						
Traf.Vol. x Shldr.Width						
Road.Width x Shldr.Width	No	No				

Table 8. Covariance analysis results for horizontal curve sites.

	Significance of F — (Level = 0.05)											
	Dependent Variable = Accident Rate											
	Factorial Design 7		Factorial Design 8		Factorial Design 9		Factorial Design 10		Factorial Design 11		Factorial Design 12	
	Cov. Anal.	ANOVA	Cov. Anal.	ANOVA	Cov. Anal.	ANOVA	Cov. Anal.	ANOVA	Cov. Anal.	ANOVA	Cov. Anal.	ANOVA
<u>Covariates</u>	No		No		No		No		No		No	
Precipitation	No		No		No		No		No		No	
Snow	No		No		No		No		No		No	
Fog	No		Yes		No		No		No		No	
<u>Main Effect</u>	No	No	No	No	No	No	No	No	No	No	No	No
Treatment												
Centerline	No	No										
Edgeline			No	No	No	No	No	No				
Post Delineators			No	No	No	No	No	No	No	No		
Traffic Volume			No	No			No	No			No	No
Degree of Curve	No	No			No	No	No	No	No	No	No	No
Roadway Width												
Shoulder Width	No	No	No	No	No	No			No	No	No	No
2-Way Interaction	No	No	No	No	No	No	No	No	No	No	No	No
CL x EL												
CL x Post Del.												
CL x Traf.Vol.												
CL x Deg.Curve	No	No										
CL x Road.Width												
CL x Shldr.Width	No	No										
EL x Post Del.			No	Yes	No	No	Yes	Yes				
EL x Traf.Vol.			No	No			No	No				
EL x Deg.Curve					No	No	No	No				
EL x Road.Width												
EL x Shldr.Width			No	No	No	No						
Post x Traf.Vol.			No	No			No	No				
Post x Deg.Curve					No	No	No	No	No	Yes		
Post x Road.Width												
Post x Shldr.Width			No	No	No	No			No	No		
Traf.Vol. x Deg.Curve							No	No			No	Yes
Traf.Vol. x Road.Width												
Traf.Vol. x Shldr.Width			No	No							No	No
Deg.Curve x Road.Width												
Deg.Curve x Shldr.Width	No	No			No	No			No	No	No	No
Road.Width x Shldr.Width												

- Edgelines were found to have little or no effect on roadway accidents.
- Generally, interaction among the independent variables was found to be nonexistent. The only significant interactions were between shoulder width and site type.

Horizontal Curve Sites

- Climatic variables, as a whole, were found to have no significant effect on roadway accidents.
- The only significant interactions among the independent variables were between:
    - edgeline and post delineator
    - post delineator and degree of curve
    - traffic volume and degree of curve.

5.3.3.3 Regression Analysis

The t-test and one-way and higher order analysis of variance described above were primarily designed to test hypotheses on whether the mean accident rates are significantly different under different roadway delineation and operational characteristics. No attempt was made to quantify these differences except where they were readily available through t-test results. It was through regression analysis that models for the accident rate from roadway delineation and traffic characteristics, and climatic parameters were developed.

The underlying functional form of the regression models is as follows:

$$\gamma = \beta_0 + \beta_1 \chi_1 + \beta_2 \chi_2 + \ldots + \beta_\rho \chi_\rho + \varepsilon$$

Where γ represents the variable to be predicted (in this case accident rate and ε is a random error. The χ_1 ($\imath$ = 1, 2 ... ρ) are the independent variables which have known values in a particular situation. The regression coefficients β_j (j = 0, 1, 2 ...ρ) are estimated from the data.

The analysis was conducted utilizing subprogram REGRESSION in SPSS. The details of the analysis are contained in Appendix C. The main features are listed below.

1. The analysis was performed using a stepwise regression procedure, where independent variables entered the regression model one at a time. At each step, the variables not in the model were evaluated against specific criteria; the variable best meeting the criteria entered the model next. At the same time, the variables in the model were re-evaluated, and any variable which ceased to meet the criteria left the model.

   Within SPSS, the stepwise criteria is specified by assigning values to parameters N, F, and T as discussed below.

   The second parameter, F, was computed to test for significance of a regression coefficient (see Appendix C for details). For a specified value of F, the procedure ensures that only those independent variables whose associated regression coefficients are signficant at the level specified by F, will enter into the regression. At each step in the analysis, F-ratios were computed for variables not yet in the equation. The F-ratio for a given variable is the value that would be obtained if that variable were brought in on the very next step. Two values for F, $F = 2.71$ and $F = 1.01$,were used. The corresponding levels of signficance are 0.10 and 0.25, respectively.

   The third parameter T is referred to as tolerance. The tolerance of an independent variable considered for inclusion is the proportion of its variance not explained by the independent variables already in the regression equation. The tolerance index has a possible range of 0 to 1. A tolerance of 0 indicates that a given variable is a perfect linear combination of other dependent variables. A tolerance of 1.0 indicates that the variable is uncorrelated with the other independent variables. A minimum tolerance of 0.1 was used in the analysis.

2. The problem of multi-collinearity was addressed by allowing only a subset of independent variables to enter the model. The problem of multi-collinearity arises when the candidate independent variables are very highly correlated. In these cases that variable having the largest simple correlation with the dependent variable was retained. See Appendix C for a detailed discussion.

3. The possible existence of nonlinear relationships between the dependent and independent variables was investigated. Scatter plots between the accident rate and each of the independent variables were developed; however, no nonlinear relationships were detected.

4. Interaction among the independent variables were investigated by developing a set of multiplicative terms as candidates to enter the model.

5. Both descriptive as well as continuous metric variables were included as candidate independent variables. For each descriptive variable, such as the presence of edgelines, the number "1" was used to indicate presence, and the number "0" was used to indicate absence.

A general description of the developed models is given in Table 9. Separate regression models were developed for tangent, winding, and horizontal curve sites. For each highway type, additional models were developed for subcategories, including U.S. region, site topography, and federal-aid highway designation.

Although many of the regression equations can be judged to have good prediction ability, few of them provide any useful information to this study. For example, many of the equations contain statistically signficant roadway, traffic and environmental variables, but do not contain a signficant (at the 0.10 level) delineation variable. In addition, some of the regression equations explain very little of the accident rate variance.

Table 9. General description of regression models.

Model Description	Type of Site: Tangent Sections			Winding Sections			Horizontal Curve Sites		
	No. of Sites	Model Developed?	Significant* Results?	No. of Sites	Model Developed?	Significant Results?	No. of Sites	Model Developed	Significant Results?
All Sites	141	Yes	No	111	Yes	No	131	Yes	No
Southwestern Sites (Calif., Ariz.)	50	Yes	Yes	20	Yes	No	24	Yes	No
Eastern Sites (Ct., Md., Ohio, Va.)	39	Yes	No	50	Yes	Yes	53	Yes	No
Northwestern Sites (Wash., Idaho)	30	Yes	Yes	22	Yes	No	42	Yes	No
Southeastern Sites (Ga., La.)	23	Yes	No	14	Yes	No	12	Yes	Yes
Flat Sites	62	Yes	Yes	N/A	No	No	N/A	No	No
Rolling Sites	78	Yes	Yes	77	Yes	No	N/A	No	No
Mountainous Sites	N/A	No	No	34	Yes	No	N/A	No	No
FAP Sites	49	Yes	No	29	Yes	No	39	Yes	Yes
FAS Sites	87	Yes	No	82	Yes	No	92	Yes	No

*Significant results indicate whether the model has a delineation term with an F value statistically significant at the 0.10 level and whether the model has an $R^2 \geq 0.40$.

Seven models listed below indicated results that give some measure of the effects of delineation treatments:

Tangents Sites

Southwestern Sites (California and Arizona)

$$Y = 1.544 + 0.958\ (PS) - 0.530\ (CLR) - 0.462\ (Posts\ 1)$$

Northwestern Sites (Idaho and Washington)

$$Y = 0.831 + 0.029\ (Fog) + 1.352\ (PS) + 1.032\ (Posts\ 1) - 0.096\ (Snow) - 0.161\ (S\ Width) + 0.981\ (EL1) + 0.0002\ (Travol) - 0.501\ (F1)$$

Flat Sites

$$Y = 1.133 + 1.176\ (PS) - 0.335\ (CLR)$$

Rolling Sites

$$Y = 0.908 + 0.013\ (Precip) - 0.415\ (F1) - 0.542\ (EL1) + 0.341\ (PS)$$

Winding Sites

Eastern Sites (Connecticut, Maryland, Ohio and Virginia)

$$Y = 13.369 - 0.074\ (Precip) - 2.442\ (F1) + 2.486\ (EL1) - 0.250\ (S\ Width) - 0.0005\ (Travol) - 1.745\ (G2)$$

Horizontal Curves

Southeastern Sites (Georgia and Louisiana)

$$Y = 0.696 + 0.665\ (Adjcnt) - 1.310\ (Posts\ 1)$$

FAP Sites

$$Y = 0.819 - 0.415\ (S\ Width) + 8.331\ (Length) + 1.283\ (EL1)$$

Where:

Y = Accident Rate

* Accidents/MVM (Acc/MVkm) for tangent and winding sites

** Accidents/MV for horizontal curves

CLR	-	RPM CL (0 = not present, 1 = present)
Posts 1	-	Posts (0 = not present, 1 = present)
EL1	-	Edgeline (0 = not present, 1 = present)
Fog	-	Days of fog (average number per year)
Snow	-	Days of snow (average number per year)
Precip	-	Days of precipitation (average number per year)
S Width	-	Shoulder width (Ft)
PS	-	Poor shoulders (0 = poor shoulders, 1 = good shoulders)
Travol	-	Traffic Volume (AADT)
F1	-	Federal aid status (0 = secondary, 1 = primary)
G2	-	General vertical alignment (0 = rolling, 1 = mountainous)
Adjcnt	-	Average distance to adjacent curves (mi.)

Table 10 summarizes the direct contribution of the various delineation treatments to the accident rate for the sites described by the models. A positive number indicates the delineation treatment increases the accident rate by that amount, and a negative number indicates the accident rate reduction benefit of the treatment. As with the previous analyses, the results are somewhat mixed. Centerlines appear to have a safety benefit for some sites, while post delineators and edgelines have benefits for some sites and disbenefits for others. Consistent with earlier results, edgelines do not generally appear to be an effective delineation treatment.

5.4 Before-After Analysis

Before-after analysis, for this study, refers to the accident analysis of those test sites where there was some major change (upgrading) in the delineation treatment during the analysis period. The premise of before-after analysis is that if, after taking out any effects trend, there is a significant difference in the accident rate between the "before" and "after" periods, this difference was caused by the test delineation treatment. For detecting time trends, a "matching-control" site associated with a "before-after site" was defined as a site indentical to the before-

Table 10. Average direct contribution of the various delineation treatments to the accident rate at various sites.

Model	Delineation Treatment			Regression Statistics	Number of Sites
	Centerline	Post Delineator	Edgeline		
<u>Tangent Sites</u>					
Southwestern Sites[1]	-0.530	-0.462		.49	50
Northwestern Sites[2]		+1.032	+0.981	.59	30
Flat Sites[1]	-0.335			.45	62
Rolling Sites[1]			-0.542	.49	78
<u>Winding Sites</u>					
Eastern Sites[1]			+2.490	.48	50
<u>Horizontal Curves</u>					
Southeastern Sites[1]		-1.310		.48	12[4]
FAP Sites[1]			+1.284	.61	39

(1) F Value = 2.71 — i.e., level of significance .10
(2) F Value = 1.01 — i.e., level of significance .25
(3) Either paint or RPM
(4) Small sample

after site except that its delineation had remained unchanged. In this study, these sites were to be selected from those used in the matching-control analysis.

The before-after analysis proceeded in three steps. First, a final selection of before-after sites was made from the available data base, and associated matching-control sites were identified where possible. Second, the analysis approach and specific statistical tests were devised and tailored to the available data. And finally, the analysis was carried out, and the results evaluated.

For the before-after study, a manual search of the data base was conducted. The many exceptions and special cases which existed precluded any type of simple indication on the tape itself. The visual search accomplished the following tasks:

- selection of the final set of before-after sites
- identification of matching-control sites where possible
- definition, in each case, of the specific delineation installation to be tested and the before-after time periods to be analyzed.

Of the 514 sites, 151 qualified for some sort of before-after analysis. Of these sites, most involved the installation of raised pavement marker (RPM) centerlines or painted edgelines. Table 11 shows the breakdown of these sites.

The remaining handful of sites were analyzed manually and yielded no positive or significant results.

It was possible to identify matching-control sites for 49 of the 151 before-after sites. Of these 49 pairings, 18 later proved unusable, usually because no accidents occurred in the matching-control site.

It should be emphasized that the pairing of matching-control sites to before-after sites was accomplished by searching through computer printouts of the data tape contents, and not by actual inspection of the sites in the field. Because difficulties were encountered in locating suitable before-after sites (with the result that a full spectrum of

Table 11. Breakdown of sites for computerized before-after analysis (number of sites).

		Tangent		Winding		Horizontal Curve	
BA	ED	AU	NAU	AU	NAU	AU	NAU
RPM	CL	2	6	—	3		
	CL + EL	—	2	—	—		
	CL + Post	—	2	—	1		
	CL + EL + Post	—	—	—	—		
EL	Paint CL	7	6	1	5	3	47
	RPM CL	4	5	—	6	—	—
	Paint CL + Post	9	1	4	7	—	13
	RPM CL + Post	—	1	—	—	—	1
	Paint CL + Guardrail	—	—	—	—	—	1

Key:
BA = Test "before-after" delineation
ED = Existing delineation
AU = Sites for which matching-control sites were available and usable
NAU = Sites for which matching-control sites were either not available or not usable
EL = Edgeline
RPM = Raised pavement markers
CL = Centerline

"before-after" delineation and site types was not found), the before-after analysis was de-emphasized in comparison to the matching-control analysis.

The tests for the before-after sites that had associated matching-control sites were:

t-Tests, before-accident rate vs. after accident rate
crude interval comparisons.

In addition, chi-square tests were performed on contingency tables such as illustrated in Table 12.

Table 12. Contingency table.

	Before-After Site	Matching-Control Site	
Before Period	b	B	b + B
After Period	a	A	a + A
	a + b	A + B	n = a + b + A + B

The chi-square expression is

$$\chi^2 = \frac{a - b \cdot \frac{A^2}{B}}{\frac{A}{B} \cdot (a + b)} \quad ; \quad \text{degrees of freedom} = 1$$

where

b = number of accidents occurring during the "before" period in the before-after site(s)

a = number of accidents occurring during the "after" period in the before-after sites(s)

B = number of accidents occurring during the "before" period in the associated matching-control site(s)

A = number of accidents occurring during the "after" period in the associated matching-control site(s)

The chi-square tests, however, gave no positive results. Likewise, the t-tests (Table 13) yielded no practical results except for the installation of edgelines to tangent sites that already have centerlines and posts present. This was the only positive result of the before-after study. For use in the benefit model, this result is comprehensively summarized in Table 14.

5.5 Recommendations on the Use of Statistical Results

A quantitative measure of accident reduction with the installation of delineation treatments is provided by the t-test results and regression models. The t-test results estimate the reduction in mean rate associated with the installation of a delineation treatment. Although this estimation is independent of roadway geometric, traffic, operational, and climatic conditions, individual estimations are provided for tangent, winding and horizontal curve sites.

Regression models, like the t-test results, also estimate the accident reduction associated with the installation of various delineation treatments. But, they also provide a measure of its dependence on other roadway characteristics and climatic parameters.

It is essential to remember, however, that the regression models provide estimates of the *average* accident rate on a particular *type* of highway section. Application of these models to an individual highway section is subject to rather large variations and should be used only as a general guide. As a further guide to interpretation, it might be mentioned that the model itself does *not* imply cause and effect. However, if sound judgment theorizes a cause-and-effect relationship which is substantiated by the mathematics, such an interpretation could be valid. Care should also be taken to apply the models only within the range of the variables used in its development. Application to values outside these ranges requires considerable caution in interpreting the results.

Table 13 . Simple before vs. after rate comparison t-values obtained with SPSS.

Site Group	Test Delineation	Number of Sites	t-Value
Tangent Sites	RPM	12	.91
Winding Sites	RPM	4	1.15
Tangent Sites			
Paint CL	EL	13	-2.17
RPM	EL	9	- .64
CL	EL	22	-1.90
CL + Post	EL	11	4.16*
All	EL	33	.39
Winding Sites			
Paint CL	EL	6	- .21
RPM	EL	6	1.90
CL	EL	12	1.00
CL + Post	EL	11	.59
All	EL	23	1.39
Horizontal Curves			
Paint CL	EL	50	- .99
CL + Post or Guardrails	EL	15	1.15
All	EL	65	- .34

* Significant at .05 level

Table 14. Confidence bands for the installation of edgelines to tangent sites with centerlines and posts already present.

Highway Situation	Treatment Combination	Effective Number of Sites	Mean	Mean Difference	Standard Error of Mean Difference ν = degrees of freedom*	Confidence Bands							
						p = .60		p = .90		p = .95		p = .99	
						Dev. From Mean	Band	Dev. From Mean	Band	Dev. From Mean	Band	Dev. From Mean	Band
	B: CL and Post		2.04				.568		.407		.335		.172
Tangent		11		.72	.173	$\pm$.152		$\pm$.313		$\pm$3.85		$\pm$.548	
	A: CL, EL, and Post		1.32				.872		1.033		1.105		1.268

Numbers are accident rates in number of accidents per million-vehicle-miles.

*ν = 10

Because of this difference of information between the t-test results and the regression models, their recommended use depends on the intended objective. General recommendations on using the results of this study are given below:

1. If the intended objective is to assess the overall reduction in accidents from the installation of a particular delineation treatment, without any specific consideration of roadway features, the results of the t-tests (see Table 5) are recommended. In the absence of t-test results, regression models can be utilized; in which case, average values of the other parameters in the model can be used (refer to Tables 9 and 10 and to specific model specifications in Appendix C).
2. If the effect of delineation treatment is to be assessed for a road with the specified geometric and operational characteristics, the regression models are recommended, if available.
3. Among the various regression models available, preference should be given to the one which best reflects the study highway environment. For example, if the intended objective is to assess the effect of delineation on California rural roads, models developed for Western states are more appropriate.

Caveates

The results reported here were obtained through the statistical analysis of accident data. They, therefore, are subject to all of the strengths and drawbacks of a statistical analysis. Accident analysis is particularly susceptible to the shortcomings of the statistical analysis.

Accident data take a long time to accumulate. Over this period the roadway environment can change, driving population may alter, and traffic regulations may be modified. In addition to these changes with time, no two roadway sites are exactly alike, causing a variation in data from site to site. These variations make a controlled study extremely difficult. Other problems in the statistical analysis of accident data relate to: (a) the variation in accident reporting procedures from state-to-state and county-to-county, (b) discrepancies and abnormalities in the data base, and (c) the excessive time and cost involved in selecting highway sites with specified characteristics. Traffic accident analysts are well aware of these problems and, therefore, no elaboration is needed here. Only some of the major problems associated with the accident analysis that are suspected as the main cause of error in this study are listed below.

1. It has long been suspected that a critical combination of roadway environment (which includes roadway geometry, traffic regulations, and weather and visibility parameters), and driver behavior culminates in a roadway accident. Although the driver is an important element in an accident, he is the least understood and is almost always excluded from explicit consideration in the analysis. If the driver's behavior and information needs remained unaltered over time and from highway to highway, his exclusion is easily justified. But, on the contrary, a complex interaction between the driver's behavior and his information needs and roadway environment is suspected. The point is easily made by realizing that poorly designed roads with little or no delineation treatment do not necessarily have higher accident rates, because the driver adjusts his driving behavior according to the needs of the road.

2. A roadway delineation treatment undergoes a periodic fluctuation in quality. Strong when newly installed, its effect decreases with time until reinstalled. This periodic fluctuation reduces its effect on traffic

accidents. For the sites selected within this study, the strength of delineation at a site varied from site to site, depending on the individual maintenance policies of the participating states. This variation tends to confound measuring the effect of the treatment on traffic accidents.

3. Two highway sites, either selected from two different states or selected in the same state but geographically separated, were almost never exactly alike, although the associated geometric, traffic, and climatic data may be alike. This made a pairwise comparison, as was done in the present analysis, somewhat less accurate. The search for sites identical in all respects, except for the delineation treatments, entailed time and costs that were beyond the scope of this study.

4. Abnormalities and inconsistencies are present in the accident data base. Requirements for reporting an accident vary from state to state and sometimes even within a state from year to year. This introduces a variation in the accident data which cannot be explained by any of the geometric and other roadway factors. The problems with the accident data base are discussed in Section 4.3.

5. There is a lack of knowledge of accident characteristics which have the strongest dependence on existing delineation treatments. Within this analysis, a set of characteristics was developed to identify accidents which could not possibly be related to the existing delineation treatment. It was hypothesized that the remaining accidents called "delineation-related" would have stronger dependence on the delineation treatments. But the analysis subsequently conducted failed to indicate any stronger dependence of these accidents on delineation treatment.

6. For horizontal curves, the problem of identifying curve-related accidents was encountered. To strengthen the analysis for horizontal curve sites, a decision to include only the curve-related accidents was made. However, no consistent criterion could be found to identify curve-related accidents. A mini-analysis failed to indicate any relationship between the curve-related accidents and location of the accident relative to the curve. This lack of relationship is attributed to the error associated with accident location at the filing of the original police report.

7. Due to the varying delineation practices in the states studied, the distribution of sites relative to the type of delineation treatment was non-uniform over the states. For example, most of the sites with a raised pavement marker centerline came from the Western states. An excessive concentration

of post delineation sites came from the state of Arizona. These regional biases also contributed in confounding the effect of delineation on traffic accidents.

6. THE ECONOMIC MODELS

This section describes the two economic analysis models which have been developed for the evaluation of roadway delineation treatments. The first, a classical Net-Present-Worth model, is designed to evaluate major delineation treatment applications, e.g., installation of edgelines. The second model, a cost analysis model, is designed to evaluate treatments for which the benefits (e.g., reductions in accidents) are assumed constant and independent of minor treatment variations, (e.g., paint or thermoplastic). In order to place the economic analysis of roadway delineation treatments in perspective, it should be noted that delineation application decisions are made based upon a bi-level decision-making hierarchy. First, the treatments which are judged cost-beneficial are identified. Then, a strategy is developed to allocate the available delineation budget among candidate projects. The models described within this section address only the first level of the decision-making process. The development of resource allocation models is outside the scope of this project.

The first model, as noted earlier, is a cost-benefit model, in that both the benefits and costs are reduced to dollar values in order to compare alternative treatments. The economic criterion chosen for this model is "net-present-worth," which is defined as present worth of "benefits" minus present worth of "costs."

An evaluation of the standard benefit-cost criteria was undertaken to choose a proper economic criterion for the subject study. A careful evaluation of the criteria indicated that all the criteria except the "cost-benefit ratio" are equivalent and would provide identical results if properly utilized. The cost-benefit-ratio method, however, unduly favors those treatments which are least expensive under a decreasing rate of return, which is the case in this analysis, and was therefore deemed inappropriate.

The second model was developed to evaluate treatments which are alterations of treatments whose benefit is known (e.g., thermoplastic line vs. paint line, lines of different gap-to-mark ratio, etc.), and for which the known benefit can be assumed independent of minor treatment alterations. The economic criterion for the cost-analysis model is "net-present-worth of cost."

The appropriate mathematical expressions for the two models are given below:

1. Cost-Benefit Model

Net Present Worth (NPW) = Net Present Worth of Benefit (PWB) - Present Worth of Cost (PWC)

where

$$\left.\begin{aligned} PWB &= \frac{AADT(365)}{10^6} \sum_{n=0}^{N} \left[RAR \times CA \times \left(\frac{1 + v}{1 + i} \right)^n \right] \\ PWC &= \sum_{n=0}^{N} \left[\frac{(TIC)_n}{(1 + i)^n} + \frac{(MC)_n}{(1 + i)^n} \right] + \frac{TC}{(1 + i)^N} \end{aligned}\right] \quad \text{(Model 1)}$$

2. Cost-Analysis Model

$$\left. PWC = \sum_{n=0}^{N} \left[\frac{(TIC)_n}{(1 + i)^n} + \frac{(MC)_n}{(1 + i)^n} \right] + \frac{TC}{(1 + i)^N} \right] \quad \text{(Model 2)}$$

Various terms used in the above models are defined below.

AADT = annual average daily traffic volume in year zero

RAR = estimated reduction in accident rate in year zero

CA = average cost of a roadway accident

v = annual percent increase in traffic volume

i = discount rate

N = analysis period

$(TIC)_n$ = total installed cost in year n

$(MC)_n$ = maintenance cost in year n

TC = terminal cost at the end of analysis period.

The procedure to execute the models is given in the following section.

6.1 Treatment Evaluation

A block flow diagram indicating how the models are executed is presented in Figure 5. The procedure starts with the identification of the highway situation and the candidate treatments which are to be evaluated. For each candidate treatment, appropriate data are compiled. The cost-benefit or cost-analysis model is then utilized to compute NPW or PWC as appropriate. NPW and PWC are indices of economic desirability and are interpreted as follows:

- Treatments with NPW ≥ 0 are all economically desirable; the economic desirability increases with the increase in NPW value.
- The treatment with the least PWC value is most economical.

The execution of the models requires the following sequence of steps:

1. identification of the highway situation
2. explicit enumeration of candidate treatments
3. development of cost data for each candidate treatment
4. estimation of service life for each candidate treatment
5. estimation of benefits associated with each candidate treatment
6. selection of analysis period
7. selection of discount rate

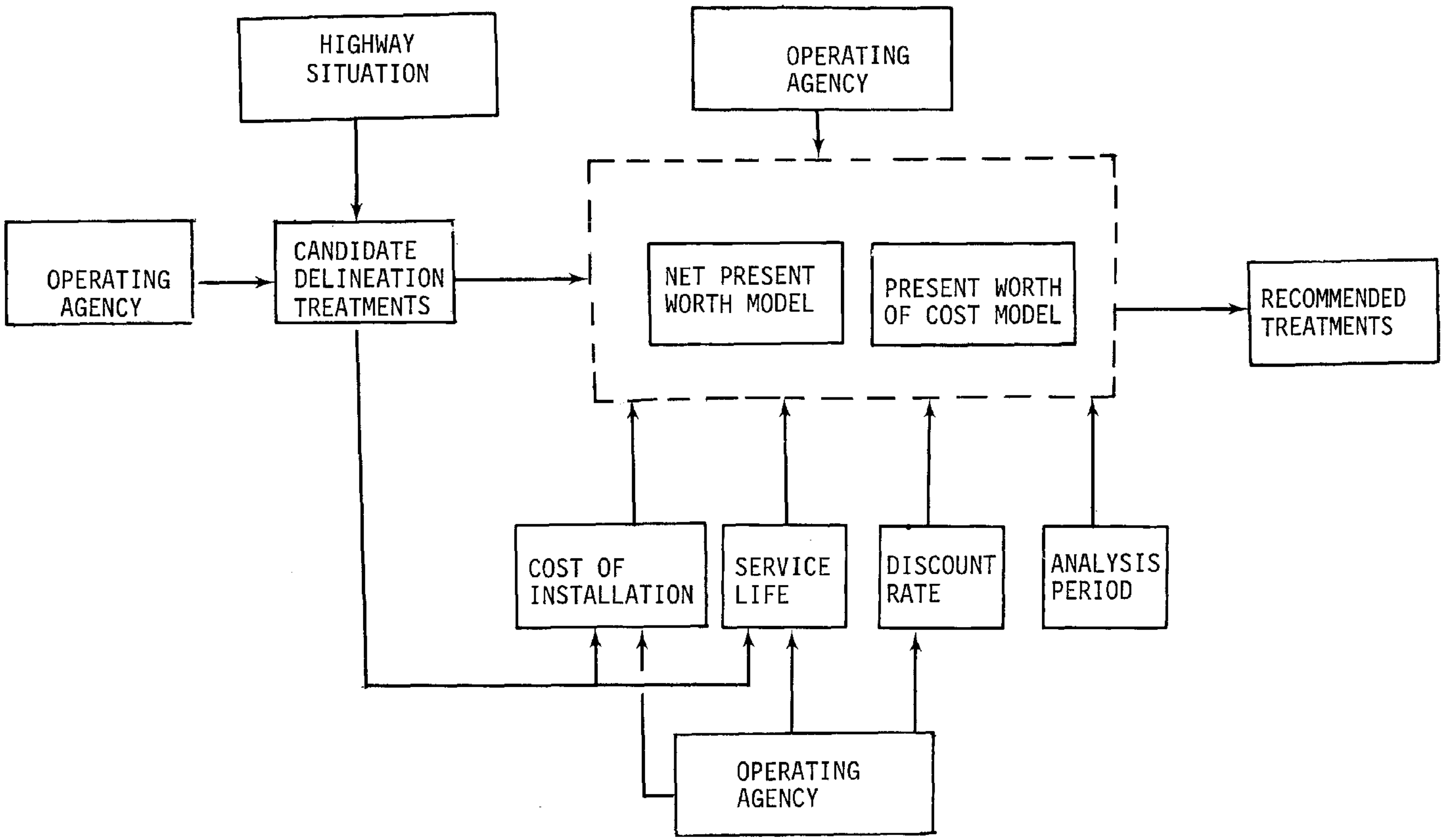


Figure 5. Schematic representation of "Cost-Benefit" and 'Cost' analysis.

8. execution of the models

9. uncertainty and sensitivity analysis.

6.1.1 Identification of the Highway Situation

The first step of the analysis is to identify the highway situation for which the candidate treatments are to be evaluated. For the execution of the models, all highway situations have been classified into two categories:

1. general highway situation

2. localized highway situation.

The first category, general highway situation, is defined as consisting of open highways, and the candidate treatments are always longitudinal pavement markings, such as painted and raised pavement marker lines and post-mounted delineators along the edge of the highway. The localized highway situations are defined as specific situations (e.g., isolated curves, gore areas, etc.), which have localized delineation needs.

6.1.2 Explicit Enumeration of Candidate Treatments

The second step is to identify alternative treatments which are to be evaluated. Current practices in roadway delineation treatments can be found in the State-of-the-Art Report.(7) Treatments contained therein and/or novel delineation systems can be chosen for evaluation.

6.1.3 Development of Cost Data

The models require three cost items; total installation cost of a treatment, the maintenance cost, and terminal cost. These costs are required in the following units:

(a) for general highway situation: cost per mile (km)

(b) for specific highway situations: cost per situation.

6.1.3.1 Total Installation Cost (TIC)

Total installation cost is assumed to consist of the cost of installation (IC) and the cost associated with the traffic interruption caused during the treatment installation operation.

Cost of Installation

This cost item includes all expenses incurred for material, equipment and labor by the agency in the installation of the treatment. Treatment costs, as reported by various agencies and states, are included in Appendix E. Models to compute treatment installation cost for centerline, edgelines and post delineators have been developed and are discussed below.

The installation cost per mile of a pavement stripe is comprised of the following cost items:

- cost of yellow paint (or thermoplastic)
- cost of white paint (or thermoplastic)
- cost of beads
- handling and storage charges for material
- equipment charges
- wages of marking crew
- efficiency factor (ratio of marking time to total time).

With the availability of the above information, the cost of striping per mile of roadway can be computed as in the following example.

1. Detailed marking patterns must first be developed. For example, assume all lines in the pattern have the same width, thickness, and bead application rate. Then, for a two-lane rural road, striping requirements may be as follows:
   - length of white edge line, $L_W = 2 \times 5280 = 10.560$ ft/mile
   - length of yellow centerline, L_y, can be computed as follows:

- length of dashed line $= \frac{\ell m}{m}(1 - p_{np})(5280)$ ft/mile
- length of double line $= 2 \times p_{np} \times 5280$ ft/mile
- hence, total length of yellow line, L_y, would be:

$$L_y = \frac{\ell m}{m}(1 - p_{np})(5280) + 10{,}560(p_{np})$$

where

ℓm = length of the mark in dashed line

m = length of the module (length of mark plus gap)

p_{np} = percentage of no-passing zones.

2. Cost of white paint (or thermoplastic) per mile of application is given by:

$$C_w = \frac{L_w P_w}{R_p}$$

where

C_w = total cost of white paint in dollars

L_w = number of feet of white paint per mile

P_w = price of white paint in dollars per gallon

R_p = application rate in feet per gallon.

3. Cost of yellow paint (or thermoplastic) per mile of application is given by:

$$C_y = \frac{L_y P_y}{R_p}$$

where

C_y = total cost of yellow paint in dollars

L_y = number of feet of yellow paint per mile

P_y = price of yellow paint in dollars per gallon.

4. Cost of glass beads per application, C_b, is given by:

$$C_b = \frac{(L_y + L_w)P_b \cdot R_b}{R_p}$$

where

P_b = price of beads in dollars per pound

R_b = application rate of beads in pounds per gallon.

5. Handling and storage charges for material (C_h): This charge is usually expressed as some proportion of the material cost. For simplicity, it is assumed that this charge is a constant proportion for the two colors of marking materials and the glass beads; if not, a separate computation for each material can be made.

$$C_h = (C_y + C_w + C_b)x_h$$

where

x_h = factor to account for handling and storage of marking materials, expressed as a percentage of the material cost.

6. Labor Cost: Proper accounting for labor cost includes labor cost associated with traffic control (e.g., placement and retrieval of traffic cones where conventional paint is used), as well as marking crew labor cost. The labor cost C_ℓ, is given by:

$$C_\ell = \frac{n_m \cdot w + \sigma(n_m \cdot w)}{R_m} = \frac{(1 + \sigma) \cdot n_m \cdot w}{R_m}$$

where

n_m = number of men in marking operation (crew size)

w = average daily wages of men involved

σ = agency overhead rate, expressed as a proportion of wages

R_m = marking rate in miles per day.

7. Equipment Cost (C_e):

$$C_e = \frac{C_d}{R_m}$$

where

C_d = daily charge for equipment utilized in marking, including any control devices required (a direct estimate of daily charges, including overhead for equipment will be required. This will vary considerably by the type of markings, etc.).

8. Efficiency Factor E: An efficiency factor will be required to provide for loading time, travel time from loading station to marking station (and return), down time due to equipment malfunction, clean-up time, etc. Several states, on being contacted, provided data on the equipment production time.

- For a district in one state, the production time of a conventional paint striper was nearly 60 percent for 1975.

- In another state, where hot paint stripes are used, the production time of hot paint stripers varied from a low of 6 percent to a high of 80 percent. The average over all districts and all stripes was estimated to be nearly 50 percent for 1975.

Hence, the cost of labor and equipment should be divided by the efficiency factor. The true labor and equipment cost then is given by:

$$\frac{C_\ell + C_e}{E}$$

where

E = ratio of marking time to total work time.

NOTE: A way to avoid the explicit consideration of efficiency factor E would be to compute R_m based upon the overall operating history of the equipment. The R_m computed this way would automatically incorporate equipment down time, loading time, etc., into cost computations.

9. Total striping cost then is given by:

$$C_t = (C_y + C_w + C_b)(1 + x_h) + \frac{C_\ell + C_e}{E} \quad .$$

The installation cost per mile of post delineators is calculated as described below:

- cost of posts
- cost of retro-reflective units
- handling and storage charges for material
- equipment charges
- wages of marking crew
- efficiency factor.

With these costs, the cost of installation can be computed as follows:

1. First, the number of post delineators per mile required is computed. This number, n_p, is given by:

$$n_p = \frac{5280}{\delta} + P_e$$

where

δ = spacing in feet

P_e = average number of extra posts per mile required for curves, intersections, guardrails, etc., on segment of highway under consideration.

NOTE: If post delineators are used on both sides of the roadway, a separate calculation should be made for each side, and then the two numbers summed.

2. Cost of posts, p_p, must be known.

3. Cost of retro-reflective units, p_r, must be known.

4. Handling and Storage Charges: This cost can be taken as a percentage of the material cost. Then, this cost, C_h, would be:

$$C_h = (p_p + p_r)x_h$$

where

x_h = factor to account for handling and storage as a percentage of material cost.

5. Equipment Charge: This cost is given by:

$$C_e = \frac{C_d}{R_p}$$

where

C_d = daily charge of equipment utilized in installation of post delineators

R_p = installation rate, in number of posts per day.

6. Labor Cost: Proper accounting for labor cost includes labor costs associated with traffic control (placement of traffic barriers, etc., if required) as well as post delineator installation. The labor cost, C_ℓ, is then given by:

$$C_\ell = \frac{(1 + \sigma)n_m w}{R_p}$$

where

n_m = number of men on installation crew (crew size)

w = average daily wages of men in the crew

σ = agency overhead rate as a proportion of wages

R_p = installation rate, in number of posts per day.

7. Efficiency Factor E: An efficiency factor, E, would be required to provide for loading time, travel time from

loading station to the installation site and back, down time, and clean-up time, etc.

Hence, the cost of equipment and labor should be divided by this efficiency factor. The true labor and equipment cost per mile, then, is given by:

$$\frac{C_\ell + C_e}{E}$$

where

E = ratio of marking time to total time.

NOTE: As noted for the striping operation, a way to avoid explicit consideration of efficiency factor E would be to compute R_p based upon the overall experience in the installation of post delineators. The R_p-computed time in this way would automatically incorporate equipment down time, loading time, etc., into cost computations.

8. The total cost, C_t, per mile of installation is then given by:

$$C_t = n_p(p_p + p_r)(1 + x_h) + \frac{C_\ell + C_e}{E} .$$

Cost Associated With Traffic Interruption

Three specific cost items associated with traffic interruption were identified. These cost items are:

1. Cost of Delay to the Motorist (DC)
2. Additional Running Cost of Motor Vehicles (ARC)
3. Cost Associated with Increased Accident Potential (IAC).

Due to the controversy over the inclusion of these costs in cost-benefit calculations, they are not considered in the delineation guidelines presented in the next section. However, a summary discussion of each cost item is presented below for completeness. A detailed discussion and procedure to estimate each item is given in Appendix E. It is recommended that each operating agency make an independent decision whether or not a particular cost item should be included in the analysis.

Cost of Delay to Motorists (DC)

The cost of delay could be a significant cost item, particularly when high-volume roads are involved. This cost can also substantially vary from treatment to treatment. The cost of delay associated with conventional paint can be shown to be substantially higher than the cost of delay for thermoplastic striping.[1]

The recommended procedure for computing this cost involves computing the cost of delay to both the passenger cars and the commercial vehicles. The total delay cost is then obtained by taking a weighted sum of the two.

Additional Running Cost of Motor Vehicles (ARC)

In addition to delay, running costs for affected vehicles can also increase as a result of traffic interruption. Studies have shown[1][9] that running costs, which include cost of fuel and tire wear, can substantially increase with the cyclic changes in vehicle speed. The installation of some of the delineation treatments can cause enough disruption in traffic, and therefore enough cyclic changes in vehicle speeds, so as to increase the running cost of vehicles by a substantial amount.

Cost of Increased Accident Potential (IAC)

This is perhaps the single most important item of the traffic interruption cost. In response to an inquiry, one engineer noted that the safety of the maintenance crew responsible for treatment installation is an important, and sometimes overriding, consideration in the delineation application decision-making process. It was noted that an important consideration in the state's decision to discontinue the use of paint stripes on its freeway system, in favor of raised pavement marker lines, was crew safety. RPM's, due to their longer life, require less overall crew exposure to traffic and were therefore considered better from the safety standpoint.

The approach suggested is based upon the hypothesis that the true measure of maintenance-related accidents is the number of vehicles exposed to maintenance-caused disruption. This hypothesis is justified if it is assumed that the accident occurrence is a purely random phenomenon - not an altogether unrealistic assumption. A discussion with CALTRANS' engineers has indicated that most of the accidents in California involving maintenance crews have been freak accidents (e.g., no apparent reason for vehicle running over the crew).

6.1.3.2 Maintenance Cost (MC)

This refers to the yearly expenses incurred to maintain a treatment at a desired level of effectiveness. For raised pavement markers, for example, the cost equals the yearly expense incurred by an agency in washing markers and replacing those broken and missing. In the absence of actual data, a fraction of the installed cost may be taken as maintenance cost. For example, for the calculations discussed in the next section, it has been assumed that the maintenance cost for the RPM lines is equal to 10 percent of the installation cost. It should be noted that the basic unit of time in these models is one year, and hence for any treatment whose service life is one year or less, the maintenance cost is taken as zero, since it is assumed to be included in the installed cost of the treatment.

6.1.3.3 Terminal Cost (TC)

This cost element refers to the cost incurred at the end of the analysis period for such work as the removal of worn stripes or markers. Any benefits accrued from a treatment after the analysis period should be converted to their value at the end of analysis period, and the negative of that should also be included in the terminal cost.

6.1.4 Estimation of Service Life

Execution of the cost-benefit model requires that estimates of service life be made for each candidate treatment under the specific traffic and environmental conditions. Although an attempt was made to develop estimation models for service life as a function of such parameters as ADT, snowfall, precipitation, and other factors, the general paucity of data at the state level precluded their development. Therefore, it is recommended that each operating agency utilize its own experience in selecting service life for treatments.

As a guide, however, a summary of the range of service life for various treatment applications is given below:

1. Painted Lines

Service Life	AADT
2 years	500
1 year	1000
0.5 year	>3000

2. RPM

   Service life ranges from 2 to 10 years and is dependent upon AADT, pavement type, application technique, traffic mix, and other factors. The service life is substantially reduced under snowplow conditions and is assumed to be one year.

3. Post-Mounted Delineators

   Data which relate to the service life of post delineators are very sparse. Based upon these few data, it appears that between 10 and 50 percent of the post delineators at a site require replacement each year. This implies a treatment service life of from 2 to 10 years.

6.1.5 Selection of Analysis Period

The analysis period is taken to be an integer number of years which forms a natural cycle for the candidate treatments. With the increased usage of thermoplastic marking materials and raised pavement markers, which have service lives of as much as ten years under favorable conditions, it appears desirable to take the analysis period as ten years. However, if the site requires an overlay or rebuilding sooner, the analysis period will have to be correspondingly reduced. As a general guide, the analysis period can be chosen as the smaller of the following two, but not less than one year.

- projected life of the treatment in years which has the longest life among the candidate treatments
- projected life of the road before it is overlayed of rebuilt.

6.1.6 Benefit Models

The measure of benefit in this study is the reduction in accident rate (RAR) attributable to the installation of specific delineation treatments under specified roadway, traffic, and environmental conditions. The objective of the statistical model development task of this project was the development of models capable of predicting the reduction in accident rate for specific treatment applications. Although the results of this task are fully discussed in Section 5 of this report, a summary is given here for convenience.

Two separate analytical approaches were undertaken. The first produced mean values for the difference in accident rate as a result of the application of a specific treatment. The results of this analysis are summarized in Table 15. Each reference treatment and the new application are listed. For example, under general sites the reference treatment in the first listing is "no treatment at the site," and the new application is "a painted centerline." No distinction is made in the analysis as to the type of marking material or the pattern; although all study sites had treatments which conform to guidelines in the MUTCD. Table 15 also contains confidence bands for the mean. For the purpose of the results reported in the next section, the 90 percent confidence band was utilized exclusively.

The second analysis approach consisted of a regression model development utilizing the reduction in total accident rate as the dependent variable and treatment type, and traffic roadway and environmental parameters as the independent parameters. The results of the regression analyses were discussed in the previous section.

It should be emphasized that for any treatment application not listed in the regression results, no correlation with accident reduction

Table 15. Confidence bands for mean difference in rate for general situation - dependent variable - accident rate.

Highway Situations	Treatment Combination	Exposure Weighting	Mean	Standard Error of the Mean	Pooled Standard Error	Degrees of Freedom	Mean Difference	Confidence Bands P = 60 Deviation from Mean	Confidence Bands P = 60 Band	Confidence Bands P = 90 Deviation from Mean	Confidence Bands P = 90 Band	Confidence Bands P = 95 Deviation from Mean	Confidence Bands P = 95 Band	Confidence Bands P = 99 Deviation from Mean	Confidence Bands P = 99 Band
General Sites	1. No Treatment	13	3.2943	0.511	0.523	13	0.947	± 0.455	0.492	± 0.927	0.020	± 1.131	-0.184	± 1.577	-0.630
	2. Painted CL	121	2.3473	0.114					1.402		1.874		+2.078		+2.524
	2&3. RPM & CL	70	2.2894	0.148	0.168	108	0.961	± 0.142	0.819	± 0.279	0.682	± 0.334	0.627	± 0.442	0.519
	4. CL & Post	88	1.3285	0.080					1.103		1.240		1.295		1.403
Tangent Sites	1. No Treatment	1	3.7740	0	0.152	50	1.536	± 0.129	1.407	± 0.255	1.281	± 0.305	1.231	± 0.407	1.129
	2. Painted CL	50	2.2375	0.152					1.665		1.791		1.841		1.943
	2. Painted CL	41	2.2375	0.169	0.288	21	0.566	± 0.247	0.319	± 0.495	0.071	± 0.599	-0.033	± 0.815	-2.249
	3. RPM & CL	10	1.6714	0.233					0.813		1.061		+1.165		+1.381
	2&3. CL & RPM	28	2.1244	0.199	0.211	34	0.992	± 0.180	0.812	± 0.357	0.635	± 0.430	0.562	± 0.576	0.416
	5. CL & Post	52	1.1323	0.071					1.172		1.349		1.422		1.568
Winding Sites	4. CL & EL	29	2.4925	0.261	0.261	29	0.562	± 0.223	0.339	± 0.443	0.119	± 0.534	0.028	± 0.719	-0.157
	6. CL & EL & Post	2	1.9306	0					0.785		1.005		1.096		+1.281

CL - Center Line
RPM - Raised Pavement Marker
EL - Edgeline
Post - Post Mounted Delineators

existed. Most prominent in this class were all horizontal curve sites where no correlation was found to exist between accident reduction and delineation.

6.1.7 Selection of Discount Rate

In order to compare cash flow occurring at different points in time, it is necessary to convert its value to a common time reference point (generally to present value) by use of an interest rate. The term used for this interest rate is discount rate. A brief discussion of discount rate and recommended values is presented in the following paragraphs.

The need for a discount rate stems from the fact that money has a time value. For example, the present worth of a project is the current value which is foregone to obtain a specified rate of return spread over several years. This rate of return is the discount rate.

Accepting that discounting is appropriate, the relevant question is: What is a proper discount rate? There are no formulas which can be utilized to calculate discount rate and no reference table from which an appropriate rate may be calculated. However, there are certain factors which generally need to be considered in choosing the appropriate discount rate. Some of the important factors are (a) the price that people are currently paying on the money they borrow, (b) the probable earning rate-of-return on private investments, and (c) the current interest rate to be paid on current borrowings by the government. These and other factors, although quite relevant in determining a discount rate, do not provide readily available guidelines on appropriate figures. Discount rates utilized in other studies can, however, be utilized to develop guidelines.

In June 1969 the Office of Management and Budget (OMB) issued its Circular No. A-94 which was revised to its current form in March 1972. The circular sets the discount rate at 10 percent, but adds the further qualification that the present values of benefits and costs are also to be calculated for "any other rate prescribed by or pursuant to law, Executive Order, or other relevant circulars." This provides guidelines currently recommended by the OMB.

In addition to government guidelines, guidelines also exist through the various values used by economists in evaluating different projects. These values generally vary between 7 percent and 15 percent.

In view of these practices and the OMB guidelines, a discount rate of 10 percent is considered appropriate for the present analysis. This value is only advisory, and the operating agency can choose other values as appropriate.

6.1.8 Cost of Accidents

The cost of a traffic accident is composed of property damage costs, injury costs, and death costs. The first two components are calculated in a straightforward manner by using actual cost incurred data from auto repair statistics and hospital statistics, respectively. The cost of a fatality is, on the other hand, highly controversial. The issues surrounding fatality costs have been fully discussed in Appendix D of this report.

In order to develop the guidelines described in the next section, a value of $2,800 was chosen for the average cost of a roadway accident. This value was developed by the National Highway Traffic Safety Administration[10] and represents the weighted average of property damage, injury and fatal accidents, and the costs associated with each.

6.2 Cost Factors

All of the cost factors developed in the sections above can be substituted into the Cost-Benefit Model and the Cost-Analysis Model, as appropriate.

7. DELINEATION GUIDELINES

This section provides a step-by-step example of the application of the cost-benefit model developed in Section 6. Benefits from installing specific delineation treatments are assumed to accrue from reductions in the expected accident rate, as derived from the accident analysis results reported in Section 5. Costs for the various treatments were estimated on the basis of information available from the literature and discussions with state highway engineers.

Also included in this section are figures illustrating relationships among treatment cost, service life, and net present worth of benefits minus costs for a number of treatments applied to tangent and/or winding highways for specific values of AADT. Figures are provided for only those treatment/situation combinations for which the accident analyses gave strong indications of significantly different accident rates. Interpretations of these figures, and observations relevant to investment in delineation treatment service life, climate, marking material type, and certain other intangible factors, are discussed.

7.1 Summary of Accident Analysis Results

A number of different types of analyses or accident rates for various highway situations, under differing delineation treatments, were made and are reported in Section 5 (and in more detail in Appendix C). The t-test and regression analysis results, as summarized in Tables 16 and 17, provide the basis for benefit estimation in this section. The results of the analyses of accident rates at horizontal curves under various delineation treatments were inconclusive, hence, the discussion is limited to tangent and/or winding sections. It is important to note that the less rigorous results of some tests (i.e., significance .20) are used in this section for illustrative purposes. These results were not discussed in detail in Section 5 because of their relatively low level of significance. Information on these results can be found in Appendix C.

Table 16. Mean accident rates.

Ident. No.	Delineation Treatment	Tangent Sites (Acc./mvm)	Winding Sites (Acc./mvm)	General Sites (Acc./mvm)	Horizontal Curve Sites (Acc./mv)
1.	No Treatment	3.7740*†	3.2243	3.2943	1.9594*†
2.	Painted Centerline Only	2.2375	2.4755	2.3473	
3.	RPM Centerline Only	1.6714*	4.1561*†	1.8984	
2.&3.	Painted and/or RPM Centerline Only	2.1244	2.5234	2.2894	1.1713
4.	Any Centerline, with Edgelines	1.9580	2.4925	2.1084	1.3253
5.	Any Centerline, with Post Delineators	1.1323	2.6510	1.3285	1.7696
6.	Any Centerline, with Edgelines and Post Delineators	1.5103*	1.9306*	1.5793*	0.9869

Notes: General Sites = Tangent Sites and Winding Sites Together

Accident rates are for <u>all</u> sites with a given treatment — i.e., no stratification by width, traffic volume, shoulder width, climate, etc.

* Ten or less sites in this category

† Relatively large variance in accident rates among sites

1 mile = 1.609 km (Acc/MVkm)

Table 17. Summary of accident analyses.

Highway Situation Type	Treatment 1	Treatment 2	Difference in Accident Rate (Tr. 1 - Tr. 2)	Statistical Significance of Difference (1)	Test Applied	Item Code (2)
All General Sites	No treatment	Painted centerline only	0.947 Acc./mvm (3)	High	t-test	G1
	Any centerline, only	Any centerline, with post delineators	0.961 "	High	t-test	G2
	Painted centerline only	RPM centerline only	0.449 "	Moderate	t-test	G3
	Any centerline, only	Any centerline, with edgelines	0.181 "	Moderate	t-test	G4
	Any centerline, with edgelines	Any centerline, edgelines, and post delineators	0.529 "	Moderate	t-test	G5
All Tangent Sites	No treatment	Painted centerline only	1.536 "	High	t-test	T1
	Painted centerline only	RPM centerline only	0.556 "	High	t-test	T2
	Any centerline, only	Any centerline, with post delineators	0.992 "	High	t-test	T3
	Any centerline, only	Any centerline, with edgelines	0.166 "	Moderate	t-test	T4
	Any centerline, with edgelines	Any centerline, edgelines, and post delineators	0.448 "	Moderate	t-test	T5
Flat Tangent Sites Only	Painted centerline	RPM centerline	0.335 "	--	Regression	T6
Rolling Tangent Sites Only	No edgelines	Edgelines	0.542 "	--	Regression	T7
Tangent Sites in Arizona and California	Painted centerline	RPM centerline	0.530 "	--	Regression	T8
	No post delineators	Post delineators	0.462 "	--	Regression	T9

Table 17. Summary of accident analysis (continued).

Highway Situation Type	Treatment 1	Treatment 2	Difference in Accident Rate (Tr.1 - Tr.2)	Statistical Significance of Difference (1)	Test Applied	Item Code (2)
All Winding Sites	Any centerline, with edgelines	Any centerline, edgelines, and post delineators	0.562 Acc/mvm	High	t-test	W1
	No treatment	Painted centerline only	0.749 "	Moderate	t-test	W2
	No treatment	Any centerline	0.891 "	--	Regression	W3(4)
Winding Sites on Federal Aid Secondary System	No treatment	Any centerline	0.951 "	--	Regression	W4(4)
Winding Sites in CT, MD, OH and VA	No edgelines	Edgelines	-2.486 "	Neg.	Regression	W5
All Horizontal Curves	No treatment	Any centerline, only	0.788 Acc/mv	Moderate	t-test	HC1
	Any centerline, with edgelines	Any centerline, edgelines, and post delineators	0.338 "	Moderate	t-test	HC2
Horizontal Curves in GA and LA	No post delineators	Post delineators	1.310 "	--	Regression	HC3
Horizontal Curves on Federal Air Primary System	No edgelines	Edgelines	-1.284 "	Neg.	Regression	HC4

(1) For t-test: High indicates level of significance less than 0.05 (one-tail test)
Moderate indicates level of significance between 0.20 and 0.05 (one-tail test)
For Regression: From regression models with F = 2.70; level of significance 0.10 (approx.) or less
Neg. indicates higher accident rate for sites with stronger delineation

(2) .Identification codes in this column are used to identify the specific test and/or result discussed in the text.

(3) 1 mile = 1.609 km (Acc/MVkm)

(4) Extremely low R^2 (<.40)

Table 16 indicates the mean accident rates for combinations of delineation treatments and highway situations considered in this study. It is important to note that the accident rates given are for all sites within a given treatment/situation class. It may be then, that the differences in accident rates are attributable to differences in climate, traffic volume, roadway width, etc., associated with particular delineation/situation combinations, rather than solely to changes in delineation. For example, at tangent sites, it would appear that sites having centerlines, edgelines, and post delineators, have higher accident rates than those with centerlines and post delineators only - i.e., the addition of edgelines increases the accident rate. (This observation would be contradicted at winding sites and horizontal curve sites.) Even though data were obtained for nearly 13,000 accidents at 514 sites in ten states, the sample sizes within each "cell" defined by delineation treatment, highway situation, geometrics (roadway width, shoulder width, etc.), and environmental factors are too small for a meaningful analysis of differences in accident rates between two single cells.

Table 17 summarizes the results of the analyses of the accident rates for various treatment/situation combinations. Only those differences found to be statistically signficant are shown.

For general, tangent, and winding sites, the following t-Test comparisons were made, in order:

1. painted centerline versus no treatment
2. RPM centerline versus painted centerline
3. any centerline (painted and/or RPM) plus edgeline versus any centerline only
4. any centerline and post delineators versus any centerline
5. any centerline, edgelines, and post delineators versus any centerline plus edgelines.

For horizontal curves the tests were, in order:

1. any centerline (painted and/or RPM) versus no treatment

2. any centerline and edgelines versus any centerline

3. any centerline and post delineators versus any centerline

4. any centerline, edgelines, and post delineators versus any centerline and edgelines.

As can be seen, each comparison is between a base treatment and another that is more expensive and intuitively stronger. Other combinations were not assessed. Further, only one-tail tests were made - i.e., if the stronger treatment had a higher accident rate, the comparison will not appear in Table 17.

In the regression analyses, the delineation factors investigated were usually "presence versus absence" of some specific treatment (e.g., edgelines, post delineators, any centerline), but some of the models also differentiated between painted centerlines and RPM centerlines. The models were run at two levels of rigor; only the results from the more rigorous models are shown in Table 17. Due to the nature of the regression analysis, indications of counter-productive delineation treatments are possible. For instance, items W5 and HC4 indicate that certain subclassifications of sites have higher accident rates when edgelines are present than when they are not. This is not so disturbing in itself, as a number of reasons for such counter-intuititve results can be put forth - small sample sizes within the subcategories, particular delineation policies within the states involved, etc. However, one must attribute these same weaknesses to the positive results and interpret them with equal caution.

Even so, the following observations seem justified.

For continuous sections (tangent and/or winding sites):

1. Highways with centerlines have lower accident rates than those with no treatment at all.

2. Highways with raised pavement marker centerlines have lower accident rates than those with painted centerlines.

3. Highways with post delineators have lower accident rates than those without post delineators (in the presence <u>or</u> absence of edgelines).

4. Results of analyses of accident rates at sites with edgelines versus those without edgelines are mixed.

5. In general, reductions in accident rates, where stronger delineation treatments are employed, are more clearly indicated for tangent sections of roadway than for winding sections.

<u>For isolated horizontal curves</u>:

1. The results of the analyses are not as definitive as for continuous sections.

2. There is some indication that sites with post delineators have lower accident rates than sites without post delineators. (However, the data in Table 16 and some of the less rigourous models not included in Table 17 indicate the opposite.

3. Accident rates appear to be somewhat lower at horizontal curves with centerlines than at curves with no delineation treatment.

Tables 16 and 17 contain information useful in the estimation of benefits to be derived from the installation of particular delineation treatments. At a minimum, these tables provide a starting point for estimates of accident rate reductions. Particular agencies may well have accident rate data more appropriate to highways in their jurisdictions, however, and they should use their own data where available.

7.2 Cost-Benefit Computations and Results

In order to determine the economic desirability of installing various delineation treatments under specific roadway and traffic conditions, the cost-benefit model described in Section 6 was exercised for representative parametric values.

The cost-benefit model and the ranges of parametric values considered are given in Section 7.2.1; an illustrative example of the application of the model is given in Section 7.2.2, and results derived from the application of the model are presented in Section 7.2.3.

7.2.1 Cost-Benefit Model and Ranges of Parametric Values

The development of the cost-benefit model, and the rationale for the particular form selected are described in Section 6. For convenience, the model itself is repeated in Figure 6. (See Section 6 for a detailed discussion of each of the individual terms.)

The results of several analyses utilizing the cost-benefit model are presented in Section 7.2.3. The calculations were carried out parametrically - i.e., representative ranges of values for all costs, service lives, and traffic parameters for each selected treatment application were chosen, and are indicated in Table 18. This approach was desirable because (1) the available data for treatment installation costs, maintenance costs, and service lives were too uncertain to permit selection of specific values for the parameters, and (2) having costs and service life factors as parameters rather than as fixed values provide the potential user with a more flexible tool.

The AADT classes were chosen as representative of the sites included in the data base. There were relatively few sites with an AADT less than 500 vehicles per day. Delineation treatments were minimal or nonexistent for these sites, and the variation in accident experience over short sections of these types of roads was very high. Hence, traffic volumes less than 500 vehicles per day were not included in the cost-benefit analysis - any extrapolation of results to this lower range of AADT's should be made with caution. Although all sites included in the data base had traffic volumes of less than 5,000 vehicles per day, the analyses were extrapolated to 7,000 vehicles per day on the assumption that accident rates, environmental factors, and delineation treatment effectiveness are relatively constant over this range.

The cost-benefit model includes a factor for traffic growth, (v). The inclusion of a 5% annual increase in AADT will always result in higher net benefits than if no growth is assumed. Thus, all the curves

Cost-Benefit Model

Net Present Worth = NPW = PWB - PWC

$$PWB = \frac{AADT\ (365)}{10^6} \sum_{n=0}^{N} \left[RAR \times CA \times \left(\frac{1 + v}{1 + i}\right)^n \right]$$

$$PWC = \sum_{n=0}^{N} \left[\frac{(TIC)_n}{(1 + i)^n} + \frac{(MC)_n}{(1 + i)^n} \right] + \frac{TC}{(1 + i)^N}$$

(Model 1)

Cost Analysis Model

Present Worth of Cost = PWC

where

$$PWC = \sum_{n=0}^{N} \left[\frac{(TIC)_n}{(1 + i)^n} + \frac{(MC)_n}{(1 + i)^n} \right] + \frac{TC}{(1 + i)^N}$$

(Model 2)

Various terms used in the above models are defined below.

RAR = estimated reduction in accident rate in year zero

CA = Cost of Accident (NHTSA average - $2,800)

v = annual percent increase in traffic volume

i = discount rate

N = analysis period

$(TIC)_n$ = total installation cost in year n

$(MC)_n$ = maintenance cost in year n

TC = terminal cost at the end of analysis period

Figure 6. The cost-benefit model.

Table 18. Ranges of values for costs, service lives and traffic parameters for various delineation treatments.

Treatment	AADT (Veh./day)	Annual Increase in AADT (%)	Service Life (Years)	Installation Cost ($/mi.)	Maintenance Cost ($/mi.)	Discount Rate (%)	Average Cost of Accident ($)
Painted Centerline	500	0	0.5	50	0	10	2,800
	1,000	5	1	100			
	3,000		2	150			
	5,000		(See Note 1)				
RPM Centerline	500	0	1	2,500	10% of installation cost, per year	10	2,800
	1,000	5	2	3,500			
	3,000		5	4,500			
	5,000		10				
	7,000						
Painted Edgelines	500	0	1	100	0	10	2,800
	1,000	5	2	150			
	3,000		5	200			
	5,000						
	7,000						
Post Delineators	500	0	2	223	36	10	2,800
	1,000	5	5	445	72		
	3,000		10				
	5,000			(See Note 3)	(See Note 4)		
	7,000		(See Note 2)				

Notes:

Table 18. Ranges of values for costs, service lives and traffic parameters for various delineation treatments (continued).

Notes:

1. AADT and Service Life related as follows:

AADT	Life (Yr.)
<500	2
1,000	1
>3,000	0.5

2. Service Life of Post Delineators:

Annual Loss	Life (Yr.)
50%	2
20%	5
10%	10

3. Installation Cost for Post Delineators:

65 delineators/mi. @ \$3.44 = \$233/mi.
130 delineators/mi. @ \$3.44 = \$445/mi.

4. Maintenance Cost for Post Delineators:

65 delineators/mi. @ \$0.55 = \$ 36/mi.
130 delineators/mi. @ \$0.55 = \$ 72/mi.

1 mile = 1.609 km

given in this report are based on the more conservative approach - i.e., no increase in the traffic volumes within the analysis period.

Estimates of treatment service lives were extracted from state highway department records and available published literature. More specific values are infeasible because of wide variations in the experiences and policies of various highway agencies. An attempt was made to select a range including the upper and lower limits of expected service life so that the results of the analyses would cover most anticipated application situations.

Total installation costs (TIC) for all the treatments are per mile (1 mile = 1.609 km) estimates and are based on delineation patterns contained within the MUTCD. However, the range of TIC was selected such that novel and other non-standard patterns are expected to be covered. For more details on the computation of installation costs, see Section 6.1.3.

Treatment maintenance cost estimates for raised pavement markers and post delineators are based on very limited data, but they are felt to be sufficiently precise for exercise of the cost-benefit model. Since painted lines are maintained by replacement only, maintenance costs for these treatments are assumed to be equal to zero. (Appendix E contains detailed information and data relative to the service lives and costs of delineation treatments.)

A discount rate of 10% and an average cost of $2,800 were used in all calculations reported in this section. The rationale for these values is given in Section 6.1.7, 6.1.8, and Appendix D. They are believed to be conservative for the development of "net present worth of benefits minus costs" for the delineation treatments studied.

The differences in accident rates for various treatments indicated in Tables 16 and 17, and the parameter values shown in Table 18, are used in the example in Section 7.2.2, and as the basis for all figures in Section 7.2.3. The cost-benefit model is flexible, however, and the individual user should use his own best estimate for each parameter -

utilizing the values in Tables 16, 17, and 18 only where more pertinent date do not exist.

7.2.2 Example Calculation Using the Cost-Benefit Model

Presented in this section is an example illustrating the application of the cost-benefit model to determine the economic desirability of substituting a raised pavement marker centerline for a painted centerline on tangent and winding sections of highways. (It is assumed that painted centerlines would no longer be required, and the cost of repainting would no longer be incurred.)

The parameter values to be used in the example are:

AADT = 3,000 vehicles per day

N = 10 years

SL_p = 0.5 year (painted centerlines)

SL_r = 10 years (RPM centerlines)

RAR = 0.449 Acc/MVM (Acc/MVkm) (from Item G3 in Table 17)

CA = \$2,800

v = 0 (assume no traffic growth)

i = 10%

TIC_r = \$2,500 per mile (1.609 km)

TIC_p = \$100 per mile (1.609 km)

MC_r = \$250

MC_p = 0

TC = 0

The present worth of benefits (PWB) from the expected reduction in accident experience over the 10-year analysis period is:

$$PWB = \frac{AADT(365)}{10^6} \times \sum_{n=0}^{N} \left[RAR \times CA \times \left(\frac{1+v}{1+i}\right)^n \right]$$

$$= \frac{(3{,}000)\ (365)}{10^6} \times \sum_{n=1}^{N} \left[0.449 \times \$2{,}800 \times \left(\frac{1 + 0}{1 + 0.10} \right)^n \right]$$

$$= 1.095 \times 0.449 \times \$2{,}800 \times 6.1446$$

$$= \$8{,}459$$ (see point labeled (PWB) on Figure 7)

in the more general form of the model, the symbol $\sum_{n=0}^{N}$ is used to indicate the time period beginning with treatment installation (n=0) and terminates at the end of the service life at 10 years. In the computational form of the model, however, the symbol becomes $\sum_{n=1}^{N}$, since there are 10 discrete years for accident reduction benefits - years 1 (time of installation to one year later), 2, 3, 4 . . . , 10 (the last complete year in the analysis period - i.e., there are no accident benefits at the end of year "0"). Using n from 1 to 10 rather than 0 to 9 indicates that benefits from the reduction in accidents are valued at the end of the year under consideration rather than at the beginning. This assumption is consistent with a subsequent assumption that maintenance costs are incurred at the end of the year.

For an RPM installation costing \$2,500, with an annual maintenance cost of \$250, and no terminal value, the present worth of all costs over the 10-year analysis period, PWC_r, is:

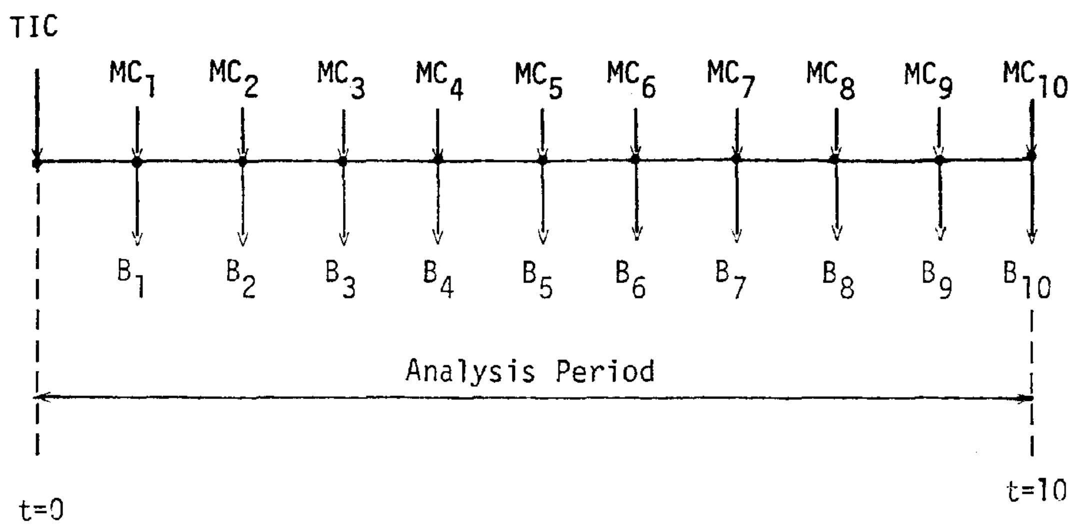
$$PWC_r = \sum_{n=0}^{N} \left[\frac{\left(TIC_r\right)_n}{(1 + i)^n} + \frac{\left(MC_r\right)_n}{(1 + i)^n} \right] + \frac{TC}{(1 + i)^N}$$

$$= \left[\$2{,}500 + \sum_{n=1}^{10} \left(\frac{\$250_n}{(1 + 0.1)^n} \right) \right] + \frac{0}{(1 + 0.1)^{10}}$$

$$= \$2{,}500 + (\$250)(6.1446) + 0$$

$$= \$4{,}036$$

(Note that TIC_r will be $2,500 for n=0, $0 for all other values of n, and MC will be $250 for all values of n from 1 to 10. The following cash-flow diagram tends to clarify these relationships.)



Since the cost of repainting the centerline will be "saved," the present worth of the annual repainting costs must be subtracted from the present worth of costs of the RPM treatment. If the annual cost of painting is assumed to be $200 per mile (1.609 km) (two paintings per year at $100 per mile (1.609 km)), with no annual maintenance charge, (PWC_p) becomes:

$$PWC_p = \$200 + \$200(5.7590) = \$1,352$$

(This calculation assumes a $200 cost at t=0, 1, 2 . . . ,9 - i.e., annual painting costs are committed at the beginning of each year.) Hence, (PWC) for changing from a painted centerline to a RPM centerline is $4,036 - $1,352 = $2,684.

Under the conditions stated, the net present worth (NPW) for this substitute installation is:

$$\begin{aligned} NPW &= PWB - PWC \\ &= \$8,459 - \$2,684 \\ &= \$5,775 \end{aligned}$$

(See Figure 7)

If an installation cost of \$3,500 for RMP is assumed:

$PWB = \$8,459$ (not affected)

$PWC_r = \$3,500 + \$350\ (6.1446) = \$5,651$

$PWC_p = \$1,352$ (not affected)

$NPW = PWB = (PWC_r - PWC_p)$

$NPW = \$4,160$ (See Figure 7)

If an installation cost of \$4,500 is assumed, the NPW becomes \$2,546 (see Figure 7).

Lines indicating the NPW - TIC_r relationship for service lives of 5, 2, and 1 years are also shown in Figure 7. (The lines converge to a value of \$9,473, the total of PWB and PWC_p.)

In preparing charts similar to Figure 7, it is essential that the same analysis period be used if direct comparisons of alternative treatments are to be made. This necessitates the use of two cycles of computations if a 5-year service life is assumed. (PWB and PWC_p will remain the same, but the computations for PWC_r must now include the present worth of the original installation and a second installation five years later - i.e., the $\frac{(TIC_r)_n}{(1 + i)^n}$ term must be evaluated for both n=0 and n=5.

7.2.3 Results and Conclusions from Application of the Cost-Benefit Model

Considering the parameter values cited in the example calculation, and shown in Figure 7 (and the attendant assumptions), the following conclusions can be drawn:

1. Painted centerlines should be replaced by RPM centerlines where a service life of five years or more can be obtained and AADT exceeds 3,000.

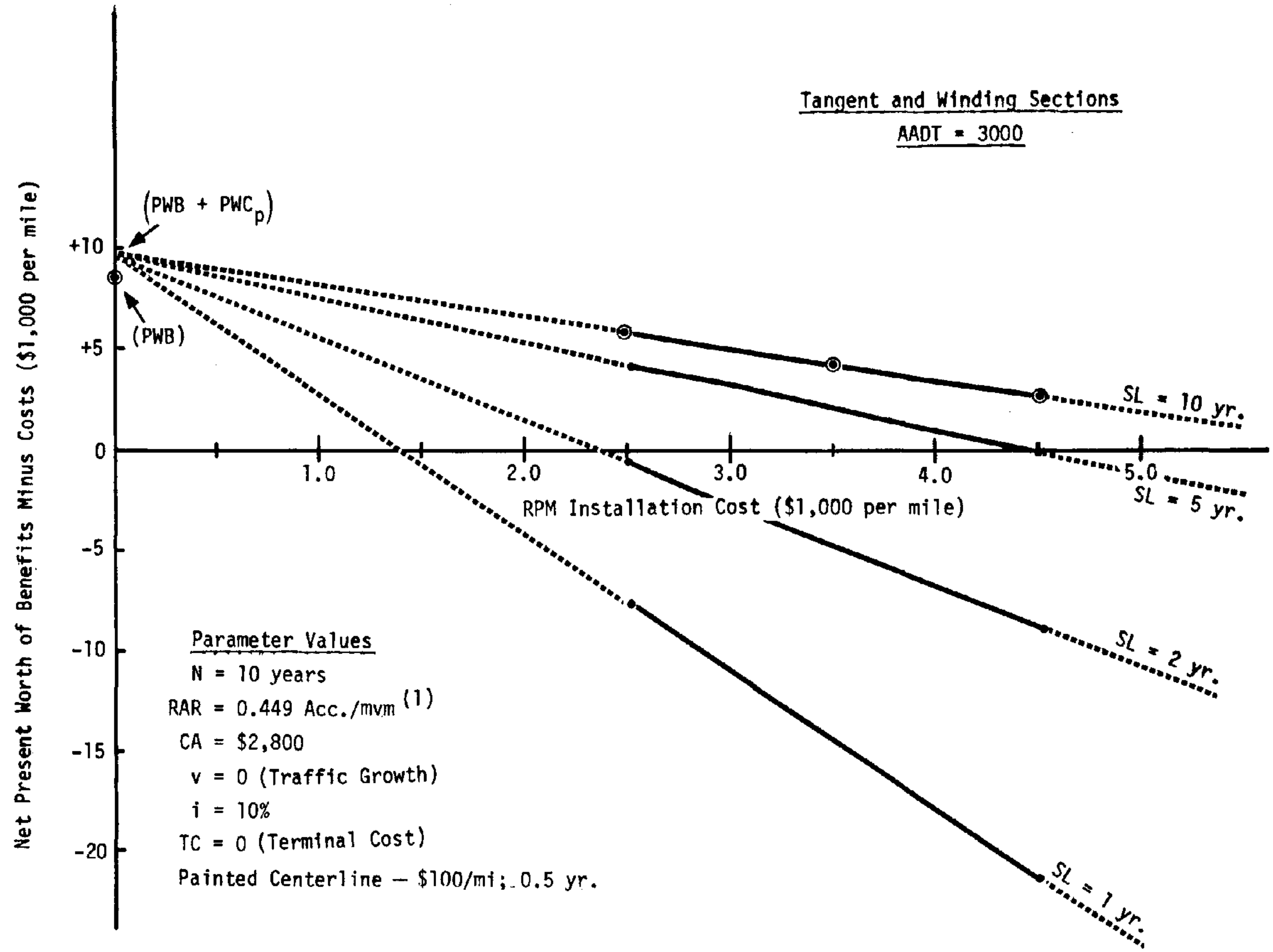


Figure 7. Cost-benefit relationships; replacement of painted centerline by RPM centerline; AADT = 3000.

(1) 1 mile = 1.609 km

2. Where the service life of raised pavement markers is expected to be less than two years, painted centerlines should be used.

3. RPM treatments with service lives between two and five years may be desirable - depending on the installation cost. (Interpolations for other service lives will be necessary.)

4. The cost-benefit relationship is relatively insensitive to the cost of painted centerlines. Reducing the cost per mile per application from $100 to $50 would drop all lines in Figure 7 by one-half the distance between the points marked (PWB) and (PWB + PWC_p).

Figure 8 shows the same basic relationships for highways with an AADT of 1,000 vehicles per day. The present worth of costs for the raised pavement marker treatment will remain the same. The present worth of costs for the painted centerline will be somewhat reduced since only one painting per year will be required. (As mentioned earlier, this cost is a relatively minor factor in the relationship.) The present worth of benefits, however, will be reduced by one-third - in direct proportion to traffic volume, since the rate of accident reduction is assumed to remain constant over the volume range considered in this study.

Figure 8 indicates that raised pavement marker centerlines are not justified for tangent and winding highways with traffic volumes of 1,000 vehicles per day - the justifiable installation costs are only about $2,200 per mile (1.609 km) for RPM's with service lives of ten years. (Table 18 indicates minimum cost for a raised pavement marker centerline is $2,500 per mile (1.609 km), and the maximum life is ten years.)

It is clear that this treatment is very sensitive to traffic volume - an expensive installation ($4,000 per mile (1.609 km)) is acceptable (if the service life is five years or more) for highways with an AADT of 3,000 or more, but is never justified when the AADT is less than 1,000.

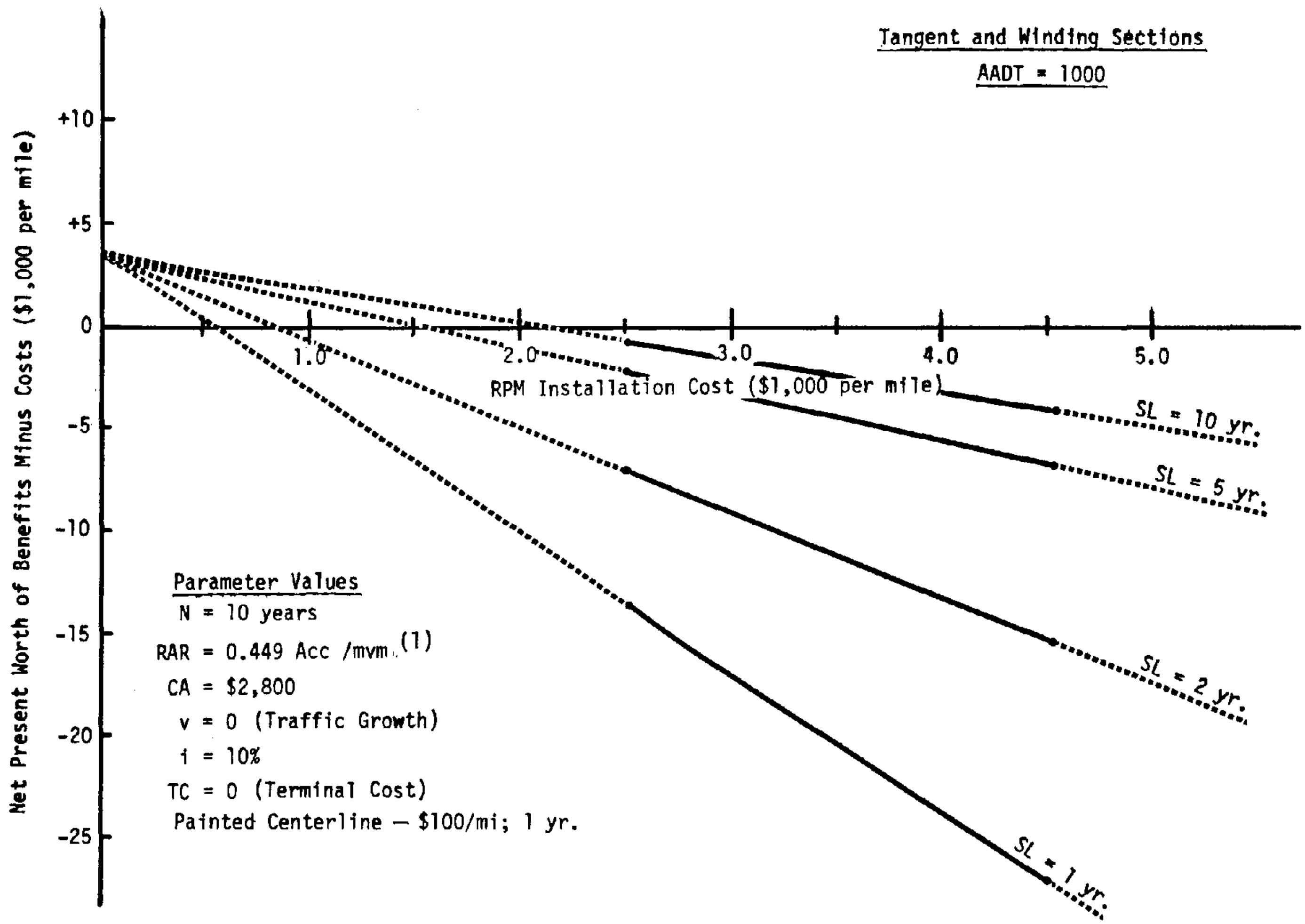


Figure 8. Cost-benefit relationships; replacement of painted centerline by RPM centerline; AADT = 1000.

(1) 1 mile - 1.609 km

Figure 9 indicates the relationships under an AADT of 5,000 vehicles per day. Note that installations of raised pavement markers with expected service lives of three years or more will be justified on these highways. If an effective RPM centerline can be installed for less than $3,700 per mile (1.609 km), installations with services lives of as little as two years can be justified. (On the other hand, even at this AADT it is infeasible to make annual RPM installations in areas of the country where snow plows remove the raised pavement markers.)

In general, it can be seen that the decision as to replacement of painted centerlines with raised pavement markers is very sensitive to the expected service life of the markers and traffic volume. Within the ranges considered in this study, the costs of installation of RMP's and the costs of painting the centerlines are not critical.

Figures 10, 11, and 12 show the cost-benefit relationships for the addition of painted edgelines. These figures are based on an expected reduction of 0.181 Acc/MVM (Acc/MVkm) after addition of the edgelines. (This value is obtained from Item G4 in Table 17, and is applicable to all tangent and winding sections of highway included in the data base.)

Examination of Figures 10, 11, and 12 indicates that edgelines with service lives of five years will be justified on all highways with an AADT of 500 vehicles per day or more. In fact, if the service life is two years, the edgelines are cost-justified when the application cost is less than $165 per mile (1.609 km). When the AADT is 1,000 vehicles per day, edgelines with service lives of one year are justified if they can be installed for $170 or less. If the service life is two years or more, they will be justified for all costs within the range specified in Table 18. At AADT's of 3,000, edgelines are clearly justified for all combinations of cost and service life listed in Table 18.

Figures 13 and 14 provide information on the cost-benefit relationships for the installation of post delineators on tangent and winding sections of highway. The reduction in accident rate,

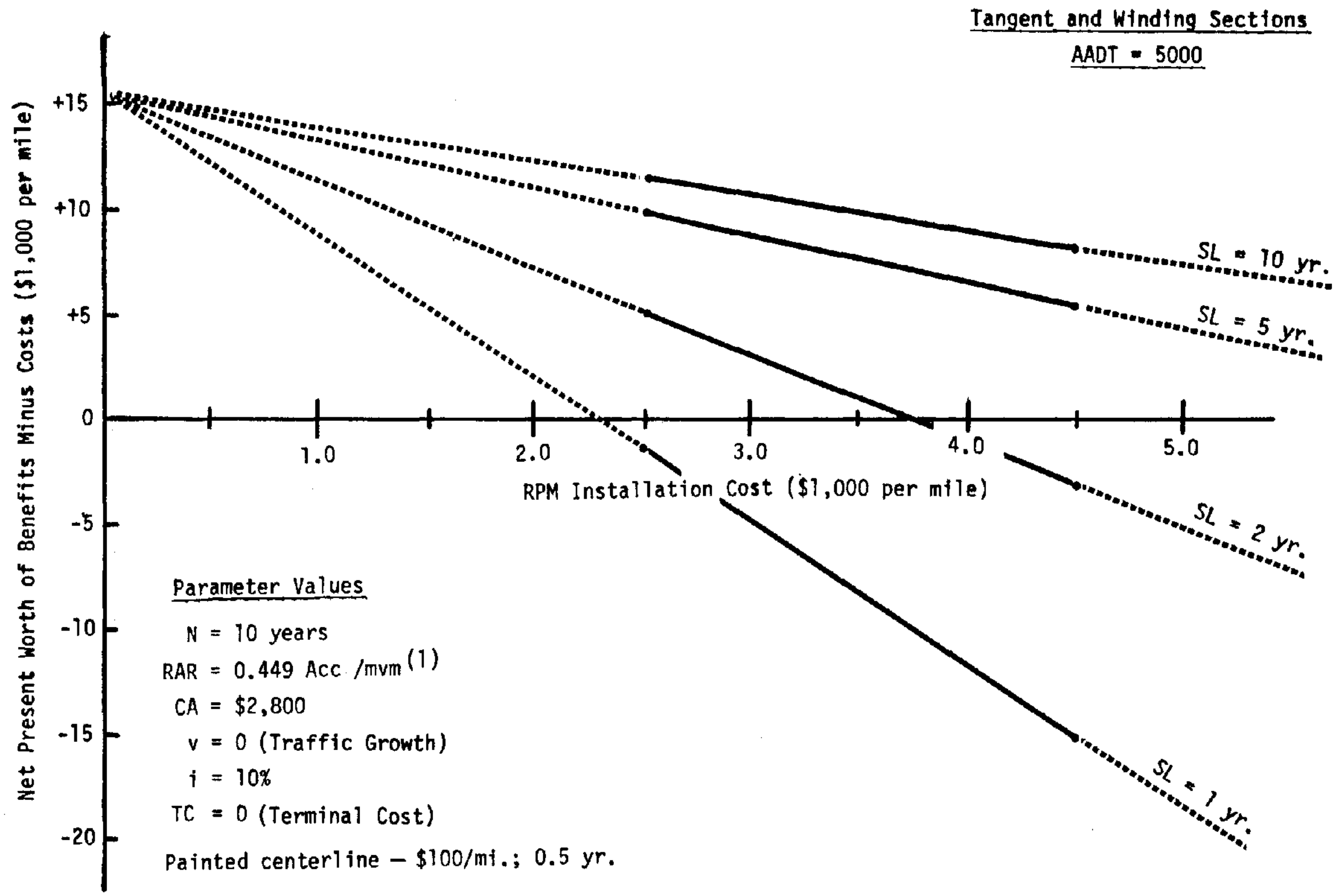


Figure 9. Cost-benefit relationships; replacement of painted centerlines by RPM centerline; AADT = 5000.

(1) 1 mile = 1.609 km

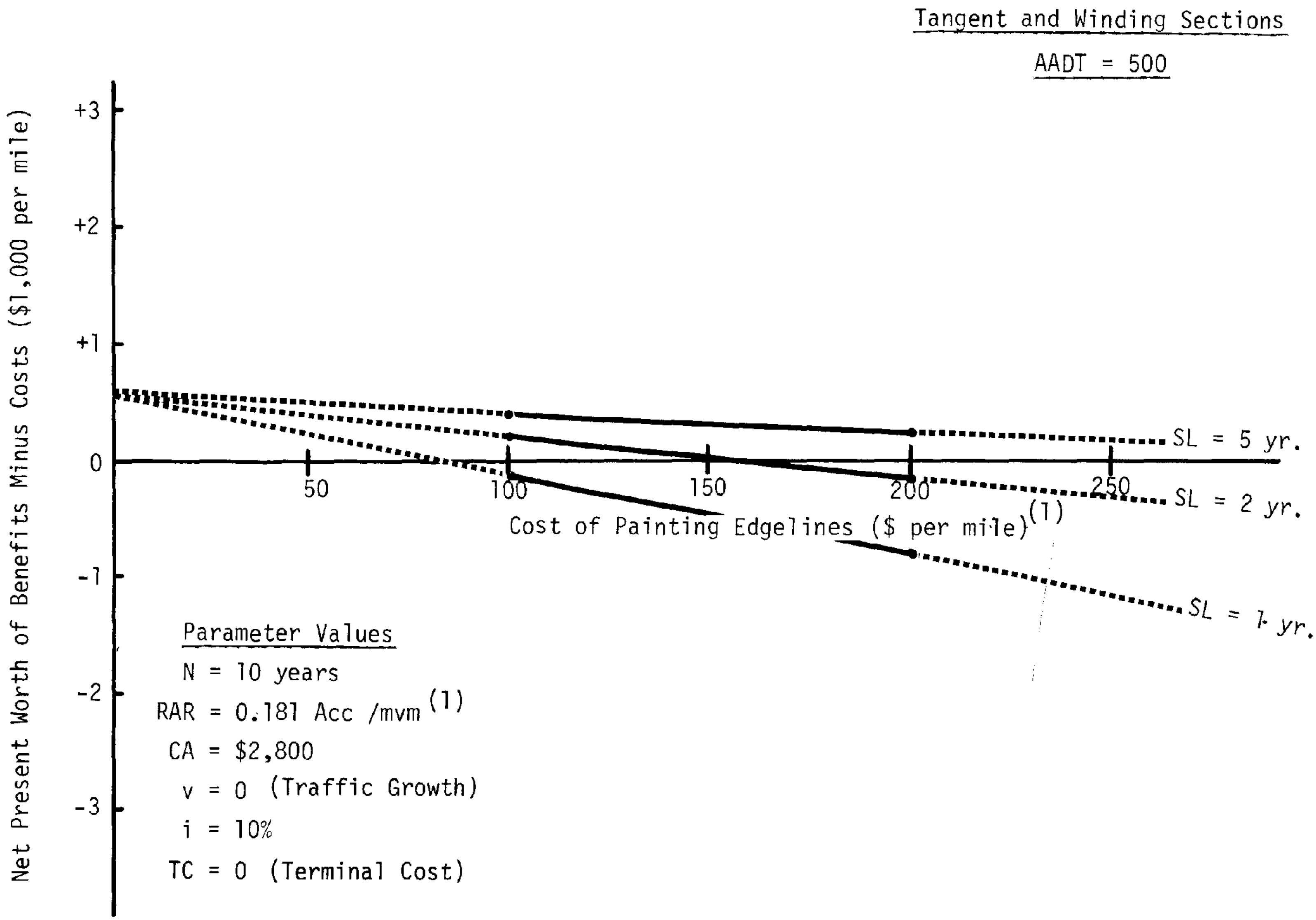


Figure 10. Cost-Benfit relationships; addition of painted edgelines; AADT = 500

(1) 1 mile = 1.609 km

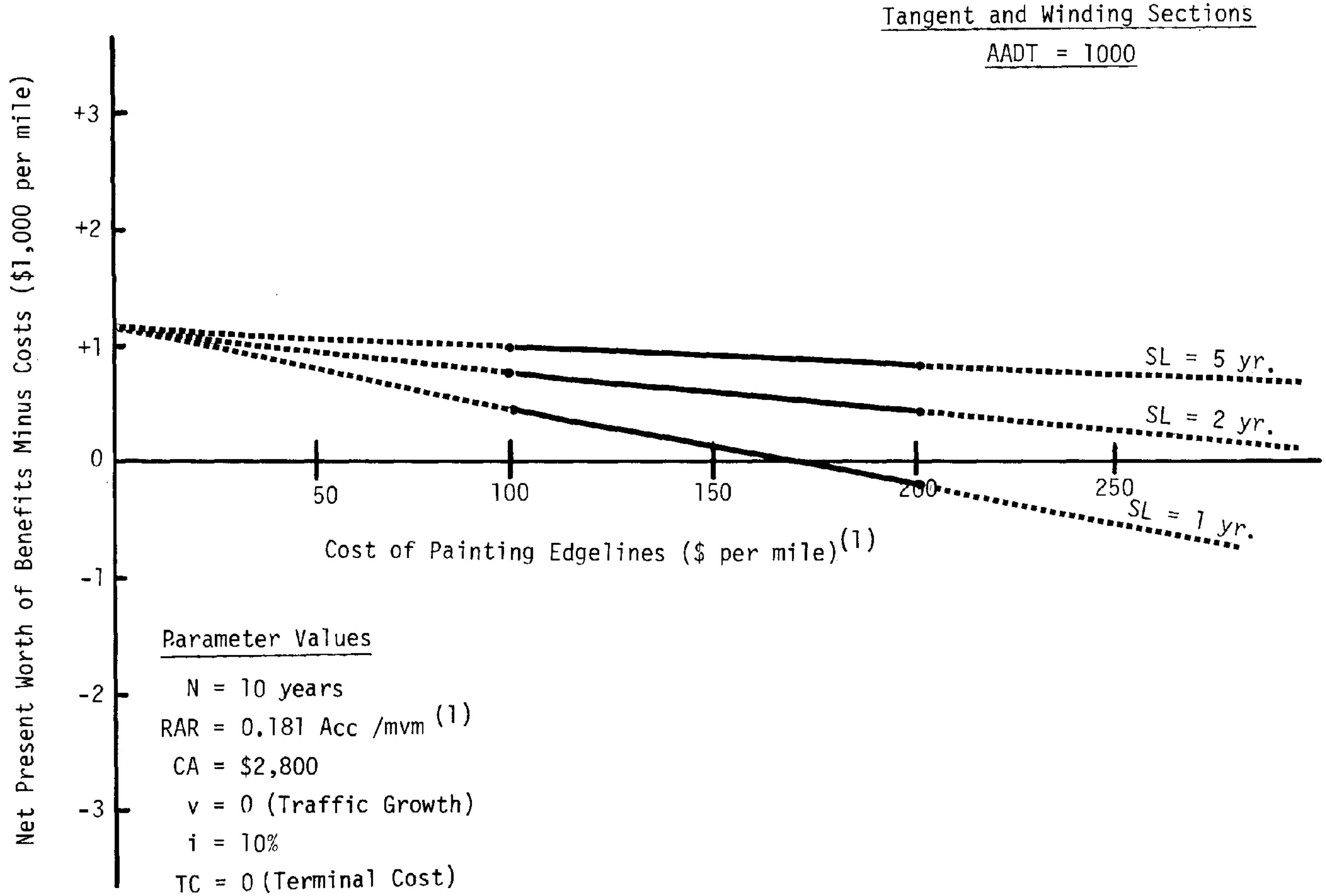


Figure 11. Cost-benefit relationships; addition of painted edgelines; AADT = 1000.

(1) 1 mile = 1.609 km

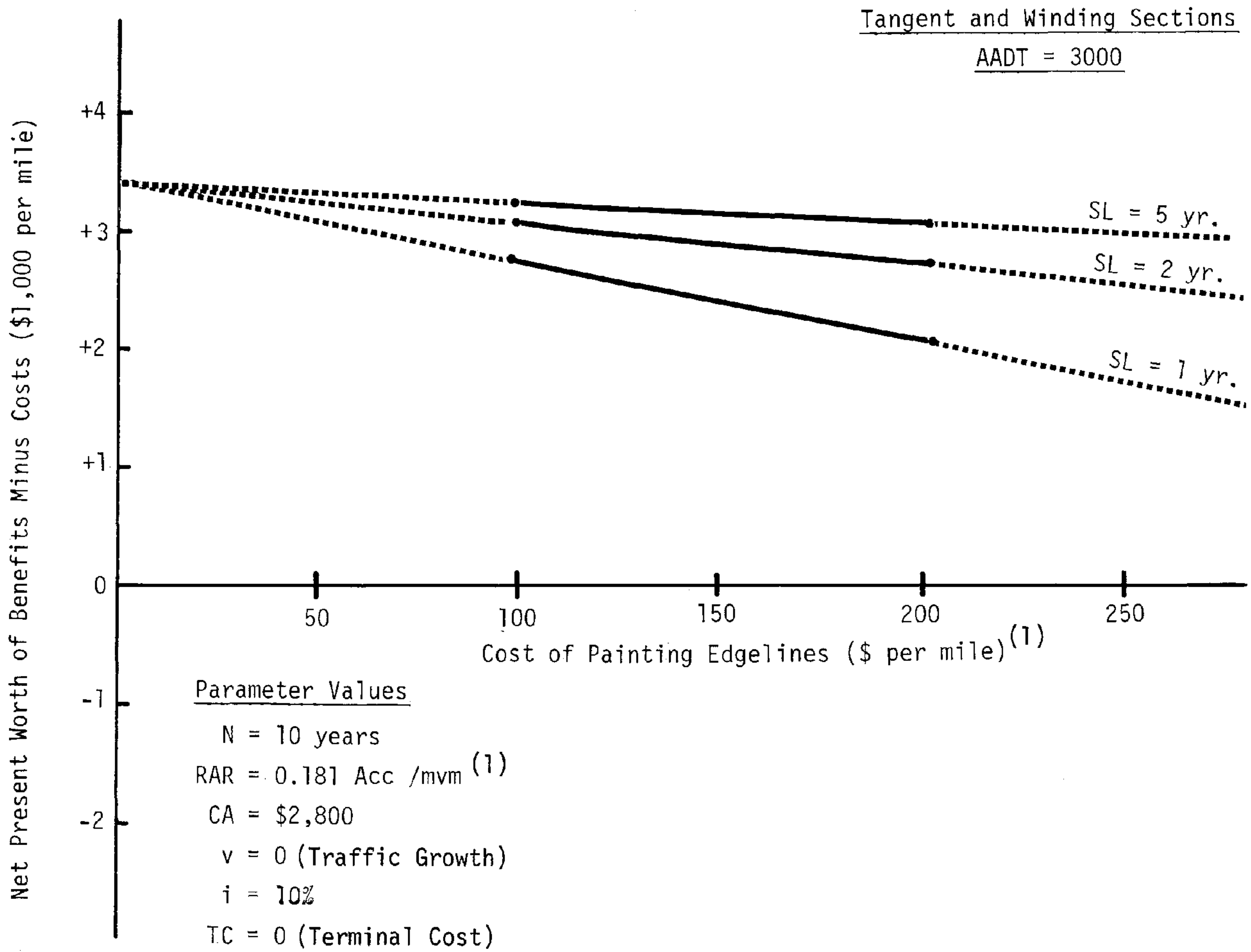


Figure 12. Cost-benefit relationships; addition of painted edgelines; AADT = 3000.

(1) 1 mile = 1.609 km

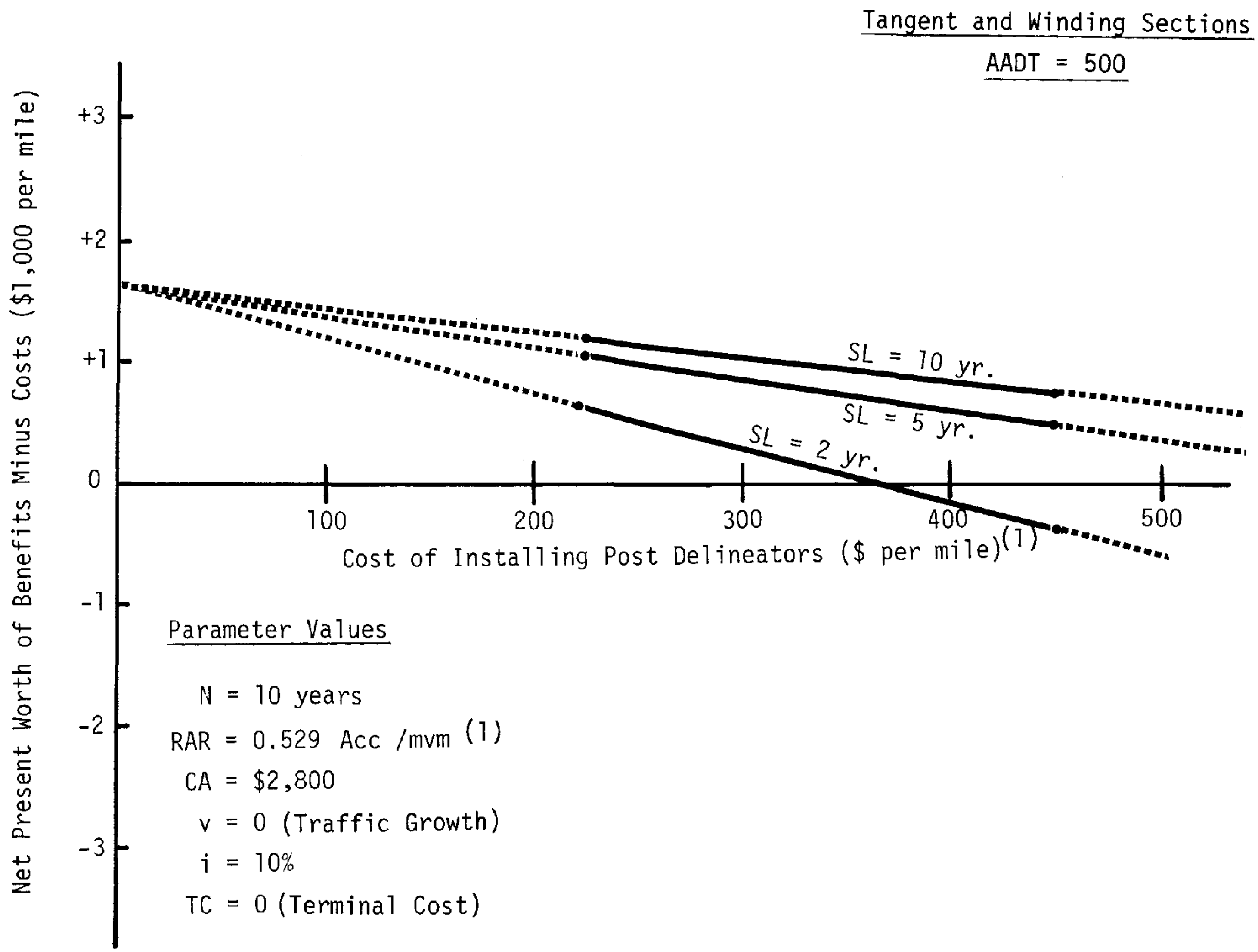


Figure 13. Cost-benefit relationships; installation of post delineators; AADT = 500.

(1) 1 mile = 1.609 km

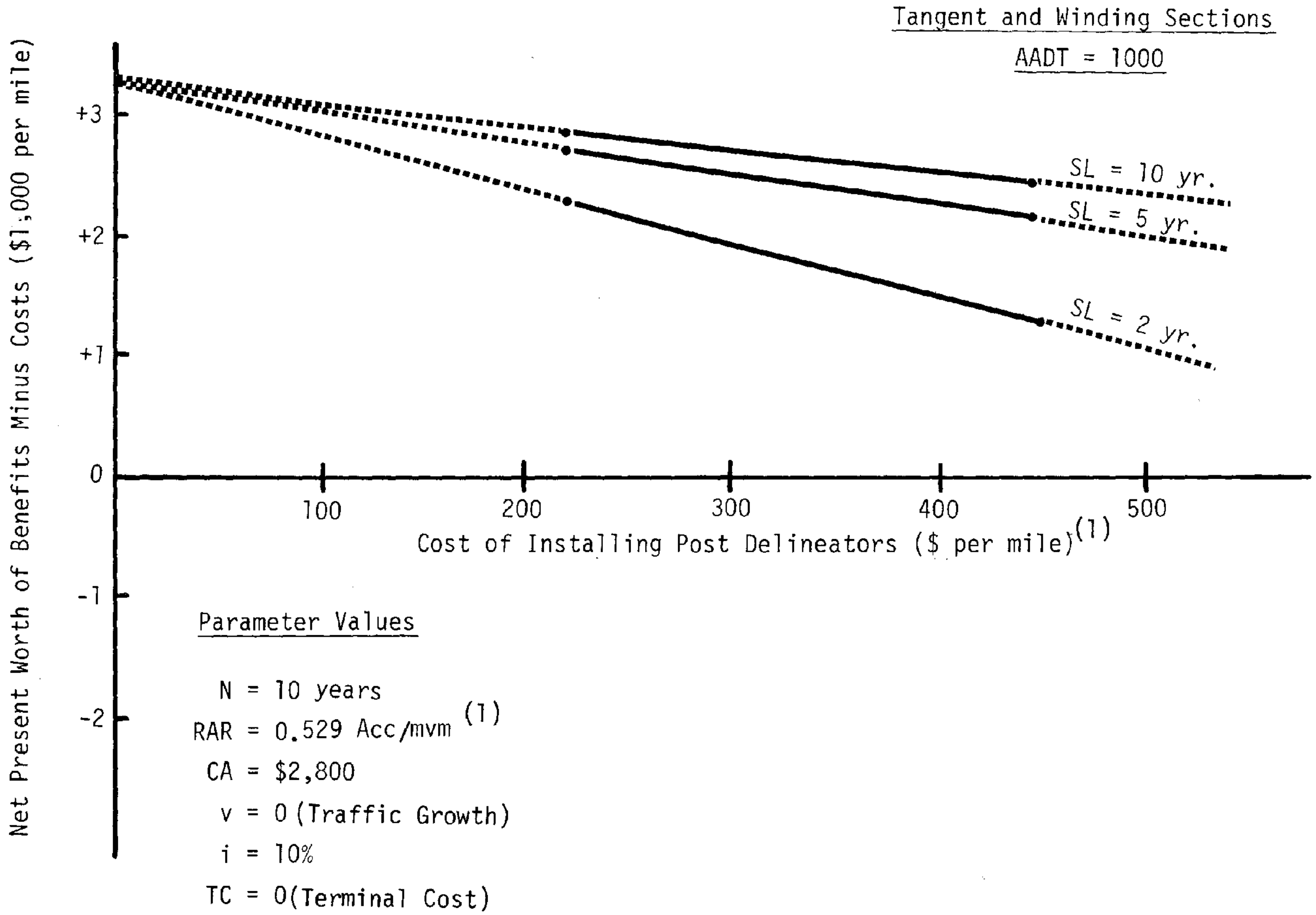


Figure 14. Cost-benefit relationships; installation of post delineators; AADT = 1000.

(1) 1 mile = 1.609 km

0.529 Acc/MVM (Acc/MVkm) is obtained from item G5 in Table 17. The charts indicate post delineators are cost-justified for all AADT's exceeding 1,000 vehicles per day, and under most conditions for AADT's as low as 500 vehicles per day. (Only installations costing more than $360 per mile (1.609 km), with service lives of two years, are excluded.)

No chart is provided for the addition of painted centerlines to highways with no treatment. The model indicates painted centerlines are justified for any combination of service life, cost, and traffic volume listed in Table 18, as well as for any of the projected accident rate reductions listed in Table 16. They will be justified any time the projected reduction in accident rate is 0.16 Acc/MVM (Acc/MVkm) for highways with an AADT of 500 vehicles per day or more.

Once again, potential users of these charts are cautioned that the parameter values apply only under the specific assumptions made in their development. The model is quite simple to use and the illustrative example should permit any agency to employ this technique to develop charts similar to those shown herein - utilizing their own estimates of the individual parameters.

Users should recognize that results are *very* sensitive to the "reduction in accident rate" factor. The best possible estimate of an appropriate value for this factor is essential to effective decision making.

7.3 Other Considerations in Applying the Cost-Benefit Model

Several other factors, which do not appear explicitly in the results given in Section 7.2.3, influence the interpretation of the cost-benefit calculations. Some of these factors are described briefly.

Weather factors affecting delineation are (1) precipitation, (2) snowfall, and (3) fog. These factors influence delineation effectiveness (benefits), service lives, and treatment installation costs.

Examination of Figure 9 underscores the importance of service life in the cost-benefit relationship for the installation of raised pavement markers. The very short service lives in areas where snow plows operate often dictate against the installation of standard raised pavement markers.

The effect on treatment cost of utilizing different delineation materials is discussed in Appendix E. Material costs for painted lines vary as a function of paint drying time, ratio of yellow to white, amount of glass beads, and wet film thickness. These are all design parameters which were taken into account in establishing the range of per mile costs shown in Table 18. Similar considerations are applicable to RPM lines and post delineators.

The pattern of roadway markings also has a direct impact on the present worth of costs. All calculations reported in this study are based on the current MUTCD recommended 3:5 mark-to-gap ratio for centerlines. A recent FHWA bulletin from the Office of Traffic Operations suggests a 1:3 mark-to-gap ratio. This new pattern would result in a reduction in material costs of about 25%, and an overall installation cost reduction of 10% to 20%, depending on agency accounting procedures.

In addition to the tangible effects of the factors just discussed, other intangible effects were considered in this study. These effects are generally classed as user costs since the costs do not impact highway department budgets directly. Three of these intangible factors are discussed in Section 6; (1) increased cost to the driver in delay time in and around areas where delineation is being installed, (2) increased costs in vehicle operation associated with this delay, and (3) costs associated with increased accident potential in construction and/or work zones. Each of these has a "societal" impact, but no direct budgetary impact on the highway agency.

The intangible costs have not been included in any of the calculations reported here because there is considerable uncertainty and controversy regarding the appropriateness of such factors in decisions regarding installation of delineation treatments. Means to arrive at reasonable estimates of the economic impact of these factors are discussed in Section 6 and Appendix E.

8. SUMMARY OF RESULTS AND CONCLUSIONS

8.1 Accident Models

Statistical analyses of these data were conducted to assess the effect of various delineation treatments on accident experience in various highway situations and under varying environmental conditions. As expected, the analyses do not isolate any single cause of roadway accidents. However, certain roadway conditions and other factors do have greater indicated effects on highway accidents than others. Briefly:

For tangent and/or winding sites:

1. Highways with centerlines have lower accident rates than those with no treatment at all.
2. Highways with raised pavement marker centerlines have lower accident rates than those with painted centerlines.
3. Highways with post delineators have lower accident rates than those without post delineators (in the presence *or* absence of edgelines).
4. Results of analyses of accident rates at sites with edgelines versus those without edgelines are mixed.
5. In general, reductions in accident rates, where stronger delineation treatments are employed, are more clearly indicated for tangent sections than for winding sections.

For isolated horizontal curves:

1. The results of the analyses are not as definitive as for tangent and/or winding sites.
2. There is some indication that sites with post delineators have lower accident rates than sites without post delineators.

3. Accident rates appear to be somewhat lower at horizontal curves with centerlines than at curves with no delineation treatment.

While the statistical relationships are not as strong as generally considered definitive, quantitative estimates of reductions in accidents associated with the installation of various delineation treatments are derivable from the t-test results and the regression models. Considering the various problems associated with accident analysis, these results certainly have application to field situations.

8.2 Recommendations on the Use of Statistical Results

A quantitative measure of accident reduction with the installation of delineation treatments is provided by the t-test results and regression models. The t-test results estimate the reduction in mean rate associated with the installation of a delineation treatment. Although this estimation is independent of roadway geometric, traffic, operational, and climatic conditions, individual estimations are provided for tangent, winding,and horizontal curve sites.

Regression models, like the t-test results, also estimate the accident reduction associated with the installation of various delineation treatments. But, they also provide a measure of its dependence on other roadway characteristics and climatic parameters.

It is essential to remember, however, that the regression models provide estimates of the *average* accident rate on a particular *type* of highway section. Application of these models to an individual highway section is subject to rather large variations and should be used only as a general guide. As a further guide to interpretation, it might be mentioned that the model itself does *not* imply cause and effect. However, if sound judgment theorizes a cause-and-effect relationship which is substantiated by the mathematics, such an interpretation could be valid. Care should also be taken to apply the models only within the range of the variables used in its development. Application to values outside these ranges requires considerable caution in interpreting the results.

Because of this difference of information between the t-test results and the regression models, their recommended use depends on the intended objective. General recommendations on using the results of this study are given below:

1. If the intended objective is to assess the overall reduction in accidents from the installation of a particular delineation treatment without any specific consideration of roadway features, the results of the t-test are recommended. In the absence of t-test results, regression models can be utilized; in which case, average values of the other parameters in the model can be used.

2. If the effect of delineation treatment is to be assessed for a road with the specified geometric and operational characteristics, the regression models are recommended, if available.

3. Among the various regression models available, the preference should be given to the one which reflects the study highway environment best. For example, if the intended objective is to assess the effect of delineation on California rural roads, models developed for Western states are more appropriate.

8.3 Delineation Guidelines

The delineation guidelines developed within this study pertain to those treatments for which benefits could be derived from the accident models. A lack of comprehensive quantitative measures of delineation treatment service lives under different roadway conditions (operational and climatic) precluded full exploration of the potential capabilities of the cost-benefit and cost-analysis models.

The calculations for costs/benefits were carried out parametrically. Representative ranges of values for all costs, service lives, and traffic parameters where chosen for each selected treatment application. This approach was followed for the following reasons: (1) the available data on treatment installation cost, maintenance cost, and service life is too ill-defined to justify specific single values for these parameters, and (2) having cost and service life factors as parameters instead of as fixed values gives added flexibility to potential users.

Economics was the sole basis for treatment evaluation in this study, with reduction in traffic accidents as the sole measure of benefits to be derived from the installation of delineation systems. A major weakness in such a procedure is the uncertainty associated with the accident models. Hopefully, better accident prediction models will be developed in the future, as the results are almost certain to be usable in the models developed.

In addition, alternative measures of delineation treatment effectiveness are being investigated, such as driver information needs and traffic performance measures of treatment effectiveness. As these measures become better understood they should be included in future cost-effectiveness studies.

This cost-benefit model is one of the major products of the study, and its use provides some of the key study results. A series of calculations was performed to develop the net present worth (NPW) of benefits minus costs of each combination of parameters for each delineation treatment type. In some cases, NPW had a value which was always positive (i.e., always cost-beneficial). In other cases, a cost-benefit tradeoff existed which was dependent upon service life, installation cost, and/or average annual daily traffic (AADT).

Delineation guidelines arrived at through the application of the aforementioned models, using the parameter values (or ranges) indicated are:

1. Adding a painted centerline on tangent and winding sections where no previous delineation treatment existed will be cost-justified over the entire range of costs, service lives, and AADT considered in this analysis.

2. Painted centerlines should be replaced by RPM centerlines where a service life of five years or more is expected (for the RPM's), *and* the AADT exceeds 3,000 vehicles per day.

3. Edgelines with service lives of five years will be justified for most highways with an AADT of 500 vehicles per day or more - they are cost-justified with service lives of two year if the installation cost is less than $165 per mile (1.609 km). Edgelines with a one-year service life are almost always justified if the AADT exceeds 1,000 vehicles per day. (However, the accident experience analyses for some subsets of roadways indicate higher accident rates where edgelines are present than where they are absent; edgelines are not justified for these highways.)

4. Post delineators are cost-justified at all AADT's above 1,000 vehicles per day; and under most combinations of installation cost and service life for AADT's as low as 500 vehicles per day.

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