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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 briefly presents an overview of the conduct of the study and results of the final report. The other volumes produced under this research study are:

Vol.	FHWA No.	Report Title
II	78-51	Final Report
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 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, System 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

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

(1) Chaiken, B., "Comparison of Performance and Economics of Hot-Extruded Thermoplastic Highway Striping Material and Conventional Paint Striping," *Public Roads*, Vol. 35, No. 6, Feb 1969.

(2) Chaiken, B., "Traffic Marking Materials - Summary of Research and Development," *Public Roads*, Vol. 35, No. 11, Dec. 1969.

dealing almost exclusively with the effectivess 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.

INTRODUCTION

In the 1973 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 is the subject of another contract. The driving performance measures resulting from this contract preclude direct

(3) Basile, A.J., "Effectiveness of Pavement Edge Marking on Traffic Accidents in Kansas," *HRB Bulletin 308*, 1962.

(4) Musick, James V., "Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio," *HRB Bulletin 266*, 1960.

(5) Field Evaluation of Selected Delineation Treatments on Two-Lane Rural Highways. Report No. FHWA-RD-77-118. October 1977.

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 assumption 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.

(6) Driver's Visibility Requirements for Roadway Delineation. Report No. FHWA-RD-77-165 (Volume I) and 166 (Volume II). November 1977.

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.

These steps are discussed in more detail below.

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 completed 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.

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(7) Bali, S., H. McGee and J. Taylor, State-of-the-Art on Roadway Delineation Systems, FHWA-RD-76-73, May 1976.

(8) Taylor, J., H. McGee, E. L. Seguin, and R. S. Hostetter, Roadway Delineation Systems, NCHRP Report 130, 1972.

Study Design and Data Collection

It was determined early in the study that the primary economic benefit, for purposes of cost-benefit analyses, 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 the analysis period
- no experimental delineation treatments
- adequate maintenance of the delineation treatments throughout the analysis period
- no overhead illumination
- at least two years of accident experience

As a result of the site selection process, only two-lane rural highway sections were identified in sufficient quantities to allow meaningful analysis. Tangent sections, winding sections, and horizontal curves were selected for study primarily because these situations encompass a large part of the rural roadway system.

Additional factors considered in selection of the study sites included delineation treatment location (centerline, edgelines, outside of shoulder), availability of information on treatment installation, roadway width, average daily traffic (ADT), shoulder width and type, degree of curvature at horizontal curves, and climate. This last criterion was accommodated through a selection of sites in various areas of the country.

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.

Tables indicating the specific combinations of highway situations, delineation treatments, and environmental factors for which data were collected are included in Appendices B and C. These tables indicate the number of sites studied in each category and the accident experience at these sites. Summaries of this information are presented in Section 5 of Volume II.

Accident Data

A critical element in the study was the identification of those accidents which could be related to the type of existing roadway delineation treatments. A list of characteristics was developed describing those accidents where the presence or absence of delineation would appear to have no effect on accident occurrence. For example, an accident involving defective brakes would not likely be related to the at-site delineation. Using this list all accident data were reviewed. Those judged as non-delineation related were initially excluded from the study. However, subsequent testing of response variables indicated the accident rate, calculated by using all accidents, was more sensitive than delineation-related accident rate. Thus, accident rate, using all accidents was used as the dependent variable in the analyses.

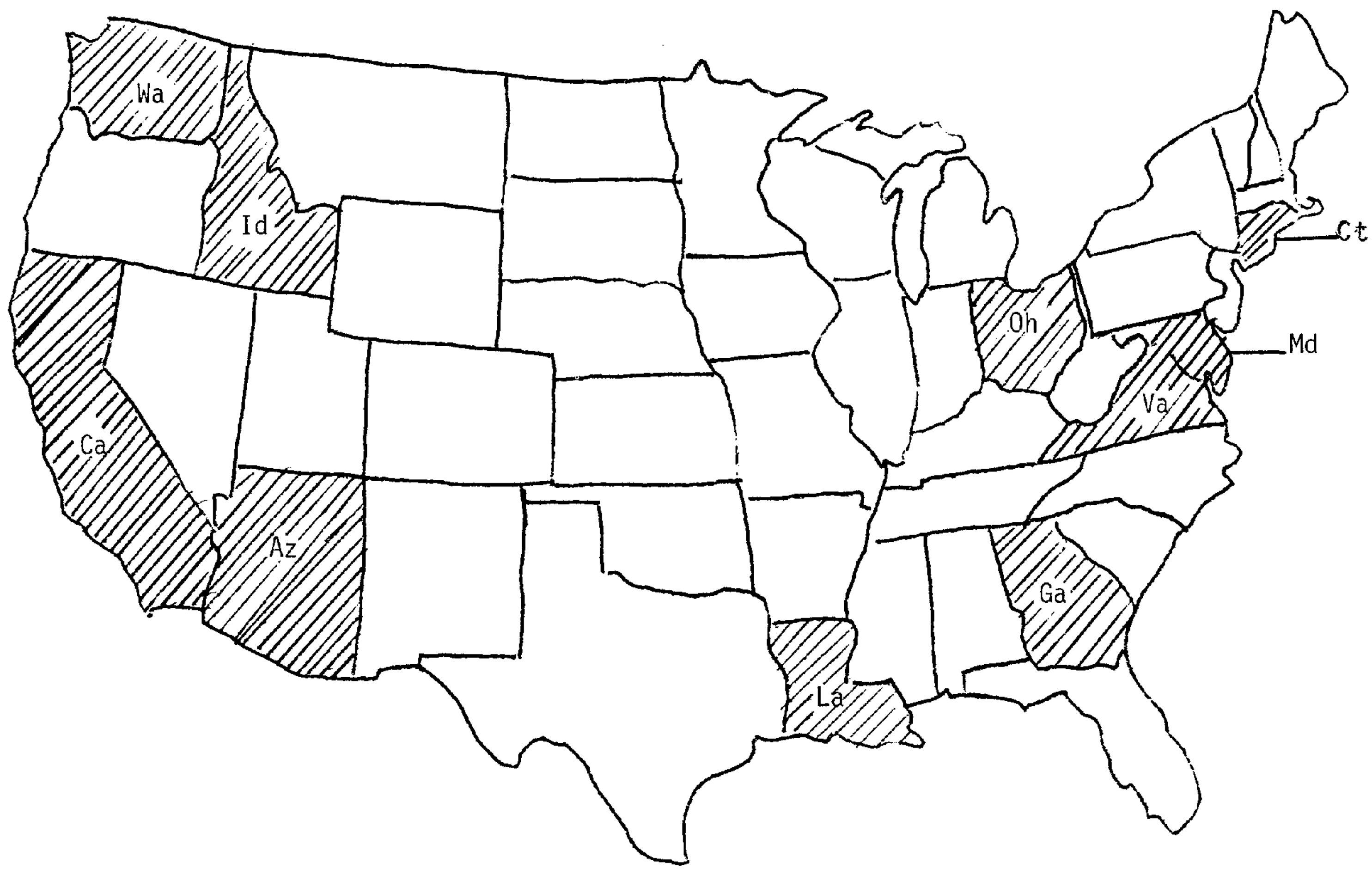

Figure 1. Geographic distribution of participating states.

Accident Analysis

Statistical analyses of these data were conducted to assess the effect of various delineation treatments on accident experience under various highway situations and environmental conditions. These analyses included development of a weighting scheme to account for differences in exposure from site to site, t-tests and regression models to provide estimates of reductions in the mean accident rate associated with the installation of various delineation treatments, and related specific analysis of variance, covariance analysis, and chi-square tests.

Important considerations and limitations encountered in the derivation of the accident experience models are:

- Many delineation treatments undergo significant periodic fluctuations in visual effectiveness - from quite intense while new to perhaps barely visible just before replacement.
- Accident records cover all conditions, and cannot be discriminated by "condition" of the delineation treatments.
- Even though a number of important site characteristics were matched or controlled in the analyses, no two sites are exactly alike in all ways that may affect accident experience.
- Accident reporting requirements and formats vary significantly from state to state.

Economic Models

A cost-benefit model was developed to permit evaluation of alternatives encompassing major changes in delineation treatments for which the associated accident rate estimation models are available. For example, this model can be used to determine whether raised pavement markers, as centerline delineation on roads with specified geometric, traffic, and climatic characteristics, are cost-beneficial.

A cost model was also developed, and is designed to permit economic comparison of variations within treatments, or to make comparisons of treatments for which accident estimation models are not available under the assumption that accident savings are not significantly different for treatments under consideration.

Factors common to both models include discount rate, analysis period, installation costs, maintenance costs, and salvage value. The cost-benefit model also incorporates estimates of the reduction in accident rate to be obtained as a result of the proposed delineation treatment, the cost of an accident[9] and increases in the traffic volume over the life of the treatment. In using these models the user can select his own set of values for each of these factors, or use the values indicated in Section 7 of Volume II, as appropriate.

SUMMARY OF RESULTS AND CONCLUSIONS

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).

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(9) Societal Costs of Motor Vehicle Accidents - Preliminary Report, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., April 1972.

(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.

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 were 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 are 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 for 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).

The delineation guidelines and general conclusions were developed on the basis of the following values, or ranges of value, for the important variables:

- Average cost of an accident: $2,800
- AADT: 500 to 7,000 vehicles per day (with provision for a five percent annual increase)
- Discount rate: 10 percent per annum

- Service Lives
  - Paint -- 0.5 to 2.0 years, dependent on AADT
  - Raised pavement markers -- 2 to 10 years
  - Post delineators -- 2 to 10 years, dependent on annual loss rate
- Installation Costs (per mile):
  - Paint -- $50 to $150 for centerlines; $100 to $200 for edgelines
  - Raised pavement markers -- $2,500 to $4,500
  - Post delineators -- $223 to $445
- Maintenance Costs:
  - Paint = 0 (replacement at end of useful life; no intermediate maintenance)
  - Raised pavement markers -- 10 percent of installation cost per year
  - Post delineators -- $36 to $72 per year

Table 1 provides the combinations of these variables.

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 (and listed above).

(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 years if the installation cost is less than $165 per mile (1.6 km). Edgelines with a one-year service life are almost always justified if the AADT exceeds 1,000 vehicles

Table 1. Summary of cost-benefit calculations.

Treatment Application	Reduction In Accident Rate*	Average Cost Of Accident	Veh/Day AADT	Percent Increase in AADT	Discount Rate in %	Service Life (Years)	Treatment Installation Cost (TIC)	Maintenance Cost $/Mile(MC)
Painted CL Added to No Treatment (Tangent Sections)	1.536	2800	500 1000 3000 5000	0.0 0.05	10	Note (1)	50 100 150	0
RPM CL Added to Painted CL (Tangent Sections)	0.566	2800	500 1000 3000 5000 7000	0.0 0.05	10	2 5 10	2500 3500 4500	10% of TIC per year
Post Delineators Added to Painted or RPM CL (Tangent Sections)	0.992	2800	500 1000 3000 5000 7000	0.0 0.05	10	Note (4)	Note (2)	Note (3)
Post Delineators Added to CL & EL (Winding Sections)	0.562	2800	500 1000 3000 5000	0.0 0.05	10	Note (4)	Note (2)	Note (3)
Painted CL Added to No Treatment (Winding Sections)	0.891	2800	500 1000 3000	0.0 0.05	10	Note (1)	50 100 150	0
RPM CL Added to No Treatment (Winding Section)	0.891	2800	500 1000 3000 5000 7000	0.0 0.05	10	2 5 10	2500 3500 4500	10% of TIC per year
Add Post Delineator to CL Site in GA, LA (Horizontal Curves)	1.310	2800	500 1000 3000 5000 7000	0.0 0.05	10	Note (4)	Note (2)	Note (3)

*Accident rate for tangent and winding sections is defined as the number of accidents per million vehicle-miles $\left(\frac{\text{Accidents}}{\text{MVkm}}\right)$.
For horizontal curves it is defined as the number of accidents per million vehicles.

CL - Center Line
RPM - Raised Pavement Marker
EL - Edgeline

Table 1. Summary of cost-benefit calculations (continued).

Treatment Application	Reduction In Accident Rate	Average Cost of Accident	Veh/Day AADT	Percent Increase in AADT	Discount Rate in %	Service Life (Years)	Treatment Installation Cost (TIC)	Maintenance Cost $/Mile(MC)
EL Added to CL and Post Delineators (Tangent Sections)	0.720	2800	500 1000 3000 5000 7000	0.0 0.05	10	1 2 5	100 150 200	0
Post Delineators Added to Paint CL AZ and CA (Tangent Sections)	0.462	2800	500 1000 3000 5000 7000	0.0	10	Note (4)	Note (2)	Note (3)
RPM CL Added to Paint CL (Flat Tangent Sections)	0.335	2800	500 1000 3000 5000 7000	0.0	10	1 2 5 10	2500 3500 4500	10% of TIC per year
EL Added to CL Posts Optional (Rolling Tangent Sections)	0.542	2800	500 1000 3000 5000 7000	0.0	10	1 2 5	100 150 200	0
CL Added to No Treatment (Mountainous Winding Sections)	1.168	2800	500 1000 2000 5000	0.0	10	Note (1)	50 100 150	0
CL Added to No Treatment (Winding Sections)	0.950	2800	500 1000 3000 5000	0.0	10	Note (1)	50 100 150	0

NOTES:

(1) AADT & Life related as follows:

Life	AADT
2 yr	500
1 yr	1000
0.5 yr	>3000

(2) TIC for Post delineators assume

$130 \frac{\text{post}}{\text{mile}} \times \$3.44$ $447.20/mile

$65 \frac{\text{post}}{\text{mile}} \times \$3.44$ $223.60/mile

(3) MC for post delineators

130 post/mile x $0.55/post = $71.50/mile
65 post/mile x $0.55/post = $35.75/mile

(4) Life of Post Delineators

Assume yearly loss =	Life
10%/year →	10 years
25%/year →	4 years
50%/year →	2 years

1 mile = 1.609 km

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.

More detailed information on the cost-benefit relationships for various combinations of delineation treatment, highway characteristics, and environmental factors is included in Section 7.

Additional Recommendations

As a result of the activity involved in data collection and analysis, several recommendations impacting on future studies of this type appear to be in order.

(1) Information on dates of installation of delineation treatments is lacking. To improve effectiveness evaluations data of this type is desirable.

(2) The research in this program should be extended to include the initial results of the 205 Pavement Marking Demonstration Program. Review of the data from the 205 Program may reveal patterns that could be helpful in interpreting the results of this study, and such review could be carried even further by classifying the sites into the analysis matrices developed herein and by using the data to expand the data base in the analyses.

(3) Photolog systems are a valuable tool to a state highway department and should be used by all states. Because a photolog can be used for a variety of purposes by personnel, without leaving the office, considerable savings in personnel time and travel cost can be accrued. If the photolog is utilized to its fullest capabilities, such savings will eventually offset the cost of implementing and maintaining the photolog.

(4) The cost-benefit model should be expanded to incorporate all measures of treatment effectiveness.