Report No. FHWA - RD-78-111

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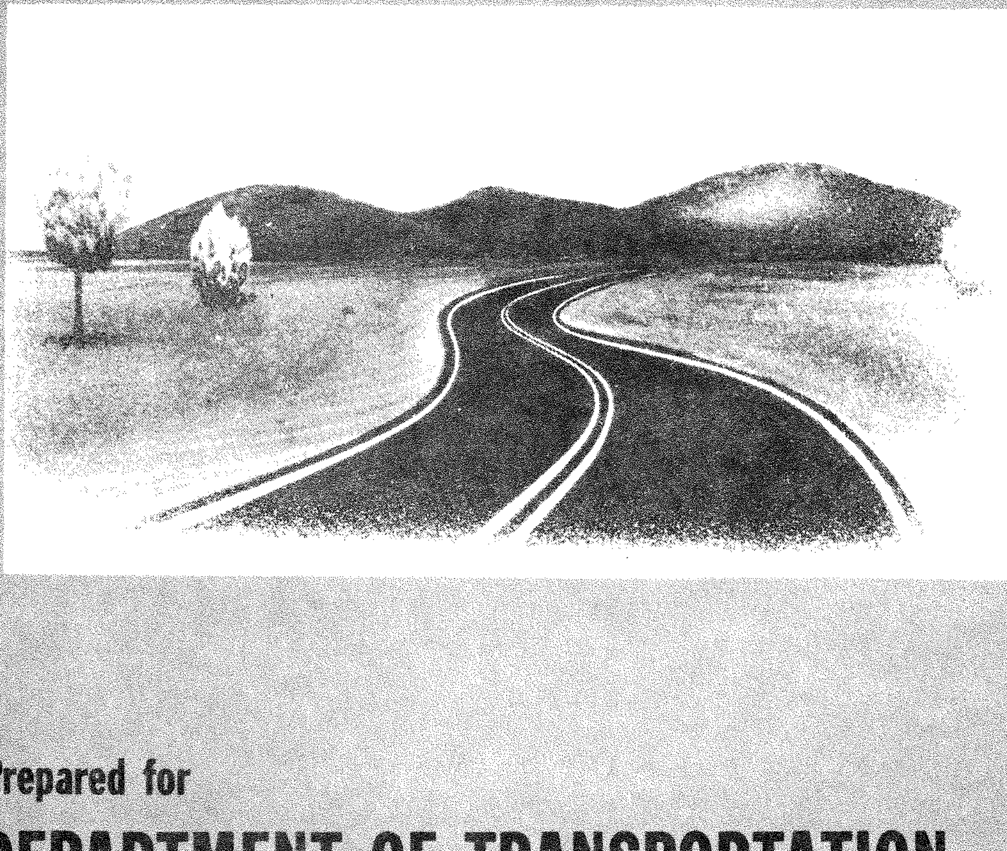
AN OVERVIEW OF ROADWAY DELINEATION RESEARCH



Prepared for

DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

Offices of Research & Development
Washington, D.C. 20590

JUNE 1978
FINAL REPORT

REPORT NO. FHWA-RD-78-111

FOREWORD

This report presents an overview of six recent FHWA sponsored studies and related efforts aimed at improving the effectiveness and utilization of roadway delineation. The report summarizes the results of FCP Task 1L3, synthesizes and interprets the findings, and provides information and advice which may be utilized to revise the "Manual on Uniform Traffic Control Devices." In addition, the authors identify and discuss several questions that require additional research.

The report was prepared as part of Contract DOT-FH-11-8834 conducted for the Federal Highway Administration, Office of Research, Washington, D.C. The report covers the period of research from September 1, 1977, to April 30, 1978.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each FHWA Regional office, Division office, and State highway agency. Direct distribution is being made to the Division offices.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

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16. Abstract

The objective of this report is to provide an overview of recent FHWA research on the subject of improving the effectiveness and utilization of roadway delineation. The report summarizes the results of 6 recent major studies and related efforts, interprets and synthesizes their findings, identifies gaps, and provides information and advice which can be used in developing plans for future implementation through the "Manual on Uniform Traffic Control Devices." Questions requiring additional research are also discussed.

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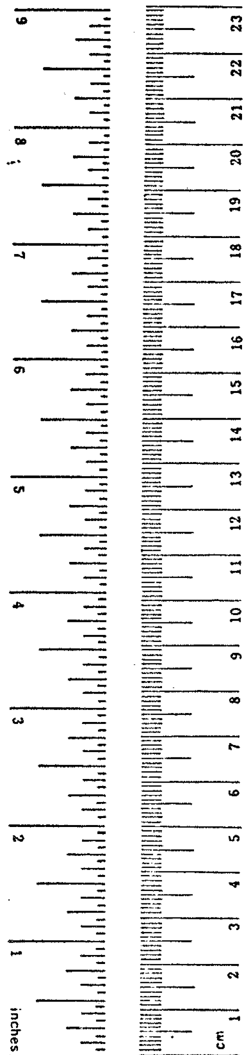
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

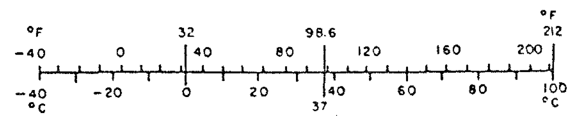
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



CHAPTER I

INTRODUCTION

This report is an overview of recent FHWA research on the subject of roadway delineation. The purpose of the overview is to summarize results to date, identify gaps, and provide information and advice which the FHWA Office of Research can use in developing a plan and program for future research on roadway delineatiin. The review includes research and studies conducted by several agencies, but the emphasis is on FHWA-funded projects, particularly those included in Task 1-L-3. The program category (1) is Improved Highway Design and Operations for Safety; Project (L) is Improved Traffic Operations During Adverse Environmental Conditions; and Task (3) is Delineation for Guidance. The 1-L-3 Task consists of a series of separate studies: some performed by private organizations under contract to the FHWA Office of Research; some by the FHWA office staff; and others by State highway agencies using Highway Planning & Research funds. The specific studies of the 1-L-3 Task are described in more detail in Chapter III. The impetus of the 1-L-3 Task is section 206 of the Federal-aid Highway Act of 1973, which authorizes funds for research and demonstration programs to improve the effectiveness and durability of various types of pavement markings and delineation. Additional delineation research was also carried out under Project 1I. This additional work dealt with the development of improved materials and technology for delineation, rather than the manner in which those materials are utilized and will not be discussed here. (For further information on Project 1I, see the December 1977 issue of Public Roads.)

The initial efforts of this review consisted of assembling all information on the 1-L-3 Task. The information included contractor work statements; progress, interim, and final reports; HPR Study Summaries and reports; and FHWA staff reports. Following the initial review, the principal investigators of the various projects were interviewed. The interviews were only partially structured, to allow a fairly wide-ranging discussion and to allow the people being interviewed to express their thoughts and views both with regard to the specific studies they had directed and future research needs.

In addition to an interview of the principal investigators, a number of FHWA staff members, both in research and in operations, were also interviewed. The people interviewed during the course of the study were:

- Dr. James Taylor
- Dr. William Berg
- Dr. James O'Hanlon
- Mr. Wade Allen
- Dr. Duane McRuer
- Dr. Shri Bali
- Dr. Donald Hausknecht
- Mr. Donald Ryan
- Mr. Edwin Granley
- Mr. Charles Niessner
- Mr. Harold Lunenfeld

The next step was to review final reports in greater detail in light of the interviews. In this review, the findings and conclusions of each study were evaluated and related to the objectives of that study. The findings were then related to those of other studies to isolate gaps in information and points where findings were not compatible. Lastly, on the basis of findings and shortcomings identified in earlier steps, recommendations were developed with regard to future research needs in the subject area of roadway delineation.

CHAPTER II
RESEARCH CHRONOLOGY

PROGRAM DEVELOPMENT

In March 1973, the Transportation Subcommittee of the U.S. House of Representatives held hearings on a four-point highway safety program which consisted of pavement markings, spot improvements, obstacle reduction, and rail-highway crossing improvements. Witnesses estimated that this program had the potential of saving up to 9,000 lives per year; at least 3,000 of these reduced fatalities attributable to pavement-marking improvements. As a result of these hearings, Congress created a pavement-marking demonstration program and a special R&D program and made them part of the 1973 Federal-aid Highway Act. The authorization for the R&D program is as follows:

> *PAVEMENT MARKING RESEARCH AND DEMONSTRATION PROGRAMS*
>
> *Sec. 206. (a) In addition to the research authorized by section 307(a) of title 23, United States Code, the Secretary of Transportation is authorized to conduct research and demonstration programs to improve the effectiveness and durability of various types of pavement markings and related delineators, to develop improved equipment and techniques for applying, erecting, and maintaining such markings and delineators, and to develop new traffic control materials, devices, and related delineators to assist the traveling public during adverse weather and nighttime driving conditions.*

Once the 1973 Act was passed, FHWA proceeded in the development of Task 1–L–3, "Delineation for Guidance," with total program funds of about one million dollars. The objective, scope, and task plan for this research are as follows:

PROJECT: IMPROVED TRAFFIC OPERATIONS DURING ADVERSE ENVIRONMENTAL CONDITIONS

TASK CODE: 1-L-3

TASK: Delineation for Guidance

I: OBJECTIVE:

The purpose of this task is to determine motorists' delineation requirements and to develop optimized delineation specifications.

II: SCOPE:

A delineation-contrast specification will be developed to insure that road markings and delineations are visible to the driver. Additional studies are concerned with the degree to which yellow road markings can be whitened and still be distinguished from white markings. Vehicular control measures will also be validated as predictors of accidents. A comprehensive cost-benefit study will be made of delineation treatments presently being used on the road.

The major research efforts are:

1. Drivers' Requirements for Roadway Delineation — concerned with contrast standards for lane markings, with the development of a technique and device to measure delineation-roadway contrast, and with the development of a more visible yellow marking paint.

2. Drivers' Understanding of Road Markings — concerned with an assessment of drivers' understanding of the meaning of the road marking code determined by answers to abstract questions and responses to actual road situations.

3. Field Evaluation of Selected Delineation Treatments — concerned with the validation of field measures as predictors of accidents and the accident reduction potential of various road markings.

4. Cost-effectiveness and Safety of Alternate Roadway Delineation Treatments — concerned with a cost-benefit analysis of conventional and experimental delineation treatments.

III: TASK PLAN FOR RESEARCH

Preliminary work on both the contrast study and the whitening of the yellow stripe study will be done in the laboratory. Laboratory results will then be tested in the field. The development of plans for a test device to measure contrast will proceed simultaneously with the other parts of the study.

The study aimed at assessing driver understanding of road marking will involve a questionnaire which will be administered to a sample of approximately a hundred persons in the Offices of Research and Development, FHWA. These persons may be expected to be more knowledgeable of delineation techniques than the general public. If they do not know the meaning of the delineations, it may be safely surmised that the general public would not, either. An additional sample of 300 persons from the general public will answer the questionnaire. Present plans call for obtaining this sample at the Smithsonian Institute, Washington, D.C.

The field evaluation will require the validation of delineation-related traffic performance measures. Field studies will then be performed to determine the effectiveness of conventional and experimental (novel) delineation methods.

The cost-benefit study requires the development of a cost-benefit model for evaluating delineation techniques. After development of the model, delineation techniques will be tested under day, night, and adverse weather conditions to determine their cost-effectiveness.

The program evolved into a series of studies, all but one of which is either completed or underway. Figure 1 shows the time-phase chart for these studies and their anticipated schedule. Figure 2 shows the interaction of the studies and the anticipated products of the program. Three of these studies (05, 07, and 09) were conducted by state agencies using HPR funds, one study was conducted by FHWA staff, and three studies were undertaken by private contractors. The development of a delineation handbook, which was deferred until completion of the other studies, is not yet underway.

Concurrent with these studies were a series of demonstration projects undertaken by state agencies in cooperation with FHWA. These demonstration projects were three basic types: raised pavement markers on construction projects, raised

Program Category: 1. Improved Highway Design and Operation for Safety
Name of Project: L. Improved Traffic Operations During Adverse Environmental Conditions

DOT/FHWA

Task Code	Study Code	Task and Study Description	Source of Funds
3	02	Driver's Visibility Requirements for Roadway Delineation	FHWA
	03	Field Evaluation of Selected Delineation Treatments	FHWA
	04	Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments	FHWA
	05	Improving Driver Performance on Curves in Rural Highways Through Perceptual Changes	HP&R Ohio
		Delineation Handbook and Curriculum Development	
	06	Driver's Understanding of Roadway Markings	Staff
	07	Economic Analysis of Pavement Marking Materials Acquisition, Distribution and Storage	HP&R Ohio
	09	Device for Evaluation of Retro-Reflective Performance of Pavement Marking Materials	HP&R Okla.

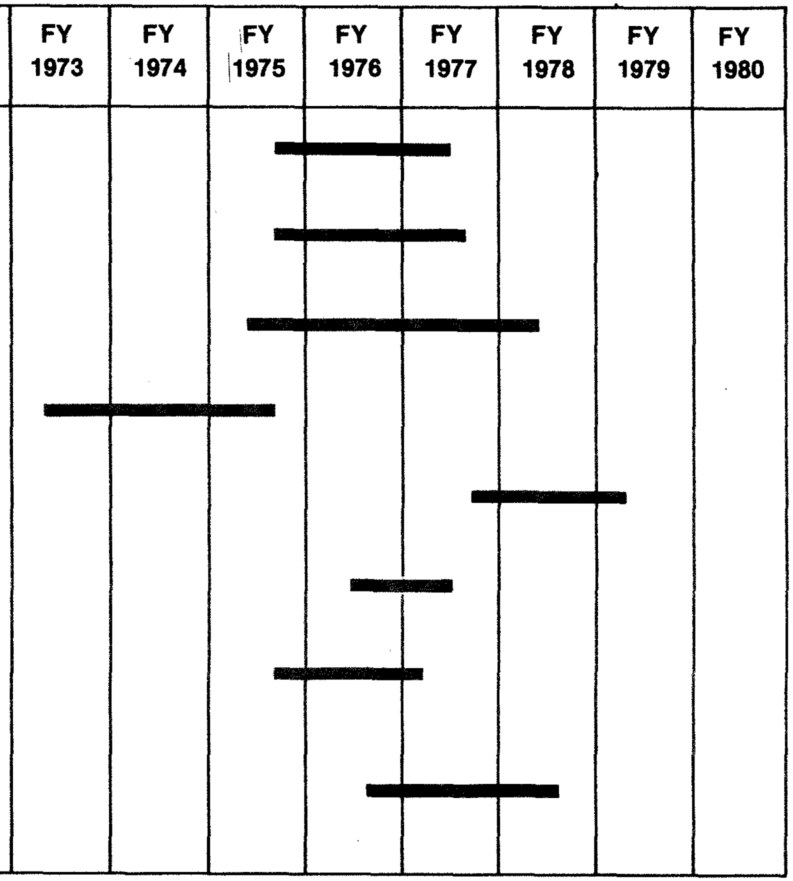


Figure 1. Project 1-L Time-Phase Chart

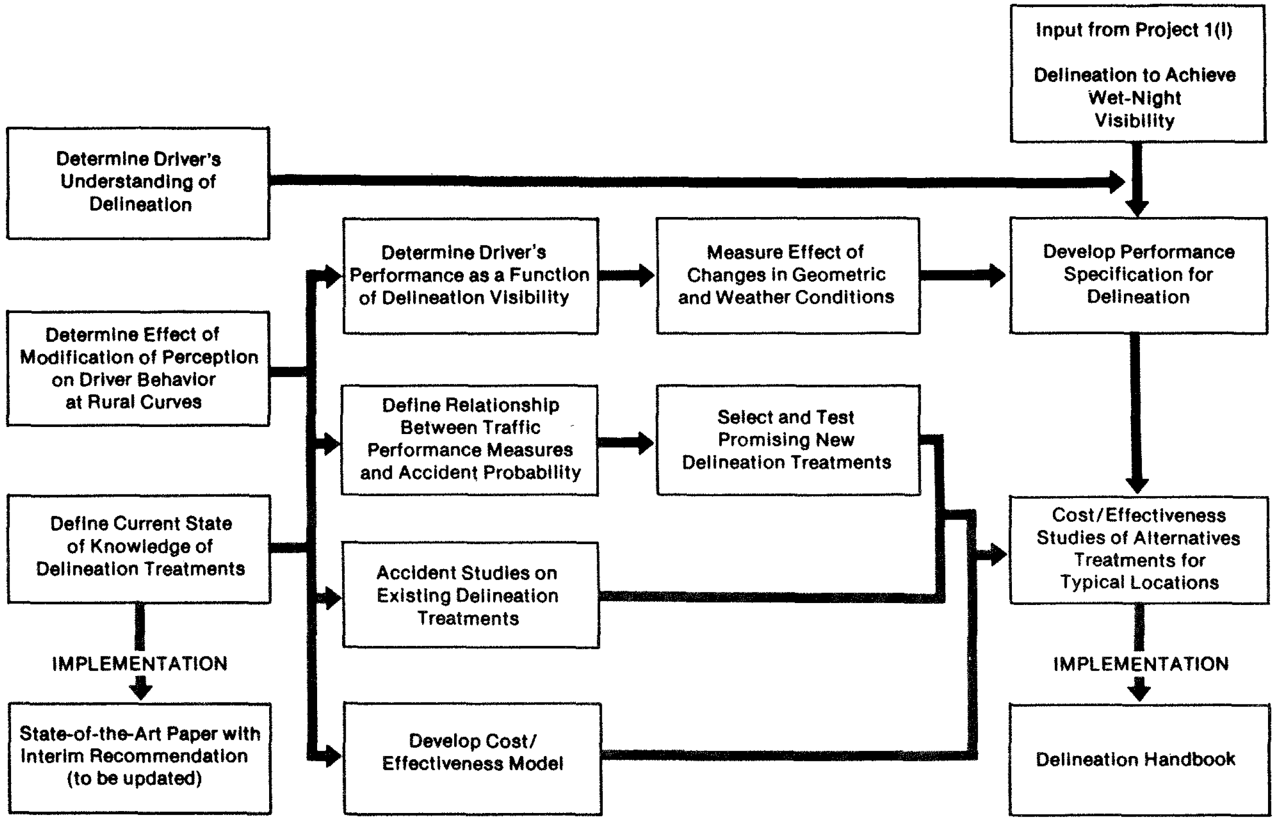


Figure 2. Project 1-L Work Flow Diagram

pavement markers at high-hazard locations, and delineator posts primarily on curves. They included evaluations of their effectiveness and of installation and maintenance costs. Other tasks were concerned with delineation and guidance during severe environmental conditions such as fog, snow, and ice.

Another related effort focused on the development of materials and procedures for the application and maintenance of marking systems; while still another series of studies are underway to develop methods for removing unwanted pavement markings and temporary applications of pavement delineation.

CHAPTER III

MAJOR DELINEATION RESEARCH EFFORTS

As indicated in Chapter II, most of the research studies under the I–L–3 program have been completed and the findings and recommendations have been documented. This section of the overview is a brief description of the 1–L–3 studies and a summary of some of their more significant findings.

DRIVER VISIBILITY REQUIREMENTS FOR ROADWAY DELINEATION(1)*

The purpose of this research was to establish visibility requirements for roadway delineation to help establish the cost-effectiveness of a variety of delineation treatments. The two basic objectives were:

- To determine optimum and minimum visual roadway delineation treatments
- To establish the lowest saturation limit of a yellow-white paint mixture that can still be distinguished from white

A combined theoretical/experimental approach was taken in pursuit of the first objective, and full-scale laboratory tests were conducted for the second objective. The combined approach first involved the development and testing of a theory for delineation visibility and driver perceptual requirements in a driving simulator. Further validation tests were then performed in an instrumented vehicle on the open highway. The simulation and field tests were then compared and using the previously developed theory, a model was used to quantify steering performance in terms of delineation contrast. The second objective involved determining how much yellow paint can be diluted with white paint without causing drivers to misperceive it as white under actual driving conditions. The yellow paint in current use has several disadvantages which could be overcome by dilution of the yellow lead chromate pigment content. Extensive laboratory tests were performed and

*See List of References in Bibliography.

specific recommendations regarding the extent of the dilution were developed. A brief description of the different phases of the research and correspondent findings are presented in the following.

Delineation Theory

Perceptual theory and past research thoroughly document that drivers require a minimum visual range for adequate steering control. In other words, driver visual characteristics require minimum contrast levels for detecting delineation targets. Also, it is recognized that delineation visual range is severely limited under adverse visibility conditions. Using this reasoning, a theory for delineation visibility was developed. This theory, involving human visual characteristics, atmospheric visibility properties, and photometric properties of light sources and road surface conditions quantifies the manner in which various adverse visibility factors limit a driver's visual range and thus establishes a relationship between delineation visibility and the effects of adverse visibility conditions.

Driving Simulator Experiments

Based on the delineation theory, a series of driving simulation tests were conducted to determine the effects of adverse visibility on driver/vehicle system performance (i.e., lane deviations), driver behavior, and driver subjective reactions. The hypothesis was that performance measures describe the consequences of adverse visibility. Behavior measures gives insight as to the effects on the driver and reaction measures give an indication of work-load changes. It was further assumed that the combination of these measures could be related to accident risk.

The first tests were a series of exploratory tests to determine the various conditions and tasks that would cause measurable effects and to develop measures that would be sensitive to these effects. Five subjects were administered a variety of conditions including various visibility ranges and delineation configurations. Driving tasks involved steering around obstacles and through curves as well as compensating against disturbances such as a wind gust. Measurements included preferred driving speed, the maximum range at which the delineation could be detected, and subjective comments. The following represents a summary of these exploratory tests:

- As visibility range is reduced, delineation configuration or pattern becomes increasingly more important. Solid edgelines, longer dashes, and shorter cycle length can counteract some of the effect of reduced visibility.

- Dashed lines lead to an interesting sampled-data problem under reduced visibility conditions. The car hood restricts minimum forward view to approximately 20 feet ahead of the driver's position; when one dash disappears below the hoodline before a succeeding dash is visible through the fog, steering performance becomes very erratic. Thus, delineation gap length is a key variable.

- Longer dashes can give some indication of road curvature even though only one dash is visible. Retroreflectors are a limiting case in that they do not provide any curvature information unless more than one is visible.

- Preferred speed decreases with reduced visibility, or at constant speed, steering performance degrades. Preferred and constant speed runs, as well as driver reaction or subjective opinion, are sensitive measures of the effects of adverse visibility.

Based on the exploratory tests, a test matrix was developed to guide the simulation testing. The matrix, illustrated in Figure 3, included three major variables: visibility range, delineation configuration, and speed.

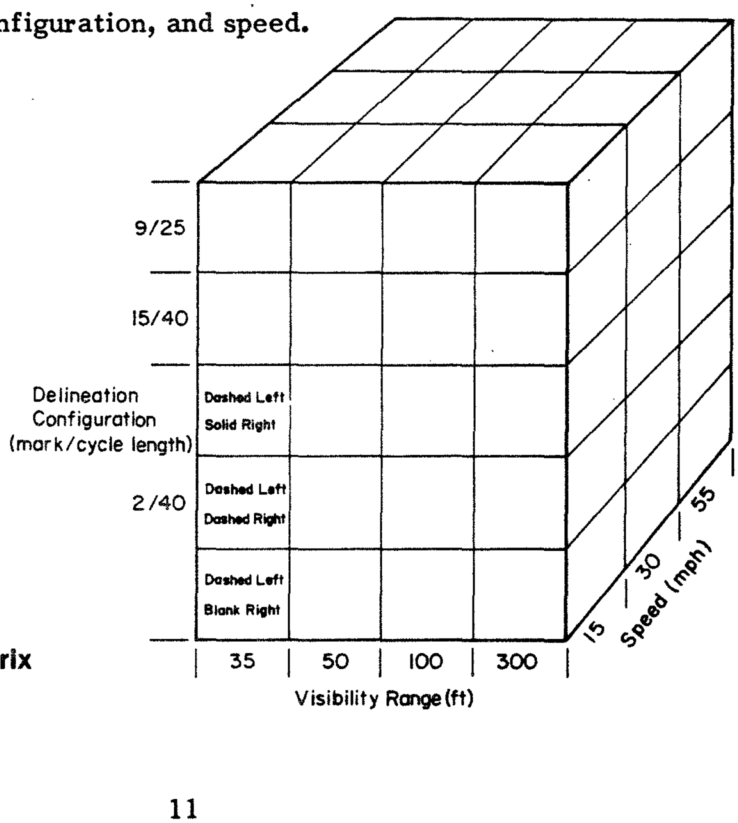


Figure 3.
Simulator Test Condition Matrix

The visibility range extended from 35 feet which was considered to be a minimum for positive steering control to 300 feet, a distance considered to be beyond that required for good control. Speed variations ranged from a very slow 15 mph to 55 mph, the current nationwide speed limit. Delineation configuration included single-lane delineation with varying centerline and edgeline configurations. It was not possible nor practical to run all combinations of the factors shown in the matrix, and therefore, emphasis was placed on those combinations likely to show degraded performance. For the final experiment, one baseline condition and 18 experimental conditions were chosen.

For each condition in the experimental design, three driving tasks were defined. One task required the driver to compensate against a random outside disturbance such as a wind gust. A second task involved following a winding road at fixed speed. The third task required the driver to follow an occasionally curved road as fast as possible, but still within a comfortable range. The measurements taken during the first two tasks involved lane deviations and subjective ratings by the driver. The measurements in the third task involved preferred speed and subjective ratings.

The results of the simulation experiments involving lane deviation indicated that steering performance is reliably affected by the combined effects of reduced visibility and delineation configuration. In other words, steering performance degrades with decreased visual range and with a reduction in the total amount of information available to the driver. This suggests that visual range and delineation configurations are important variables in the design of delineation systems. For example, extending the visual range of a driver by increasing delineation contrast, or by improving the quality of delineation configuration with an increase in the stripe-to-gap ratio will improve steering performance. This will reduce the probability of a vehicle leaving its lane and, in turn, will reduce the probability of a potential accident. Similarly, adding a solid right edge lane will give an improvement in steering performance since it will increase visual range.

The simulation tests also indicated that steering performance is affected by roadway geometry. In the runs involving path-following around discrete curves, the subjects were asked to drive as fast as they thought prudent without crashing, which would occur if the vehicle were driven more then two feet off the roadway boundary. The test results showed that the preferred speed under the various experimental conditions were linearly related to the visual range. In other words, this data is fairly consistent with the performance relationships found with the constant speed experiments. This suggests that delineation visual range may be restricted simply by roadway curvature, and in these cases, it is highly desirable to improve the quality of delineation information available to the driver.

Field Test Experiments

Field test experiments were performed to complement and validate the simulation studies and to include various effects that could not be duplicated by the simulation. The field tests were performed in two separate experiments. The first was designed to measure the critical aspects of a driver's lateral and longitudinal vehicular control over a segment of highway which had different delineation contrast levels. The second was designed to compare indices of driver lateral and longitudinal vehicular control under both wet and dry pavement conditions. Both tests were conducted with an instrumented 3/4-ton van and performance measures were monitored by an in-vehicle observer as subject drove over the experimental course. The physical features of the two test courses are given in Table 1.

Table 1. Physical Features of Test Courses

Characteristic	First Experiment	Second Experiment
Experiment Name	Contrast Variations	Rain Effects
Limits of Circuit	20 mi. Each Way, I-80	25 mi. Each Way, I-5
General Terrain	Mountainous, Upgrade Eastbound	Level in Southern 10 mi., Mountainous Grades North
Adjacent Land Use	Rural	Urban & Suburban South, Rural North
Number of Lanes (1-way)	2 @ 12ft.	2-3 @ 12ft.
Pavement Type	PCC Lane, AC Shoulder	PCC Lane, AC Shoulder
Lane Line Delineation (All California Standard 9:15 Stripe-to-Gap Ratio)	Phase I - 4-mi. Treatment Segments w/ 2,4,6, & 8 lbs. of Beads per Gallon; Phase II - All Paint Very Worn Phase III - All Repainted at 6 lbs./gallon.	Southern Section - Stripe Supplemented w/non-reflective RPM's @ 3ft.; Reflective Crystal RPM's in Alternate Gaps (i.e., @ 48ft.). North - Striping Only
Edge Delineation	No Edgeline; Retroflective Paddle Delineators (Spacing not Given; Assume 1/10 mi. on Tangents, Closer on Curves)	Edgelines: Yellow on Left, White on Right; Paddle Delineators (Std. Spacing); South - Yellow Reflective RPM's on Left Edge @ 24ft.

The analyses of the field test data revealed several important effects of delineation visibility on vehicular control. When delineation visibility was reduced, either by reduced contrast (increased wear) or by a covering film of water, the reactions were generally as follows:

- The drivers shifted their vehicle's mean lateral lane position away from the left lane line to approximately the center of their traffic lane.
- Lateral control performance deteriorated as indicated by a substantial increase in the vehicle's lateral position variability.
- Mean speed was not appreciably affected except in the rain experiments. Even there, the average speed reduction was only on the order of 2 mph under the worst visibility condition.
- Speed control seemed to be generally unaffected although the vehicle's speed variability was uniformly higher in the rain.

The major result that emerged from the contrast experiment was the demonstration of a systematic relationship between pavement striping contrast and lateral position variability. The significance of this is that the expression for this relationship has a potential for predicting the probability of inadvertent vehicular excursions from a traffic lane as a function of striping contrast. Thus, a relationship between contrast and accident potential can be established.

The results of the rain experiment strongly indicate the effectiveness of retroreflective pavement markers and the inadequacy of pavement striping delineation for guiding drivers in the rain. With only striping for guidance and in wet weather, the drivers demonstrated a potentially dangerous combination of increasing lateral placement variability and decreasing mean distance from the lane line. At the same time, they were showing signs of heightened arousal, indicating they were exerting greater effort. When they returned to a roadway section where raised pavement markers supplemented the pavement striping, their performance recovered and their psychophysiological status returned to its normal level. Even in dry weather, the drivers controlled their vehicle with less lateral position variability when pavement markers were used with striping. It cannot be concluded from this that the addition of pavement markers improves performance under <u>all</u> circumstances, but there is certainly an indication that this is definitely a possibility.

Simulator and Field Test Comparisons

The simulator and field test performance measures were analyzed and a fairly good comparison was obtained. Figure 4 shows a comparison of this data. As is shown, the two curves are quite similar in the range of contrast values greater than 0.5. Given this tie-in between the two experiments, the implication of specifying a minimum acceptable contrast level was developed. This involved establishing a relationship between (1) the probability, at any instant in time, of a vehicle traveling outside of its lane boundries and (2) a delineation contrast value. This relationship is shown in Figure 5. As can be observed, the curve becomes asymptotic in the range of contrast values of 2 and beyond. This suggests that delineation contrast should be maintained at a minimum value of 2 to achieve adequate steering performance. However, a note of caution is needed. These relationships were established from data obtained under relatively good night driving conditions. For adverse visibility conditions (i.e., fog) it may be desirable to maintain delineation contrasts at even higher values. This, however, is highly dependent on the cost-effectiveness of maintaining a given level of delineation contrast, and a rationale for specifying a higher contrast level should always include an appropriate cost/benefit analysis.

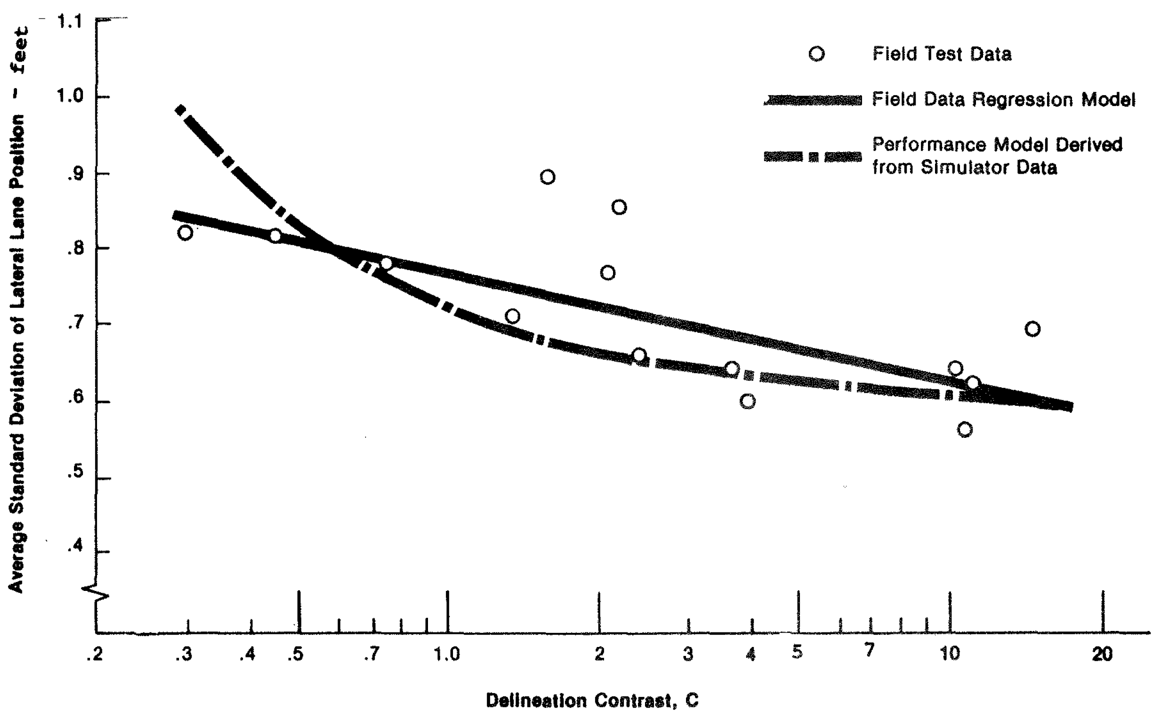


Figure 4. Comparison of Performance Model to Field Test Data

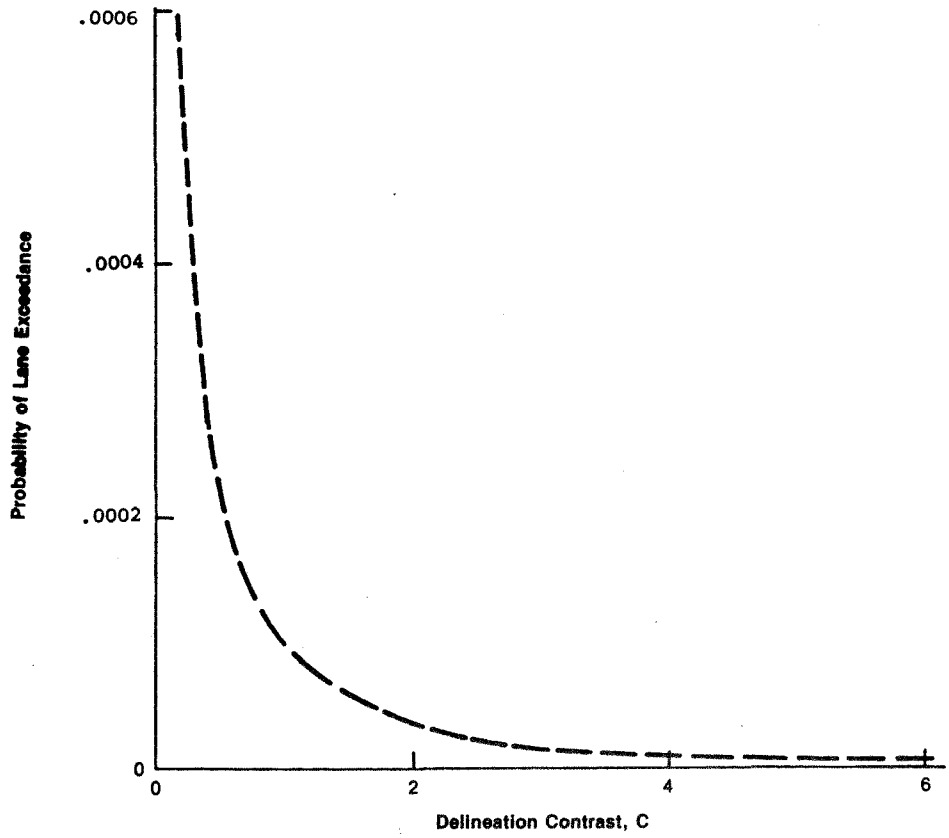


Figure 5. Effect of Delineation Contrast on the Probability of Lane Exceedance

A Study of Yellow/White Paint Mixture

This study investigated the extent ot which yellow highway paint can be diluted with white and still be reliably identified as yellow under a variety of day and night lighting conditions. Due to its lower reflectance and contrast with pavement, the yellow highway paint currently used is often not as visible as white paint under adverse lighting and weather conditions. In addition, the yellow lead chromate pigment is more toxic and more expensive than white pigment.

The experimental approach involved a series of paint mixture samples ranging from 100 percent yellow to 100 percent white applied to 8 feet by 4 inch stripes of thin sheet metal simulating highway delineation stripes. Yellow/white color judgments were made by 20 subjects observing the sample stripes from the driver's seat of a parked vehicle at distances of 30 feet, 60 feet, and 90 feet, both with and without a 100 percent white reference sample in the field of view and under various day and night lighting conditions.

The results of this study indicate that yellow paint can be diluted with up to 50 percent white pigment (by weight) without losing yellow color identity under lighting conditions where color is usually visible. Replacing half of the yellow pigment with white pigment would result in an annual cost savings in this country of more than one million dollars, while increasing visibility and reducing toxicity of the paint.

Comments on the Research

This work represents a well-designed and carefully developed piece of research and its findings contribute significantly to a better understanding of the application and the use of pavement delineation systems. The findings involving the human-factor aspects of the research provide considerable insight as to the requirements for adequate delineation visibility under adverse visual conditions of night, i.e., rain, fog, etc. The application of these findings will provide important guidance in the design and maintenance of delineation systems and can be used quite effectively in studying the cost-effectiveness of various systems.

The findings involving the color identification of yellow delineation paint as a function of yellow/white pigment mixture ratio are significant in that yellow paint can be diluted up to 50 percent (by weight) without losing color identity under lighting conditions where color is usually visible. The application of this finding would substantially reduce the cost of striping and at the same time would maintain a good level of visibility and would reduce the toxic problems associated with yellow paint.

FIELD EVALUATION OF SELECTED DELINEATION TREATMENTS(2)

The purpose of this research effort was to establish relationships between traffic performance and accident probability on two-lane rural highways, to evaluate the effect of selected delineation treatments on traffic performance and associated accident probability, and to develop recommendations for the design and use of delineation treatments. The study was conducted in two phases with Phase I involving the development of models correlating delineation-related accidents to selected performance measures and Phase II involving the testing of the correlation models and the evaluation of unique delineation systems. Each of these research activities and their resultant finds are briefly described as follows.

Phase I Studies

The Phase I studies consisted of two major work efforts. The first involved the design and conduct of field studies to establish a data base for accident-probability modeling. Speed and lateral placement data were collected at 32 field-study sites on two-lane bi-directional roadways having ADT's of 540 to 5,000.

The second effort involved the collection and processing of accident data at each of the study sites and the development of regression modeling to derive a relationship between performance measures, geometrics, and accidents. The hypothesis studied was that the performance measures and geometric variables could be used to predict a portion of the accident potential. The performance measures would indicate the manner in which drivers traverse a given section of roadway and the geometric variables would define the available factor of safety inherent in the roadway design. Extreme values of traffic performance measures in combination with a limited factor of safety would be expected to result in an above-average accident rate.

Utilizing stepwise multiple linear regression, a family of four models was developed in an attempt to model accident experience for a tangent/winding roadway situation for dry nighttime operating conditions. The two most explanatory variables were:

- Centrality Index — Describing the degree to which the average driver operates off-center in the delineated lane.
- Difference in Placement Variances — This measure is the arithmetic difference between the lateral placement variances sampled independently at two critical points on a roadway's horizontal alignment, normalized (or divided) by lane width.

Based on extensive analysis of the available data it was found that for a rather minimal sacrifice in data fit, the two-variable-model was sufficiently reliable to be used in evaluating the safety effectiveness of alternative delineation treatments. Hence, the two-variable model using centrality index and placement variances was adapted for evaluating the Phase II data.

Phase II Studies

The first of the Phase II studies involved the field evaluation of the safety effectiveness of alternative delineation treatments. Twelve unique delineation treatments, as shown in Figure 6, were installed sequentially at nine field test sites. Speed and lateral placement data were collected at these sites and then processed to test for significant differences between various delineation treatments, performance measures, and operating conditions. The following is a summary of some of the findings:

- Single Solid Centerline — A single, solid-yellow centerline was tested with and without edgelines on a passing restricted S-curve and comparisons were made to the standard double-yellow centerline with edgelines. Measurements showed that the average driver was much less centrally positioned within the travel lane in the absence of either the edgeline or the standard 2-stripe centerline.

- Narrower Striping — Traffic performance as measured by the centrality index and lateral placement variances was not significantly changed when the 2-inch wide center striping and edge striping was widened to the standard 4 inches.

- Post Delineators — Post delineation along a basically tangent highway showed a negligible effect on mean lateral placement. However, significant reductions in lateral placement variances were documented. These reductions, when input to the accident/probability model, resulted in significant decrease in predicted delineation-related driving hazard.

  Post delineators were also tested on both sides of a 5-degree horizontal curve. The delineators were found to have a large beneficial effect on the average vehicle's lane centrality on the outside of the curve.

- Reduced Stripe-to-Gap Ratio — On a 24-foot tangent section with edgelines, it was found that the average driver operated more centrally within his lane with a 5:35 broken centerline than he did with

Experimental Delineation Treatment	Base Delineation Treatment
Reduced stripe-to-gap ratio for centerlines and lanelines	Standard stripe-to-gap ratio of 3:5
Single solid stripe as centerline where passing is prohibited	Double striping
*RPM's as replacement for painted centerline or lanelines	Paint stripes only
Substantially variant spacing of **PMD's (i.e. greater than 500 ft.)	Traditional close spacing of about 200 ft.
Narrower striping for some centerlines, lanelines, and edgelines	Standard 4- to 6-inch wide striping
Continuous edgelines on narrow roads (less than 22 ft.)	Centerline only
RPM's as supplement to painted centerline or lanelines	Paint stripes only
PMD's just on curved sections of roadway	Centerline only
PMD's just on curved sections of roadway	Centerline with continuous edgelines
RPM's just on curved sections of roadway	Standard paint striping only
RPM's as supplement to painted edgeline	Standard painted edgeline
Continuous PMD's as supplement to edgelines	Standard continuous edgelines

*RPM's: Raised Pavement Markers
**PMD's: Post Mounted Delineators

Figure 6. Delineation Configurations Selected for Phase II Testing

the MUTCD standard 15:25 centerline. Also, the lateral placement variance was significantly smaller for the less paint-intensive centerline. A 10:30 broken centerline was also tested on two stretches of a 22–foot wide roadway with edgelines. On one stretch, the centrality index was reduced but on the others there was no conclusive effect. The lateral placement variance was unaffected in both tests.

- <u>RPM Supplements</u> — Substantial decreases in centrality index was obtained for the dry-night tests when using RPM supplements. Also, the estimated delineation-related accident ratio for all RPM supplement treatments showed a sharp decline from the base condition rate.

Based on the findings of the field test experiemnts and the knowledge developed throughout the two-year research study, twenty-one (21) unique delineation systems were developed and evaluated with regard to their relative effects on nighttime variances of lateral placement and speed, predicted dry-night driving hazards, and initial installation cost. Eighteen of the systems applied to long sections of tangent or winding alignment and the other three systems were applicable only at isolated horizontal curves.

The tangent/winding delineation systems were segregated into four distinct categories, i.e., striping only, striping and RPM's, striping and post-mounted delineators, and raised pavement markers. In every case, the experimental system was compared to a base condition of standard MUTCD centerline with edgelines. Table 2 summarizes the most pertinent findings as to the cost and effects of these various systems. On the basis of these findings, the report recommended a series of delineation systems summarized as follows:

- For rural, two-lane highways, consideration should be given to a system of delineation which consists of a 4–inch, 10:30 centerline with 4–inch edgelines. At two sites where this was studied, the predicted hazard on a dry night was found to be either unchanged or substantially reduced. Also, if such a system is implemented beginning with the next paint cycle, a cost savings of about 4 percent could be realized.

- Where practical, consideration should be given to the use of reflective pavement markers as a supplement to the centerline to overcome possible target value problems associated with adverse visibility conditions (i.e., fog and rain). A combination of one-way and two-way amber markers is suggested, with reflective elements at 80–foot intervals where passing is allowed and 40–foot intervals where passing is prohibited. The use of such a system has the potential of greatly reducing delineation-related driving hazards.

Table 2. Evaluation of Costs and Effects of Continuous Delineation Systems

Delineation Category	Experimental Delineation System — Description	% Changes to Base Characteristics — Initial Cost to Install	Night Variances — Speed	Night Variances — Placement	Predicted Dry-Night Hazard
Striping Only	Single solid centerline				
	• w/o edgelines	↓74	↓60	↓30	-
	• w/4-in. edgelines	↓26	-	↓30	↑71
	4-in., 5:35 centerline				
	• w/4-in. edgelines	↓8	↓25	↑30	↓82
	2-in., 10:30 centerline				
	• w/o edgelines	↓78	-	-	-
	• w/2-in. edgelines	↓20	↓40	-	↓31
	4-in., 10:30 centerline				
	• w/o edgelines	↓75	-	-	↑++
	• w/2-in. edgelines	↓16	-	-	-
	• w/4-in. edgelines	↓4	-	-	-
		↓4	-	-	↓49
Striping and RPM's	4-in., 5:35 centerline • Ctr. RPM's @ 80 ft. (w/4-in. edgelines)	↑71	↓35	-	↓27
	4-in., 10:30 centerline • Ctr. RPM's @ 80 ft. (w/4-in. edgelines)	↑75	↓35	-	↑96
	4-in., 15:25 centerline • Ctr. RPM's @ 80 ft. (w/4-in. edgelines)	↑78	-	↓25	↓41
	4-in., 15:25 centerline • RPM's on both sides of lane @ 80 ft. (w/4-in. edgelines)	235 ↑	-	30 ↓	45 ↓
	4-in., 15:25 centerline • RPM's on both sides of lane @ 40 ft. (w/4-in. edgelines)	471 ↑	60 ↑	-	48 ↓
	Centerline of reflective & non-reflective RPM's				
	• w/4-in. edgelines	783 ↑	-	-	3 ↑
	• w/4-in. edgelines supplemented by RPM's @ 40 ft.	888 ↑	-	-	68 ↓
Striping and PMD's	4-in., 15:25 centerline • w/PMD's @ 528 ft. (w/4-in. edgelines)	78 ↑	-	30 ↓	21 ↓
	4-in., 15:25 centerline • w/PMD's @ 264ft. (w/4-in. edgelines)	157 ↑	30 ↓	25 ↓	32 ↓
RPM's Only	Centerline of reflective & non-reflective RPM's • w/o edgelines	736 ↑	50 ↑	-	12 ↑

(↑++ means a statistically significant increase of percentage shown),

(↑ means a statistically significant increase of percentage shown),

(↓ means a statistically significant decrease of percentage shown),

(– means any change was statistically insignificant).

- Where target value problems are evident and the 80-foot RPM centerline supplement cannot be applied because of snow-plowing problems, consideration should be given to continuous post-mounted delineators installed at intervals of 400-528 feet on tangents. The present MUTCD spacing recommendations should be retained on curves. This system seems to have the greatest benefits in terms of initial costs versus predicted safety effectiveness.

- No adverse safety effects were predicted at the two locations where 2-inch edgelines were tested in combination with a reduced centerline stripe-to-gap ratio. Therefore, consideration should be given to the use of narrower edgelines with the 10:30 centerline. With this combination, a costs savings of about 12 percent could be achieved.

- The delineation systems with a 4-inch, 15:25 centerline with supplemental RPM's on both sides of the centerline did not appear to yield a safety gain in sufficient size to justify the very large installation expense. With this system, there is a very rapid diminishing return on the initial investment. Likewise, the extremely expensive systems involving an RPM-only centerline did not yield sufficient safety benefits to justify their general application on two-lane rural highways.

The curve specific delineation systems studied included centerline raised pavement marker supplements and post-mounted delineators, used separately and in combination. Based on the traffic performance measures obtained at the field study sites, the following recommendations are offered for treatment of high-hazard horizontal curves:

- Where their use is feasible, RPM's are preferred over post-mounted delineators. RPM's serve well as both "near" and "far" delineations. They present a more accurate perspective of the driving surface and they have a more significant effect on mean lateral placement than post-mounted delineators.

- To benefit drivers on the outside of the curve without adversely affecting the lateral placement of vehicles in the opposite direction, consideration should be given to the use of one-way RPM's on the centerline. These markers, containing amber reflective elements and placed at 40-foot intervals, should substantially reduce the probability of potentially hazardous centerline encroachments.

- When RPM's cannot be used because of economic or maintenance problems, consideration should be given to the installation of post-mounted delineators on the outside of the curve. Although not likely to be as beneficial as RPM supplements, the post-mounted delineators do provide some degree of "near" as well as "far" delineation.

Comments on Research

This research represents an attempt to develop a model relating accident rate to various traffic performance measures and to utilize that model to evaluate unique delineation treatments. All analyses were conducted on two-lane rural highways. The first phase resulted in the development of accident probability models which were used in testing the hypothesis that each of several traffic performance measures and geometric variables could be used to independently predict a portion of the accident potential along a section of a tangent/winding road. Due to resource constraints, only very limited data were available for model development. A limited validation effort using field data for the tangent/winding sites, resulted in a model which contained only two variables (centrality of vehicular path and lateral placement variances) instead of the original five variables. In addition, it must be recognized that the models deal only with the expected accident rate of delineation-related, non-intersection accidents occurring during the hours of darkness and on dry pavements for various types of highways. The models should not be used as a tool to predict the overall accident rate for any particular section of a two-lane rural highway. They may add credibility to the use of traffic performance measures as evaluative measures or indicators of delineation-related driving hazards. Use of more data in development and validation of these models would certainly aid in substantiating their credibility.

The second phase involves the evaluation of twenty-one (21) unique delineation treatments. While this analysis resulted in recommendation for revising several currently used delineation systems, the sparcity of data throughout this study must temper applicability of results. These recommendations, based on estimates of relative installation costs and overall performance in terms of operational changes, deal only with basic delineation concepts, i.e., the presence or absence of a delineation treatment. While the basis for the recommendations are intuitively sound, consideration of test conditions must be considered in the application of the results. In addition, these results must be restricted to the types of locations and operating conditions considered.

A separate element of the Phase II work involved development of a general methodology for the field evaluation of delineation systems. This methodology, developed and refined during the course of the research project, specifies a procedure for field data collection and analysis and should be of considerable value to those interested in developing delineation evaluation programs.

COST-EFFECTIVENESS AND SAFETY OF ALTERNATIVE ROADWAY DELINEATION TREATMENTS(3)

This research study was the third major contractual effort undertaken by FHWA and was aimed toward determining the cost-effectiveness of various delineation treatments on two-lane rural highways. The assumption was that there is a relationship between particular delineation treatments and accident experience, that accident rate reduction can be expressed in monetary terms, and that these reductions constitute the primary benefits to be derived from delineation. The two major objectives of the research were:

- To develop a cost-benefit methodology for evaluation of specific delineation treatments.
- To develop cost-effective guidelines for delineation of various highway situations under differing geometric, traffic and climatic conditions.

The results and findings of this research are divided into four major areas:

- State-of-the-art report on roadway delineation treatments
- Statistical analyses to estimate accident reduction associated with various delineation treatments
- Economic analysis models to evaluate specific delineation treatments
- Delineation guidelines

State of the Art

This part of the research was an update of the comprehensive state-of-the-art summary of delineation found in Appendix A of NCHRP Report 130, "Roadway Delineation Systems."(4) Part I is a review of studies reported since the publication of NCHRP Report 130. Part II consists of recommendations and general guidelines for the effective application of delineation treatments. The recommendations in Part II are essentially those reported in NCHRP Report 130 modified to a minor degree by research findings since 1970. The report contains updated information on cost, service life and effectiveness of delineation treatments as well as general delineation application guidelines.

Statistical Analyses

This element of the research was designed to evaluate the effect of alternative delineation treatments on accident experience in various highway situations and under varying environmental conditions. To meet this objective, over 500 test sites were selected in ten states, and accident, geometric, traffic and environmental data for these sites were collected. These data were then statistically analyzed to identify important parameters which alter the effects of delineation on accident occurrence and to assess the reduction in accidents associated with various treatments.

In carrying out this analysis, both hypothesis testing and estimation procedures were used. Hypothesis testing procedures were used to assess whether the changes in accident rate resulting from changes in site delineation treatment were statistically significant. These procedures used the t–test, one-way analysis of variance, two-way and higher-order analysis of variance, and covariance analysis. The t–test and one-way analysis of variance provided a means to test for statistical differences in mean accident rate under different treatment categories. Two-way and higher-order analysis of variance and covariance analysis provided a means for studying how these differences were affected by other variables such as roadway geometrics, traffic operations, and climatic parameters. The estimation procedures included the t–test and regression analysis and were used to quantify the changes in the accident rate resulting from different delineation treatments, changes in geometrics, and traffic operational conditions.

Within this study, two types of highway sites were used. The first, termed "matching-control" sites, were those for which the delineation treatment remained unaltered over the analysis period. The second, termed "before-and-after," were those sites for which accident data were available for both before and after the installation of a test delineation treatment.

The general findings resulting from the statistical testing using matching-control sites and using accident rate as a dependent variable were as follows:

For Tangent and/or Winding Sites

- Highways with centerlines have lower accident rates than those with no treatment at all.
- Highways with raised pavement marker centerlines have lower accident rates than those with painted centerlines.
- Edgelines seem to have insignificant effect on traffic accidents.
- Highways with post delineators have lower accident rates than those without post delineators.

For Isolated Horizontal Curves

- There is a slight indication that sites with post delineators have lower accident rates than sites without post delineators.
- Accident rates appeared to be somewhat lower at horizontal curve sites with centerlines than at horizontal curve sites with no delineation treatment.

The analysis of the"before-after" sites yielded insignificant results for all the tests and therefore could not be accepted with any degree of confidence. It was felt that the small sample (31 pairings) was a major contributing factor to the lack of positive results.

Economic Analysis Models

This element of the research involved the development of two economic models that could be used to evaluate roadway delineation treatments. The first, a cost-benefit model, was designed to compare major delineation treatment applications. The second, a cost-analysis model, was designed to evaluate treatments for which the benefits are assumed constant and independent of minor treatment variations; i.e., paint versus thermoplastic.

The geometric, traffic, and climatic parameters are not entered directly into either of the models, but these variables do enter through their effect on traffic accidents and the cost and service life of candidate treatments. The two models are also supplemented by installation-costing procedures designed to provide a uniform basis for computing treatment installation costs.

The mathematical expressions for the two models are:

- Cost-Benefit Model

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

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

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

- Cost -Analysis Model

  Present Worth of Cost = PWC

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

where:

AADT	=	annual average daily traffic in year zero
RAR	=	estimated reduction in accident rate in year zero
CA	=	cost of accident
v	=	annual percent increase in traffic volume
i	=	discount rate
N	=	analysis period
$(TIC)_n$	=	total installed cost in year n
TC	=	terminal cost at the end of analysis period
$(MC)_n$	=	maintenance cost in year n

The block flow diagram shown in Figure 7 indicates the procedure for executing the models. First, the highway situation and the candidate treatments are identified. Next, appropriate data are compiled for each candidate treatment. Either the cost-benefit or the 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 an increasing value of NPW.
- The treatment with the least PWC value is most economical.

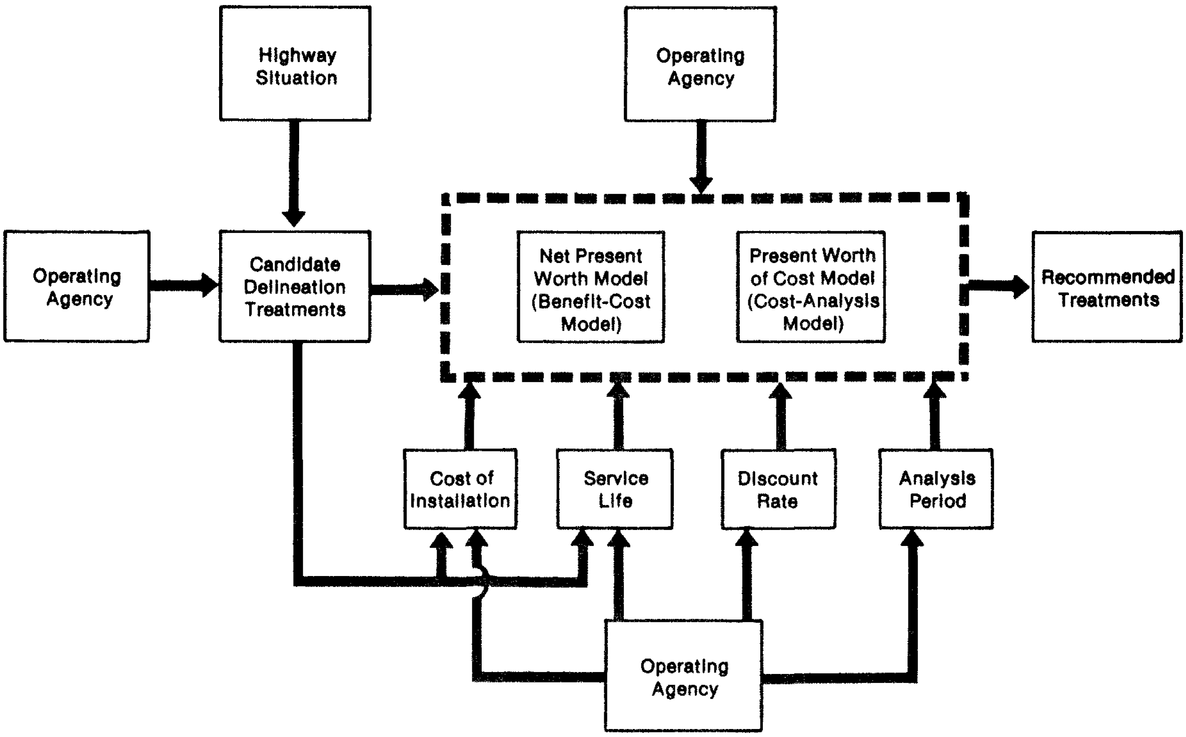


Figure 7. Schematic Representation of "Benefit-Cost" and "Cost Analysis" Models

Delineation Guidelines

This element of the research involved the application of the cost-benefit model to a set of specific delineation situations to determine the desirability of specific treatments applied under specific roadway and traffic conditions. The scope of the cost-benefit calculations included continuous delineation applications along both tangent and winding sections, as well as spot improvements at 2 horizontal curve sites. The types of treatment applications considered are shown in Table 3.

Table 3. Treatment Applications Used In Cost-Benefit Calculations

Type of Site	Description of Treatment
Tangent Sections	Painted Centerline Added to No Treatment Raised Pavement Markers Added to Painted Centerline Post Delineators Added to Painted or RPM Centerline Edgeline Added to Centerline with Post Delineators RPM Centerline Added to Painted Centerline Edgeline Added to Centerline (Post Delineators Optional)
Winding Sections	Post Delineators Added to Centerline with Edgeline Painted Centerline Added to No Treatment RPM Centerline Added to No Treatment Centerline Added to No Treatment (Mountainous) Centerline Added to No Treatment (Level)
Horizontal Curves	Post Delineators Added to Centerline at Sites in Georgia and Louisianna

The cost-benefit calculations were carried out parametrically where ranges of values for all costs, service lives, etc., were chosen for each selected treatment application. Economics was the sole basis for the evaluation of the various treatments with reduction in traffic accidents as the sole measure of benefits to be derived from the delineation systems. One fallacy in this procedure is the uncertainty associated with the selected accident model. If the accident model is questionable, then the cost-benefit is likely to produce questionable results.

Utilizing the cost-benefit model, a series of calculations were performed to develop the benefits and costs for each combination of parameters for each treatment type Some general conclusions based on the calculations are:

- A painted centerline added to tangent and winding sections with no previous treatment was cost-beneficial for all values of cost, service life and AADT considered.
- RPM centerlines were more cost-effective than painted centerlines where a service life of five years or more is expected from the RPM's and the AADT exceeds 3,000 vehicles per day.
- Post delineators were cost-justified at all AADT's above 1,000 vehicles per day and under most combinations of installation costs and service lives for AADT's as low as 500 vehicles per day.
- Edgelines with service lives of five years or more were cost-effective for most highways with an AADT of 500 vehicles or more per day. If this installation cost is less than $165 per mile, they are cost-effective with service lives of two years. If the AADT exceeds 1,000 vehicles per day, they are almost always cost effective with a one-year service life.

Comments on the Research

Although this was a very extensive and comprehensive analysis of the cost-effectiveness of various delineation treatments, it is important to recognize that the results of this research were obtained through the statistical analysis of accident data and therefore are subject to all the strengths and drawbacks which a statistical analysis entails. Of particular concern are the shortcomings of statistical analysis related to the accident data base. Accident data take a long time to accumulate. Over this period, the roadway environment can change, driving population may alter, and traffic regulations can be modified. In addition to such changes over time, no two roadway sites are exactly alike, causing a variation in data from site to site. These variations make it extremely difficult to conduct a controlled study, a prerequisite for good statistical results. Other problems encountered in statistical analysis of accident data relate to the variation in accident reporting procedures from state to state and county to county, discrepancies and abnormalities in the data base, and the time and cost involved in selecting highway sites with specified characteristics.

It is therefore important that the use of the statistical results be used with some care. The t–test results estimate the mean reduction in accidents for a particular delineation treatment but these results do not take into account roadway geometrics, operational conditions and climatic conditions.

Regression models, like the t–test results, also estimate accident reduction associated with various delineation treatments, but unlikethe t–test, they provide a measure of its dependence on other roadway characteristics and climatic parameters. It is important to remember, however, that although the regression models provide estimates of the average accident rate on a particular section of highway, the application of these models to an individual highway section can be subject to rather large variations and should be used only as a general guide.

General recommendations on the use of the results of this accident modeling research are:

- If the intended objective is to assess the overall reduction in accidents from the installation of a particular delineation treatment without regard to consideration of roadway features, then the t–test results should be applicable.
- If the effect of delineation treatment is to be assessed for a given highway and geometric and operational characteristics are of concern, then the regression models should be considered.

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

The economic models developed to evaluate various roadway delineation treatments include all the important variables that need to be considered and seem to provide a good basis for computing the costs and benefits of different systems. As better accident models are developed, the economic models can become better planning and research tools for evaluating different forms of delineation treatments.

IMPROVING DRIVER PERFORMANCE ON CURVES IN RURAL HIGHWAYS THROUGH PERCEPTUAL CHANGES(5)

This three-phase research study was performed by the Driving Research Laboratory of Ohio State University using HPR funds. The objectives of the first two phases were to investigate the perceptual processes involved in curve negotiation and to relate these processes to road and curve characteristics, to high- and low-accident curves, and to individual differences in perceptual style and information processing. The objectives of the third phase were to implement these findings through selective modifications in curve perceptual structure, and to assess the effects on both test driver data and radar speed data.

The experimental phases consisted of overlapping research conducted on test drivers on the road, test drivers in the laboratory, and statistical analysis of curve-accident files. The principal results from each of these studies follow.

Road Studies

Five drivers drove an instrumented vehicle on a two-lane rural highway route consisting of 22 curves (three high-accident curves and 19 low- and no-accident curves) and two straight road segments (one tree-lined and the other open). Eye-movement search and scan patterns were video-taped, and driver control actions and vehicular dynamics were measured. Significant findings included:

- The visual search pattern follows closely that of the road geometry. The curve scan process starts in the approach zone, approximately 2.5 seconds before the curve.

- When the curve is partially or wholly obscured, drivers rely on continuous scenery for curvature cues.

- Fixation durations are shorter and travel distance between fixations is longer in curves than on the straight road. Both are indicators of increased uncertainty in the curve.

- The approach section immediately prior to the curve exhibits eye movements similar to those on curves rather than those on straight roads. Thus, the perceptual process of curve negotiation starts well in advance of the curve.

- A Preview Index (PI), defined as the velocity differential between approach and curve velocity divided by the length of the approach zone, correlated with accidents (r=.51). The more time the driver has to assess the curve, i.e., the longer the approach zone, the lower the accident liability of the curve.

- A test-driver performance-based measure of Effective Curvature (EC) was developed. The EC, defined as the ratio between maximum lateral acceleration and the (velocity) at this point, correlated with accidents (r=.57). Curves having EC <100 are considered safe, whereas when EC ≥ 100, a curve may be accident-liable.

- Tree-lined roads elicited slower speed than open roads. With 60 mph instructions, the test driver's average speed was seven miles faster on the unbordered open road, supporting the hypothesis that peripheral structured patterns enhance speed perception and increase the velocity estimation.

Laboratory Studies

Eleven subjects (of which the five test drivers were a subsample) participated in several laboratory experiments aimed at measuring individual differences and general ability in perceptual and information processing tasks related to curve negotiation. The main findings of these studies were:

- When presented with an arc of 90° or less, curvature is consistently underestimated. The error in estimation is inversely proportional to the length and radius of the arc visible. Thus, the less visible the curve, the less accurate the driver is in assessing the curve.

- Visual illusions of verticality (Rod and Frame Test and Zollner's illusion) were combined, and it was shown that they can be used to effectively attenuate or enhance each other's effect. The additivity of these effects can be used to perceptually enhance curvature.

- Comparison betwen pictures of high and no-accident curves showed that:

  - High accident curves do not appear sharper or more dangerous, thus neither the actual or phenomenal curvature are related to accident rate.

  - High accident curves are erroneously perceived as more visible than in fact they are.

  - Inside perspective angle (measured from the pictures) was found to be significantly sharper in high-accident curves (50^{o} on the average) than in no-accident curves (68^{o}). The implication is that vertical curvature in combination with horizontal curvature may be relevant to accidents.

- Speed profiles in a movie simulation of driving through curves were identifiable for high- and no-accident curves.

- Individual differences in information processing rates and perceptual style were related to eye movement in driving.

  - Field dependent drivers fixate less on the road and more at the horizon than field independent drivers. Thus, field dependency is associated with a less adaptive visual search pattern.

  - Slow information processors (based on a choice reaction time task) fixate closer to the center of the visual field. This process is adaptive but suggests that relevant information away from the center might be overlooked.

<u>Analysis of Ohio DOT Curve-Accident Files</u>

Curve-accident files were analyzed to assess statistical significance of curve parameters on accidents. The findings showed that:

- The correlation between accident rate and traditional measures of curvature was very low.

- The effects of expectancy were indirectly assessed by studying the relationship between the geometry of adjacent curves. Various measures were developed, but in all cases the correlation was less than 0.2. These results may be more indicative of the inapplicability of actuarial data to cause-effect analysis than the lack of effect found.

The results of Phases I and II of this study point out that a curve's accident liability can be measured more effectively in terms of driver performance and driver perceptions than with traditional measures of curve geometry. It has been further shown that high-accident curves do not appear to be so, and the simulated speed profiles in their approach zone are similar to those recorded for no-accident curves. Therefore, improper curve negotiation is related to perceptual assessment problems. To correct for perceptual errors, a technique of counteracting the effects of one visual illusion with another was tested and was found to be effective under limited laboratory conditions.

As a follow-up to Phases I and II of the project, five rural curves were modified to influence user behavior. Two were given special signing and three were given special pavement markings (i.e., one transverse striping, one a widening of the inside edge marking at the curve, and one with markings designed to make roadway appear narrower at the beginning of the curve). Both regular road users and test drivers in instrumented vehicles were studied before and after the modifications at each site and 30 days after modification at three positions prior to each curve.

It was found that driver speed profiles on rural curves can be affected by novel pavement markings designed to provide specific perceptual effects. High speeds were most susceptible to change due to the modifications, but the speed reductions were not found after 30 days of acclimation. Intersubject speed variablity was also found to be reduced. The most effective modification was the accent on the inside edge marker; in comparison, special signs had little effect. These results argue for the use of painted markings instead of signing to remedy high-accident curve sites.

Comments on the Research

This work represents a good analysis of the perceptual processes involved in curve negotiation. The field and laboratory tests were positively correlated with the major finding that a curve's accident potential can be measured more effectively in terms of driver performance and driver perceptions rather than with traditional measures of curve geometry. It was also substantiated that the better remedy for accident curve sites is the use of pavement markings rather than signing.

STUDIES OF THE ROAD MARKING CODE(6)

This research was an FHWA staff study designed to evaluate driver reactions to various types of pavement delineation. Studies were made in two general areas: driver understanding and acceptance of present marking standards and a so-called "ideal" marking system based on driver preferences. The following summarizes the findings of the studies and their implications.

Driver Understanding and Acceptance of Present Marking Standards

This phase of the research was concerned with driver understanding of road marking patterns and driver acceptance of standard road marking applications. It involved the administering of a comprehensive questionnaire to 104 persons in the FHWA Office of Research and Development and to 126 Coast Guard recruits stationed in Cape May, New Jersey.

In respect to driver understanding, the respondents did not show a very favorable understanding of currently used road markings. For example, a very large percentage of the respondents could not correctly identify the meaning of a single solid white line, single width white markings, double broken yellow line, and a single broken white line. The respondents did, however, understand that the double solid yellow lines prohibit passing and that the single broken yellow marking is intended to convey that passing is permitted in both lanes.

In respect to driver acceptance of standard markings, the respondents seemed generally satisfied. The applications that were mostly favored seemed to be those that show the driver's path of travel under adverse conditions or when he is performing a difficult maneuver. Those marking applications that seemed to be less acceptable were those that generally attempt to communicate meanings which the driver may find difficult to interpret or ones which he may consider unnecessary. Examples of these were markings to indicate a narrow bridge, markings to indicate where to stop at a stop intersection and markings to advise approaches to a toll booth.

Development of "Ideal" Coding System Based on Driver Preferences

The second study was concerned with driver preferences for road markings as indicated by their choices of "the most logical and understandable" markings to fit a variety of common highway situations. Subjects of the study were 23 Baltimore firemen and 73 Coast Guard recruits tested at Cape May, New Jersey. Highway situations were taken from the Manual on Uniform Traffic Control Devices (MUTCD) and a multiple choice questionnaire was used to investigate driver's preference for a particular roadway marking to match the highway situation.

Respondents selections of the "most logical and understandable" markings that coincided closely with MUTCD recommendations were:

- Single broken white marking used to separate lanes of traffic moving in the same direction
- Single solid white to show the curb marking of a highway
- Double solid yellow lines used to separate travel in opposite directions where crossing is not permitted

Respondents' selections of markings that tended to disagree with the MUTCD recommendations included:

- Double solid white marking for lanes of a multi-lane one-direction highway where changing to or from that lane is prohibited
- Double solid yellow center marking of a two-lane road (one lane in each direction) as the road approaches an intersection
- Single broken yellow center marking of a two-lane highway (one lane in each direction) where traffic heading in both directions is legally permitted to overtake and pass

Most of the respondents agreed that they relied mainly on their recall of road markings in making their choice of markings. Thus, it is likely that many drivers are largely unaware of the design principles underlying the road marking code.

Comments on the Research

This work represents a limited but a representative survey of how drivers interpret various types of pavement delineation. It was quite clear by the large number of respondents that had problems correctly identifying the meaning of different types of delineation, that many of the currently used pavement marking standards are not very well understood. The implication is that there should be attempts to increase the driver's knowledge of the standard system or else there should be greater emphasis to develop more efficient standards with meanings that are more understandable.

The research findings also bring into question the use of yellow markings to show separation of counter-moving traffic. Since many of the respondents were unaware that yellow markings are intended to indicate the opposite movement of traffic on the adjacent lane, and since yellow paint has the disadvantages of being toxic, being more expensive, and has less visibility under adverse weather conditions, there is a good rationale for considering the elimination of yellow as a standard to show separation of counter-moving traffic.

ECONOMIC ANALYSIS OF PAVEMENT MARKING MATERIALS ACQUISITION, DISTRIBUTION, AND STORAGE(7)

The purpose of this research was to analyze the pavement traffic marking program in the state of Ohio, to investigate the economic aspects of materials acquisition, distribution of materials acquisition, distribution and storage, and to develop a set of feasible alternatives and recommendations that could reduce the $2.5 million dollar annual investment without having a reduction in the level of service. The product of this research was an inventory control system for Ohio's pavement marking materials. Important features of this system included:

- A material requirements planning program for specifying a delivery schedule for pavement paint and a reorder system for controlling glass bead inventory.
- A procedure for the acquisition, distribution, and storage of delineation materials

- Policy and procedure recommendations involving a four-day work week, multi-line striping with fast-dry paint, purchase of specialized equipment to facilitate handling problems, conversion of old stripers to handle fast-dry paint, and the retention of a local paint supplier to deliver short-term emergency orders.

It was concluded that the implementation of the materials control systems, along with the policy and procedure recommendations, would result in an estimated savings of about $100,000 per year.

Comments on the Research

This work represents a thorough analysis of the pavement-marking operations of a very large number of states as to their current practices and problems. It also develops a very comprehensive "Materials Control Plan" for the acquisition, distribution, and storage of pavement delineation materials and incorporates all the necessary work flow procedures for carrying out an efficient pavement marking program. The application of this research by all states would likely result in a significant increase in the efficiency of their pavement marking programs.

CHAPTER IV
OTHER SIGNIFICANT DELINEATION ACTIVITIES

The previous chapter concentrated on the research projects of the 1-L-3 study with a synopsis of findings and recommendations. This chapter is a documentation of other significant delineation activities that have a relationship to the 1-L-3 study.

OPTIMIZATION OF TRAFFIC LANE DELINEATION(8)

In 1976, the California Department of Transportation, in cooperation with the Federal Highway Administration, conducted a major study of pavement delineation practices in California. The purpose of the study was to review and evaluate existing pavement delineation practices, analyze costs and application methods for different delineation systems, and determine an optimum system of delineation practices for use on California highways. The scope of the study included an analysis of the following areas:

- Use of glass beads
- Paint thickness
- Physical properties of raised pavement markers
- Raised pavement marker installation methods
- Raised pavement marker effect on safety
- Delineation patterns
- Maintenance operations
- Mechanical placement of raised pavement markers

The following summarizes some of the more significant findings and recommendations of this study:

- Glass beads — Bead applications less than 3.5 lbs. per gallon of paint are ineffective. Beads applied in excess of 6 lbs. per gallon are not retained. The use of 4 lbs. of beads per gallon of paint on all stripes is recommended. Unbeaded or partially beaded stripes are not recommended.

- Paint thickness — The expected life of a painted stripe is not directly related to its thickness. Paint applied in excess of 5 mils has decreased proportional wear. It is recommended that a dry film paint thickness of 5 mils be used for all edgelines, lane lines, and centerlines.

  Hot spray thermoplastic provides a stripe with excellent night reflectivity, but the high initial cost of this material requires a considerably greater life than paint. Tests are still being conducted to determine effective life, and it is recommended that this material not be adopted as a standard for lane lines until the durability tests can be completed.

- Physical properities of raised pavement markers — Low-profile markers as well as reflective markers with rounded profile seemed to provide less durability, and the use of these markers is not recommended.

  A patterned bottom for non-reflective markers demonstrated a significant decrease in marker losses, and it is recommended that the specifications for non-reflective markers require a patterned bottom rather than a flat bottom.

- Raised pavement marker installation methods — The use of currently specified epoxies for installation of raised pavement markers performs satisfactorily if properly applied and good quality control is achieved. Certain guidelines must be followed and some of these include:

  - Delay placement of markers on asphalt concrete until at least 60 days after paving
  - When replacing lost markers, always sandblast contact area of pavement
  - Allow at least one year of weathering before placing any markers on asphaltic concrete that has received an application of an asphalt rejuvenating agent
  - Avoid placing markers on longitudinal joints in asphalt concrete pavement

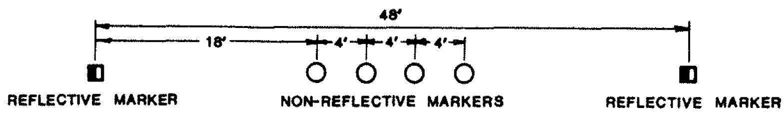
- Raised pavement markers effect on safety — An analysis of the effect of raised pavement markers compared before and after accident rates on existing freeway sections in California. The results of this analysis indicated that the accident rate remained constant on rural freeways but increased on urban freeways with the installation of pavement markers. However, there were major fluctuations in the accident rates, and it is believed that the change in accident rates could not be totally attributed to the use of the markers.

- Delineation patterns — This element of the study investigated patterns for centerlines, lane lines, barrier stripes, and edgelines.

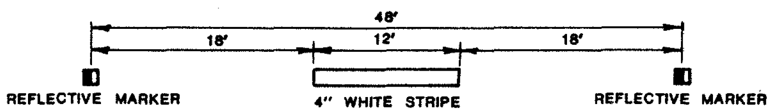
The first test consisted of evaluating 23 test patterns of proposed centerline and lane line configurations.

A second test was conducted to determine proper spacing for reflective markers. A third test investigated the spacing of reflective yellow markers in conjunction with the left edgeline. Some of the recommendations resulting from these studies are:

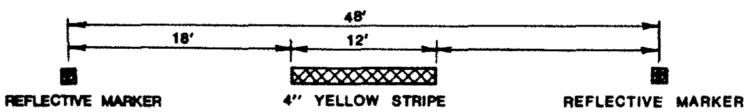
- The spacing of reflective markers on lane lines, centerlines, and median edgelines should be at 48-foot centers maximum.
- In certain areas where either horizontal or vertical sight distances are limited or restricted, the reflective marker spacing may be shortened to 24 feet.
- The basic marker pattern for lane lines on freeways, expressways, and multilane undivided highways should be:



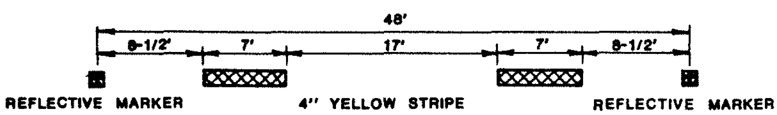
- The following alternate pattern may be used for lane lines on rural freeways and expressways with low rainfall, and on multilane undivided highways:



- The basic marker and paint patterns for centerline on two-lane conventional highways should be:



HIGH SPEED (45 MPH OR MORE)



LOW SPEED (LESS THAN 45 MPH)

- <u>Maintenance operations</u> — Maintenance, traffic, and construction personnel in each CalTrans district office were contacted to obtain data regarding their maintenance operations pertaining to pavement delineation. The following is a summary of the findings of this survey:

  - Epoxies currently being used have been greatly improved and do not appear to be a problem area.
  - Marker loss is proportional to vehicles changing lanes over the line.
  - Many markers are lost from newly placed asphalt concrete.
  - Sandblasting is the best method of preparing pavement for marker installation.
  - Markers should not be placed on longitudinal pavement joints—on either asphalt concrete or Portland Cement concrete.
  - Excessive paint restriping is done for cosmetic purposes. A computerized paint schedule and activity summary can be effective in reducing this item.
  - Washing painted stripe to prolong its effective life is not practical.
  - There should be greater use of thermosplastic for pavement markings.

- <u>Mechanical placement of raised pavement markers</u> — As part of this study, a thorough analysis was conducted to evaluate the feasibility of using a pavement marker placing machine. It was concluded that the construction of such a machine is feasible, but the capabilities of such a machine cannot be defined until additional development and design work can be done. As far as California is concerned, the development of such a machine cannot be economically justified. However, under different circumstances in other states, the development costs may be warranted.

Comments on the Research

This study represents a comprehensive examination of three systems of pavement delineation (paint, raised pavement markers and hot spray thermoplastic) on different types of highways in California. The specific recommendations are sound for the environmental conditions under which the testing was performed and many of the findings should be applicable on a widespread basis in many states in helping to establish policies and procedures for traffic lane delineation.

DELINEATION CONFERENCES(9)

As part of FHWA's delineation research program, two delineation conferences featuring a full range of subjects on delineation by a group of knowledgeable persons in the field, were held in both the eastern and western sections of the U.S. in the spring of 1977. Major objectives of the conferences were to identify the most current usable information and to pinpoint gaps where additional knowledge is needed. A synopsis of some of the significant findings resulting from these conferences follows:

- The use of raised pavement markers has greatly increased in the past ten years. The major advantages of raised pavement markers are improved wet-weather delineation, reduced maintenance, and more positive nighttime delineation. The major disadvantages are the high cost of installation and their incompatibility with snowplowing.

- Raised pavement markers bring about a significant reduction in lateral placement variance and cause drivers to adopt a more central position in their lanes. The use of raised pavement markers also results in fewer centerline encroachments while negotiating a curve.

- Thermoplastics are beginning to play a much larger role in delineation, especially at locations where heavy wear is expected. To be cost effective, thermoplastic installations must remain maintenance-free for three to five years. In hot, dry locations, there have been problems with thermoplastic in that it becomes badly stained.

- The reduction of the stripe-gap ratio to save materials is needed. This can be done without sacrificing effectiveness.

- There is a lack of good information regarding the safety aspects of delineation. Previous research in this area has been somewhat fragmented and often non-comprehensive. The major problems have been the inability to maintain a controlled environment along with inadequate traffic accident records.

- It has been observed that basic delineation will provide major safety benefits where there was no previous delineation. It has also been observed that major improvements in delineation treatments on roadways that have some form of delineation can produce measurable changes in traffic performance.

- Edgelines have become an accepted practice, but they have limitations on narrow roads where they tend to force the driver to the center of the road.

- Post delineators appear to have little effect on traffic performance. However, they provide excellent "far" delineation and often are the only cues to the motorist during wet weather and snow conditions.

- During daylight hours under clear conditions, the visibility of road surface delineation has very little effect on driver performance.

- Retroreflective pavement markings have a significantly beneficial effect upon vehicular control in rain and darkness. These markings reduce lateral position variability and also reduce the tendency of driver to encroach upon the lane line.

- The most commonly used delineation treatment is the painted stripe with beads. Experience indicates that bead application ratios between four and six pounds per gallon are effective. Beads applied in excess of six pounds per gallon are not retained. Unbeaded or partially beaded stripes are not recommended.

- Delineation systems are designed to satisfy the needs of drivers in both daytime and nighttime conditions. However, conventional painted stripes lose their effectiveness under adverse conditions (i.e., rain, snow, fog, dust). Reduced visibility and loss of delineation have a significant effect on driver control, as evidenced by lateral placement variability of vehicles in the traffic lane.

- The most commonly used mechanism to counteract the effect of adverse weather is the raised pavement marker. Studies have shown that such markers enhance wet nighttime driving as well as normal nighttime driving. The retroreflective raised pavement marker is not designed to replace paint striping, but is used in conjunction with paint striping.

- Recessed pavement markings have also been used to enhance delineation under adverse weather conditions. One type is a grooved paint stripe in combination with cross-drainage channels to allow water to escape. Another is a reflectorized marker placed in a groove in the pavement surface. The grooved paint stripe has not been very successful, but the recessed reflectorized marker appears to have a good potential in snow areas.

- Delineation systems used to enhance driving during snow or on snow-covered roads when conventional systems are not visible include use of colored sand, cinders, coal, and lampblack. Snow posts are also a valuable aid to both the drivers and snowplow operations.

- The more significant research needs identified during the workshops are:

  - Visibility requirements of a driver under adverse weather conditions, especially during wet weather conditions at night

- Replacement of the painted stripe with an economical, all weather, permanent delineation system that would be applicable in snow areas
- Determination of standard spacing and coding treatments for raised pavement markers
- Development of delineation concepts for wet-nighttime conditions that can withstand snowplowing
- Development of an efficient and economical delineation treatment that can be used temporarily in construction zones
- Evaluation of the durability and effectiveness of flexible post delineators
- Use of reflectorized cones or posts as replacements for wooden barricades in construction zones

Comments

The delineation conferences were good in that they offered a forum where the researchers and practitioners could interact and exchange knowledge on delineation practices in the U.S. It is significant that there was almost unanimous agreement that the most pressing needs in the delineation field today is a better system of delineation for maintaining driver visibility under adverse weather conditions and the development of an efficient and economical delineation system that can be used in construction zones. Both of these areas are currently being addressed by ongoing FHWA research projects.

PAVEMENT MARKING DEMONSTRATION PROGRAM(10)

The Federal-aid Highway Act of 1973 also authorized a demonstration program of pavement markings to bring any highway, either on or off the Federal-aid system, up to specified marking standards. Priority for these markings was given to rural roads. All states, with the exception of Alaska, are participating in the program, and over 940 projects have been authorized.

For the first three years of the program, a total budget of $116,078,141 has been obligated. In addition to painting centerlines and edgelines, the funds are being used for supplementary markings such as stoplines, crosswalks, school zones, and railroad crossings. In some cases, thermoplastic pavement markings and raised pavement markers are being installed. The effectiveness of this program is being evaluated in accordance with the legislation mandate, and preliminary data indicate that this program is offering significant reductions in injury and property damage accidents for a relatively low cost. A final evaluation will be developed upon the completion of the program at the end of FY 1978.

AN EVALUATION OF THE 10:30 CENTERLINE MARKING PATTERN(11)

This was a research study conducted by the Virginia Highway and Transportation Research Council in July, 1977, of the feasibility of adopting a 10-foot stripe and a 30-foot gap centerline pattern for use on 2-lane and 4-lane rural roads. This centerline was to be in lieu of the current practice of a 15:25 pattern. The study included field studies of traffic speed and lateral placement on rural highways, a motorist opinion survey, and an estimate of expected benefits. The key findings were as follows:

- In the field studies, it was found that speeds on roads with the 10:30 pattern were from two to four miles per hour greater—a statistically significant finding.
- With the motorist opinion survey, over 96 percent of the motorists did not notice that the pattern had been changed from 15:25 to 10:30. Of those respondents who were aware of the different patterns, the 10:30 pattern was preferred by a 7 to 1 margin.
- In the economic evaluation, it was estimated that the State of Virginia could realize a cost savings of from $50,500 to $89,500 per year by changing to the 10:30 pattern. This estimate was based on 1976 unit costs and the miles of centerline markings in Virginia.

Based on these findings, the Research Council recommended that Virginia implement the 10:30 centerline pattern on rural highways. They also recommended that further study be conducted to evaluate the 10:30 pattern in urban areas.

The updated version of the Manual on Uniform Traffic Control Devices (MUTCD) will include provisions for a 1:3 stripe-to-gap ratio for rural highways, with a 10-foot stripe and 30-foot gap.

EFFECT OF PAVEMENT EDGE MARKING ON TWO-LANE RURAL STATE HIGHWAYS IN OHIO(12)

In one of the earliest attempts to determine the effect of edgeline markings, the Ohio Department of Highways conducted a study of pavement edge marking on 2-lane rural highways which were at least 20-feet wide. The research involved a study of nine sites with each site consisting of a test section (pavement edge marked) and a control section (pavement not edge marked). Analyses were made of all reported accidents on each of the test sections both before and after edge marking. The "before" period was one year prior to the marking and the "after" period was one year following the application of the marking. The experience on the control sections was used to determine anticipated accidents on the test sections if they had not been treated with edge markings. A summary of the principal findings of this study are:

- There was a significant reduction in fatality and injury-causing accidents.
- Accidents at intersections, alleys, and driveways were significantly reduced but accidents between access points showed no significant change.
- There was no significant change in day accidents; night accidents were reduced but the change was only marginal.

EFFECT OF PAVEMENT EDGE MARKINGS ON TRAFFIC ACCIDENTS IN KANSAS(13)

Patterned after the earlier study in Ohio, the Kansas Highway Commission undertook a research project in 1960 to determine the effectiveness of edge markings in Kansas. A controlled type of "before" and "after" accident comparison study was used. A total of 29 study sections (distributed throughout the state) were selected for study purposes. Analyses were made of all reported accidents on each test and control section both before and after edge marking. A period of one year before and after application of edgelines was used as the basis for the accident analysis. Significant findings of this research were:

- Accidents at intersections and driveways were significantly reduced during both daytime and nighttime conditions. Accidents between access points were not significantly changed. This finding was very similar to that reported in the earlier Ohio study.

- There was no significant change in the total number of accidents. This was also a finding of the Ohio study.

- There was a significant reduction in the number of fatalities, but there was no significant change in the injury accidents. This differed somewhat from the Ohio study findings and the difference is difficult to explain.

Comments

Both the Ohio and Kansas studies demonstrated that edgeline markings on two-lane rural roads do not have a significant beneficial effect in reducing overall accident frequency. However, there was evidence in both studies that the edgelines were effective in reducing the severity of accidents and the number of accidents at major access points, i.e., intersections and driveways. These findings are very similar to those reported in the study of Cost-Effectiveness and Safety of Alternative Delineation Treatments.(3)

INTERVIEWS(14)

As explained in Chapter I, one element of this overview consisted of interviews with a selected group of individuals who have considerable experience in the pavement delineation field. The purpose of these interviews was to identify the general philosophy of each individual regarding delineation and to identify those areas of research that seem to be the most pressing. The following is a generalized summary of the results of these interviews and is presented in the form of statements:

- The pavement marking demonstration program was the first significant effort to develop a widespread program of delineation markings on rural two-lane roadways. It has had a significant impact in that it focused attention on the need for delineation on roads that are not on the heavily traveled primary and Interstate systems. Problems have developed as a result of this program, however. Some states were reluctant to initiate programs of this nature since they feel that the demonstration program will be discontinued and when this happens, there will not be sufficient resources to maintain the pavement markings. Most everyone is awaiting the results of the final evaluation of the various demonstration projects before they decide whether the program has been effective.

- Almost everyone agreed that the best performance measure for studying the effectiveness of delineation is the variability of lateral placement. This measure is intuitively appealing as well as being the most sensitive to differences in delineation systems both in the laboratory and in the field.

- There was considerable skepticism that you could ever find a good relationship between accidents and small changes in delineation treatments. It was felt that the interaction of the many variables involved is extremely complex and this, in combination with the fact that accidents or delineation accidents are such rare events (especially on the low-volume rural roads), make the isolation of small changes in delineation almost impossible. It was agreed, however, that it was possible to use accidents to measure the effectiveness of major changes in delineation treatments, such as the case of "no delineation" versus a standard "centerline and edgeline" treatment.

- A common thread throughout most of the interviews was the noted scarcity of knowledge about the driver and his needs. It was generally felt that considerably more research is required to determine the driver's perception of various delineation treatments. We don't really understand what information a driver needs, especially during adverse visibility. A good parameter for looking at the problem of driver needs is "Configuration Visibility," which quantifies the combined effects of delineation configuration and visual range. This parameter was developed in the research entitled "Driver's Visibility Requirements for Roadway Delineation."(1)

- A major problem in performing field studies of delineation is the lack of a good data base and the inability to establish controlled conditions that permit the isolation of variables. There is a feeling that continuing studies of delineation that do not occur under controlled conditions are not of much value. There is also a feeling that studies of delineation treatments under dry/daylight conditions do not offer much since, under these conditions, delineation treatments are generally not needed by the driver.

- There is some concern that sufficient attention has not been given to the allocation of resources for pavement delineation. A view was expressed that it is totally unrealistic to solve a problem by spending a large sum of dollars in a short period of time. We desperately need a policy evaluation framework to answer the question as to how we should allocate the delineation dollar over an extended period.

- There was considerable support of the statement that we now have a fairly good set of minimum pavement delineation standards and that the major energies should be diverted toward improving delineation at spot locations where you can isolate the problems of driver expectancy and get significant benefits for minimum investments. The really big "payoffs" in delineation can be achieved by seeking to reduce the cost for standard treatments and by applying special treatments at critical spot locations.

- A major problem in many states is the lack of priorities given to providing good delineation treatments. The public complains about bad signs and poor signals, but it is seldom that complaints are made regarding faded delineation. As a result, many highway departments place delineation low on their list of priorities. There is need for greater emphasis on establishing highly effective delineation programs that are carried out on a continuing basis.

- Some of those interviewed felt that we should take a more aggressive approach toward the use of delineation by establishing mandatory requirements for certain roadways. At the present time, centerlines are not required on any highway except the Interstate system. When you use delineation, you have to follow established standards, but there is no universal mandatory requirement for using any delineation. It is felt that the existing body of knowledge about delineation has established that certain treatments are indeed needed to enhance safety and that these treatments should be a requirement rather than a recommendation.

- The research that seems to be the most critical is the need for a better system of vertical delineation, the need for a better system to provide for temporary markings, the need for a better system to remove markings, and the need for a better understanding of what the driver requires. This latter need seems to be the area where the least amount of information is currently available.

CHAPTER V
INTERPRETATION AND SYNTHESIS OF FINDINGS

The previous chapters were primarily concerned with the documentation and summary of the findings of the 1-L-3 delineation research. This chapter is a discussion of the more significant delineation issues and an interpretation and synthesis of the relationship of the research findings to these issues. The material is organized by broad delineation category (i.e., striping, raised pavement markers and post-mounted delineators) and by the application issues within each category (i.e., stripe-to-gap configuration, narrower striping, etc).

STRIPING

The most commonly used delineation treatment is the painted stripe and standards for the use of this treatment have evolved through many years of practice. In recent years, however, several issues have been raised relative to these standards and some of the 1-L-3 research addressed various aspects of these issues. The following is a discussion of the more important points.

Need for Centerline

This issue is somewhat controversial, particularly with regard to the low-volume, two-lane rural highway situation. The cost-effectiveness study (3) concluded that for the general highway situation (tangent and/or winding sites), highways with centerlines have significantly lower accident rates than those with no treatment at all. The reduction was 0.947 accidents per million vehicle miles and was significant at the 0.05 level. This finding was supported by the opinion of those interviewed and by statements at the delineation conference which concluded that significant reductions in accident rates can be attained through the application of standard delineation treatments where there was no previous delineation existing. This finding was also supported by a recent delineation study in the State of Illinois (15) which indicated that the addition of a centerline to an unmarked roadway reduced the predicted delineation-related hazard almost 50 percent (Figure 8). It is not clear whether this finding is attributable to differences in climate, traffic volume, roadway width, etc. rather than solely to the addition of a centerline delineation. There is evidence, however, that a centerline is a valuable delineation aid. Therefore, it is recommended that a centerline be required whenever a roadway is paved with a G-type surface or better.

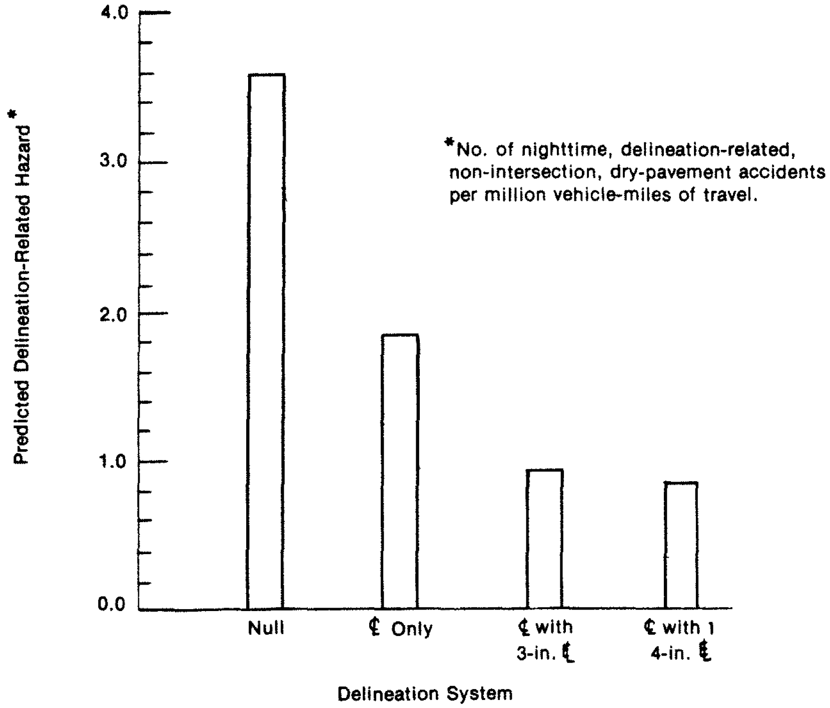


Figure 8. Delineation-Related Driving Hazard on a Dry Night (Tangent Sites Only)

<u>Edgelines</u>

The use of edgelines has become an accepted practice in most states although an occasional question is raised in connection with the cost-effectiveness of this type of treatment. The findings related to this issue are:

- <u>Driver's Visibility Requirements for Roadway Delineation (1)</u> — The driver simulator element of this study paid particular attention to this issue and found that providing a solid edgeline resulted in significantly improved driver performance over a dashed edgeline or no edgeline at all. The field tests did not directly address this issue.

- <u>Field Evaluation of Selected Delineation Treatments (2)</u> — The results of this study indicated that the use of edgelines resulted in very definite improvements in traffic performance. The findings are supportive of the use of edgelines on all roadways equal to or greater than 20-feet in width.

- Cost Effectiveness and Safety of Alternatives Roadway Delineation Treatments (3) — In this study, the results of analyses of accident rates at sites with edgelines versus those without edgelines were mixed. There were significant improvements in tangent sections, but less certain results on winding roads. However, using an expected reduction of .181 accidents per million vehicle miles after addition of edgelines on the general highway situation, it was found that edgelines with service lives of five years or more are justified on all highways with an AADT of 500 vehicles per day or more. In fact, if the service life is just two years, the edgelines are cost-justified if the application cost is less than $165 per mile with an AADT of 1,000 vehicles. At AADT's of 3,000 or more, edgelines are clearly justified for all combinations of cost and service life. These findings are supportive of their state-of-the-art report recommendations (16) which state that edgelines should be used on all roads equal to or greater than 22-feet in width, especially if the AADT exceeds 5,000 vehicles per day.

- Effect of Pavement Edge Markings on Traffic Accidents in Kansas (13) — This study concluded that although there was no significant change in total number of accidents as a result of the use of edgelines, there was a significant reduction in the number of fatalities and in the number of accidents at intersections and driveways at those locations where edgelines were used.

- Effect of Pavement Edge Marking on Two-Lane Rural State Highways in Ohio (12) — Similiar to the Kansas study, this research also concluded that there was no significant change in the total number of accidents resulting from the use of edgelines. However, as with the Kansas study, it was found that those sites with edgelines did have a significant reduction in fatality and injury-causing accidents and a reduction in accidents at intersections, driveways, and alleys.

- Interviews (14) — Among those interviewed, there was a general feeling that edgeline markings were beneficial and that they should be used on all roads greater than 20-22-feet in width, especially if the AADT is in the range of 3,000-5,000 vehicles per day.

- Delineation Conferences (9) — This group concluded that edgelines have become an accepted practice but have limitations on narrow roads where traffic tends to crowd the center of the road.

With these findings, it can be comfortably concluded that edgelines are an important element of a painted delineation system and should be used on all roads greater than 20-22 feet in width where traffic volumes justify the expenditure. If traffic safety is the only consideration, it appears that AADT's of 500-1,000 vehicles are justifiable boundaries. If other factors, such as road maintenance, etc., are considered, it is possible that lower AADT boundaries could be established. Although it has been difficult to establish that the use of edgelines will result in a significant reduction in total numbers of accidents, there is evidence that certain types of accidents (i.e., fatalities) can be reduced.

Need for Two-Color System

In the U.S., road markings and delineations have been coded to convey information to the driver. The basic elements of the code are yellow versus white color, continuous versus dashed patterns, and single versus double line. For a number of reasons, the use of the two-color system has been questioned in recent years. Yellow paint is more expensive than white and under adverse weather conditions it is not as visible. Also, it has been conjectured that many drivers don't fully understand the use of yellow markings. "Studies of the Road Marking Code" (6) addressed this specific issue in some detail and the findings indicate that color coding is not readily understood by the driver. In a majority of the cases, yellow colored markings were associated only with hazardous conditions and not with the MUTCD meaning of traffic moving in the opposite direction. The implications are that the standards regarding the use of yellow paint are not understood and therefore either a more aggressive attempt at driver education is required or else a simplification of the coding system is needed.

Stripe-to-Gap Configuration

The 1971 MUTCD standard for centerline stripe-to-gap ratio is 15:25. A change to a 10:30 stripe-to-gap ratio was recommended by FHWA in May of 1977. Other ratios have also been suggested by many of the states. The basic rationale for reducing the ratio is the savings in paint cost that could be accrued. The research findings and the general concensus relative to this issue are as follows:

- Driver's Visibility Requirements for Roadway Delineations (1) — This study concluded that changing the stripe-to-gap ratio has a very significant effect on steering performance with a degradation in performance as the stripe-to-gap ratio is reduced and the total cycle length is increased. Under relatively good visibility conditions (clear night) the effect may not seriously affect steering performance, but under more adverse conditions (night fog) the effect may be critical. Thus, for regions which experience adverse weather conditions (i.e., rain, fog, blowing dust, etc.), the larger stripe-to-gap ratios may be preferred.

- Field Evaluation of Selected Delineation Treatments (2) — This study concluded that in dry weather, there is no significant difference in traffic performance measures with either the 5:35, 10:30, or 15:25 stripe-to-gap ratios. There was some evidence, however, that under wet-night conditions, significant benefits can be derived with use of the RPM supplements. Therefore, consideration should be given to the use of RPM supplements with the 5:35 or the 10:30 stripe-to-gap ratios if adverse visibility is of serious concern.

- Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments (3) — The analytical portion of this research did not address the stripe-to-gap configuration issue because of the lack of enough study sites to do a meaningful accident study. However, the state-of-art report (16) prepared under this contract did suggest that a decreased ratio could be used under certain conditions. The use of such a ratio, however, should be increased on curves and on approaches to no-passing zones.

- Optimization of Traffic Lane Delineation (8) — California had been using a 9:15 stripe-to-gap configuration but based on the results of this study and the concern of the increasing costs of traffic paints, a recommendation was made to revise their stripe patterns to a 12:36 stripe-to-gap configuration for freeways and rural highways with design speeds of 45 mph or more and a 7:17 stripe-to-gap configuration for conventional urban and rural roadways with design speeds less than 45 mph. The same patterns should be used for major segments of a given route and not interchanged indiscriminately. Under special conditions such as blowing sand areas and areas of extreme rainfall and fog, an RPM supplement is recommended.

- An Evaluation of the 10:30 Centerline Marking Pattern (11) — This study concluded that in terms of traffic performance and public reaction, there is no significant difference between the 10:30 configuration and the 15:25 configuration. Most of the experiments were performed under normal weather conditions and therefore no conclusions were developed relative to the use of the 10:30 configuration under adverse conditions.

- Interviews (14) — The interviews revealed that the majority of professional traffic engineers feel that a reduction in the 15:25 configuration would not adversely affect either driver behavior or safety under normal driving conditions. However, there was some concern that such a reduction under adverse weather conditions may create serious negative effects.

- Delineation Conferences (9) — It was reported at these conferences that some states are reducing their standards for the stripe-to-gap configuration below the 15:25 recommended in the 1971 MUTCD. The basis for this is to save on paint materials.

Based on the findings of this research and based on the general consensus of those most knowledgeable persons in the delineation field, it can be concluded that the standard stripe-to-gap configuration of 15:25 can be reduced without having an adverse effect on traffic performance and safety under dry weather conditions. However, there is substantial evidence that a reduced stripe-to-gap configuration should always have a supplement such as raised pavement markers if adverse visibility, i.e., wet-weather conditions, is a primary concern. Future research needs to explore in greater depth whether a reduced stripe-to-gap configuration is adequate at hazardous locations such as horizontal curves and under adverse weather conditions such as rain, fog, and blowing dust.

Narrower Striping

There has been much discussion about the possibility of reducing the current 4-inch standard width of a centerline or edgeline in order to reduce overall delineation costs. The only research that addressed this specific issue was the field delineation study and the cost-effectiveness study. The research findings and expert opinions related to this issue are described in the following.

- Field Evaluation of Selected Delineation Treatments (2) — The evaluation of the 2-inch edgeline indicated that there were no adverse safety effects where narrower edgelines were tested in combination with a reduced 2-inch centerline. This testing however, was limited to two locations and not under marginal or adverse weather conditions.

- Cost Effectiveness and Safety of Alternative Roadway Delineation Treatments (3) — Study of narrower pavement marking was not part of the experimental design of this research but the issue was addressed by the state-of-the-art report (16). It was generally felt that the 4-inch wide striping should be maintained but there is some evidence that narrower striping may be used in certain situations (i.e., edgelines).

- Interviews (14) — Most of the interviewees expressed a preference to maintain the 4-inch standard for pavement markings. It was a general feeling that the savings to be accrued from using a narrower striping would not be great enough to offset the potential disbenefits that may occur.

Although the field evaluation study indicated that systems with 2-inch wide pavement markings had traffic performance measures similiar to those produced with the 4-inch wide lines, there doesn't seem to be sufficient evidence nor support from those who are most knowledgeable in the field to recommend a change in the currently accepted practice of using a standard 4-inch wide pavement marking. There are some indications that the use of the narrower 3-inch striping for edge-lines may have some merit but only after their effectiveness and durability have been clearly established, particularly in reduced visibility conditions such as in winding sections.

RAISED PAVEMENT MARKERS

The use of pavement markers has greatly increased in the past ten years and they now play an important role in many delineation systems. The major advantages of markers are improved wet weather delineation, reduced maintenance and more positive nighttime delineation than can be provided by a painted stripe. The major disadvantages are the high initial cost of installation and the fact that they are not compatible with snow plowing, except in limited situations, such as where rubber blades are used. The following is a discussion of the more significant issues related to the use of raised pavement markers.

Raised Pavement Marker Centerline

The raised pavement marker (RPM) has gained widespread use as a replacement of the paint line for daytime marking and, in combination with retroreflective markers, it serves both day and night uses. The use of these markers is intuitively beneficial in that they discourage encroachments on the opposing lane. Findings relative to their use are as follows:

- Driver Visibility Requirements for Roadway Delineation(1) — In the field experiments of this study, a portion of the test section had delineation which consisted of reflective and non-reflective markers used with striping to create lane-line delineation The results of this testing revealed that with this delineation the lateral placement variance was almost 50 percent less than that observed on those test sections having striping-only as a lane-line delineation., The evidence also showed that the drivers were considerably more tense when required to operate in the rain with only striping for guidance. These results strongly indicate the effectiveness of the raised pavement markers.

- Field Evaluation of Selected Delineation Treatments(2) — This study investigated a series of delineation systems involving an RPM-only centerline. However, because of the tremendous initial costs of such systems, none seemed to yield sufficient safety benefits to justify their general application on two-lane rural highways. One system, consisting of a centerline of reflective and non-reflective RPM's used in conjunction with 4-inch edgelines supplemented by RPM's @40-foot spacing, did show a substantial 68 percent reduction in predicted hazard, but its initial cost was about 9 times as great as the base condition of painted centerline and edgelines.

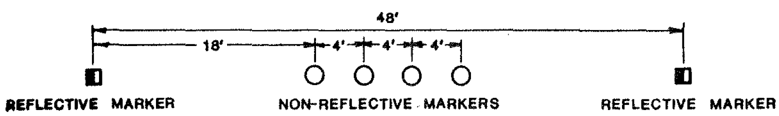
- Cost Effectiveness and Safety of Alternative Roadway Delineation Treatmentss(3) — In this study, heavy emphasis was given to comparing RPM centerlines with painted centerlines. The results were clear that use of the RPM treatment is very sensitive to traffic volume and expected life of the marker. An expensive installation (i.e., $4,000 per mile) 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. Some of the conclusions that were made, based on the attendant assumptions, are:

  - RPM centerlines with a service life of 5-years or more and an AADT in excess of 3,000 is more cost-effective than painted centerlines.

  - Where the service life of a raised pavement marker system is less than two years, painted centerlines are more cost-effective.

  - RPM centerlines with service lives between two and five years may be desirable but are dependent on the installation costs.

- Optimization of Traffic Lane Delineation(8) — In this investigation of different patterns for pavement delineation systems considered for use in California, it was concluded that pavement markers are a satisfactory substitute for a painted line if the markers are placed at 4-foot spacing. The pattern recommended consists of both reflective and non-reflective markers as shown below.



  In certain areas where either horizontal or vertical sight distances are restricted, the reflective marker patterns can be shortened to 24-feet.

- Delineation Conferences(9) — Although the particular issue of using RPM's as a centerline marking was not addressed in detail at the conferences, there were some general statements which reflect on the use of RPM's. They are:

- "The use of pavement markers has greatly increased in the past 10 years. The major advantages of markers are improved wet weather delineation, reduced maintenance, and more positive nighttime delineation. The major disadvantages are the high initial cost of installation and the fact that they are incompatible with snow plowing."

- "Retro-reflective pavement markers have a strikingly beneficial effect upon vehicular control in rain and darkness."

- "The general performance of raised pavement markers has been very good and studies have shown that they have a favorable benefit/cost ratio."

The essence of these findings is that RPM's can be an effective replacement for painted lines but only under certain conditions of traffic volume, service life and installation cost. The most effective system is one where a combination of reflective and non-reflective markers are used to gain both daytime as well as nighttime delineation.

Raised Pavement Markers As A Continuous Gap Supplement To Painted Centerlines

Due to the high initial cost of RPM's, many states have developed systems which consist of the standard painted centerline supplemented with retroreflective pavement markers. The objective is to achieve an all-weather delineation system at minimum cost. Some of the findings related to these systems are:

- Driver Visibility Requirements for Roadway Delineation(1) — As reported previously, part of this research was conducted on a roadway which used ceramic RPM's on a white painted line supplemented with retroreflective markers on 24-foot spacing. The results indicated improved driver performance on both wet and dry pavements.

- Field Evaluation of Selected Delineation Treatments(2) — In this study, the evaluation of the use of RPM's as a supplement to a painted centerline yielded highly significant benefits with all stripe-to-gap configurations. The wet-day and the wet-night evaluations showed that it is possible to achieve a hazard reduction of up to 30-40 percent.

- Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments(3) — The cost-effectiveness element of this research did not address the issue of using RPM supplements. However, the state-of-the-art report(16) did report that RPM supplements are good in that they do provide the "far" delineation that is lacking with pavement markings. This is especially true on rainy nights.

- Optimization of Traffic Lane Delineation(8) — The use of RPM's as a supplement is a California standard for use with either the 4-inch white stripe or non-reflective markers on 4-foot spacing.

There is strong support for the use of RPM's as a supplemental treatment. The system offers an all-weather delineation treatment, the costs are reasonable, and they are effective in improving safety.

Raised Pavement Markers As A Spot-Location Supplement

Although the literature suggests that RPM's can be a very effective supplemental treatment at curves on two-lane roads, there have been very few studies of the effects of this system. The NCHRP research on "Roadway Delination Systems"(4) performed one experiment involving the evaluation of RPM's on a rural curve. Their findings indicate that the treatment consisting of RPM's and painted edgelines produced the most desirable effect in terms of vehicular placement variability. The next best treatment was RPM's only. Both treatments brought about a reduction in placement variability as well as a more central position in the traveled lane and since both treatments incorporated RPM's, it was concluded that the improvements were due to the presence of the raised pavement markers. The State-of-the-Art report(16) concluded that raised pavement markers can be a very effective supplemental treatment at curves on two lane roads where the expense may not be justified for continuous application on tangent sections. They provide excellent "near" as well as "far" delineation and present a more accurate perspective of the driving surface than do other forms of supplement. The field evaluation study(2) supported this latter statement with findings that RPM's are more effective on isolated horizontal curves than are post delineators. This study also recommends the use of one-way RPM's, when used as a supplement on isolated horizontal curves to minimize off-center driving in both directions. The general concensus seems to indicate that RPM's used as a spot-location supplement can be very effective, especially at isolated horizontal curves.

POST DELINEATORS

Post delineators of various forms and shapes are used widely throughout the U.S. for they have proven to be effective during nighttime and during inclement weather when standard pavement markings are ineffective. In recent years, however, several issues have been raised relative to the use of post delineators and their effectiveness in comparison to other forms of delineation. The following is a discussion of some of these issues.

Post Delineator Spacing

A number of experimental studies have addressed this issue but none have produced sufficiently reliable results to prove that one pattern was far superior to another. However, there is enough evidence to provide some general guidelines for post delineator spacing. In the field evaluation study,(2) tests were conducted to compare traffic performance at a tangent site using striping only, striping with post delineators at a 528-foot spacing, and striping with post delineators at a 264-foot spacing.

In these tests, there was some evidence that lateral placement was less variable along the highway with the delineators in place. The effect on placement variance was somewhat stronger with the closer delineation spacing, but when the lateral placement measures were input to the accident-probability model, the 100 percent increase in installation cost associated with the 528-foot spacing was found to yield only a marginal decrease in predicted hazard. In the NCHRP study of Roadway Delineation Systems,(4) several post delineator patterns were evaluated and although their conclusions are not fully supported by experimental data, a subjective evaluation of the researchers indicated that a spacing of 400-feet along the right side of two-lane roads is adequate to serve simply as indicators that the roadway alignment is straight ahead. The interviewees(14) and attendees of the delineation conference(9) tended to agree with these findings, so there seems to be a concensus that in the general application of post delineators along tangent roadways, the spacing of the delineators should be about 400 feet, with at least three delineators visible at all times.

Cost-Effectiveness of Post Delineators

Although post delineators appear to have little effect on traffic characteristics, the cost-effectiveness study(3) did conclude that highways with post delineators do have lower accident rates than those without post delineators (in the presence or absence of edgelines). Carrying this through to the cost-modeling, it was further concluded that post-delineators are cost-justified for all values of cost and service life with AADT's exceeding 1,000 vehicles per day. They are also justified under most conditions for AADT's as low as 500 vehicles per day. Only installations costing more than $360 per mile with service lives of two years are excluded. In general, there are mixed feelings about the effectiveness of post delineators, although many agencies feel that the post delineator systems used as a supplement to standard pavement markings produce a very effective delineation system, especially during wet weather and snow conditions. This feeling appears to be substantiated by the cost-effectiveness study(3).

Post Delineators As A Spot Supplement

As with raised pavement markers, the selective use of post delineators as a supplement to standard striping is a cost-effective application of delineation. The field evaluation study(2) reported significant improvements in traffic performance (placement variance) with the use of post delineators on horizontal curves. However, the study did indicate a preference for raised pavement markers as a supplement to the centerline where economics or maintenance problems do not preclude their use. The cost effectiveness study(3) reported that there is some indication that horizontal curve sites with post delineators have lower accident rates than sites without post delineators. However, not all of the data support this finding and some of the less rigorous statistical models indicated the opposite. The NCHRP Roadway Delineation Systems study[4] evaluated six post delineation patterns on one two-lane rural horizontal curve site. Although the results of these evaluations were inconclusive in that they did not show that any of the patterns improved driver performance, there was some indication that amber delineators placed on the outside of the curve do provide increased guidance to the motorist. This study also concluded that post delineators are very effective when used as a supplement in merge and diverge areas, and with stop approaches. The evidence to date does not permit a positive recommendation of a standard for the use of post delineators as a supplement, but there is sufficient information which indicates that their use can be very effective under certain conditions.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The 1–L–3 research program has produced a great deal of valuable information and the findings are quite consistent with other research and experience. However, as with any program with such complexities, there are still some unanswered questions and there is still some difference of opinion within the research community concerning priorities for future research. This section is a summary of some of these issues and concludes with a reasonable consensus about the current status of pavement delineation for two-lane rural highways.

GENERAL CONCLUSIONS

- Delineation of the centerline and the outside edges of the traveled lanes is highly desirable on two-lane rural roads having paved surfaces at least 20 feet in width. It has been shown conclusively that such delineation results in significantly less lateral deviation, reduces driver stress, and in some cases, reduces accident potential. Drivers understand these markings and regard them as important to the driving task.

- There is substantial evidence that delineation markings provide important guidance to the motorist, especially as visibility range decreases due either to adverse weather conditions and/or nighttime conditions. There is also substantial evidence that there is little difference between different delineation systems as long as they have an adequate contrast level (delineation contrast of 2 or more) and are sufficiently continuous to ensure that the driver has enough information to detect the direction of the lane ahead. For these reasons, least-cost systems are generally preferred for the general roadway situations. The current state-of-the-art is now well enough established to provide minimum standard treatments for general situations in terms of line width, paint color, stripe-to-gap configuration and contrast.

- The statements above do not rule out the need for delineation in excess of the minimum standards at certain locations. For example, standard delineation systems supplemented by special delineation treatments to improve traffic flow in non-standard situations is generally very effective and the really big "payoffs" in delineation can be achieved by applying special treatments at critical spot locations. The results of the current demonstration projects may be a useful vehicle to help identify and classify the non-standard situations so that appropriate standards can be developed.

- Research which relies on assembling roadway traffic and accident data from several states is fraught with problems of completeness, accuracy, comparability, and interpretation. Additionally, the small numbers of accidents on two-lane rural roads and the high variability of accident frequencies and severities make it extremely difficult and very risky to draw conclusions about the effects of minor changes in delineation treatments. For example, it is possible to show positive benefits when comparing no-delineation vs. standard delineation. However, minor variations within treatments such as spacings, color, line width, etc., are not very sensitive to accident frequencies or severities; and other techniques should be used in evaluating these variations.

- Although delineation is clearly intended as an aid to drivers, its design and application, until recently, has largely rested on intuitive understandings of driver needs, limitations, and capabilities. The more recent studies, especially those in the 1–L–3 program provide much useful information which can greatly narrow the range of conjecture and which can be directly applicable to the development of improved delineation design techniques. First, it was found that drivers have a poor understanding of some widely used striping codes intended to convey rather important messages. Second, the results of the research provide the means for predicting how well a driver can discern his preferred path for any particular delineation design. These very basic findings form a solid base for developing improved delineation systems and can be used to illustrate the advantages and disadvantages of alternative delineation treatments.

SUGGESTED RESEARCH

- Delineation contrast is correlated with driver performance in that it provides a measure of the total information available to the drivers. For good steering performance under clear night driving conditions, it has been concluded that delineation contrast should be maintained at a value of 2 or greater. For adverse visibility conditions (i.e., rain, fog, dust, etc.), delineation contrast should be maintained at even higher levels. The implication is that there is an important tradeoff between driver performance and the cost of maintaining a certain level of delineation contrast. Research should be pursued to determine the cost-effectiveness of maintaining various levels of delineation contrast. Further research should also be directed toward the refinement of a calibrated device and methodology for measuring the contrast of pavement delineation. The device developed by the California Department of Transportation and the one being developed in Oklahoma for this purpose would seem to be a good place to begin.

- To date, there have been only a few studies which addressed the effects of various stripe-to-gap ratios on driver performance, and many of these have been conducted very cursorily. More extensive research is needed to determine an optimum stripe-to-gap configuration for both rural and urban applications and under alternative visibility conditions.

- The research involving drivers' visibility requirements contributed significantly to the body of knowledge on driver needs and capabilities. However, the research was limited to a relatively few conditions of restricted visibility, and then only on a high-type facility (freeway). Thus, the need for more longer-term research is for additional study of the driver, especially under more adverse visibility conditions than dry/wet night conditions and on facilities with lower design standards (i.e., two-lane rural highways).

- Although the 1–L–3 program did include studies of post delineators, none of the research looked at the traffic performance effects of continuous post delineation in the absence of edgelines. There needs to be an evaluation of post-mounted delineators installed over long sections of a two-lane highway with particular emphasis on the narrower and more winding alignments. Tradeoffs should also be studied between delineation spacing and the selective use of edgelines. Most of the recommendations that have been developed to date with regard to post delineation have been principally on the basis of subjective evaluation.

- The importance of maintaining good driver visibility, especially under adverse weather conditions, was a finding of almost all of the 1–L–3 research projects. The studies also concluded that adverse weather conditions such as rain, fog, snow, or dust all tend to reduce the effectiveness of conventional or standard delineation systems. Thus, the need was defined for an economical and all-weather pavement delineation system. Considerable effort is being expended toward the development of such a system (i.e., snowplowable, raised pavement marker; flexible, self-erecting delineator posts, etc.) but it is generally felt that much more emphasis is warranted.

- A cost-benefit model for evaluating delineation systems was one of the major products of the 1–L–3 research program. In this model, economics is the basis for evaluating various delineation treatments with reduction in traffic accidents or the measure of benefits to be derived. Since pavement delineation cost is so critical, both in terms of ability to provide delineation over many miles of the national road system and also, to achieve a higher rate of return from the investment, there is a need for additional research to refine and validate the accident models that can serve as major input to the cost-benefit analyses.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

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Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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